# Optimization of High Voltage Electrodes for Post Insulators used in 400kV Transmission System

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***Abstract :*** Insulators for Extra High Voltages (EHV), exceeding 200 kV, may have grading rings installed at their terminals. The design and testing of the HV electrodes (Corona rings, Bus conductors etc.) is most important because high voltage fields affect the performance of equipments with regard to voltage stresses near the HV ends and also influence the voltage distribution. This paper describes the optimization of electric field and potential distribution along Station post insulators of rating 420kV. A number of different corona ring geometries were compared. The effect of changing ring diameter, overall diameter and placement along the insulator were investigated. Modelling and simulation of high voltage electrodes for the EHV bus post insulators is done by using coulomb 3D software, which used Boundary Element Method (BEM). The results of the simulation studies, carried out to optimize the High Voltage Electrodes (Corona rings, Bus conductors etc.) geometries that have to be provided at the live end of 400kV station post insulators, are presented. The corona onset gradients for the various configurations of the Grading ring were calculated and compared with the maximum gradients obtained in the simulation studies.

***IndexTerms* - Insulators,Coronarings,BusConductor.**

## I. INTRODUCTION

Insulators are very important elements of electric power systems, especially in the field of electricity transmission. Long-rod post insulators are one of the main devices for the operation of power transmission lines and related substations. In the electrical and mechanical point of view, these insulators should withstand the electric field stress and mechanic field stress. The porcelain post insulators have not only excellent insulation characteristic, but also outstanding mechanical strength. A number of such insulator units are connected together, depending on the system voltage. As each unit has a number of sheds, without any metallic parts, the voltage distribution along the surface is more non uniform, compared to that of a string of cap and pin insulators used in the transmission towers. The electric field distribution of porcelain insulators with hardware fittings at line and ground end distorts badly around the line end. To improve the voltage-sharing characteristic and safe operation reliability of EHV/UHV long-rod post insulators, grading rings are usually employed to improve the electric field distribution of insulators.High voltage transmission lines are used for efficient transmission of electrical energy over long distances. For optimal design of line insulators (ceramic/glass, non ceramic), it is important to calculate the electric field and potential distribution along the insulator surface. Knowledge of the surface electric field for non-ceramic insulators is even more critical to avoid corona induced insulator degradation. Several techniques have been developed for the analysis and optimisation of electric field is Boundary Element Method (BEM), Finite difference method (FDM), Finite element method (FEM), Charge simulation method, Monte-Carle method etc. The Corona ring diameter, overall ring diameter and position of the corona ring have an effect on Electric field distribution across the post insulator and also on voltage distribution. The presence of bus bar on top of the insulator has a shielding effect on the grading ring; the models are simulated with the bus bar conductor of appropriate size and length.

## II. METHOD OF CLCULATION

The method of calculation uses a BEM. Numerical electric field analyses can be broadly classified under domain and boundary methods. The domain methods include Finite Element and Finite Difference techniques, while the boundary methods include Charge Simulation and Boundary Element techniques. Domain methods use differential equations and for the purpose of calculation; the domain is divided into regular volume elements. The electric potential is calculated over the region such that it satisfies the given boundary conditions. BEM uses integral equations for calculations and is shown in figure3. Volume integrals are transformed into surface integrals using Green's theorem. Therefore, elements are considered only along the boundary of different materials. The dimension of the problem is reduced by an order of one. The simulation accuracy depends on the number, shape and distribution of boundary elements utilized.

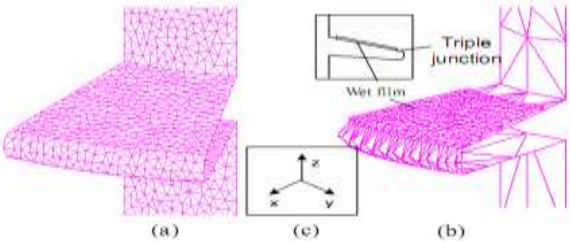

Figure3.3. Boundary elements along a segment of a station post insulator under (a) dry conditions (b) wet conditions (c) co-ordinate axes in Coulomb.

