Optimization Design of Composite Insulator Grading Ring for ±800 kV UHVDC Lines

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ABSTRACT: The model of grading ring of the composite insulator string is built, and the potential distribution long insulator surface and electric field strength distribution of V-typed overhang composite insulator strings for ±800 kV UHV DC lines before and after the installation of grading rings are calculated. The influences of shield depth, external diameter and internal diameter of grading ring on electric field strength are discussed. Calculation results show that when grading rings are not installed, the potential distribution on insulator surfaces is extremely uneven, and electric field at conductor side appears serious distortion; when large and small grading rings are configured at conductor side and medium-sized grading ring is configured at the tower side, the electric field distributions at conductor side, especially at the fitting-side, core rod of insulator and sheath interface, are effectively improved, which also contribute to corona prevention and improving reliability of insulator operation; increasing shield depth and external diameter of grading ring can evidently improve the electric field distribution at insulator surface, and it is discovered that the pipe diameter of grading ring notably impacts the surface electric field strength of grading ring itself. Finally, the optimal configuration scheme of grading ring of composite insulator strings for ±800 kV UHVDC transmission line is recommended. After the installation of optimized grading ring, the maximum electric field strength along insulator surface is 0.457 kV/mm while the electric field strength on grading ring surface is 1.7 kV/mm, and it meets the requirement of UHVDC power transmission project..

KEY WORDS: UHVDC power transmission lines; composite insulators; grading ring; shield depth

FOREWORD: Composite insulator, featured with outstanding flashover prevention property, light weight, easy installation and maintenance, is widely applied in AC/DC transmission lines of all voltage level. According to calculation by the State Grid, gross number of domestic composite insulator in operation is over 2.2 million by the end of 2006, second only to America. Following the successive start of construction of the projects of Xiangjiaba-Shanghai ±800kV DC transmission line and Yunnan-Guangdong ±800kV DC transmission line, V-type composite insulator string is widely applied to straight-line tower. However, exorbitant electric field intensity at where the composite insulator is positioned will cause severe electric corrosion to umbrella dress sheath, causing serious accident of end seal damage and brittle failure[1-5]. Corrosion and squalidity of insulator metal ends is more severe under DC high voltage than AC high voltage, possibility for insulator failure is also higher[6-8]. Due to longer insulating distance of ±800kV DC composite insulator, severer voltage distribution distortion, high voltage end electric field intensity liable to concentrate, composite insulator is not only vulnerable to electric corrosion, but also generates strong corona and wireless interference, therefore influence reliable operation of the transmission line[9-10]. In order to lower electric field intensity at both ends of the composite insulator, regular solution is to install grading ring to both ends. Configuration of grading rings not only contributes to efficiently lower electric intensity at both ends of the insulator, but also suppress electric corrosion loss at the insulator surface, protect end hardware fittings and umbrella dress sheath from flash burn and prevent corona generated from grading ring itself, thus optimization design for grading ring is necessary.

Current methods for grading ring optimization design mainly include experimental method and numerical method. Measurement for DC electric field intensity is far more difficult than AC electric field intensity measurement,

which requires infinite test equipment input impedance[11-13], thus direct measurement of DC electric field strength is unlikely. The only way to control hardware fitting field strength that generates corona is through fitting corona test in engineering, yet due to high cost of corona test and long cycle of design, production and test, improvement of grading rings with inconsistent pipe diameter, ring diameter and shape through separate pilot production and test is very difficult, moreover, impact of grading ring towards composite insulator cannot be quantified via test. Thanks to amplification of computer storage capacity and leaping progress in computation speed, numerical calculation method have shown advantage in solving sophisticated electromagnetic field engineering problems. Without limitation of environment and condition, numerical calculation method is capable of altering factors like dimension and position of the computational model, highly flexible and simplified optimization design for grading rings. Article [9-10] studied in specific to the project of Yunnan-Guangdong ±800kV applying I-type composite insulator string corona ring structure, article [14] optimized grading ring configuration of ceramic-cored composite post insulator for ±800kV system.

