How to Optimize the Grading Ring for 330kV Transmission Line

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Abstract: The simulation and calculation model is set up by the finite element method; the surface field strength of grading rings of 330kV transmission line with 4 kinds of different pipe diameters and 2 kinds of different curvature radius are calculated and analyzed. The visible corona tests are conducted at the UHV outdoor test field and AC test base climate lab to obtain the surface field distribution of grading rings with different structure types, comparison results and curves of corona inception voltage at different altitudes. The research results indicate that optimization of pipe diameter and curvature radius can effectively reduce the surface field strength of grading rings and enhance the corona inception and extinguishing voltages.

Key words: high altitude, grading ring, corona discharge, finite element method, electric field distribution, altitude correction

Introduction

Harms caused by corona discharge such as corona noise, wireless interference or electrostatic effect attract increasing attention from people. Results of relevant studies indicate that the corona discharge of 330kV AC transmission line grading rings in northwest high-altitude area is serious and grading rings have become one of main parts causing electromagnetic pollution. Given characteristics of corona discharge, it is difficult to meet the requirements of high-altitude operation.

The factors affecting corona discharge of grading rings are complicated. Parts where the field strength is high are mainly located at the curves of uneven field strength distribution. The radius of electrode curvature at the curve is small so it is likely to have partial corona discharge; meanwhile, the discharge of grading rings are easily affected by operating conditions, including pressure, temperature and humidity etc.

In this paper, the finite element method is used to set up a simulation model for grading ring; its surface electric field distribution is calculated and analyzed with the influence of surrounding wires, towers and equipment into consideration; corona characteristics of grading rings of many structures are studied at UHV outdoor test filed of China Electric Power Research Institute and UHVAC test base climate lab; the ultraviolet imager is used to measure corona parameters and get characteristic curves; the altitude correction method which meets the requirements of project is put forward.

1. Modeling and Analysis

1.1 Modeling of strain insulator grading ring

The strain insulator of 330kV AC transmission line is used to make modeling; the model of grading ring is shown in Fig.1. The nominal height of model is 15.5m; the length of strain insulator is 3255mm; the wire is aluminum conductor steel-reinforced cable 2xLGJ-300/40 with the diameter 23.9mm; split spacing is 23.9 while the pipe diameter of grading ring is 32mm.

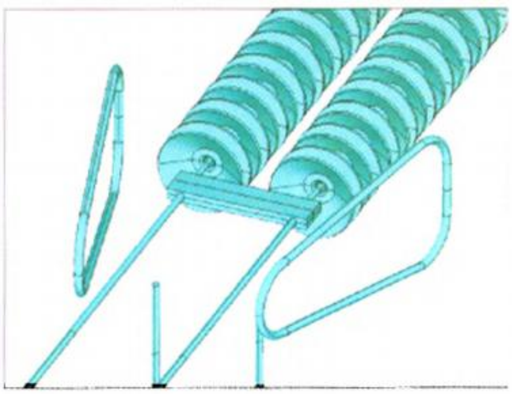

Fig.1. Calculation model of grading ring

According to the model shown in Fig.1, the applied voltage of single phase in the calculation is the voltage peak of maximum running voltage. It can be seen that the maximum field strength of grading ring surface with the pipe diameter 32mm is 27.8kV/m shown in Fig.2. The value is close to the critical field strength under standard conditions. To facilitate the usage on the high-altitude area, measures should be taken to improve electric field distribution, reduce the partial high field strength and enhance the whole dielectric strength of insulation structure. Two methods - increase in the pipe diameter of grading ring and improvement in the radius of curvature are utilized to optimize the design.

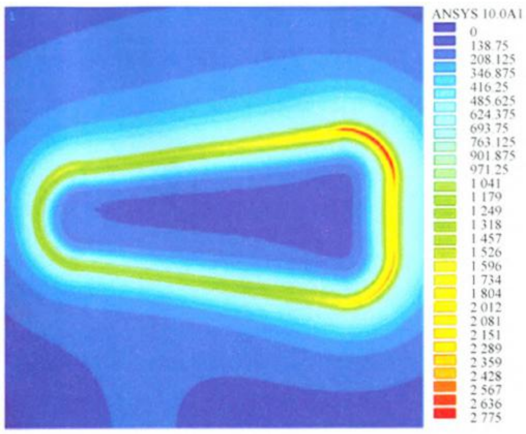

Fig.2 Surface electric field distribution of grading ring (the diameter of pipe: 32mm)

1.2 Increase in the pipe diameter of grading ring

Do calculation according to three pipe diameters: 42mm, 45mm and 50mm. Through the simulation calculation, the maximum field strength corresponding with three different diameters is 24.1kV/cm, 23.1kV/cm and 21.7kV/cm respectively. See the Tab.1.