## III. MODELING OF BUS POST INSULATOR

The modeling of bus post insulator is done using one of the 3 dimensional software named as COLOUMB 3D. This software is calculates the electrical field calculations. The geometry of the line post insulator of example is shown in the Figure 2. All the dimension of the insulator is in millimeter (mm). The following points are taken into consideration during simulation.

- The porcelain is used as the material of the insulator.
- The insulator is surrounded by an air.
- The high voltage is applied to the top and zero voltage is applied to the bottom of the insulator.
- The applied voltage is sinusoidal with 50 Hz.
- The insulator is considered as axis-symmetric with two dielectrics.

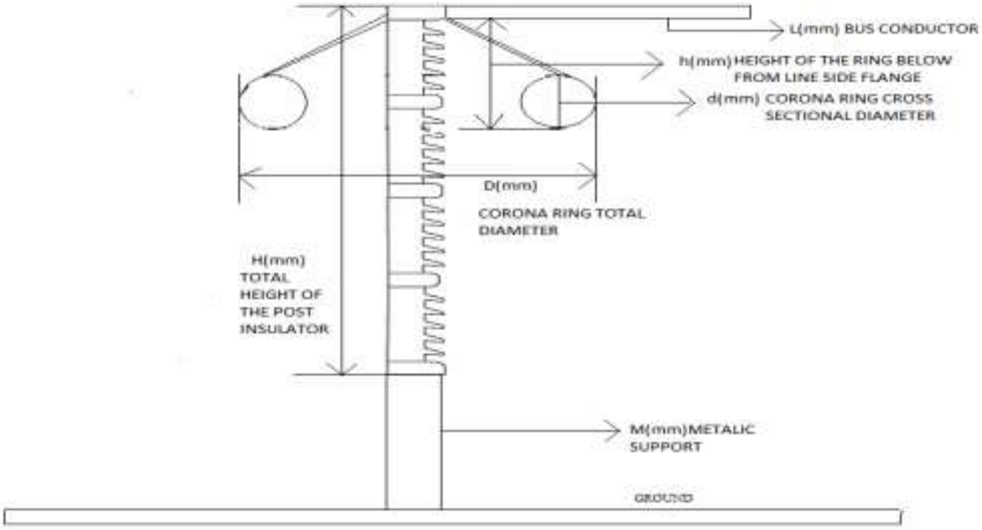

Figure3: The schematic diagram of bus post insulator.

Where H=Total height of the bus post insulator

h= Height of the corona ring below from the line side flange

D = Corona ring overall diameter

d = Corona ring cross sectional diameter

L = Length of bus conductor

M =Height of Metallic support above ground

The electric field and the potential at the tip of the larger sheds lying on a straight line, beginning from the high voltage end, are presented. The corona onset gradient for each grading ring is calculated and compared with the maximum electric field at the surface of the grading rings. The corona onset gradient is calculated using the empirical formula

$$E_d = 32.4 * m * Req-0.3 \quad \text{-------- (1)}$$

Where $R_{eq}$ =2*R1*R2/ R1+R2,

R1 =radius of the corona ring in mm,

R2 =cross sectional radius of the ring in mm,

m =roughness factor (For all cases it is taken as 0.9)

In order to optimize the of high voltage electrode dimensions, different case studies have been carried out by varying various parameters viz., D, d, h. which are shown in the following case studies. For 400kV Bus post insulator, the number of porcelain post insulator units used is two.

## IV. CASE STUDIES

In all cases H is held constant at 3.727m, M at 2.5m and L at 2.5m. The case studies are done by varying the overall diameter D (580mm, 610mm, 650mm) of the corona ring and location H (102.5mm, 115mm) of this corona ring for three different corona ring diameters(40mm, 50mm, 65mm). The high voltage is applied to the top electrode of post insulator and it is 254kV (i.e.(400/√3)*1.11) and 0 voltages is applied to bottom electrode. The different case studies have been carried out by varying various parameters viz., D, d, h are presented in cases 1 to 6.

