Design of Grading Rings for ±800 kV DC Tension String on Duplex Composite Insulators

WANG Liming[1], LIU Min[1], GUAN Zhicheng[1], ZHAO Yuming[2], XIE Zhuqing[3], YU Jie[3]
(1. Graduate School at Shenzhen, Tsinghua University, Shenzhen, Guangdong 518055, China; 2. Electric Power Research Institute, CSG, Guangzhou 510080,China; 3 Shenma Electric Power CO.,LTD., Nantong, Jiangsu 226553, China)

Abstract: In order to serve reasonable arrangement forms of grading rings for the tension string with composite insulator of ±800 kV DC power transmission, and with the domain decomposition method to decompose the whole 3D electric field into several limited parts, this paper adopts the finite element method to calculate the electric field distribution around tension string with duplex composite insulators. A 3D model of ±800 kV DC power transmission consist of tower configuration, bundled conductors and tension insulator string is established based on ANSOFT software, and the influence of the ring diameter, ring tube diameter and the ring position of the grading ring on the string's electric field distribution is researched, resulting in an optimum scheme for the grading ring structure. The calculation results applying the finite element method show that with the designed grading ring installed, the electric field intensity around the sheath, metal fitting and the grading ring are controlled satisfactorily.

Key words: UHVDC power transmission; tension insulator string; composite insulator; arrangement form; grading ring; electric field intensity

Compared to electric porcelain insulator, composite insulator is featured with high intensity, light weight, high wet-flashover and flashover voltage, easy operation maintenance, strong ability of impulse withstand, widely applied to transmission line suspension string[1-8], and has spread application in tension string in recent years[9-12]. Surface field distribution and potential distribution for composite insulator without grading ring is greatly uneven, due to composite insulator structure characteristics and high resistivity feature of silicon rubber, surface field density is highest at mandrel and steel cap joint, distribution voltage is highest at first umbrella dress near high voltage end[13]. Exorbitant surface field density not only generate corona discharge, affect transmission line electromagnetic environment, produce audible sound pollution, but also cause strong electric erosion, causing further insulator aging[14-15]. Grading ring installation is the normal solution to the problem of uneven potential field density distribution at insulator high voltage end. Installation of grading ring helps to transfer maximum field density from insulator surface to grading ring surface, thus effectively improves electric field distribution on insulator surface.

Optimal allocation for tension string and grading ring installed can be realized via on-site test study, yet with high cost and difficulty in operation, therefore finite element calculation is one economic and efficient way for electric field analysis. This essay establishes a simplified 3D model for ±800kV DC circuit including tower, divided conductor and tension string insulator, based on finite element calculation, studies the rule of the influence of duplex insulator tension series interval on electric field distribution and on this basis studies influence caused by different grading ring parameters, thus finalize solution to grading ring distribution.

1. Electric field calculation model and grading ring design

Based on Yunnan-Guangzhou ±800 kV actual DC project, tower applies simplified model of monolithic

free-standing tension support J-30, norminal height 45m, actual height 60m (including tower head), calculation for insulator applies 550kN composite rod insulator, insulating length 10120 mm, face to face dimension 10600 mm, conductor applies 6×ACSR-720/50 aluminum steel-reinforced conductor, sub-conductor diameter 46.2 mm, interval 450mm[17].

Simplification principle and assumptions for modeling as following[18-19]:

1) Neglect earth wire with minus influence on composite insulator string potential and electric field distribution;
2) Umbrella dress has little influence on string potential and electric field distribution, neglect umbrella dress while calculating in order to improve calculation speed, a small amount of umbrella dress is installed to the both ends of the insulator when concerning the electric field around the umbrella dress.
3) Assuming that during simulating computation, composite insulator, hardware fittings, conductor and the grading ring surface are within a dry, clean natural environment.

Finite element software can only calculate electric field within limited area, thus calculation model applies coupling boundary and divide 3D unbounded domain into bounded sub-domain inside coupling surface and unbounded sub-domain outside coupling surface, apply finite element method to electric field distribution calculation within bounded sub-domain inside coupling surface[20-21].

