RESEARCH ARTICLE OPEN ACCESS

# Effects of Corona Ring Parameters on Electric Field Sharing Along Suspension Insulator String under Lightning Impulse Overvoltage Based On FEM

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***Abstract***

Porcelain insulators are extensively used in high voltage transmission lines. One practical way to reduce electric field stresses on insulator string is corona ring installation at the energized side. This paper presents a 3-D finite element method simulation of electric field distributions around HV insulator string under lightning impulse voltage. Also, The impact of corona ring parameters on reduction of electric field stress is determined for 230kV cap and pin type porcelain insulator string under lightning impulse excitation.

***Keywords:*** Porcelain Insulator, Electric Field Distribution, Lightning impulse voltage, Corona Ring Parameters, Finite Element Method (FEM)

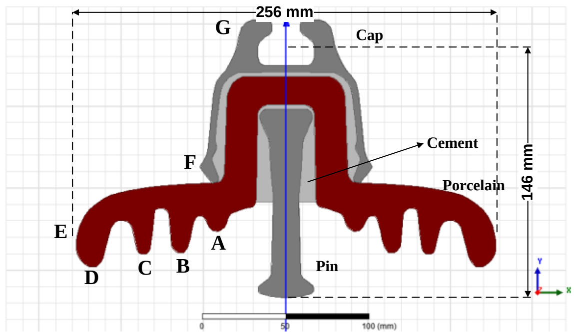
## I. Introduction

Porcelain insulator strings are widely applied in outdoor high voltage insulation systems. This is due to their high mechanical strength, easy installation and operation and low cost. Discharge activity on surface of high voltage equipments such as insulators is caused by the local electric field having a value higher than the ionization level of the ambient air. Electric field around the insulator strings are results of environmental condition such as rain, pollution, etc. if the surface electric field under different conditions can be calculated or measured, it will be helpful to improve the design of insulators, corona rings and field grading hardware [1]. Three dimensional Finite Element Method (3-D FEM) is particularly a suitable tool for such purposes since both symmetrical (mirror or rotational) as well as non-symmetrical geometries can be taken into account in the field calculation [2]. At higher voltage levels, electric field strength can be high enough to cause surface flashover on insulators and create corona discharges in the vicinity of the insulators; therefore grading devices need to be used to reduce the electric field to acceptable levels [1,3]. Measurements of electric field and potential distribution along composite insulator length under AC voltage have been the subject of many investigations [4,5,6]. Ilhan et al [7] used some 3D-electrostatic simulations and some laboratory tests for corona ring optimization used in 380kV V-insulator string. Also, these researchers [8] applied Boundry Elements Methods (BEM) to investigate the lightning and switching impulse performance of the string equiped with the existing racket type corona rings and circular type corona rings. Li et al [9] used Finite Element Method to calculate the potential and electric field distribution over ceramic insulators in 1000kV substations. Their method considered all factors influence on the calculation results.

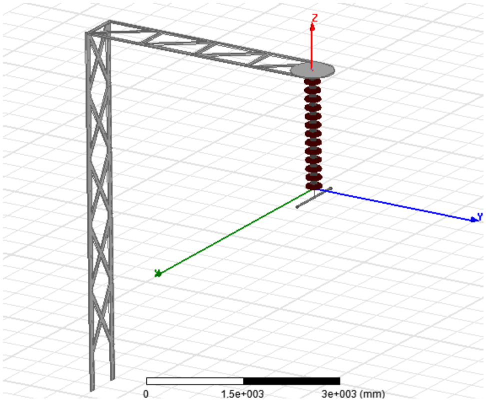
This paper employs a commercially available program (MAXWELL v.14) for three-dimensional (3-D) problems to investigate the effects of corona ring parameters on reducing the electric field stress around and along a typical 230kV I-string insulator under lightning impulse voltage.

## II. Model Parameters

Figure1 shows the basic dimensions of a porcelain insulator unit and a simplified model of a transmission tower used in 230kV transmission system.