## Case 1

| D=580mm,h=102.5mm | | | | | | |
|---|---|---|---|---|---|---|
| d=40mm | | | d=50mm | | d=65mm | |
| | Bottom corona ring | Top corona ring | Bottom corona ring | Top corona ring | Bottom corona ring | Top corona ring |
| Bottom point of the ring | 3.40 | 2.43 | 3.96 | 2.02 | 2.72 | 0.82 |
| Top point of the ring | 2.42 | 3.00 | 1.74 | 2.84 | 0.47 | 2.49 |
| Right point of the ring | 2.44 | 2.20 | 2.05 | 1.95 | 1.75 | 1.64 |
| Left point of the ring | 1.29 | 1.33 | 1.03 | 1.36 | 0.78 | 0.9 |
| **D=580mm, h=102.5mm** | | | | | | |
| **d=40mm** | | | **d=50mm** | | **d=65mm** | |
| | Voltage across post | | Voltage across post | | Voltage across post | |
| Unit 1 | 125 | | 125 | | 125 | |
| Unit 2 | 129 | | 129 | | 129 | |

For this case the calculated maximum fields stress obtained E onset from empirical formulae (1) is 9.23kV/cm and we refer case 1 above we observe that the optimized field stress is 3.96kV/cm for d=50mm compared to other two are d=40mm,d=65mm and their field stress are 3.40kV/cm, 2.72k V/cm respectively.

## Case 2

| D=610mm,h=102.5mm | | | | | | |
|---|---|---|---|---|---|---|
| d=40mm | | | d=50mm | | d=65mm | |
| | Bottom corona ring | Top corona ring | Bottom corona ring | Top corona ring | Bottom corona ring | Top corona ring |
| Bottom point of the ring | 3.03 | 2.43 | 3.59 | 1.88 | 2.70 | 0.83 |
| Top point of the ring | 2.40 | 2.99 | 1.55 | 2.80 | 0.44 | 2.56 |
| Right point of the ring | 2.20 | 1.99 | 2.37 | 2.45 | 1.78 | 1.64 |
| Left point of the ring | 1.17 | 1.17 | 1.54 | 1.22 | 0.78 | 0.84 |
| **D=610mm, h=102.5mm** | | | | | | |
| **d=40mm** | | | **d=50mm** | | **d=65mm** | |
| | Voltage across post | | Voltage across post | | Voltage across post | |
| Unit 1 | 125 | | 125 | | 125 | |
| Unit 2 | 129 | | 129 | | 129 | |

For case 2 dimensions the calculated maximum fields stress obtained E onset is obtained in same procedure using equation (1) is 9.25kV/cm and we refer case 2 above we observe that better field stress is 3.59kV/cm for d=50mm compared to other two are d=40mm, d=65mm and their field stress are 3.03kV/cm, 2.70kV/cm respectively.

## Case 3

| D=650mm,h=102.5mm | | | | | | |
|---|---|---|---|---|---|---|
| d=40mm | | | d=50mm | | d=65mm | |
| | Bottom corona ring | Top corona ring | Bottom corona ring | Top corona ring | Bottom corona ring | Top corona ring |
| Bottom point of the ring | 2.99 | 2.12 | 3.28 | 2.01 | 2.00 | 0.58 |
| Top point of the ring | 2.24 | 2.91 | 1.67 | 2.94 | 0.37 | 2.11 |
| Right point of the ring | 1.99 | 1.89 | 2.10 | 2.11 | 1.05 | 0.99 |
| Left point of the ring | 1.52 | 1.16 | 1.11 | 1.32 | 0.32 | 0.89 |
| **D=650mm, h=102.5mm** | | | | | | |
| **d=40mm** | | | **d=50mm** | | **d=65mm** | |
| | Voltage across post | | Voltage across post | | Voltage across post | |

| | | | |
|---|---|---|---|
| Unit 1 | 125 | 125 | 125 |
| Unit 2 | 129 | 129 | 129 |

For case 3 dimensions the calculated maximum fields stress obtained E onset is obtained in same procedure using equation (1) is 9.26kV/cm and we refer case 3.3 above we observe that better field stress is 3.28kV/cm for d=50mm compared to other two are d=40mm,d=65mm and their field stress are 2.99kV/cm, 2.11kV/cm respectively.

