Corona Ring Design Impact on the Electric Field Distribution Surrounding an Insulator String

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***Abstract*—Insulator strings are used on high-voltage transmission lines to insulate the line conductors from the grounded transmission towers. The electric field distribution along an insulator string is not uniform when an AC voltage is applied on it. To prevent unwanted phenomena such as corona discharge or flashover from happening, the electric field near the energized end of the insulator string must be minimized. This can be done by installing a corona ring. It is important to obtain a suitable design of corona ring so that the electric field magnitudes can be reduced significantly. Therefore, the effect of the design of corona ring on the electric field distribution along a 10-unit porcelain insulator string was evaluated by using Finite Element Analysis (FEA) in this work. From the simulation results, it was found that the parameters of the corona ring such as the vertical height of the corona ring along the insulator string, the outer diameter of the corona ring, and the inner diameter of the corona ring tube have an impact on the electric field distribution surrounding the insulator string. At the end, a suitable design of corona ring is proposed, which gives the lowest electric field magnitude along the insulator string based on the results obtained. A suitable design of corona ring for the modelled 10-unit porcelain insulator string was found to be 350 mm outer diameter of the corona ring, 65 mm inner diameter of the corona ring tube and 300 mm vertical height of the corona ring along the insulator string.**

Keywords— Electric field distribution, corona ring, insulator string, finite element analysis

I. Introduction

Since all the processes in the power system are important, it cannot afford to break down as it will affect the whole system. Therefore, all equipment in the power system from power generation to power transmission and finally to power distribution must always be able to perform its function well. An insulator string is generally used in high-voltage transmission lines to carry the line conductors along the transmission towers. The voltage distribution is not uniform along the insulator string when AC voltage is applied to it [1]. Since the electric field magnitude is larger near to the grounded and energized ends of an insulator string and the energized end is exposed to the highest field magnitude, it is necessary to decrease the electric field magnitude at the area. One of the solutions to reduce the electric field around the energized ends is by installing a corona ring. Therefore, it is important to obtain a suitable design of corona ring so that the electric field magnitudes can be reduced significantly.

Several works related to simulation on insulator strings have been done since the past. A work in [2] reported on simulation and comparison of the voltage distributions of various 230 kV different porcelain and glass type insulator strings to study the effect of different insulator types on the voltage distribution. It was found that insulators of different materials and dimensions or size have a direct impact on the voltage distribution. In [3], the parameters of the corona ring such as the ring diameter, the diameter of the ring tube and the vertical position of the corona ring along the insulator were taken into consideration together. They were used to determine the maximum field along the surface of the insulator such that the maximum field does not exceed the corona inception level.

Suat Ilhan et. al. published a paper related to optimization of corona ring for 380 kV glass type V-insulator string [4]. The purpose of the simulation is to determine the most suitable corona ring design parameters such as the ring diameter, corona tube diameter and the installation height of the corona ring along the insulator string. A work reported in [5] discusses the effect of corona rings on the impulse withstand performance along 380 kV V-insulator strings, which are commonly used in Turkish National Power Transmission System. The parameters such as flashover routes, times to flashovers, lower flashover probability levels and withstand voltages are determined under dry and wet test conditions.

The calculations of the electric field and potential distribution of a 10-unit U100 BLP insulator string, which is used in 154 kV Turkish National Power Transmission System was reported in [6]. Simulations were performed for different corona ring design and locations to study the effect on the electric field and potential distribution along the insulator string. The factors that needed to be taken into consideration when choosing a corona ring to be added to a polymer insulator are the attachment type, hot stick-able design, ordering, mating feature and packaging [7].

In the process of selecting the optimum design of the corona ring for a 400 kV non-ceramic insulator, two parameters of the corona ring were changed [8]. The parameters that were varied are the corona ring diameter and the tube diameter. The impact of the corona ring design such as the ring dimensions on the electric field distribution of a 132 kV glass type insulator string was reported in [9]. Based on the results, the most suitable parameters of the corona ring that affect the electric field distribution most is determined and may be used to develop a better corona ring which can reduce the electric field intensity along the energized end of the insulator string in the future.