(a)




(b)

Figure1. (a) Basic dimensions of cap and pin type porcelain insulator unit, (b) Simplified 3-dimensional simulation model of tower

The vertical suspended string contains 13 insulator units. Figure2 shows the basic design of corona ring, such as corona ring tube diameter (R), corona ring diameter (D) and corona ring mounting height (H).

A 1.2/50µs, 950kV$_{peak}$ lightning impulse voltage is applied to corona rings, line conductor and pin of the first line side insulator unit, while tower, cap of the last insulator and additional metal links between last insulator units and tower are grounded. All simulation results are expressed in peak values of the time dependent voltages (t=1.2µs).

Simulation studies are focused on maximum electric field intensities, $E_{max}$ on critical regions of three line-side insulator units. The critical regions of each insulator unit designated as A, B, C, D, E, F and G in figure 1(a). In all simulations the insulator surfaces are assumed to be dry and clean.

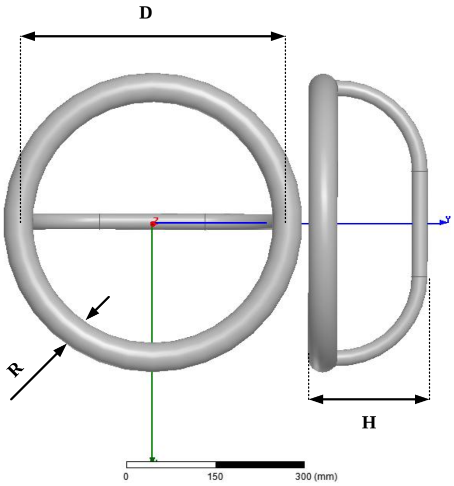



Figure 2. Dimensions of corona ring

## III. Simulation Results

### 3.1. Field Without Corona Ring

The electric field distribution on surface of, and within insulator string is a function of numerous parameters such as applied voltage, insulator design parameters, tower configuration, corona ring parameters, etc. figure 3 illustrates the electric field strength along a set of lines running parallel to (and at different distance from) the axis of insulator string under the peak values of lightning impulse voltage excitation.

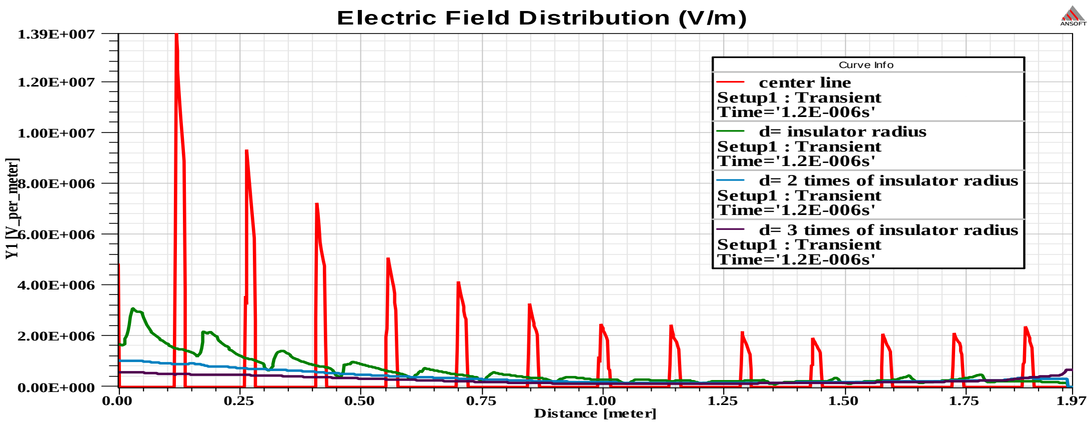



Figure 3.Electric field strength along lines parallel to the insulator axis (at different distance)