## Case 4

| **D=580mm,h=115mm** | | | | | | |
|---|---|---|---|---|---|---|
| **d=40mm** | | | **d=50mm** | | **d=65mm** | |
| | Bottom corona ring | Top corona ring | Bottom corona ring | Top corona ring | Bottom corona ring | Top corona ring |
| Bottom point of the ring | 3.00 | 1.82 | 3.28 | 2.01 | 2.82 | 0.79 |
| Top point of the ring | 1.00 | 2.12 | 1.67 | 2.94 | 0.39 | 2.52 |
| Right point of the ring | 1.92 | 1.56 | 2.10 | 2.11 | 1.80 | 1.74 |
| Left point of the ring | 1.02 | 1.00 | 1.11 | 1.32 | 0.86 | 0.95 |

| **D=580mm, h=115mm** | | | |
|---|---|---|---|
| **d=40mm** | | **d=50mm** | **d=65mm** |
| | Voltage across post | Voltage across post | Voltage across post |
| Unit 1 | 125 | 125 | 125 |
| Unit 2 | 129 | 129 | 129 |

For case 4 dimensions the calculated maximum fields stress obtained E onset is obtained in same procedure using equation (1) is 9.26kV/cm and we refer case 4 above, we observe that better field stress is 3.28kV/cm for d=50mm compared to other two are d=40mm, d=65mm and their field stress are 3.00kV/cm, 2.82kV/cm respectively.

## Case 5

| **D=610mm,h=115mm** | | | | | | |
|---|---|---|---|---|---|---|
| **d=40mm** | | | **d=50mm** | | **d=65mm** | |
| | Bottom corona ring | Top corona ring | Bottom corona ring | Top corona ring | Bottom corona ring | Top corona ring |
| Bottom point of the ring | 2.55 | 1.71 | 3.01 | 2.34 | 2.35 | 0.79 |
| Top point of the ring | 1.31 | 2.91 | 2.24 | 2.88 | 0.47 | 2.51 |
| Right point of the ring | 1.89 | 1.78 | 2.00 | 1.59 | 1.52 | 1.o4 |
| Left point of the ring | 1.35 | 1.00 | 1.91 | 1.99 | 0.58 | 0.67 |

| **D=610mm, h=115mm** | | | |
|---|---|---|---|
| **d=40mm** | | **d=50mm** | **d=65mm** |
| | Voltage across post | Voltage across post | Voltage across post |
| Unit 1 | 125 | 125 | 125 |
| Unit 2 | 129 | 129 | 129 |

For case 5 dimensions the calculated maximum fields stress obtained E onset is obtained in same procedure using equation (1) is 9.26kV/cm and we refer case 3.5 above, we observe that better field stress is3.01kV/cm for d=50mm compared to other two are d=40mm,d=65mm and their field stress are 2.91kV/cm, 2.51kV/cm respectively.

## Case 6

| **D=650mm,h=115mm** | | | | | | |
|---|---|---|---|---|---|---|
| **d=40mm** | | | **d=50mm** | | **d=65mm** | |
| | Bottom corona ring | Top corona ring | Bottom corona ring | Top corona ring | Bottom corona ring | Top corona ring |
| Bottom point of the ring | 3.03 | 2.43 | 3.52 | 1.8 | 2.00 | 0.58 |
| Top point of the ring | 2.40 | 2.79 | 1.55 | 2.83 | 0.37 | 2.11 |
| Right point of the ring | 2.20 | 1.99 | 2.00 | 1.91 | 1.02 | 0.99 |
| Left point of the ring | 1.17 | 1.16 | 1.53 | 1.22 | 0.32 | 0.89 |
| **D=650mm, h=115mm** | | | | | | |

| **d=40mm** | | **d=50mm** | **d=65mm** |
|---|---|---|---|
| | Voltage across post | Voltage across post | Voltage across post |
| Unit 1 | 125 | 125 | 125 |
| Unit 2 | 129 | 129 | 129 |