The design of the corona ring for a 400 kV composite insulator was studied focusing on the electric field and electric potential along the insulator string [10]. In [11], studies were done on the potential distribution and electric field inside and around one, two and five cap and pin insulators string along the 400 kV AC transmission lines. It is known that the factors that affect the potential distribution and electric field are voltage magnitude, influence of tower, environmental conditions and corona ring.

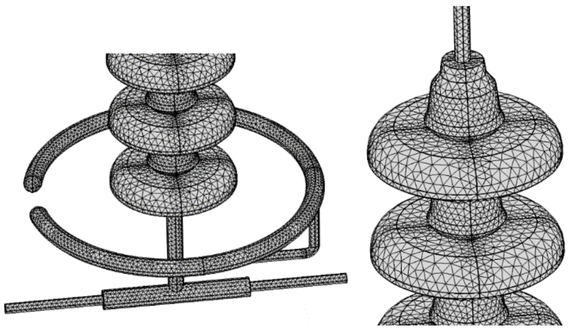
II. Methodology

Fig. 1 shows the meshing of simulation model in COMSOL Multiphysics software. The model consists of an insulator string, a conductor and a corona ring. The equations used to calculate the electric field and electric potential for finite element analysis in COMSOL Multiphysics software are given by [12-14]

$$\vec{E} = -\nabla V \tag{1}$$

$$\nabla \varepsilon_0 \varepsilon_r = \rho_v \tag{2}$$

where ρ_v denotes the volume charge density, ε_0 denotes the vacuum permittivity and ε_r denotes the dielectric material relative permittivity.



(a) (b)

Fig. 1. Meshing of model in COMSOL Multiphysics; (a) corona ring part and (b) insulator string part

The relative permittivity used for the materials is shown in Table 1.

TABLE I. RELATIVE PERMITTIVITY USED FOR THE MATERIALS

Material	Relative Permittivity
Air	1
Copper	1000
Porcelain	5
Cement	2

The boundary conditions set during the simulation of the model in COMSOL Multiphysics are the topmost insulator along the insulator string is connected to ground terminal where the voltage = 0 V at that point. The bottommost insulator along the insulator string is connected to a high voltage terminal of 33 kV.

The “Electrostatic” sub-module under “AC/DC Module” in COMSOL Multiphysics is used to simulate the model. The “Electrostatic” interface is used to compute the electric field, the electric displacement field and potential distributions in dielectrics under conditions where the electric charge distribution is explicitly prescribed. The formulation is stationary but for use together with other physics, also eigen frequency, frequency-domain, small-signal analysis and time-domain modelling are supported in all space dimensions. The physics interface solves Gauss' Law for the electric field using the scalar electric potential as the dependent variable.

Fig. 2 shows the structure of the insulator string used in this work. The parameters of the corona ring attached to the insulator that were varied are:

- Outer diameter of corona ring
- Inner diameter of corona ring tube
- Vertical height of the corona ring

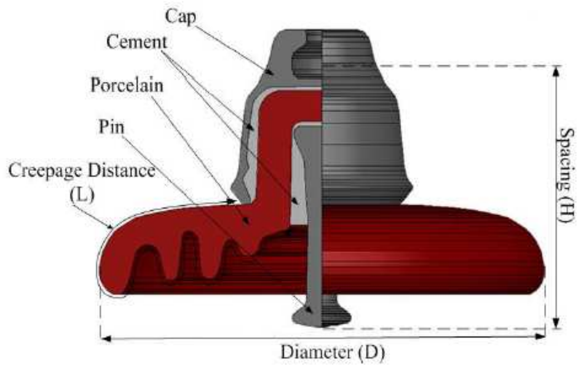


Fig. 2. Structure of the insulator string

III. Results and Discussion

Fig. 3 shows the electric field (V/m) and electric potential (V) magnitude along the line extracted across the insulator string without corona ring by using “Cut Line 3D” evaluation under “Results” tab in COMSOL Multiphysics software. It can be seen that the electric field of the first insulator, which is at point 0 of Arc length axis, is around 17500 V/m. The value of the electric field gradually decreases until point 70 of Arc length, which is around the fifth insulator or sixth insulator along the insulator string. Then, it gradually increases again from point 70 of Arc length axis to point 150 of Arc length axis, which is the top most insulator along the insulator string. The electric field of the top most insulator along the insulator string is around 22000 V/m.

