EFFECTS OF CORONA RING DESIGN ON ELECTRIC FIELD INTENSITY AND POTENTIAL DISTRIBUTION ALONG AN INSULATOR STRING

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ABSTRACT

This paper presents electric field and potential distribution calculations by using Finite Element based computational software along a 10-unit U100 BLP insulator string that is used in 154 kV Turkish National Power Transmission System. Simulations are conducted for several different corona ring designs and locations. Corona ring diameter, corona tube diameter and vertical position of corona ring are optimized for power frequency excitations.

I. INTRODUCTION

Corona rings are used to improve the performance of the insulator strings. They reduce corona discharges as well as associated audible noise level and radio and television interference levels. Corona rings do also improve the voltage distribution along the insulator string by reducing the percentage of the voltage on the unit nearest to the power transmission line. Moreover, they also alleviate corona degradation of non-ceramic materials [1, 2]. But, there are some design standards of corona rings for insulator strings used in 154 kV and 380 kV Turkish National Power Transmission Systems.

In this study, electric field intensity and potential distribution along 10-unit clean U100 BLP insulator strings are simulated by a two dimensional finite element model of the string. In fact, this problem is not an axi-symmetric one due to the existence of power transmission line, hardware and transmission tower effects. In order to simplify the model and to use axi-symmetric in the cylindrical coordinate system, transmission line and ground effects are not taken into account in the simulations.

All simulations are conducted with FEM 4.0, finite element simulation program. This program solves electrostatic and electromagnetic problems separately. Because of this limitation, only clean insulator strings are handled in the simulations.

The presence of pollution along the string results in a leakage current flow along the surface of the units. Therefore, this case requires both the electrostatic and the electromagnetic simulations at a time [3, 4].

II. MODELING OF AN INSULATOR STRING AND A CORONA RING

FEM model of insulator string and corona ring is shown in Fig.1. R, D and H show design parameters of the corona ring. R, D and H denote the radius, the tube diameter and the vertical position of the corona ring, respectively. Reference point of H in Fig.1 is (0, 0).

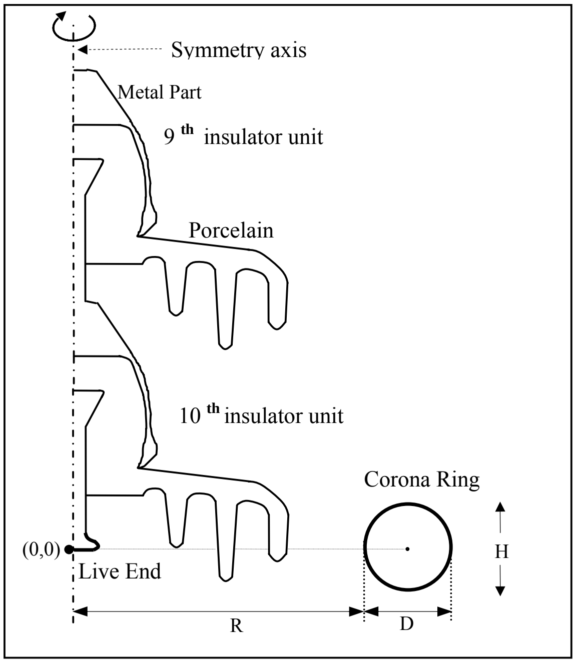

Figure 1. FEM model of insulator string and corona ring

In simulations, insulator string is assumed to suspend 20 meters above from the ground level. Artificial boundaries are selected at least 20 meters away from the insulator string. Circular corona ring and the insulator pin of the lowermost unit are subjected to a power frequency voltage of 88.91 kV, where the uppermost unit is grounded by means of tower. All the remaining caps and the pins of the units are assumed to be at floating potentials which will in turn be evaluated by the simulations. Relative permittivity of the insulators in a free space is assigned to be 6.0.

III. POTENTIAL DISTRIBUTION ALONG THE INSULATOR STRING

There are several methods to calculate the potential distributions along the insulator string. Circuit analysis for lumped parameter modeling is fast but generally do not provide sufficient accuracy in many cases [5-7]. FEM or other methods utilize distributed parameter modeling together with fast numerical calculation methods [1-4, 8].