Calculation model as seen on figure 1, suppose conductor length is over 8 times of insulator length, influence on electric field distribution is similar, therefore conductor length is decided at 96m, sag height 7m. bounded sub-domain is tailored as 110m×110m×110m, simulate the ground with 110m×110m plane.

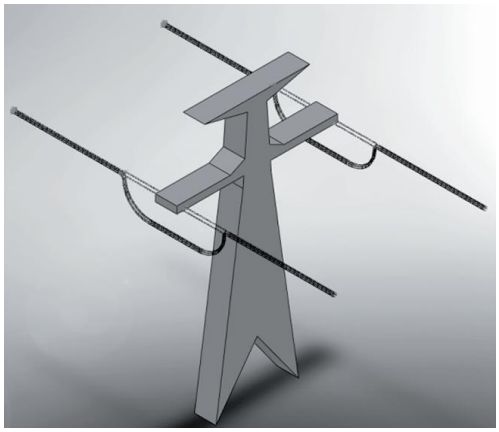

Figure 1 3D Electric Field Calculation Mode

Grading ring at high voltage end of composite insulator tension string apply the design of one large and one small racetrack ring, as seen on figure 2, insulators are positioned at the two center of the racetrack ring semicircle. See figure 3 for composite insulator interval L, grading ring pipe diameter d, ring diameter D and raised height H.

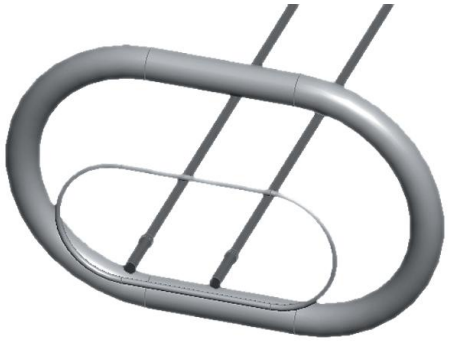

Figure 2 Grading Ring Type of Tension Insulator String

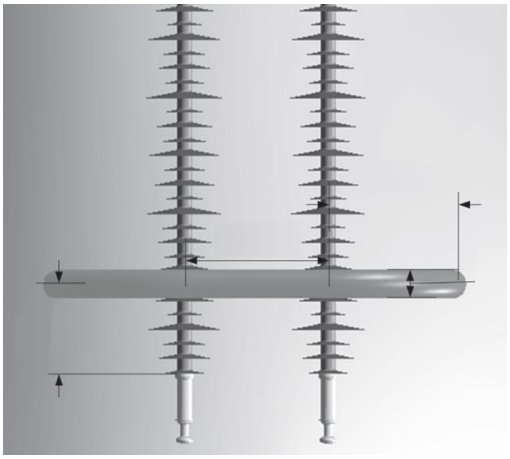

Fig 3 Geometry Parameters of Grading Ring

2. Two composite insulator tension string electric field calculation and grading ring design

2.1 Two composite insulator tension string electric field calculation

For line-shaped layout of two composite insulator, the deciding diameter for this layout is insulator interval L. See figure 4 for insulator interval and tension string electric field distribution, take into consideration of electric field intensity of high voltage end hardware fitting and insulator sheath surface, duplex tension string interval is decided to be 700mm.

2.2 Two composite insulator tension string grading ring design

Electric field of composite insulator sheath and hardware fitting surface is required to be limited within certain range, meanwhile ensure no corona discharge is generated on the grading ring surface, in consideration of margin reserved for actual production, requires limitation for electric field intensity of hardware fitting and grading ring surface within 20kV/cm, maximum electric field intensity shall be limited within 5 kV/cm.

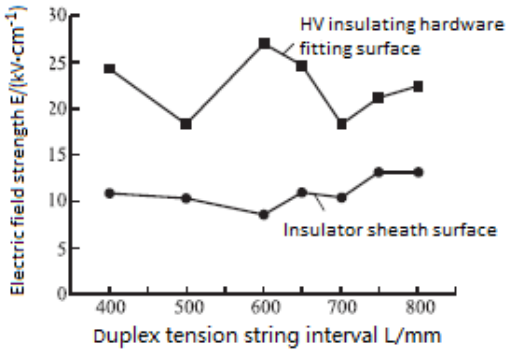

Figure 4 Effect of Geometry Parameter L of Tension Insulator String on the Electric Field

Take grading ring structure parameter on figure 3 (ring diameter, tube diameter d, raised height H) as variate, value optimized interval 700mm, to conduct design of grading ring structure optimization. First take into consideration of the large racetrack ring, take two structure parameters as constant, after modifying the other, calculate maximum field strength of high voltage end hardware fitting surface, insulator sheath and grading ring surface, see result as shown on figure 5.