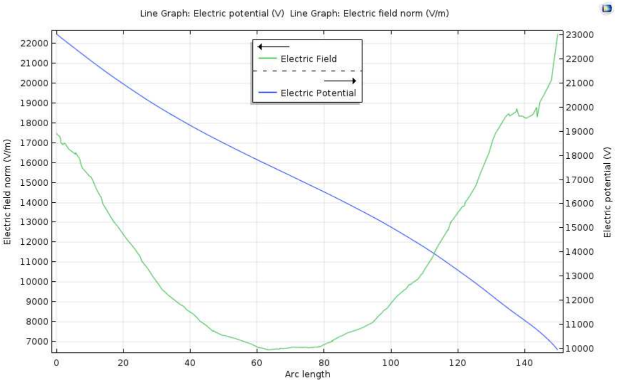


Fig. 3. Electric field and electric potential along the line across the insulator string without corona ring

From Fig. 4, it can be seen that the electric field on the first insulator, which is at point 0 of Arc length axis, is around 13000 V/m. The value of the electric field increases until 15000 V/m at point 15 of Arc length axis, then gradually decreases until point 70 of Arc length axis, which is around the fifth insulator or sixth insulator along the insulator string. Then, it gradually increases again from point 70 of Arc length axis to point 150 of Arc length axis, which is the top most insulator along the insulator string. The electric field of the top most insulator along the insulator string is around 24000 V/m.

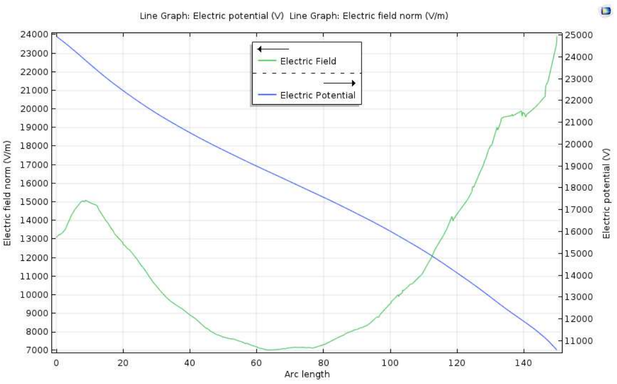


Fig. 4. Electric field and electric potential along the line across the insulator string with corona ring

The analysis of the effect of the vertical height of the corona ring on the electric field was done by varying the vertical height of the corona ring (Thick2) and fixing the outer diameter of the corona ring (Dout_ring), inner diameter of the corona ring tube (Din_ring) and the gap between both end of the corona ring (Gap). A total of ten different values of the vertical height of the corona ring were used in the simulation which ranges from 100 mm to 550 mm with a step size of 50 mm. The simulation includes obtaining the maximum electric field of the first porcelain insulator nearest to the high voltage terminal (33 kV).

Referring to Fig. 5, it can be seen that the relationship between electric field (V/m) and the vertical height of corona ring, Thick2 (mm) is non-linear. The graph represents a "U" shape, which have a turning point at Thick2 = 300 mm. For all the values before Thick2 = 300 mm, the electric field is decreasing gradually. However, all the values after Thick2 = 300 mm, the electric field starts increasing again. This indicates that the optimum vertical height of the corona ring along the insulator string shall not exceed 300 mm to minimize the maximum electric field of the first porcelain insulator.

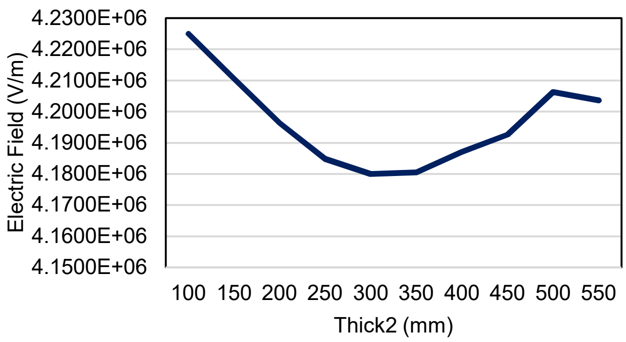


Fig. 5. Maximum electric field versus the vertical height of the corona ring along the insulator string

This analysis on the effect of the outer diameter of the corona ring on the electric field was done by varying the outer diameter of the corona ring (Dout_ring) and fixing the vertical height of the corona ring (Thick2), inner diameter of the corona ring tube (Din_ring) and the gap between both end of the corona ring (Gap). A total of ten different values of the outer diameter of the corona ring were used in the simulation, which ranges from 300 mm to 750 mm with a step size of 50 mm. Referring to Fig. 6, it can be seen that the relationship between electric field (V/m) and the outer diameter of corona ring, Dout_ring (mm) is proportional. The graph represents an increasing line slope. As the outer diameter of corona ring increases, the electric field increases. This indicates that the optimum outer diameter of the corona ring installed on the insulator string shall be as small as possible to minimize the maximum electric field of the first porcelain insulator.

