Electric Field Distributions around Composite Insulators under AC and Impulse Voltages

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Abstract— **This paper presents simulations of electric field distributions around 154 kV composite insulators used in Turkish National Power Transmission Systems. Simulation studies are performed for different corona ring settings under AC excitation and impulse excitation. Electric field strength and potential values on the critical parts of the insulator unit are compared for different corona ring diameter, tube diameter and vertical positions of corona ring to attain optimal parameters.**

Keywords- Corona Ring, Electric Field, Potential Distribution

I. INTRODUCTION

Composite insulators have been increasingly used by utilities to replace porcelain and glass insulators because of their advantages coming from lower weight, ease of handling, reduced installation and maintenance costs, etc. [1-4] The ratio of non-ceramic insulators used in Turkish National Power Transmission Systems is around 5 %. However it is expected to increase in the near future.

High electric field strengths around the insulators create corona discharges in the air surrounding the insulators. Corona discharges may result in corona cuttings, degradation and ageing of the insulators. Due to the worse electric field distributions, composite insulator manufacturers provide the corona rings together with the insulators [1-4]. However, corona ring settings must be optimized for improved string performance.

This study presents electric field and potential distributions around 154 kV composite insulators and its grading device design for an improved performance.

Simulation studies cover potential and electrical field distributions which are in turn used for determination of optimum corona ring settings both for AC and for lightning impulse voltages. Electro-2D [5] commercial software is used for all modeling and simulations. Effects of corona ring on the field distribution along the critical parts of the composite insulator string are investigated for different design parameters such as corona ring diameter, tube diameter and position of the ring along the insulator axes. Maximum electrical field strength on the live side, side sheds and corona ring itself are determined for each corona ring settings and optimum ring parameters are determined on the basis of maximum field gradients.

II. MODELLING OF INSULATOR STRING AND CORONA RING

Fig. 1 shows composite insulator unit and associated corona ring used in the simulation studies. Composite insulator unit contains 21 big and 20 small sheds. Relative permittivities of insulator part and fiber glass rod are assumed to be 3.5 and 7, respectively. Detailed simulation parameters are given in Table 1. Simulation studies are focused on maximum electrical field intensities, E_{max}, on critical regions designated as A, B, C, D, E, F and G in Fig. 1.

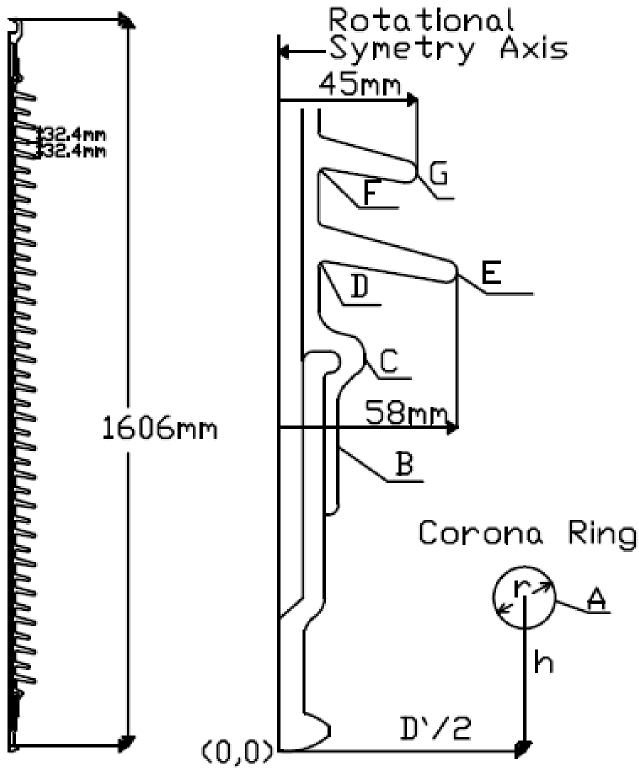

Figure 1. Model of composite insolator and corona ring

TABLE I. SIMULATION PARAMETERS

Material	**Relative Permitivity**	**Conductivity (Mho/m)**
Air	1	0
Silicine Rubber	3.45	$1x10^{-17}$
Fiber Glass Rod	7	$1x10^{-17}$

III. AC SIMULATION RESULTS

AC simulation studies are performed for 50 Hz frequency and 100 kV_{rms} line voltage. Optimization parameters are corona tube diameter, r, corona ring diameter, D and vertical position of the ring, h. Depending upon the past experience and some visual thoughts, limited number of alternatives are taken into consideration. They are 25, 30 and 35 mm for tube diameter, 200, 250, 300 and 350 mm are for ring diameter and finally 0, 50, 100, 150 and 200 mm are for vertical position of the ring.