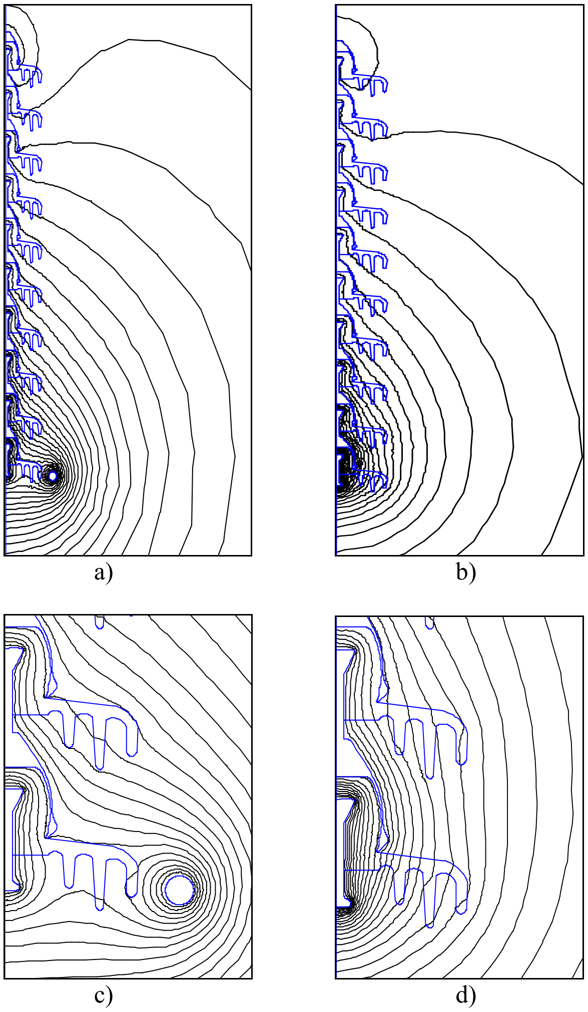
a) b) c) d)

Figure 2. Equipotential contours around 10-unit insulator string

a) and **c)** contour plots with corona ring

b) and **d)** contour plots without corona ring

In this study we preferred FEM modeling. Fig. 2 illustrates the potential contours around 10 element cap and pin type porcelain insulator string. String equipped with a corona ring and not-equipped with a corona ring is simulated separately to identify the effects of the ring. We can easily see from Fig. 2 that the voltage percentage of the bottommost insulator is reduced by using a corona ring.

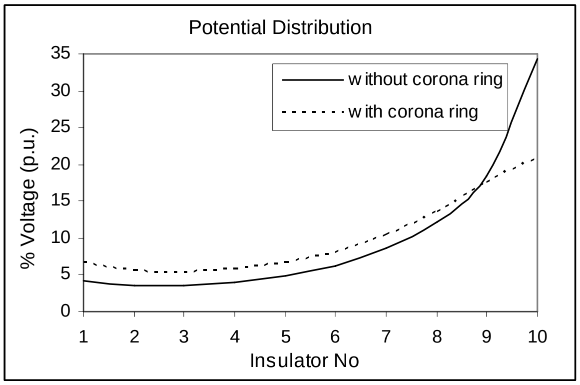

Figure. 3. Potential distribution with and without corona ring

Fig. 3. shows the potential distribution along a clean insulator string. It is obvious that the line voltage is not equally shared by the insulator units. Insulators near the live end side share the big amount of the line voltage and the probable surface discharges or failures take place on these elements. The usage of corona rings improves the voltage distribution along the insulators. Numerically, the percentage on the 10th insulator decreases from 34 % to 21 %.

Table 1. Horizontal displacement of corona ring

Insulator No	Without corona ring	With corona ring,D=3 cm, H = 0			
		R 15 cm	R 17 cm	R 19 cm	R 21 cm
1	4,11	6,63	6,87	7,00	7,41
2	3,58	5,54	5,72	5,82	6,11
3	3,60	5,33	5,47	5,55	5,78
4	4,02	5,70	5,82	5,88	6,06
5	4,90	6,60	6,67	6,73	6,86
6	6,30	8,08	8,12	8,16	8,23
7	8,57	10,34	10,28	10,28	10,21
8	12,17	13,51	13,26	13,16	12,85
9	18,49	17,40	16,84	16,57	15,88
10	34,26	21,13	20,95	20,85	20,62

Table 1 and Table 2 show the % potential distribution for different corona ring designs. Table 1 shows the effect of the diameter of the corona ring. The higher the diameter of the ring, the lower the voltage percentage of the lowermost insulator. However, the decreasing rate is slow. On the other hand, higher ring diameters result in increases in voltage of uppermost units.