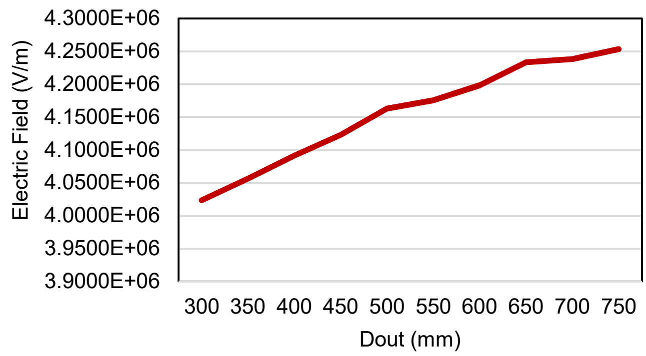


Fig. 6. Maximum electric field versus the vertical height of the corona ring along the insulator string

The analysis on the effect of the inner diameter of the corona ring tube on the electric field was done by varying the inner diameter of the corona ring tube (Din_ring). However, the vertical height of the corona ring (Thick2), outer diameter of the corona ring (Dout_ring) and the gap between both end of the corona ring (Gap) are fixed. A total of ten different values of the inner diameter of the corona ring tube were used in the simulation, which ranges from 20 mm to 65 mm with a step size of 5 mm. Referring to Fig. 7, it can be seen that the relationship between electric field (V/m) and the inner diameter of corona ring tube, Din_ring (mm) is inversely proportional. The graph represents a decreasing line slope. As the inner diameter of corona ring tube increases, the electric field decreases. This indicates that the optimum inner diameter of the corona ring tube installed on the insulator string shall be as thick as possible but other factors such as the weight, cost and practicality must also be taken into consideration to minimize the maximum electric field of the first porcelain insulator.

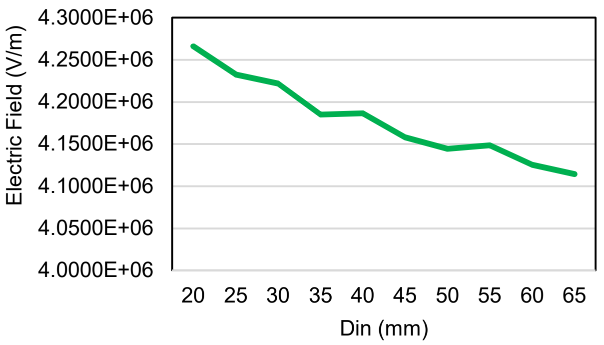


Fig. 7. Maximum electric field versus the inner diameter of the corona ring tube

IV. Conclusions

A model of three-dimensional (3D) 10-unit porcelain insulator string geometry without and with a corona ring has been successfully developed using the finite element analysis (FEA) software, COMSOL Multiphysics. The effect on the distribution of the electric field in the model was studied by varying the corona ring parameters such as the vertical height of the corona ring along the insulator string, outer diameter of the corona ring and the inner diameter of the corona ring tube.

Different values for each of the corona ring parameters were used in the study. It was found that the relationship between the vertical height of the corona ring along the insulator string and the electric field is not linear. When the vertical height of the corona ring is within the threshold, for this case is 300 mm, the electric field magnitude decreases. However, once the vertical height of the corona ring exceeds the threshold, the electric field magnitude increases again. In addition, the relationship between the outer diameter of the corona ring and the electric field is proportional. As the outer diameter of the corona ring increases, the electric field magnitude increases. On the other hand, the relationship between the inner diameter of the corona ring tube and the electric field is inversely proportional. As the inner diameter of the corona ring increases, the electric field magnitude decreases.

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