Table I. $E_{max}$ on critical regions of 3 line-side insulator units under lightning impulse voltage

| $E_{MAX}$(kV/cm) | A | B | C | D | E | F | G |
|---|---|---|---|---|---|---|---|
| **First Ins.** | 27.76 | 17.4 | 7.24 | 9.51 | 19.89 | 33.46 | 63 |
| **Second Ins.** | 31.5 | 24.29 | 11.58 | 8.72 | 17.55 | 18.46 | 42.69 |
| **Third Ins.** | 28.4 | 16.69 | 11.34 | 5.58 | 11.43 | 11.02 | 33.69 |

As can be seen from the figure, the Electric field magnitude is large closed to the energized and grounded end of the insulator string. Typically the energized end is subjected to the highest field magnitudes, along the center line of the string, E-field within metal part (cap and pin) is zero and sharp local maximum represents the areas where the line passes through cement and porcelain. Electric field contour around the line-side insulators are shown in figure 4. As shown in figures 3 and 4, there are some critical regions in the vicinity of highly stressed live end side of the string where the field strength were much greater than the ones on the other side of the systems. Maximum electric field strength on critical regions of three line-side insulator units are tabulated in table 1 for a string without using corona ring.

The field strength distribution show that $E_{max}$ (maximum of electric field) in region G, F and A (designation in figure 1(a)) are greater than others. $E_{max}$ in region G, as a most critical region of each insulator, were found to be 63, 42.6 and 33.6 kV/cm on first, second and third insulator, respectively.

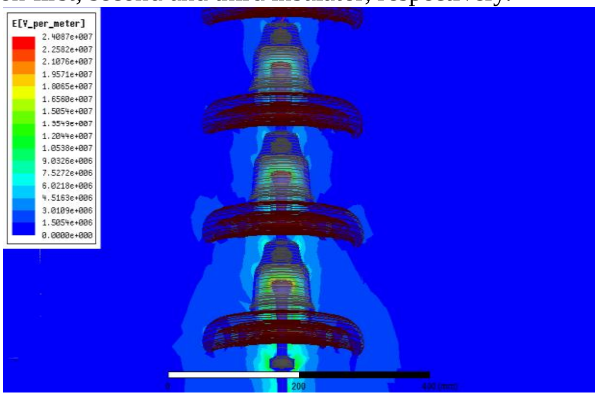


Figure 4. Electrical field contours around three line-side insulator units

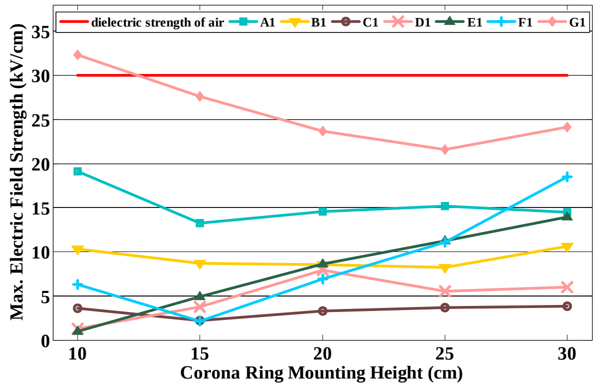
### 3.2. Field Calculation in Presence of Corona Ring

The application of corona ring to reduce electric field stress and corona effects is a known solution in transmission systems operating at 230kV voltage levels and above [5]. The effects of corona ring parameters (mounting height, ring diameter, ring tube diameter) on electric field strength on surface and center line of the 230kV suspension string was investigated. Corona ring parameters are investigated as follows:

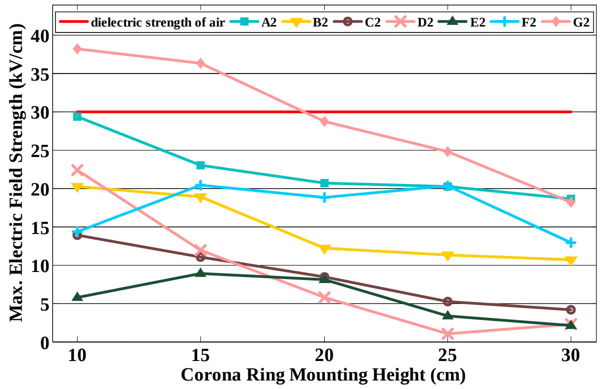
- Mounting height of corona ring (H): 10, 15, 20, 25, 30 cm
- Corona ring diameter (D): 30, 35, 40, 45, 50, 55, 60 cm
- Corona ring tube diameter (R): 4, 5, 6 cm

#### *3.2.1. Corona Ring Mounting Height (H)*

In order to study the effects of vertical position of corona ring, maximum electric field of critical regions on insulator surface, under lightning impulse voltage are calculated with different corona ring location. These calculations are represented in figure 5.




(a)

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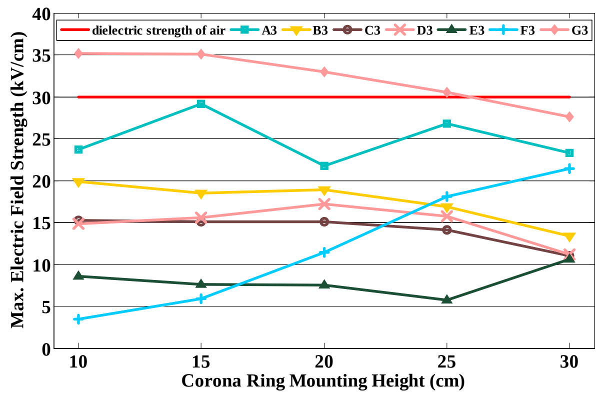



(c)

Figure5. $E_{max}$ versus corona ring mounting height for the critical regions on insulator surface (D=50cm, R=4cm). (a) First insulator, (b) Second insulator, (c) Third insulator

From figure 5(a) to 5(c), the followings are concluded:

- Maximum electric field strength on critical regions of insulators is greatly affected from the vertical position of corona ring.
- High electric field strength occur on region G and A of each insulator, while lower field strength occur on remaining part of insulator surface.

- H=25 cm and above, seems to be the proper mounting height of corona ring under lightning impulse voltage ( when R=4 cm, D=50cm)
- There is no direct correlation between the maximum field of region G and region F on surface of each insulator.

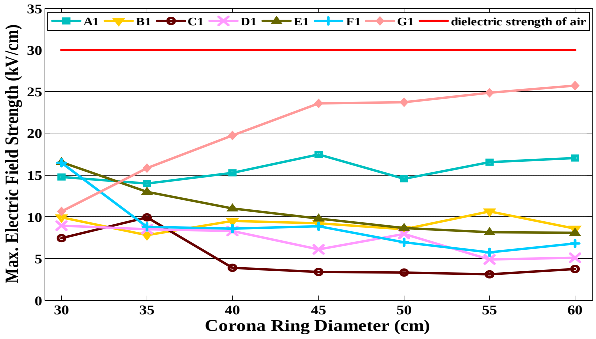
Table 2 illustrates the effects of corona ring mounting height (H) on maximum electric field strength along center line of insulator string. As can be seen from table 2, as corona ring was moved form the live-end of the string towards the ground end in range investigated, the maximum electric field strength was reduced. However, beyond the height about 25cm, the vertical position of the ring does not have much further effect on Emax along the string axis.