Table 2. Vertical displacement of corona ring

Insulator No	With corona ring, D=3 cm, R = 17 cm				
	H=4 cm	H=2 cm	H= 0 cm	H=-2 cm	H= -4 cm
1	6,98	6,92	6,87	6,80	6,76
2	5,83	5,77	5,72	5,66	5,62
3	5,60	5,54	5,47	5,40	5,36
4	5,97	5,89	5,82	5,74	5,67
5	6,88	6,78	6,67	6,59	6,50
6	8,37	8,25	8,12	8,01	7,89
7	10,57	10,43	10,28	10,16	10,02
8	13,44	13,36	13,26	13,15	13,01
9	16,35	16,65	16,84	16,93	16,98
10	20,01	20,41	20,95	21,56	22,19

Table 2 shows the effects of the vertical position of the ring of R=170 mm. H = 4 cm seems to be the optimal and the reasonable location for that ring.

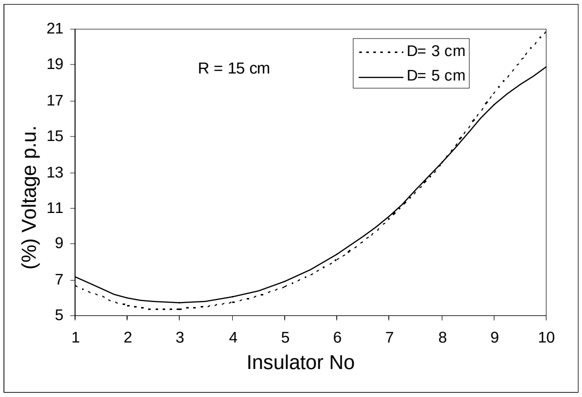

Figure 4. Effects of corona tube diameter on potential distribution

Fig. 4 shows the corona tube diameter on the potential distribution along the insulator string. The more increase in the corona tube diameter, the less voltage percentage on the bottom most insulators. On the hand, increasing the corona tube diameter will increase voltage sharing for uppermost insulators.

III. ELECTRIC FIELD INTENSITY ON THE CORONA RING AND THE LIVE END

Fig. 5 illustrates the two critical points A and B, where the field intensities are first need to be thought. Since the field intensities at the remaining parts of the string are less than those of the values at these two points, we will concentrate ourselves on the field strengths of points A and B. A is the live end point and B is a point on the segment on the outer radius of the corona ring. Points B, C, D and E are the points on the corona tube.

Table 3 and Table 4 show the maximum electric field intensity on the corona ring and on the live end, respectively. Maximum electric field intensity on the corona ring at point B decreases as the corona ring diameter and the corona tube diameter increase.

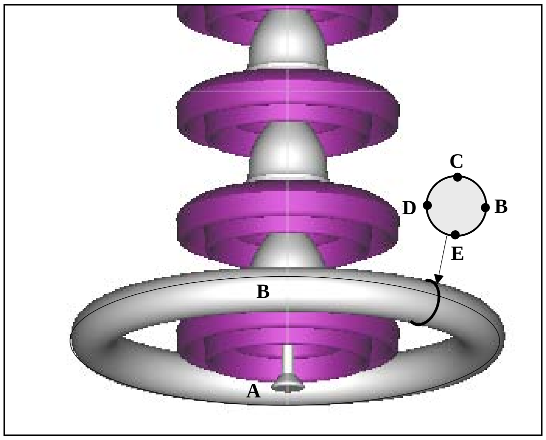

Figure 5. Electric field calculation points

The effect of vertical location of the string is of second importance. Maximum electric field intensity on the live end at point A without corona ring was about 56.3 kV/cm. The usage of corona ring will sharply reduce this value on the live end. Furthermore, increasing the corona tube diameter also has a dominating effect on the maximum electric field intensity at this point.

Table 3. Maximum electric field intensities on the ring

	Maximum Electrical Field Intensity (kV/cm)				
D = 3 cm	H 4 cm	H 2 cm	H 0 cm	H -2 cm	H -4 cm
R = 15 cm	15.18	15.33	15.24	15.22	15.32
R = 17 cm	14.72	14.72	14.87	14.81	14.63
R = 19 cm	14.45	14.39	14.35	14.36	14.20
R = 21 cm	14.01	13.96	14.09	13.92	13.86
D = 5 cm	H 4 cm	H 2 cm	H 0 cm	H -2 cm	H -4 cm
R = 15 cm	11.07	11.06	10.95	10.99	10.92
R = 17 cm	10.68	10.64	10.64	10.61	10.63
R = 19 cm	10.30	10.32	10.30	10.29	10.23
R = 21 cm	9.97	10.05	9.97	9.98	10.01