For case4.6 dimensions the calculated maximum fields stress obtained E onset is obtained in same procedure using equation (1) is 9.26kV/cm and we refer case 3.6 above we observe that better field stress is3.52kV/cm for d=50mm compared to other two are d=40mm, d=65mm and their field stress are 3.03kV/cm, 2.11kV/cm respectively.

## V. OBSERVATIONS

In order to optimize the of high voltage electrode dimensions, different case studies have been carried out by varying various parameters viz., D, d, h which are shown in the above cases. From the above all cases it is observed that the voltage distribution is almost same. But there is difference in field stress control of high voltage electrode. The field stress is varied for different cases. For every case the diameter d of dimension 65mm is obtained is very low field stress compared to calculated field stress value i.e. E onset value. And diameter d of dimension 50mm is obtained is high compared to the 65mm diameter. And the diameter d =40mm is obtained high compared to d =50mm, and more compared to d =65mm.

## VI. RESULTS

Different case studies are performed on the 400 kV Bus Post Insulator containing two porcelain post units. In all cases Voltage distribution along the two post units are same and in linear in nature. The computed field stress values are compared with calculated values for different variations of corona ring overall diameter, location of corona ring diameter and corona ring diameter. From all case studies it is observed that the optimized field stress value and linear voltage distribution obtained for corona ring diameter d=50mm, overall diameter d=580mm, and location of corona ring is at H=102.5mm.The resultant graphs and contours of voltage distribution and electric field intensity for this optimized case are shown in figures 3 to figures 6.