Table II. Maximum electric field strength along center line of the insulator string (D=50cm, R=4cm)

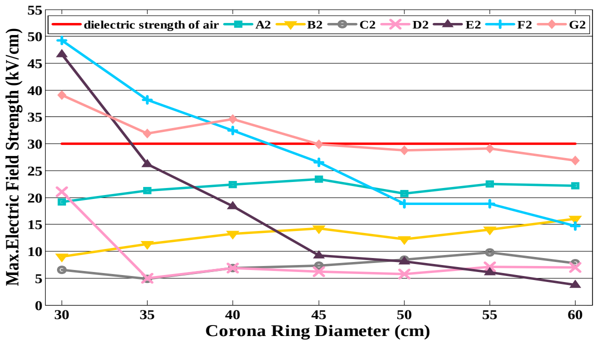
| Vertical Position (cm) | 10 | 15 | 20 | 25 | 30 |
|---|---|---|---|---|---|
| $E_{max}$ (kV/cm) | 76.32 | 70.165 | 68.54 | 66.36 | 67.1 |

*3.2.2. Corona Ring Diameter (D)*

Figure 8 shows the effects of corona ring diameter (D) on maximum electric field on critical regions of insulator surface under lightning impulse voltage excitation. The following conclusion can be derived from the curves given in figure 6(a) to 6(c):




(a)

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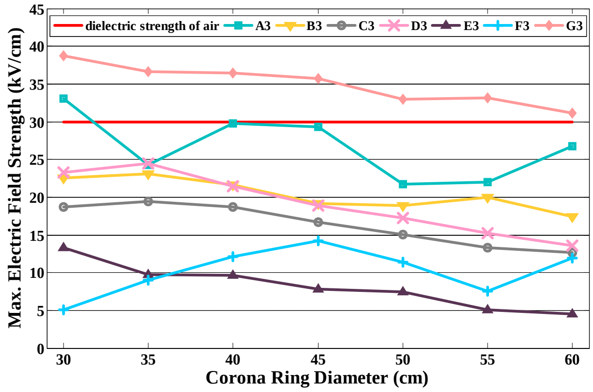



(c)

Figure 6. Regional $E_{max}$ versus corona ring diameter. (H=20cm, R=4cm), (a) first insulator, (b) second insulator, (c) third insulator

- Electric field strength along the insulator surface is greatly affected from the ring diameter (D).
- By increasing ring diameter, all critical regions of first and second insulator are become lower than the critical value of air strength in standard conditions.
- The most critical region on third insulator, G3 shows less sensitivity to ring diameter increase. It seems to be better to reduce the maximum electric field strength on this critical point by changing the other ring parameters simultaneously.

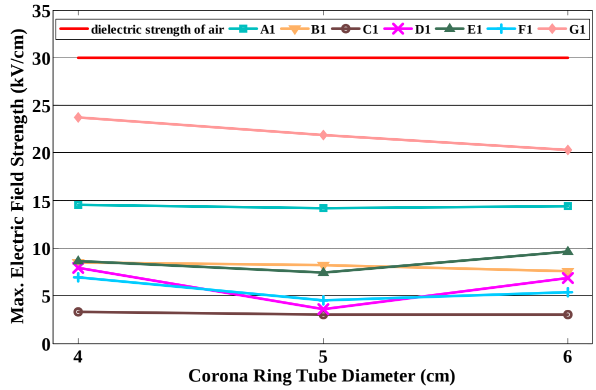
Table 3, shows the effects of corona ring diameter (D) on maximum electric field strength along the center line of insulator string. The calculation results show that, there is no direct correlation between ring diameter (D) and maximum field strength along string axis. Although increasing the diameter of corona ring in range of 30-60 cm does not significantly effect on Emax along center line of insulator string, as seen in table 3, but it is an important factor in controlling electric field stresses around the string, as shown in figure 6.