Calculation result shows that tube diameter d=160mm, ring diameter D=1200mm, raised height H=500mm is optimal configuration for duplex tension string large racetrack ring.

Small racetrack ring optimization design is on basis of large racetrack ring optimal configuration. Take two of the small racetrack structure parameters D, d, H as constant, vary the other, calculate maximum field strength of high voltage end hardware surface, insulator sheath, large grading ring and small grading ring surface, see figure 6 for calculation result.

The result shows that tube diameter d=30mm, ring diameter D=600 mm, raised height H=100mm, which is the optimal configuration for duplex tension string small racetrack ring.

Apply designed optimal configuration for both large and small racetrack ring, electric field distribution on duplex tension string hardware fittings, insulator sheath surface, large racetrack ring and small racetrack ring surface as shown on figure 7. Maximum electric field intensity for tension string composite insulator sheath is 2.47 kV/cm, maximum field strength on hardware fittings surface is 5.12 kV/cm, maximum field strength on large racetrack ring surface is 16.19 kV/cm, maximum field strength for small racetrack ring surface is 10.37 kV/cm. Electric field intensity satisfies design requirements and within admissible range.

Figure 8 shows potential distribution along duplex insulator tension string before and after installation of grading ring, observed from figure 8, potential distribution along composite insulator is evidently improved.

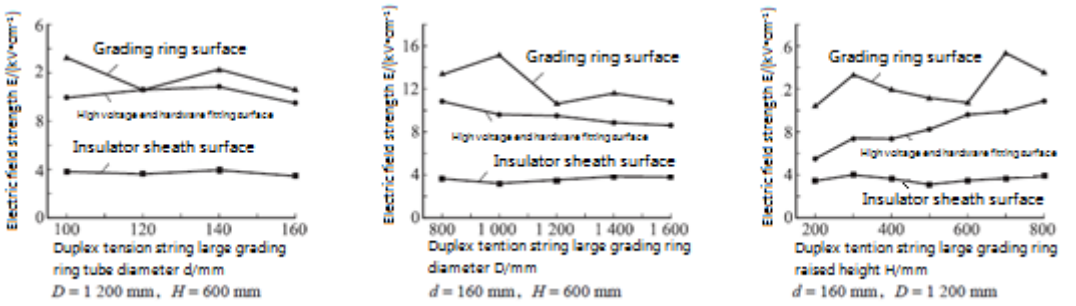

Figure 5 Effect of Geometry Parameter of Larger Grading Ring on the Electric Field

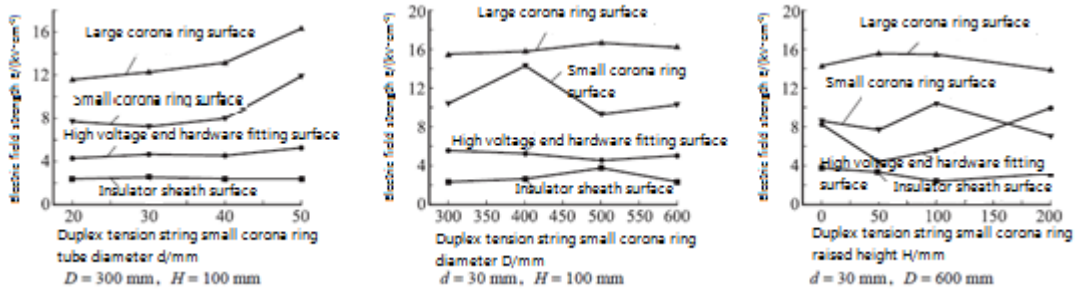

Figure 6 Effect of Geometry Parameter of Smaller Grading Ring on the Electric Field