Tab.1 Electric field strength of grading rings with different pipe diameters

Pipe diameter/mm	Strength / (kV·cm^{-1})	Decreasing amplitude/%
32	27.8	
42	24.1	13.3
45	23.1	16.9
50	21.7	21.9

1.3 Increase in the radius of curvature

The electric field strength of grading ring surface is proportional to surface charge density. At the curve, the radius of curvature is small and the surface charge density is great, so the strength of electric field is high and the corona is likely to happen. Its field strength can be effectively reduced through increasing the radius. Through simulation modeling, the radius increases from 120mm to 220mm, which is shown in Fig.3. Following the optimization, the maximum field strength is 21.6kV/cm. Please see Fig.4. The value is close to the one of grading ring with the diameter 50mm.

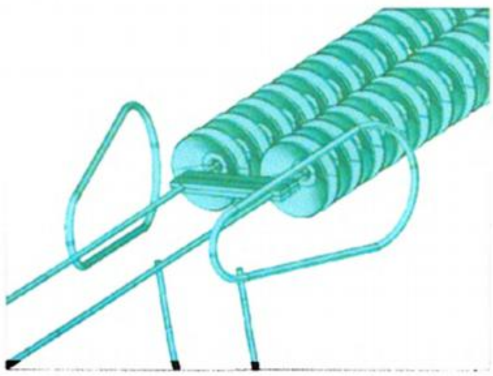

Fig.3. Optimized model of grading ring

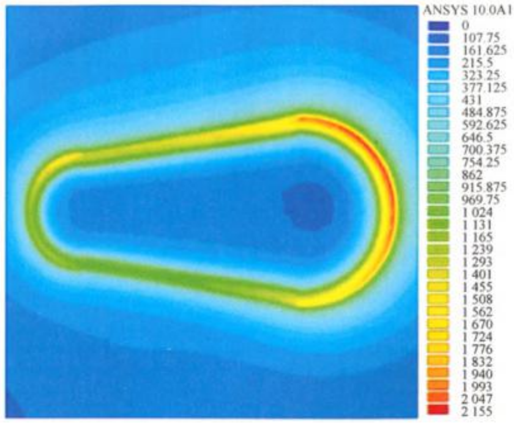

Fig.4 Surface electric field distribution of grading ring (pipe diameter: 42mm)

But an increase in the pipe diameter directly affects the production cost of grading ring. Through optimizing the design of structure and increasing the radius of curvature, the surface field strength can be reduced and requirements are met. In addition, production cost is also cut.

2. Corona Test of Grading Ring

2.1 Test conditions and object of study

The power supply of UHV outdoor test site is power frequency test transformer with 2250kV nominal voltage and 9000kV·A nominal capacity. In the UHV climate lab, the diameter of tank is 22m and the height is 32m. The atmosphere pressure can be reduced to 50kPa, simulate different altitudes, the test power supply is power frequency test transformer with 1500kV nominal voltage and 6000kV·A nominal capacity. The length of aluminum wire is 8m and split spacing is 400mm. One end of aluminum is connected with grading ring while the other end is connected with shielding ring with the external diameter 1m; the test object is 4m away from the ground. The grading ring with two kinds of pipe diameters 32mm and 42mm is used to carry out the corona inception voltage tests. Meanwhile, to study the influence of altitude on the inception voltage, the corona tests of grading rings at different simulated altitudes are done at the UHVAC test base climate lab.

2.2 Test method and observing equipment

In this paper, a ultraviolent imager is used to observe and record the whole process of corona discharge. The ultraviolent imager shown in Fig.5 is placed 13m away from grading ring. Suspend two ends of prepared strain insulator under cross-arm by means of insulation ropes. Hang the whole object under the bushings by crane at the climate lab. When testing, boost the applied voltage gradually until the ultraviolent imager shows that the corona generates; keep for 5 minutes and mark the voltage as the inception voltage of grading ring corona; then reduce the applied voltage until the corona disappears; record this voltage as the extinguishing voltage; keep for 5 minutes. Repeat the procedure three times and take the average value as the inception and extinguishing voltage of corona.

Fig.5 Ultraviolet imager

3. Test Results and Analysis

3.1 Optimization test of grading ring

The optimization test of grading ring is carried out at the outdoor test site. The corona discharge tests are conducted for the grading ring before and after optimization. Before optimization, the pipe diameter is 32mm while the radius of curvature is 120mm. After optimization, there are two structures: ① to increase pipe diameter to 42mm and not change the radius; ② to increase pipe diameter to 42mm and the radius of curvature to 220mm. Results of corona tests for three types are shown in Tab.2.