Equipotential contours and electric field intensity graph for D = 300 mm h = 150 mm ring are given in Fig. 2 and Fig. 3, respectively.

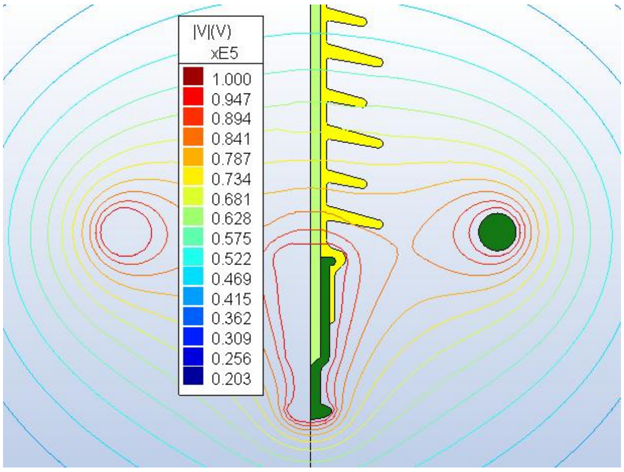

Figure 2. Equepotential contours around silicone insulator

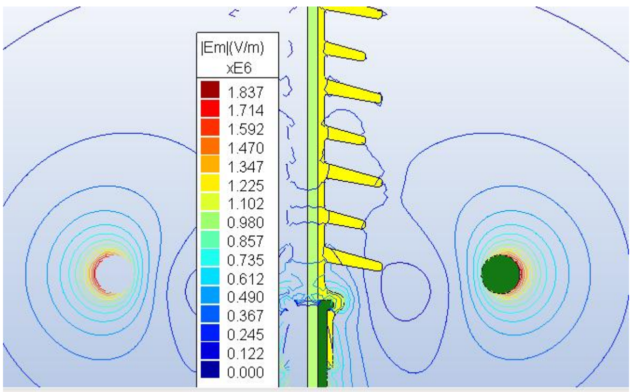

Figure 3. Electrical field contours around silicone insulator

A. *Determination of optimal corona ring location for minimum electrical fleld strengths*

One of the effective parameter on electric field distribution is the location of the corona ring. The first simulations are devoted to corona ring location effects, where the corona ring diameter and tube diameter are held fixed.

Fig. 4 shows the maximum electric field strength versus corona ring location for a corona ring diameter of 200 mm and for a ring tube diameter of r = 30 mm. In order to identify the magnitudes, ranges and the variances, field strengths of the critical regions A, B,..,G are given separately.

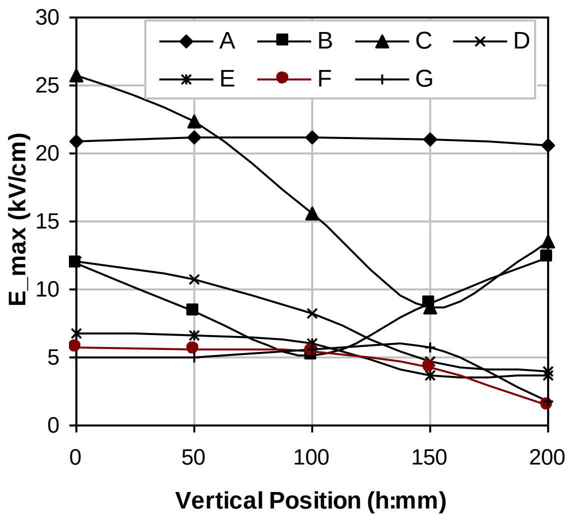

Figure 4. E_{max} versus vertical position of the corona ring for the critical regions. (r = 30 mm, D = 200 mm)

The most important features of the field strength curves in Fig. 4 are:

- Maximum electrical field strengths along the insulator surface (region B, C,..., G) are greatly affected from the vertical position of the corona ring. However, maximum filed strength on the corona ring itself (region A) is not affected from this parameter.
- High electrical field strengths occur on the surface of corona ring (A) and around the spherical region just below the first shed (C), whereas lower field strengths occur on the remaining parts of the insulator surface (B, D,.., G). However, there is not a positive correlation between the maximum field strengths of Region A and Region-C
- E_{max} on the shed points are low compared to other critical parts.
- There is a positive correlation between the field strengths on the insulator surface besides the ones in region B.
- C is the most critical region of the insulator surface where the maximum field strengths are greatly affected from the ring location.