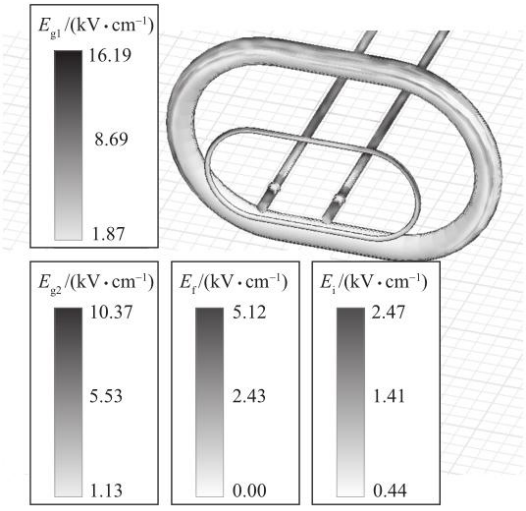

Figure 7 Electric Field Distribution of Grading Rings Insulator Tension String

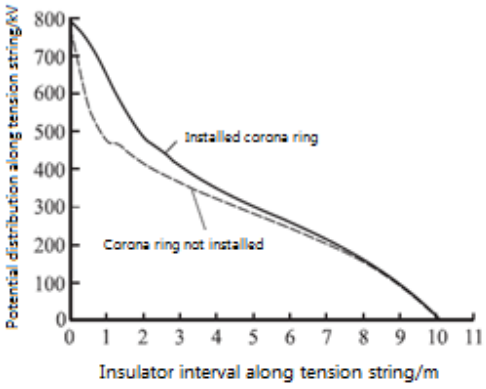

Figure 8 Potential Distribution along Composite Insulator Tension String

3. Summary and discussion

Design proposal for composite insulator tension string is shown as table 1, due to minor influence of the low voltage end arcing ring on electric field, it is recommended to apply the same design as the smaller ring at the high voltage end.

Table 1 Design of Grading Rings for Tension String

L/mm	Grading ring	d/mm	D/mm	H/mm
700	Large racetrack ring	160	1200	500
	Small racetrack ring	30	300	100

Conclusion for the design of large and small racetrack ring of line-shaped composite insulator tension string as following:

4) On condition that field strength on insulator surface when tube diameter for large racetrack ring is 120mm is lower than 100mm tube diameter, when tube diameter enlarge from 120mm, influence on insulator surface field strength goes through minor fluctuation, optimal tube diameter is 160mm, which already satisfies design requirement, keep enlarging tube diameter

is not as economic.

5) Along with increase of large racetrack ring diameter D, field strength on insulator surface is first reduced and then increase, optimal ring diameter is 1200mm.
6) Enlarge raised height H of the large racetrack ring, field strength on insulator high voltage end hardware fittings also increases, field strength on insulator sheath surface experience minor change, no significant regularity is detected, optimal raised height is 500mm.
7) Under circumstances of optimal configuration of large racetrack ring, optimal small racetrack ring diameter is 30mm, optimal ring diameter 300mm,optimal raised height 100mm.
8) After installation of grading ring, electric field and potential distribution on insulator surface are evidently improved, potential drop along 1m high voltage end tension string fall from 323.13kV to 148.15kV.

4. Conclusion

The solution to uneven potential field strength distribution at insulator high voltage end is normally installation of grading ring. After installing grading ring, maximum field strength transfer from insulator surface to grading ring surface, efficiently improve electric field distribution on insulator surface. Tension string and grading ring optimal configuration can be solved via on-site test study, yet with high test cost and difficult operation, therefore finite element calculation is an economic and efficient way to solve electric field distribution.

To provide rational grading ring configuration scheme for ± 800kV DC power line composite insulator tension string, this paper established 3D model for ± 800kV DC power line composite insulator tension string pole tower and split conductor, calculate electric field distribution for line-shaped tension string composite insulator, obtained optimal interval for line-shaped duplex tension string.

This paper also studied influence of grading ring structure parameter on electric field distribution, obtain the outcome of optimized design. Application of designed grading ring structure, efficiently improved field strength distribution on insulator surface, limit insulator sheath, high voltage end hardware fittings and grading ring surface field strength within range of design.