Table 4. Maximum electric field intensities on point A

	Maximum Electrical Field (kV/cm)				
D = 3 cm	H 0 cm	H 2 cm	H 4 cm	H 6 cm	H 8 cm
R = 15 cm	32.27	31.27	32.57	30.47	32.47
R = 17 cm	32.21	31.56	30.95	30.47	31.97
R = 19 cm	32.19	32.13	30.87	30.36	31.58
R = 21 cm	31.89	31.27	30.71	34.00	31.30
D = 5 cm	H 0 cm	H 2 cm	H 4 cm	H 6 cm	H 8 cm
R = 15 cm	27.49	26.45	25.38	25.30	27.11
R = 17 cm	27.56	26.71	26.00	25.45	27.04
R = 19 cm	27.44	26.66	26.06	25.48	27.04
R = 21 cm	27.26	26.50	26.00	25.63	27.02

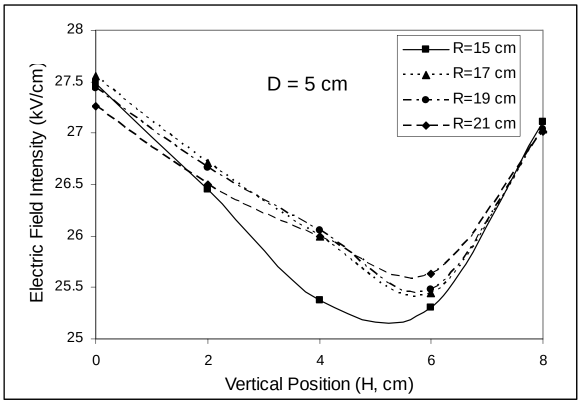

Figure 6. Maximum electric field on live end

Fig.6 shows the effect of the vertical position of the ring on the maximum field strength at the live end. The results are given only for a corona ring of 5 cm tube diameter. Similar results can also be derived for the other rings. Maximum field strength shows a minimum value for the value of H = 5 - 6 cm, depending on the value of ring diameter. This feature must be thought together with the remaining parameters, such as arc distance, lightning impulse.

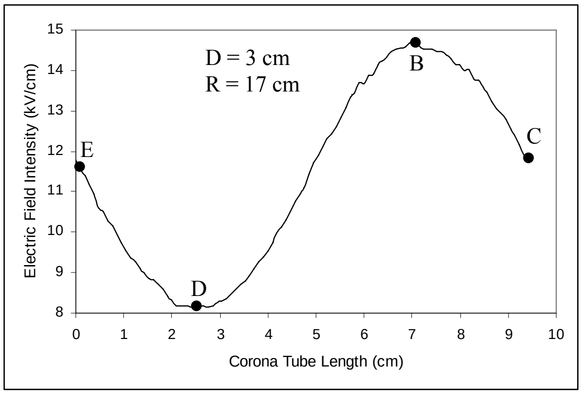

Figure 7. Electric field variation on the corona tube

Fig.7. shows electric field variation around the corona tube for a ring of 3-cm tube. The maximum and the minimum electric field strengths are at point B and D, respectively. Increasing the corona tube diameter and corona ring radius will reduce maximum electric field values on the corona ring surface (See Table 3).

IV CONCLUSIONS

Corona ring usage improves the performance and the reliability of porcelain insulator strings. Corona ring radius, corona tube diameters, vertical and horizontal positions of the corona ring are the important design parameters. They affect the electric field and the potential distributions along the string. Computational analyses give the following results:

- Usage of corona ring in an insulator string will significantly decrease the voltage percentage on the lowermost insulators and will slightly increase the voltage sharing on the uppermost insulators. That is, potential distribution will be more uniform with the help of corona ring.
- As the corona tube diameter increases, voltage sharing of the insulators those are near to the power side degreases.
- Maximum electric field strengths on the live end side will importantly decrease with the usage of corona ring. The value of this field strength depends on the corona tube settings. On the basis of vertical position of corona ring, electric field on the live end gets its minimum value.
- Electric field on the corona ring surface can also change with the design parameters. Maximum electric field is on the outer radius of the ring. However, minimum electric field is on the inner radius of the ring.
- The results of this computational analysis must be considered together with the other lightning impulse behavior and pollution performance of the string.

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