This paper will analyze surface electric field intensity and potential distribution of ±800kV UHVDC transmission line V-type composite insulator applying grading rings with different parameter, and come up with grading ring optimization design scheme, provide technological basis for optimal configuration of ±800kV UHVDC composite insulator grading ring.

1. Grading ring modeling

All composite insulator installed on ±800kV UHVDC transmission line straight-line tower along Xiangjiaba-Shanghai apply V-type string. See 300kN single V-type composite insulator string grading ring model as shown on figure 1. Composite insulator string is 10.2m in length, core rod diameter is 34mm, sheath thickness is 6.5mm, with one large, one medium and four small umbrellas, diameter of large umbrella is 246 mm, diameter for medium umbrella is 186 mm, diameter for small umbrella is 98 mm, tower cross arm nominal height is 81m, conductor is made of 6 × ACSR-720/50 steel core aluminum twisted wire.

Calculation is based on following consumptions:

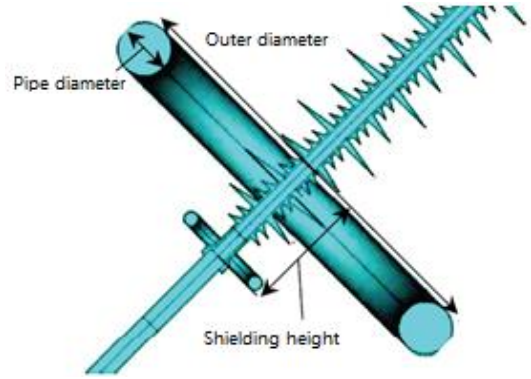

Figure 1 Grading ring model

1) Earth wire is neglected for its minor impact on composite insulator string potential and electric field distribution.
2) Assume composite insulator and fitting surface is clean and within dry nature environment.
3) Altitude of insulator string, tower, fitting and conductor within the model is 0.
4) By reason that space charge and ion flow can improve electric field distribution on insulator string surface, and consideration of ion flow influence is quite difficult within 3 dimensional electrostatic fields[9,15], thus space charge and ion flow influence are unreflected during calculation.

2. Potential distribution and electric field distribution without grading ring

Figure 2 shows curve of potential distribution along composite insulator core rod axes track without installation of grading ring. As shown on figure 2, insulator axial potential distribution is greatly uneven without grading ring, 50% voltage distributed within range of 2m along the conductor side axial. Due to shielding effect of tower, last fragments of insulator on the insulator string near tower share lower voltage than corresponding segment of insulator string distant from the tower. Take insulator string near the tower as an example, select a route penetrating large medium and small umbrella along composite insulator axis, figure 3 represents electric field distribution curve along this route. As drawn from figure 3, electric field

distortion appears seriously at the conductor side, electric field intensity reaches 1.907 kV/mm at hardware fitting and sheath connection interface, high electric field intensity like this not only tend to cause partial discharge at hardware fitting surface, bringing problems of audible noise and wireless interference, but also apt to electrolytic corrosion of silicone rubber urging early aging of the insulating material.

