Analysis of Electric Field of 800 kV UHVDC Bushing

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***Abstract** - The reason for flashover of the bushing during operation has been analyzed in this paper. The 2D model of UHVDC bushing was modeled using COMSOL Multiphysics software. In this, Finite Element Method analysis is employed for determining the distribution of electric field and potential along the length of the bushing. In the original model, bushing without grading ring at the flange side, the non-uniform filed distribution is encountered and the joint of flange, shed and sheath has maximum electric field which provides the way for flashover. As a remedy, this paper proposes a model of adding grading ring at the flange end to reduce the field intensity and for uniform distribution of electric field. From the results, it is evident to use bushing with grading ring at the flange side for better performance and to reduce the probability of flashover.*

***Keywords:** Finite Element Method, Grading ring, Composite bushing, flashover.*

I. INTRODUCTION

There is an imbalance in geographical distribution between the energy sources and the power loads in China. Due to its advantages of long distance, high capacity, low loss and saving land resource, etc, the 1000 kV ultra-high voltage (UHV) transmission system has got rapid growth. Converting transformer bushing is the key equipment to develop the ultra-high voltage power transmission project. Converting transformer bushing provides the connection of the converting transformer, converting semiconductor valve and transmission lines. When in operation, bushing not only have to bear the action of AC voltage, DC voltage, superposition of AC&DC voltage, lightning surge, switching surge, and etc, but also have to bear the impulse voltage caused by polarity inverting when phase is converting or the power transmission of the system is reversing. Therefore, the design requirements of converting transformer bushing are higher than that of common transformer bushing. Gas filled composite bushing is extensively used for UHVDC project due to their superior properties such as they can bear additional mechanical stresses, temperature, and can even operate in tough conditions. Bearing in mind the electric field behavior, the voltage distribution along the surface of the bushing is uneven. Thus the field concentrated in the flange edge can increase the probability of flashover along the bushing surface. Thus in order to find out the reason for the flashover of the bushing through the flange, 2D model of 800 kV bushing is modeled and the field distribution along the length of the bushing is determined to calculate the weakest portion. The design optimization for the grading ring is carried for better performance.

II. HIGH VOLTAGE BUSHINGS

High Voltage Bushing is employed for the safe passage of conductor. The profile of non-ceramic bushing is shown in Figure 1. It consists of the following main parts: Copper has been chosen as the material for conductor with the conductivity of 5.8e7. The basic insulation is Sulphur-hexafluoride (SF6), which is not poisonous non-flammable and has good dielectric, arc-extinguishing and thermal capabilities. These characteristics enable it to be widely used in MV and HV equipments. The main SF6 insulating features are non aging, compressibility, less sensitivity to humidity and air, possibility of controlling the dielectric strength through the control of SF_6 gas density (pressure).

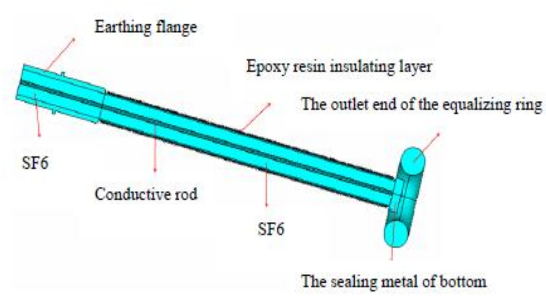

Fig.1 Profile of high voltage bushing

The external insulator is made of composite insulator (resin fiberglass envelope covered by silicone sheds) glued to the metal parts. This system offers high mechanical strength during normal and above normal service conditions. The alternating shed configuration (short long sheds) is the most effective solution and has been proven by salt spray tests. Other benefits include better behavior against weather elements, such as pollution and rain, due to the hydrophobic property of silicon rubber, high mechanical withstand in case of impact, shocks and/or vibrations during handling, transportation or in service, such as for seismic activity, higher safety for personnel and equipment in case of an internal fault (explosion-proof design). The flanges of the insulators, are made of cast aluminum and are fastened with screws and nuts and provided with O-ring seals.

III. ANALYSIS USING FINITE ELEMENT METHOD

The electric field analysis of the UHVDC bushing along the surface of is more complicated due to complex internal and external insulation structure. The failure of the external insulation is mainly due to flashover during the test. Thus the key for solving the flashover problem is mainly employed with calculating the electric field of UHVDC bushing accurately. For calculating the electric field of external insulation of high voltage electrical apparatus, there are many methods available including boundary element method [12], Finite element method [6], finite element boundary element combined method [15,16] and CSM-Finite element combined method [7]. BEM is simple and can obtain direct and accurate solution of electric field and is used to calculate open boundary field. The complex model occupies huge computational memory and adds difficulty to the computation as the stiffness matrix is a full coefficient matrix.