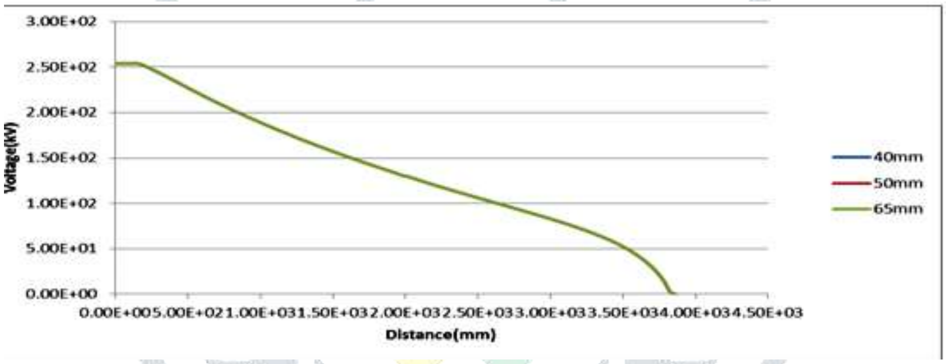

**Figure 3:** Voltage Distribution of D=580mm, d=50mm, H=102.5mm

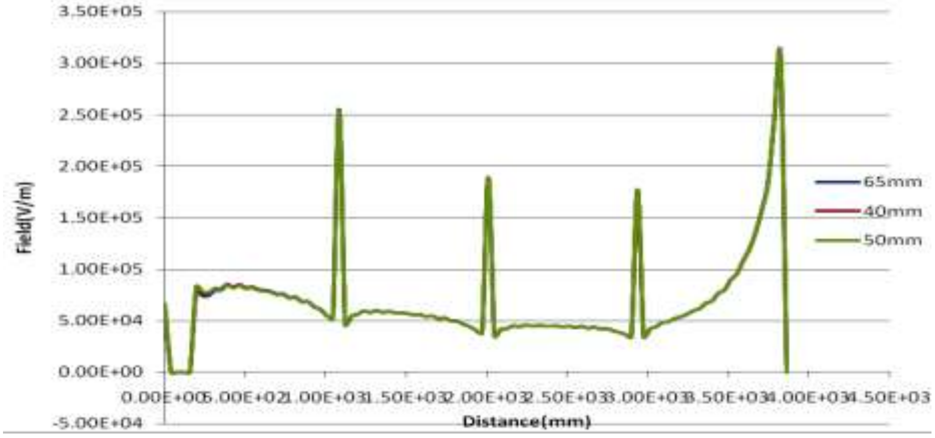

**Figure 4:** Voltage contours of D=580mm, d=50mm, H=102.5mm.

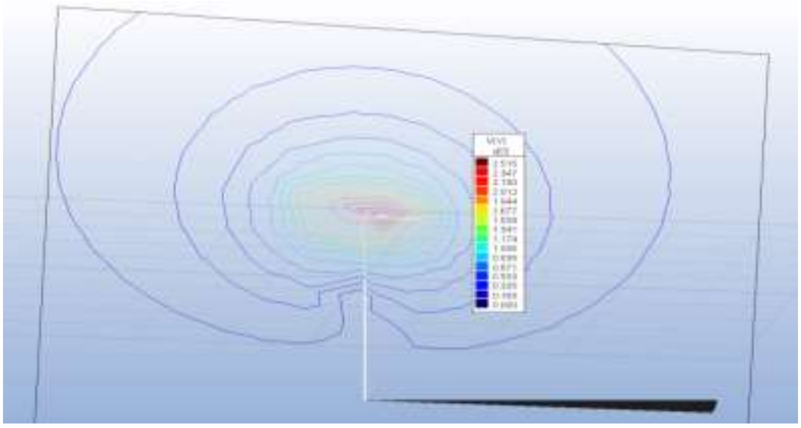

**Figure 4:** Electric Field Distribution for D=580mm, d=50mm, H=102.5mm.

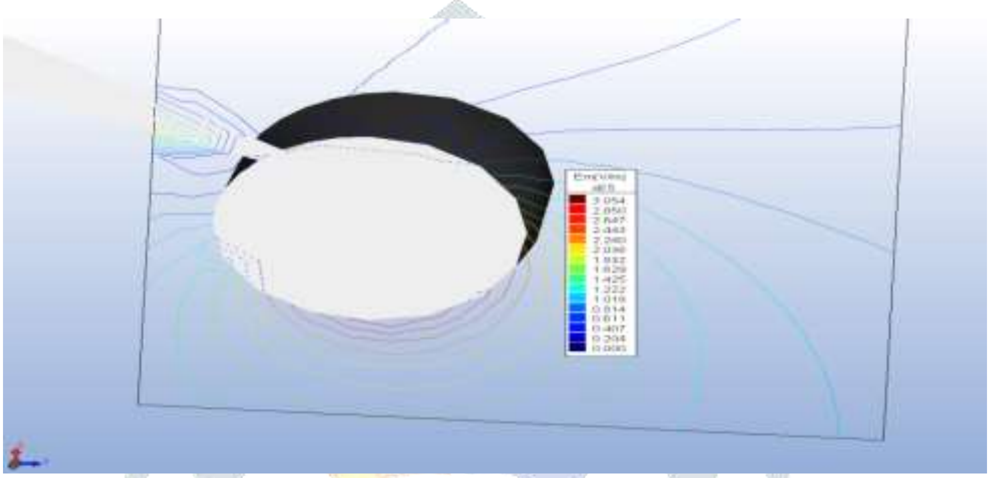

**Figure 6:** Electric Field contours of D=580mm, d=50mm, H=102.5mm.

## VII. RESULTS

The electric fields along the surface of the Post insulators of rating 420 kV are non uniform. And the voltage distribution of the Post insulators of rating 420 kV is with consideration of bus conductor electrode gives linear in nature. Grading Rings of appropriate sizes need to be used to make the distribution more uniform. From the simulation study, the following observations can be made.

1. The diameter of the grading ring does not have much effect on the voltage distribution.
2. Increase in the overall diameter and the vertical distance of the grading ring improves the voltage distribution.

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