Reference:

[1] LIU Zehong. Present Situation and Prospects of Applying Composite Insulators to UHF Transmission Lines in China [J]. Power System Technology, 2006, 30(12):1□7.

[2] WANG Jingyi. Discussions on Application of Composite Insulators on UHVDC Projects [J]. Power System and Clean Energy,2010,26(5):15−8.

[3] SU Hongtian, QI Xu, WU Yun. Study on Market Demand of UHVDC Power Transmission in China [J]. Power System Technology, 2005, 29(24):1□4.

[4] ZHANG Rui, WU Guangya, YUAN Tian, et al. Development Historyand Direction of Composite Insulators on Important ManufactureTechnique [J]. High Voltage Engineering, 2007, 33(1):106 110.

[5] WU Jie, MA Jing, ZHANG Jianxing. Analysis of Variation Trend ofInsulator Non-Soluble Deposit Density Based on Grille Curve [J].Power System and Clean Energy,2010,26(5):69.

[6] [J] ZHANG Wenliang, WU Weining, HU Yi, et al. The InsulatorsDevelopment and Application of Our Country [J]. High VoltageEngineering, 2004, 30(1):10□12.

[7] MA Linyang, ZHANG Xiangquan,LI Yunge,et al. Fault Analysisof the 750 kV GIS Supporting Insulators[J].Power System and Clean Energy,2009,25(12):33□35.

[8] WU Guangya, CAI Wei, LUO Zhenhai. The Operation CharacteristicAnalysis of Composite Insulators [J]. High Voltage Engineering, 2000, 26(2):59□62.

[9] ZHU Haitao, WAN Rongxing, FANG Yong ,et al. Studies on IonMigration Mechanism of DC Suspension Insulators [J]. Power System and Clean Energy,2008,24(3):30−36.

[10] TENG Guoli, XU Lixian, ZHANG Haian. Revelation About Composite Insulator Used for ±500 kV Tension Strings[J]. High Voltage Engineering, 2005, 31(4):90□91.

[11] ZHANG Rui, WU Guangya. Application Research and Operation Testing Analysis for Tension String Consisted of ±500 kV DC Composite Insulators [J]. High Voltage Engineering, 2006, 32(9):129□131.

[12] FAN Lingmeng, XIAO Yong, ZHOU Huamin. Operation Condition Analysis of Tension Strands Consisting of Composite Insulators on Probation for Polluted Region in Guangdong Power

Grid [J]. Power System Technology, 2006, 30(12):37□41.

[13] WANG Kun,GU Yonggang,PENG Qingning, et al.Research on Preventing Icing Flashover of Ultra High Voltage Transmission Line Glass Insulator Chain in Mountains[J].Power System and Clean Energy,2008,24(8):9-12.

[14]MAO Fenglin , WANG Xuesong. Effect s of Grading ring of Polymer Insulator on the Field Distribution [J]. High Voltage Engineering, 2000, 26(4):39□42.

[15] SIMA Wenxia, YANG Qing, SUN Caixin, et al. Optimization of Grading ring Design for EHV Composite Insulator Using Finite Element and Neural Network Method [J]. Proceedings of the CSEE, 2005, 25(17):115□120.

[16] ZHAO Tiebin, COMBER M G. Calculation of Electric Field and Potential Distribution along Non-Ceramic Insulators Considering theEffects of Conductors and Transmission Towers [J]. IEEETransactions on Power Delivery, 2000, 15(1):313□318.

[17] ZHANG Bo, HAN Shejiao, HE Jinliang, et al. Numerical Analysis of Electric-Field Distribution around Composite Insulator and Head of Transmission Tower [J]. IEEE Transactions on Power Delivery, 2006,21(2):959□965.

[18] LIU Zhen, BIAN Xingming, WANG Liming, et al. Design of Grading Ring of UHVDC Transmission Line [J]. High Voltage Engineering, 2006, 32(12):137□141.

[19] BIAN Xingming, ZHANG Fuzeng, WANG Liming, et al. Design of Grading Rings for 1000 kV AC Composite Insulator [J]. High Voltage Engineering, 2009, 35(5):980□986.