- Maximum filed strength for region-C shows a minimum value around at h = 150 mm height.

On order to assure the effects of vertical location, maximum electric field strength versus corona ring location for a corona ring diameter of 300 mm and for the same ring tube diameter of 30 mm is given in Figure 5..

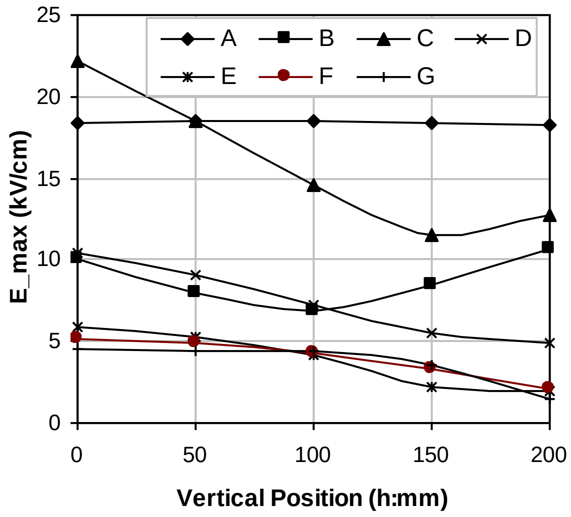

Figure 5. E_{max} on the critical points (r = 30 mm, D = 300 mm)

We can easily conclude that:

- The shapes of the curves are similar to those of the Fig. 4.
- Maximum field strengths on the insulator surface are again more sensitive to the vertical position of the ring.
- Maximum field strength for the most critical region on the insulator surface (Region C) shows a minimum again at h = 150 mm location.
- E_{max} values are on the corona ring are not affected from the vertical location. However, they are less than the values for the previous configuration. That is, increasing corona ring diameter has decreased the strengths on the corona ring
- In addition, increased corona ring diameter has improved the field strengths of some regions on the insulator surface.

Figure 4 and 5 have shown that region A and region C dominates the corona ring design. Therefore, the remaining illustrations will be concentrated on these dominant regions.

Fig. 6 shows E_{max} variations on the corona ring surface for different vertical positions for constant corona ring diameters.

One can easily conclude From Figure 4 that maximum field strength on corona ring surface is mainly determined by corona ring diameter. In addition, vertical positions of h = 150-200 mm provide slight improvements.

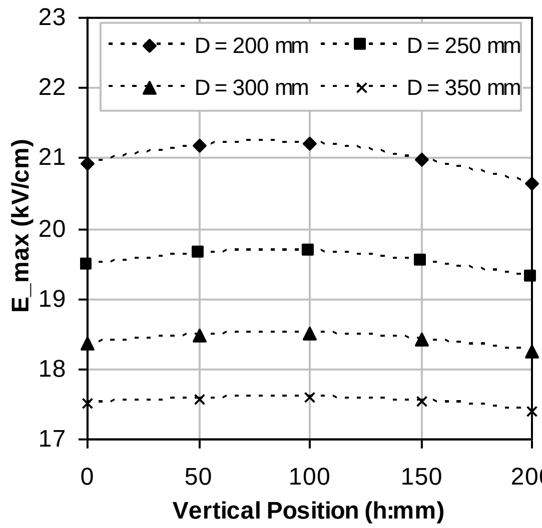

Figure 6. E_{max} on the corona ring surface, A (r = 30 mm)

As mentioned above region-C is the other dominating region. Fig. 7 shows the variations of E_{max} with the vertical location for constant ring diameters.