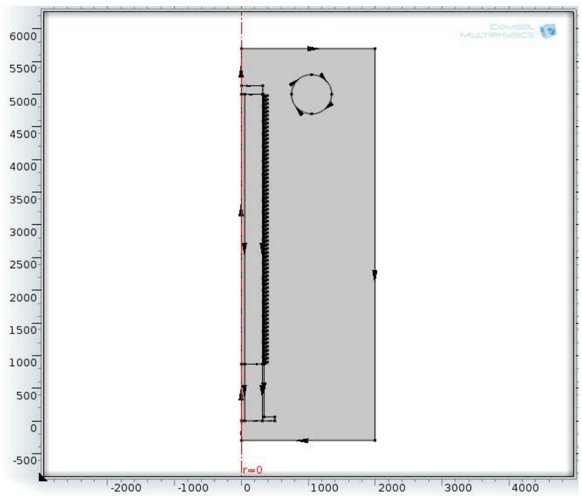

Fig. 2. 2D axisymmetric FEM model of high voltage bushi

In the finite element method, the stiffness matrix is zonal sparse matrix and the computational memory is low and thus it is used to achieve better results with greater efficiency. Considering the model, accuracy of computational speed and result, COMSOL Multiphysics software is adopted in this paper.

The 2D axisymmetric simulation model of 800 kV bushing on COMSOL Multiphysics is shown in Fig. 2. The materials used in the modeling of bushing have to be paid great attention such as flange, shed, sheath, conductor and external insulation. The material properties i.e., permittivity and conductivity of each material in the model are tabulated and shown in the Table I. During discretization of the model, fine partition is carried out to ensure the accuracy of the calculation.

TABLE I. MATERIAL PROPERTIES USED FOR BUSHING MODELING

Material	Relative permittivity, ε_r	Conductivity σ, (s/m)
Air background	1.000536	0
copper rod	1	5.998e7
Aluminum	1	3.774e7
Silicone rubber	4.3	2.5e-15
Epoxy resin	3.6	1.0e-14
SF_6 insulation	1.002026	0.2e-18

The boundary conditions employed to the model are set according to experimental conditions. The potential of about 960 kV is loaded to the conductor and metal cap of the bushing. A potential of 0 V is loaded to flange and external insulation.

IV. ELECTRIC FILED ANALYSIS

A. Analysis of the Test Model

FEM analysis is conducted on the bushing model. During the post processing stage, the potential distribution and the field intensity are observed and analyzed. The potential distribution of the model is quite correct. Due to reasonable discretization and satisfactory calculation accuracy, the overall electric field distribution of the bushing has clearly visible contour lines. Fig. 3 shows the partial enlarged figure of field distribution contour plot before adding grading ring.

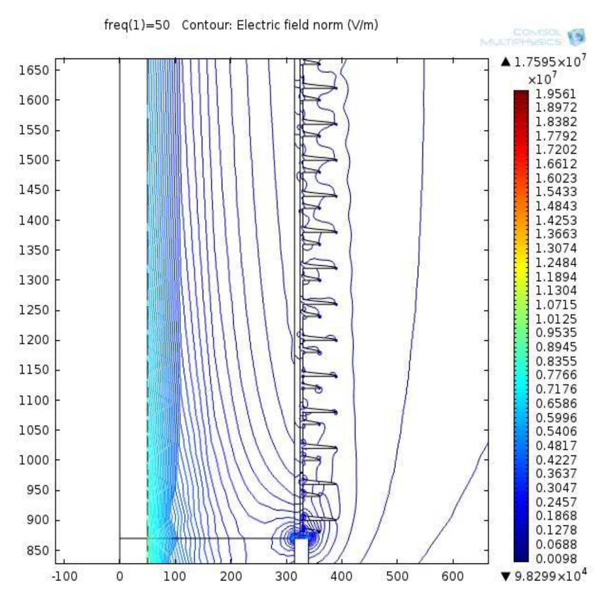

Fig. 3. Enlarged figure of field distribution contour plot before adding grading ring

The electric field intensity around the surface of the flange increases from side walls to shed and sheath. The joint of flange, shed and sheath has field intensity reaching 1.84 kV/mm. According to the result, the maximum field intensity at the shed and sheath is 1.84 kV/mm and around the grading ring, the field intensity is 1.17 kV/mm. The joint of flange, shed and sheath is the weak point on the surface of the bushing, which is the starting point of flashover.

Fig. 4 shows the distribution of electric field of the original model along the length of the bushing. To limit this problem, a grading ring is added at the flange side such that the field intensity is reduced and the occurrence of flashover is reduced.