Tab.2 Corona test results of grading rings with different types

Structure	Inception voltage/kV	Extinguishing voltage/kV
Diameter mm	245	228
Pipe diameter 42mm (radius 120mm)	296	289
Pipe diameter 42mm	307	297

(radius 220mm)		

From the Tab.2, it can be seen that the corona inception and extinguishing voltage rise by 20.8% and 26.8% respectively after optimizing the pipe diameter; after further improvement in the radius of curvature, the inception and extinguishing voltage goes up by 25.3% and 30.3%. Results indicate that two methods are workable.

3.2 Simulation of high-altitude test

To get the law between corona characteristics and the altitude, the corona discharge test of grading ring with the pipe diameter 42mm is conducted at the climate lab where the pressure is changed to simulate the 19-4300m altitude. Test results are shown in Fig.6. In the Fig.6, U_i is inception voltage, kV; H: altitude, km.

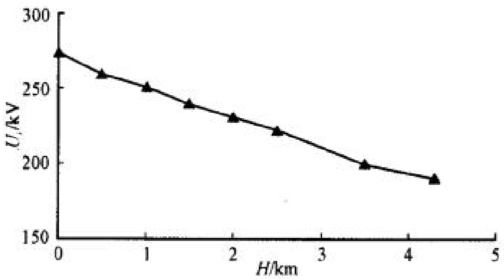

Fig.6 Corona inception voltage of grading ring at different simulated altitudes

According to the above test results, the corona inception voltage reduces as the altitude rises. At 4300m the corona inception voltage is 190kV, down by 30.4% than 19m. Hence, when the grading ring works at high altitude area, the problem - the high altitude causes the reduction of corona inception voltage and serious corona discharge must be taken into account.

4. Altitude Correction of Corona Inception Voltage for Grading Ring

At present, there are two methods about altitude correction according to national and international standards:

GB311.1-1997 K=1/(1.1-0.1H)

In the formula:

H: altitude, km

The method is applicable for the voltage correction of internal insulation and dry-type transformer insulation test between 1000m and 4000m. Take the 1000m as the start point and the correction coefficient under 1000m is 1.

IEC 60071-2:1996 presents the correction coefficient:

$$K = e^{m(H/8.15)}$$

In the formula:

m: correction coefficient related to voltage type and gap structure

m=1 for short power frequency test.

The available correction method is based on finite test data at low altitude. In this paper, several simulated altitudes are selected to obtain the correction method based on test data. Set the corona inception voltage of grading ring at 19m as the standard value and the following data can be obtained.

Tab.3 Correction coefficients of different methods

Altitude/km	Corona inception voltage/%	Correction factor
0.019	100.0	1.00
0.5	94.9	1.05
1.0	91.9	1.09
1.5	87.9	1.14
2.0	84.6	1.18
2.5	81.3	1.23
3.5	73.3	1.37
4.3	69.6	1.44

According to the Tab.3 the correction coefficient:

$$K = 1.001e^{0.085H}$$

The above three methods are used to correct the inception voltages of simulated altitudes. Compare the correction results with those of 19m altitude to obtain the correction errors shown in Tab.4.

Tab.4 Correction errors of different methods

Altitude/km	Correction error/%		
	GB311.1	IEC60071-2	Method
0.5	−5.13	0.87	−0.91
1.0	−8.06	3.94	0.20
1.5	−7.46	5.68	−0.03
2.0	−5.98	8.15	0.40
2.5	−4.33	10.51	0.67
3.5	−2.32	12.56	−1.26
4.3	3.88	17.96	0.41

The GB311.1 correction error is negative deviation within 3500m and the maximum deviation is -8.06%; the IEC60071-2 correction error is positive deviation, which is proportional to the altitude. The deviation absolute value can be controlled within 2% through the correction method obtained in this paper. Please refer to the method proposed in the paper when designing the grading ring of high-altitude area transmission line. Select the size of equipment according to the altitude to meet the requirements.

5. Conclusions

1) Use the finite element method to perform the simulation calculation of electric field and set up the simulation model to obtain surface electric field distribution. When increase the pipe diameter of grading ring to 42mm, the maximum field strength reduces to 24.1kV/cm; further increase the radius of curvature to 220mm, the surface maximum field strength falls to 21.6kV/cm.

2) Results of corona tests indicate that the optimization of pipe diameter can improve the corona inception voltage and extinguishing voltage by 20.8% and 26.8% while the radius of curvature by 25.3 and 30.3%.

3) As the altitude rises, the corona inception voltage of grading ring reduces and the discharge becomes more serious. The deviation absolute value can be controlled within 2% through the correction method obtained in this paper. Please refer to the method proposed in the paper when designing the grading ring of high-altitude area transmission line.

The builders worked on wooden platforms suspended by ropes from the roof of the building.