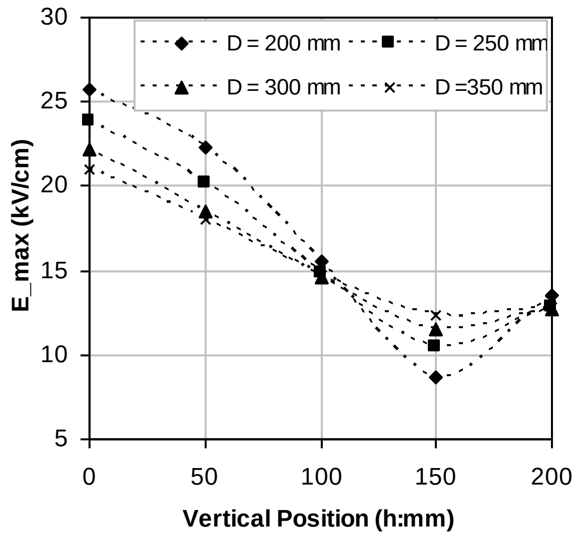

Figure 7. E_{max} on the critical point C (r = 30 mm)

Figure 7 shows that h = 150 mm is the optimal location, minimizing the maximum field strength at region-C for all corona rings. In addition, increasing corona ring diameters bring a secondary improvement for the field strengths of the region.

Maximum field strengths on the corona ring surface as well as on the insulator surface are tabulated in Table 2 for a tube diameter of 30 mm.

TABLE II. MAXIMUM AC FIELD STRENGTHS FOR SEVERAL DIFFERENT CONFIGURATION

D[mm]/ h[mm]	Maximum regional field strength (E_{max} : kV/cm) tube diameter = 30 mm						
	A	**B**	**C**	**D**	**E**	**F**	**G**
200 / 0	20.91	11.85	25.68	12.01	6.72	5.68	4.95
200 / 50	21.17	8.35	22.31	10.78	6.55	5.59	5.07
200 / 100	21.22	5.20	15.53	8.30	6.07	5.39	5.62
200 / 15 0	20.99	8.99	8.70	4.70	3.64	4.28	5.70
200 / 200	20.65	12.37	13.52	3.92	3.67	1.42	1.80
250 / 0	19.46	10.78	23.81	11.15	6.26	5.39	4.74
250 / 50	19.64	7.98	20.22	9.81	5.87	5.20	4.76
250 / 100	19.67	6.20	14.83	7.63	4.89	4.80	4.97
250 / 15 0	19.52	8.54	10.40	5.16	2.08	3.68	4.29
250 / 200	19.30	11.32	12.86	4.48	2.28	1.83	1.30
300 / 0	18.36	10.11	22.21	10.43	5.83	5.12	4.51
300 / 50	18.48	7.92	18.48	9.11	5.30	4.85	4.43
300 / 100	18.51	6.92	14.64	7.29	4.21	4.35	4.37
300 / 15 0	18.41	8.45	11.52	5.50	2.24	3.37	3.52
300 / 200	18.26	10.65	12.73	4.94	1.91	2.09	1.52
350 / 0	17.50	9.72	21.00	9.86	5.46	4.87	4.29
350 / 50	17.58	8.00	18.00	8.63	4.87	4.55	4.13
350 / 100	17.60	7.46	14.67	7.12	3.85	4.03	3.90
350 / 15 0	17.53	8.52	12.37	5.78	2.46	3.20	3.08
350 / 20 0	17.41	10.24	12.83	5.32	2.08	2.26	1.66

The following conclusions can be made with respect to Figure 4-7 and Table 2.

- Electric field strengths along the insulator surface are greatly affected from the ring diameter and from the vertical location.
- Region C is the most critical region on the insulator surface. D = 200 mm and h = 150 mm values are the optimal parameters providing the best field distribution along the insulator surface so thus along Region-C.
- On the other hand, vertical location has a secondary effect for corona ring itself. Increased corona ring diameter provides significant improvement. D = 350 mm and h = 200 mm case seems to be the best.
- Increased corona ring diameters bring some other visual and constructional disadvantages. Therefore, corona ring tube diameter will better be used for the improvement of the field distribution on the corona ring.

B. Determination of corona ring tube diameter for minimum electrical flelds.

Effects of the parameters held so far showed that the tube diameter should also be considered for further field distribution improvements. Fig. 8 shows regional field strengths versus corona ring tube diameter for a ring diameter of D = 200 mm and a vertical location of h = 140 mm.