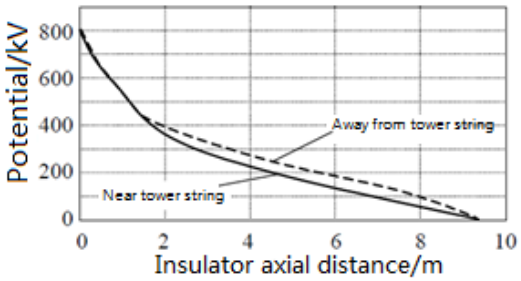

Figure 2 Potential distribution along rod of insulators without grading ring

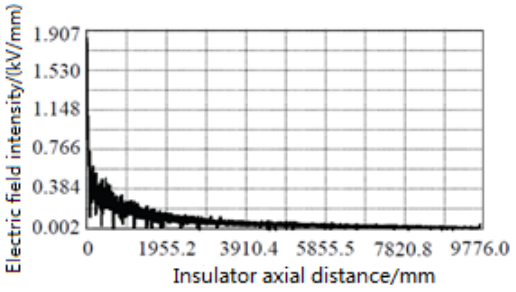

Figure 3 Electrical strength along the path through sheds without grading ring

3. Influence on electric field distribution by grading ring dimension

Grading ring is supposed to have a reasonable configuration, capable of corona control on insulator and hardware fitting and improve electric field distribution. Basic requirement for grading ring shape would be appropriate shield coverage and not too sophisticated. Combined grading ring is applied to tension insulator string on 1000kV UHVAC transmission line in Japan; suspension insulator string applies circular grading ring without installing shielding ring. Grading rings and shielding rings are not applied to suspension insulator string, circular grading ring and shielding ring are applied to tension insulator string on former Soviet Union 1150kV UHVAC transmission line. For 1000kV UHVAC test and pilot project along Southeast Shanxi-Nanyang-Jinmen in China, suspension insulator string applies circular or racetrack ring, tension insulator string applies racetrack ring and circular ring.

Referring to the optimization configuration scheme of suspension insulator string grading ring for domestic 1000kV UHVAC transmission line, in this article, 800kV UHVDC transmission line composite insulator on conductor side is configured with nesting-structured large circular ring and small circular ring, medium circular ring is configured on tower side. In order to optimize grading ring configuration, the following analysis concerns influence on electric field intensity caused by variation of either parameter among pipe diameter, outer diameter and shielding depth of large grading ring on conductor side on condition of identical small ring on conductor side and medium ring on tower side.

1) Shielding depth influence on electric field intensity

Along with shielding depth increase, grading ring shielding effect will cause upper shift of low field intensity zone on conductor side, field intensity peak value at composite insulator surface will decline, whereas field intensity at large grading ring surface will increase accordingly, shielding effect of large grading ring towards small grading ring on conductor side will decrease, hence field intensity at small grading ring surface will increase. Pipe diameter of large grading ring is 120mm, suppose outer diameter is 1m, variation of electric field intensity along with shielding depth as shown on table 1. As drawn from table 1, shielding depth increase within certain range can improve electric field distribution on conductor side, yet excessive shielding depth increase of large grading ring will minish dry-arc distance and affect lightening surge flashover voltage of composite insulator.

Table 1 Maximum electric field intensity along with large grading ring shielding depth variation

Shielding depth/mm	Maximum electric field intensity (kV/mm)		
	Composite insulator surface	Large grading ring surface	Small grading ring surface
180	0.468	1.65	1.1
210	0.463	1.65	1.05
240	0.457	1.7	1.1
270	0.45	1.8	1.12
300	0.442	1.8	1.18
330	0.436	1.9	1.2
360	0.433	2.0	1.3

2) Outer diameter influence on electric field intensity

Table 2 shows maximum value of electric field during outer diameter variation. As drawn from table 2, outer diameter increase can effectively minish umbrella dress electric field strength at the heading of conductor side on large grading ring and composite insulator string, yet will minish shielding effect of large grading ring toward small grading ring, causing field strength increase at small grading ring surface.

Table 2 Maximum electric field intensity along with large grading ring outer diameter variation

Outer diameter/m	Maximum electric field strength/(kV/mm)		
	Composite insulator surface	Large grading ring surface	Small grading ring surface
0.8	0.486	1.85	1.0
0.9	0.471	1.8	1.0
1	0.457	1.7	1.1
1.1	0.446	1.7	1.1
1.2	0.436	1.65	1.2

3) Pipe diameter influence on electric field intensity

Table 3 shows maximum value of electric field intensity during large grading ring variation. As drawn from table 3, increase of large grading ring pipe diameter has little impact on composite insulator electric field distribution, yet has great influence on ring surface electric field intensity. The larger the pipe diameter, the lower the electric field intensity will be on grading ring surface, and less likely to generate corona. On condition of grading ring pipe diameter increased to 120 mm, tendency of maximum field intensity on grading ring surface decrease slowed down, field intensity are generally lower than initial discharge field intensity by 2.0 kV/mm.