*3.2.3. Corona Ring Tube Diameter (R)*

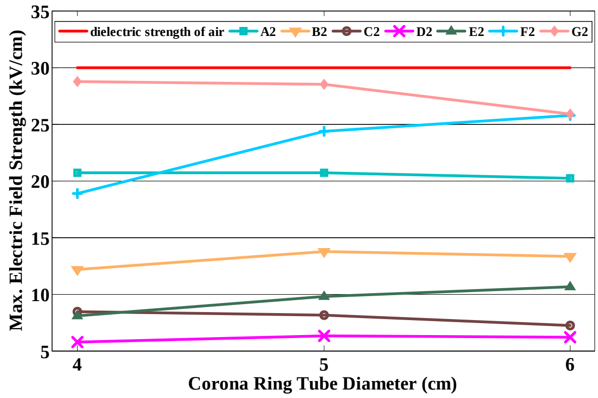
Figure 7 shows the effects of corona ring tube diameter (R) on $E_{max}$ of critical regions on insulator surface. From figure 7(a) to 7(c), it can be concluded that:

Table III. Maximum electric field strength along center line of insulator string. (R=4cm, H=20cm)

| **Ring Diameter (cm)** | **30** | **35** | **40** | **45** | **50** | **55** | **60** |
|---|---|---|---|---|---|---|---|
| **$E_{max}$ (kV/cm)** | 73.89 | 69.91 | 71.38 | 70.76 | 68.54 | 71.21 | 70.01 |




(a)

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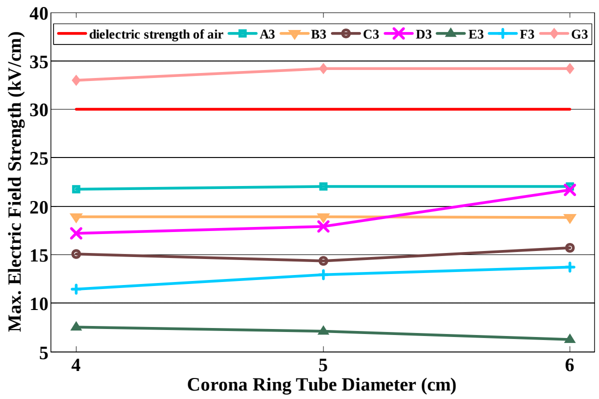


(c)

Figure 7. Regional $E_{max}$ versus corona ring tube diameter. (H=20cm, D=50cm), (a) first insulator, (b) second insulator, (c) third insulator

- The maximum electric field on these 3 insulators shows less sensitivity to the ring tube diameter than two other ring parameters.
- The maximum electric field values on all regions of first and second insulator are lower than critical values of air strength.
- Increasing ring tube diameter (R) from 4 to 6cm causes a slight increase in field strength on region G3.

Table 4 illustrates the influence of corona ring tube diameter (R) on maximum electric field strength along insulator string under lightning impulse voltage excitation. As can be seen from the table 4, by increasing ring tube diameter (R), The maximum electric field along string axis was decreased slightly.

Table IV. maximum electric field strength along center line of insulator string. (D=50cm, H=20cm)

| **Ring Tube Diameter (cm)** | **4** | **5** | **6** |
|---|---|---|---|
| **$E_{max}$ (kV/cm)** | 68.54 | 66.36 | 65.29 |

## IV. Conclusion

This study presents electrical field distribution for 230kV cap and pin porcelain insulator string under lightning impulse voltage. Electric field analysis program based on 3-D finite element method have been employed to study the effects of corona ring design parameters on highly stressed string insulator. In all simulation the strings insulators were assumed to be dry and clean.

Following conclusions were derived from the study:

- An effective way to control the maximum electric fields on critical regions of insulator string is changing corona ring parameters such as ring mounting height (H), ring diameter (D) and ring tube diameter (R).
- The most critical regions on the surface of each insulator unit is region G. (on the cap of each insulator)
- Increasing ring mounting height (H) and ring diameter (D), decrease the maximum fields on critical regions to some extent.
- Corona ring tube diameter (R), is found to be the least effective parameter on regional field values.
- Corona ring parameters also change maximum electric field strength along center line of insulator string. Increasing mounting height of ring (H) and ring tube diameter (R), decrease $E_{max}$ along string axis, while no correlation was

found between ring diameter (D) and maximum electric field.

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