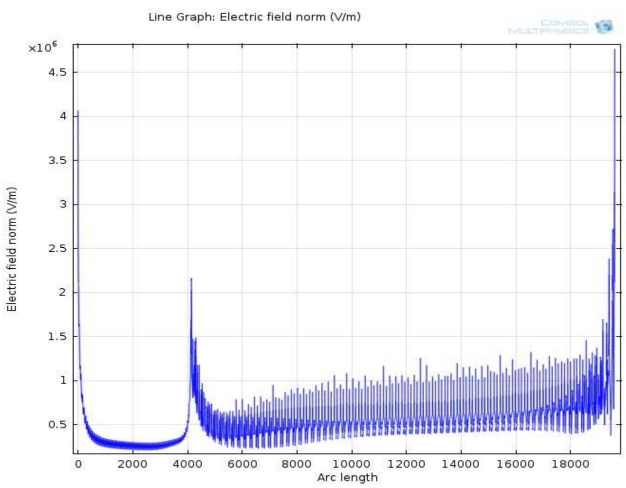

Fig. 4. Electric field distribution of the original model

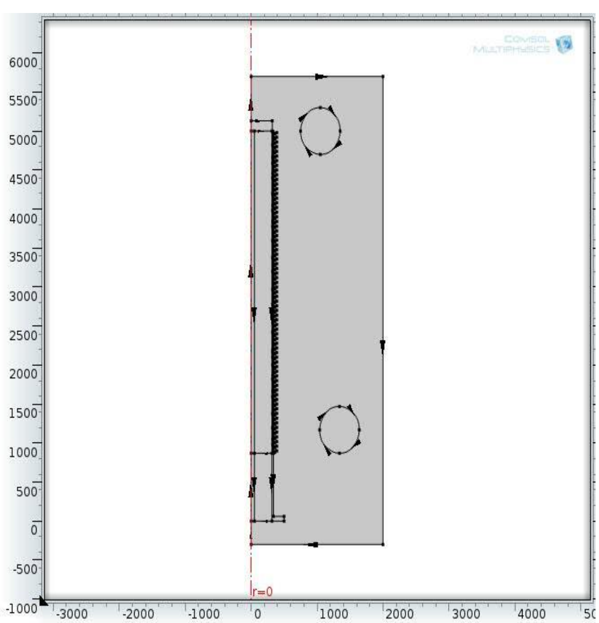

Fig. 5. 2D axisymmetric FEM model after adding grading ring

B. Analysis of the Model after Adding Grading Ring

The larger diameter of the bushing at the flange side is considered and a grading ring is added at the flange side but the ring diameter should be greater than that of the high voltage side and the pipe diameter remains the same. The configuration parameters of the grading ring at the flange side is considered to be: diameter of the ring: 238cm, pipe diameter: 60cm. The analysis is made on the electric field distribution around the flange, shed and sheath, grading ring at the flange side and high voltage side.

The grading ring at the flange side is loaded with potential of 0V and the boundary conditions remain the same. Fig. 5 shows the 2D axisymmetric FEM model of the bushing after adding grading ring. The computation of electric field and the potential distribution is quite complicated. The electric field is discretize into 2 lakh mesh elements.

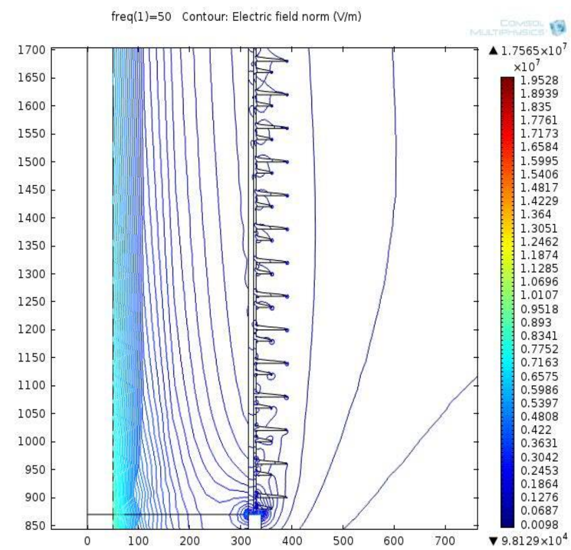

Fig. 6. Enlarged figure of field distribution contour plot after adding grading ring

Fig. 6 shows the partial enlarged figure of field distribution contour plot before adding grading ring. The field intensity increases from the side walls of valve hall to the shed and sheath. The maximum field intensity at the joint of shed and sheath is 1.49 kV/mm and around the grading ring, the field intensity is 0.451 kV/mm..

V. CONCLUSION

Thus the 2D bushing model was modeled and the electric field intensity is computed. Referring to the calculations, comparisons has been made on the electric field intensity around the flange, shed and sheath of both the original model and model with grading ring at the flange end. The field intensity after adding grading ring has been reduced considerably. From Table II, it is inferred that the field intensity around the flange reduced to 26.6% and around the surface of shed and sheath, the field intensity has been reduced to 31.1%.

TABLE II. VARIATION OF FIELD INTENSITY AFTER ADDING GRADING RING

Part	Flange	Shed and Sheath	Grading Ring Added
Before adding grading ring	1.84	2.16	0.451
After adding grading ring	1.35	1.49	
Variation (%)	-26.6	-31.1	

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