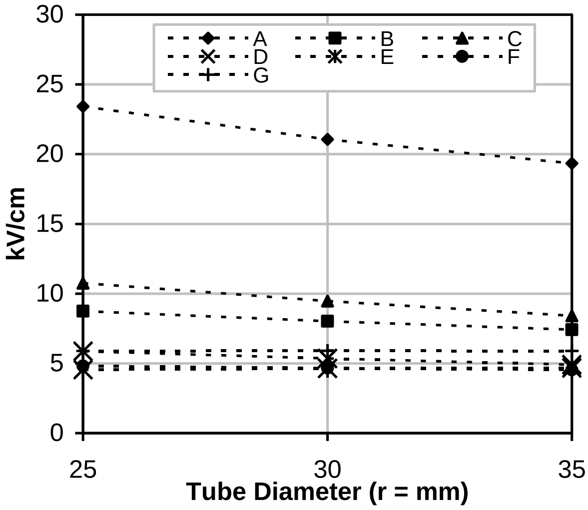

Figure 8. E_{max} on the critical points (D = 200 mm, h=140 mm)

Figure 8 show that, increased corona ring tube diameters improve the corona ring field strengths as well as insulator surface field strengths. However, the best improvement is for the corona ring surface field strength. If we combine these results with the previous ones, we can easily conclude that corona ring having a diameter of 30 mm, a tube diameter of 30-35 mm located at h=140-150 mm provides reasonable field distributions.

On the other hand, it is known that another indication of improved field strengths on the insulator surface is the potential distribution along the insulator. Fig. 9 and Fig. 10 show potential distribution along the insulator surface versus vertical position of the corona ring for two different ring diameters.

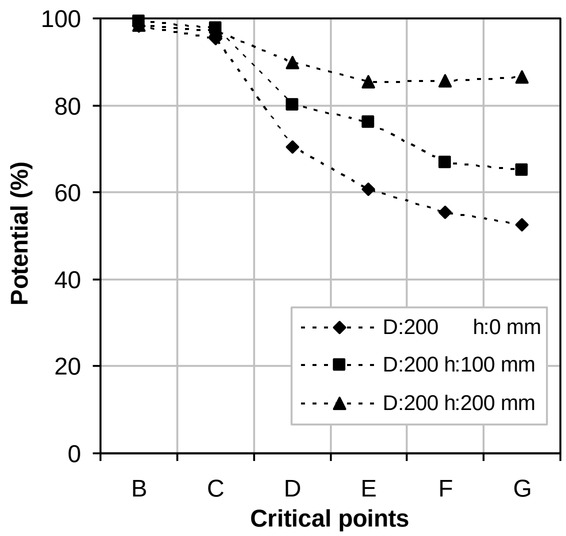

Figure 9. Potential distribution along the critical points for D = 200 mm and r = 30 mm

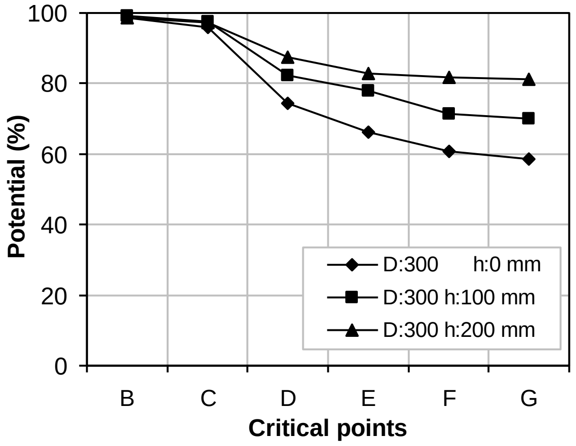

Figure 10. Potential distribution along the critical points for D = 200 mm and r = 30 mm

It is clear from Fig. 9 and Fig.10, vertical position of the corona ring alters the potential distribution along the insulator surface. Horizontal curves indicating better voltage distributions are obtained for higher vertical locations (h = 200 mm) values for the parts. Similar behavior is observed for the other configurations.

IV. IMPULSE VOLTAGE SIMULATION RESULTS

All the simulations so far are related with power frequency excitations. On the other hand, insulation performance of the line insulator is also the concern of transient phenomena. Therefore, this part is devoted to transient simulations.

1.2/50 µs lightning impulse voltages given in Fig. 11are used for transient electrical field and potential distributions. Simulations are conducted for a constant magnitude of 100 kV_m. For the sake of calculation speed, 0-20 µs time interval is considered with time steps of 0.1 µs. All the following simulation results are the peak values of the time dependent voltages.