Table 3 Maximum electric field intensity along with large grading ring pipe diameter variation

Pipe diameter/mm	Maximum electric field intensity/(kV/mm)		
	Composite insulator surface	Large grading ring surface	Small grading ring surface
60	0.458	2.4	1.5
80	0.457	2.1	1.35
100	0.457	1.9	1.2
120	0.457	1.7	1.1
140	0.458	1.6	1.0
160	0.458	1.5	0.9

Figure 4 shows electric field distribution on hardware fitting surface at conductor side under circumstances

of with and without grading ring at the conductor side. As drawn from figure 4, on condition of no small grading ring installed at the conductor side, maximum electric field intensity at hardware fitting, core rod and sheath surface increase from 0.5kV/mm to 1.1kV/mm; on condition of no medium grading ring installed at the tower side, maximum electric field intensity increase from 0.3kV/mm to 0.6kV/mm, electric field intensity increase evidently at link fitting surface. Therefore installation of small and medium grading ring helps to efficiently improve electric field distribution on conductor side link fitting, especially on surface of fitting, core rod and sheath interface, which contributes to preventing accidents of end encapsulation damage caused by electric corrosion and brittleness, ensure reliable operation of insulator.

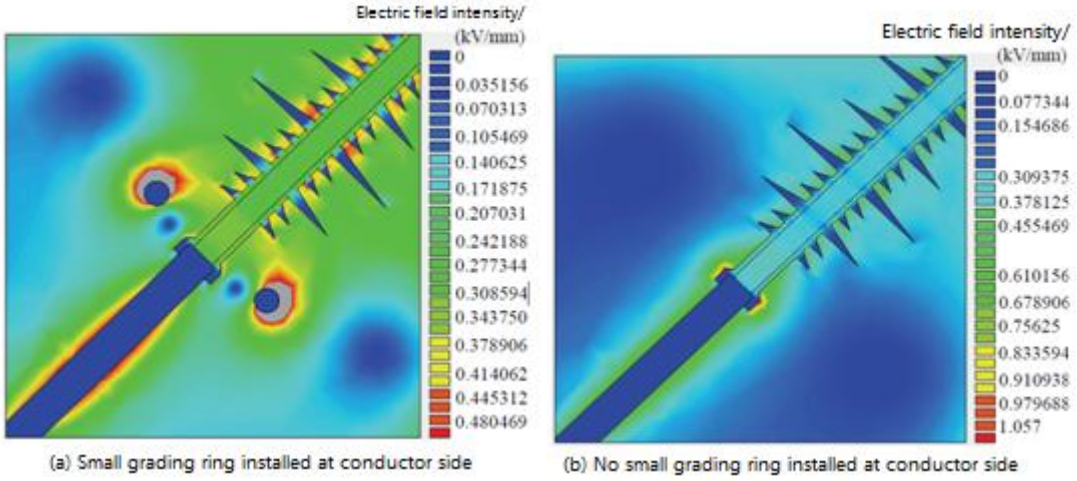

Figure 4 Electric field strength at fitting, core rod, sheath interface of the conductor side

Table 4 Optimal configuration scheme of grading ring

Grading ring configuration scheme		Pipe diameter/mm	Outer diameter/mm	Shielding depth/mm
Conductor side	Large circular ring	120	1000	240
	Small circular ring	32	232	32
Tower side	Medium circular ring	60	500	60