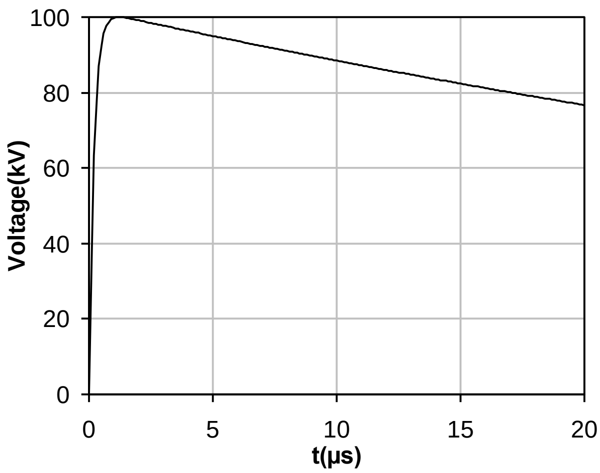

Figure 11. Lightning impulse test voltages for transient simulations.

Fig. 12 illustrates an example of regional field strength versus vertical location of the ring for a lightning impulse excitation.

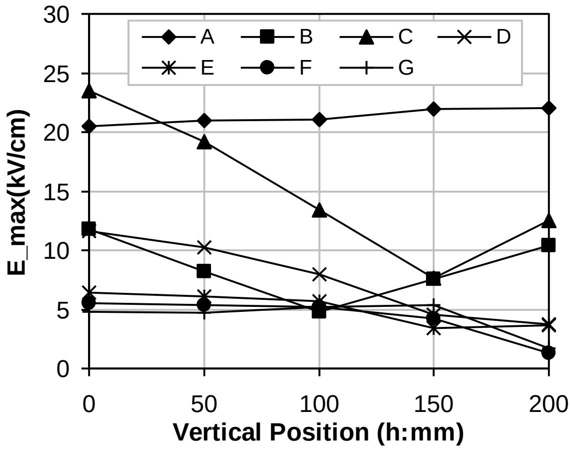

Figure 12. Regional E_{max} versus vertical position of the ring . (r = 30 mm, D = 200 mm)

The following conclusions can be derived from the variation of the curves given in Fig.12 as well as from the comparison with the ones given in Fig.4.

- Filed strength distribution looks like the case of AC excitation. Field strengths in region A (corona ring) and in region C is greater than the others.
- Maximum electrical field strengths along the insulator surface are again sensitive to vertical position of the corona ring.
- Maximum filed strength on the corona ring is slightly affected from the vertical position of the corona ring. However, unlike the AC excitation, it increases with an increasing h.
- There is not a positive correlation between the maximum field strengths of Region A and Region-C
- E_{max} on the shed points are low compared to other critical parts.
- There is a positive correlation between the field strengths on the insulator surface besides the ones in region B.
- C is the most critical region of the insulator surface where the maximum field strengths are greatly affected from the ring location.
- Maximum filed strength for region-C shows a minimum value around at h = 150 mm height. However, there is a slight increase in corona ring surface field strength.
- h = 100 seems to the best location for impulse voltages.

Other simulations for the other corona ring diameters and for the other ring tube diameters give similar results obtained for AC excitations. Therefore they will not be reproduced here.

V. CONCULUSIONS

This study has presented electrical field and potential distributions for 154 kV composite insulators under alternating voltages and lightning impulse voltages. Simulations are conducted for clean and dry insulator cases. Electric field and potential distributions are obtained for the critical points along the energized part of the composite insulator. Simulations are repeated for different corona ring settings and locations. Effects of corona ring diameter, corona ring tube diameter and corona ring installation height on the field results are obtained for different settings.

Following summarizes the alternating and impulse voltage simulation cases:

- Corona ring usage changes the potential and field results for the critical points. Maximum field gradients occur on the corona ring surface almost for all corona rings.
- The most critical part along the energized part of the insulator is the part C. E_{max} on this part shows a minimum value depending on the vertical location of the ring. Approximately, h = 150 mm height value seems to be optimum value minimizing the E_{max} on point C.
- E_{max} on the part B also shows a minimum point value at about h = 100 mm case. E_{max} on the other critical parts decreases with the increase of vertical position of the corona ring.
- Corona ring settings also changes the potential distributions for the critical part of the insulator. The bigger vertical position of the ring, the more uniform field distribution along the energized part of the unit.
- Field values for alternating and impulse voltage case are approximately similar. However, simulation field results under impulse voltage are slightly less than those under alternating voltages.
- Finally, D = 300 mm, r = 30-35 mm and h = 140 mm seems to be the optimum values from the point of maximum filed strengths on the critical parts of the system for AC excitation and impulse voltage excitation.
- These results are valid for clean insulators. Other environmental conditions and contaminated insulators should also be taken into consideration before the final design process.

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