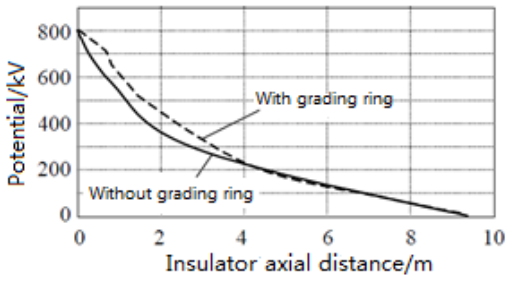

Figure 5 Potential along core rod axis after grading ring optimization

4. Grading ring optimal configuration

According to analysis above, grading ring optimal configuration scheme as shown on table 4. Potential distribution along core ride axis after optimization as shown on figure 5, as drawn from figure 5, after installation of optimized grading ring, potential distribution at conductor side improved evidently whether for insulator string near tower or distant from tower. Take insulator string near tower as an example, once grading ring is added, voltage borne within range of 1m in axis direction at conductor side diminish from 35% to 29%, potential distribution of the whole composite insulator is more even. Select a route penetrating large, medium and small umbrella along axis near tower string composite insulator, which is the same route as shown on figure 3, figure 6~7 respectively show electric field intensity variation curve of insulator string within tower and outside tower along this route. As drawn from figure 6~7, once grading ring configuration is optimized, maximum field intensity on umbrella sheath surface at conductor side will be diminished to 0.457kV/mm (lower than 0.5kV/mm) which is in accordance with engineering requirements, due to insulator string

outside tower influenced by tower shielding effect, electric field intensity increased slightly at insulator earth terminal.

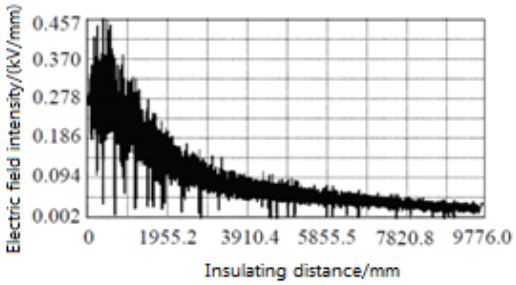

Figure 6 Electric field intensity of insulator string inside tower along the route penetrating large medium and small umbrella after optimization

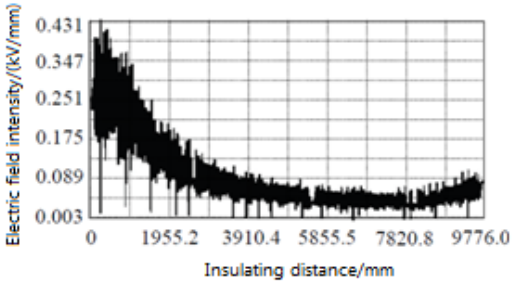

Figure 7 Electric field intensity of insulator string outside tower along the route penetrating large medium and small umbrella after optimization

5. Conclusion

1) Potential distribution along composite insulator core rod axis is greatly uneven without grading ring, 50% voltage is distributed within 20% insulating distance at conductor side, plus severe electric field distortion at conductor side, especially at the junction between fitting and silicon rubber umbrella dress sheath surface, electric field intensity reaching 1.907 kV/mm, such high electric field intensity can easily cause fitting partial discharge and early aging of silicon rubber organic material.

2) Configure large and small grading ring at conductor side and medium grading ring at tower side helps to efficiently improve electric field distribution at conductor side especially on fitting, core rod and sheath surface, which contribute to preventing corona and improving insulator operation reliability.

3) Shielding depth rise within certain range helps to diminish electric field intensity at composite insulator surface, during which field intensity on surface of large grading ring and small grading ring will increase accordingly, exceeding increase of large grading ring shielding depth will shorten dry arc distance thus influence lightening surge flashover voltage of composite insulator, recommended shielding depth for large grading ring is 240 mm.

4) Enlarge grading ring outer diameter helps to improve electric field distribution of composite insulator at conductor side and field intensity at large grading ring surface, yet field intensity at small grading ring surface will increase accordingly. Taking into account of shielding range and weight of grading ring, large grading ring outer diameter is recommended to be tailored as 1m.

5) Enlarge grading ring pipe diameter causes minor variation to electric field distribution of composite insulator, yet evident decline of electric field intensity on grading ring surface. Once pipe diameter is increased to 120mm, decline rate of maximum field intensity at grading ring surface will retard and all field intensity are lower than initial air discharge field intensity by 2.0kV/mm, large grading ring pipe diameter is recommended to be 120mm.

6) After optimization of grading ring, maximum field intensity at composite insulator surface is 0.457kV/mm, maximum electric field intensity at large grading ring surface on conductor side is 1.7kV/mm, maximum electric field intensity of small grading ring surface is 1.1kV/mm, all in accordance with engineering requirements.

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