# Electric Field and Potential Distributions along Dry and Clean Non-Ceramic Insulators

## ABSTRACT

The electric field and potential distributions in the vicinity of non-ceramic insulators under dry and clean conditions are presented. A three-dimensional electric field analysis program, COULOMB, has been used for the calculations. A three-phase 765 kV power line tower geometry is considered for the potential distribution calculations along the insulators. For three-phase energization, two-dimensional contours of the three-dimensional equipotential surfaces are presented in selected vertical planes. The effects of the presence of power line conductors and of the three phase vs. single phase energization on the electric field and potential distributions have been investigated.

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# Electric Field and Potential Distributions along Dry and Clean Non-Ceramic Insulators

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*Abstract*: **The electric field and potential distributions in the vicinity of non-ceramic insulators under dry and clean conditions are presented. A three-dimensional electric field analysis program, COULOMB, has been used for the calculations. A three-phase 765 kV power line tower geometry is considered for the potential distribution calculations along the insulators. For three-phase energization, two-dimensional contours of the three-dimensional equipotential surfaces are presented in selected vertical planes. The effects of the presence of power line conductors and of the three phase vs. single phase energization on the electric field and potential distributions have been investigated.**

## INTRODUCTION

Control of the electric field strength around non-ceramic insulators is very important. High electric field strength may cause corona around the insulators, which may result in the degradation of the housing materials. When the non-ceramic insulators are installed on a three phase power line, the conductors, the grading ring, the tower configuration, and the other two phases of the three phase system can influence the electric field and potential distributions (EFPD) in the vicinity of the insulators. To analyze the EFPD of an insulator in service, it is important to study the influence of these effects from a practical standpoint.

Several studies related to the EFPD around power line insulators have been published recently. Zhao and Comber [1] described single-phase calculations of the EFPD in the vicinity of 345 kV non-ceramic insulators considering the effects of the conductors, grading ring and tower configuration. Chakravorti and Steinbigler [2] studied the insulator shape effects on the electric field strength on the surface of the insulator. A common feature of these studies is that for the analysis of the EFPD along non-ceramic insulators single-phase energization was assumed. However, power line insulators are exposed to conditions related to three-phase energization. Therefore, the influence of the other two phases of the three phase system on the EFPD in the vicinity of the insulators is to be studied.

Considering the complex geometry of the insulators, numerical methods are preferred for solving the EFPD. Numerical methods can be divided into two groups. The first group is to discretize the underlying integral equations. These are the charge simulation method and the boundary element method. These two methods are preferable for open boundary problems, such as insulators or power lines. The second group is to solve the governing differential equations. These are the finite element method and the finite difference method. These two methods are commonly used in the field analysis of problems with limited boundary conditions, such as rotating machines or transformers [1].

For the studies described in this paper, the commercially available program COULOMB, based on the boundary element method, developed by Integrated Engineering Software, has been employed.

In this paper, the effects of the fiberglass rod, polymer sheath and weather sheds, and the power line conductor on the EFPD around an insulator are analyzed. The influence of the other two phases of the three phase system are evaluated on an I-string and a V-string of a 765 kV tower.

## INSULATOR TO BE MODELED

The basic insulator model employed for the electric field analysis in this section is a 34.5 kV non-ceramic insulator. Its detailed geometric dimensions are shown in Figure 1.

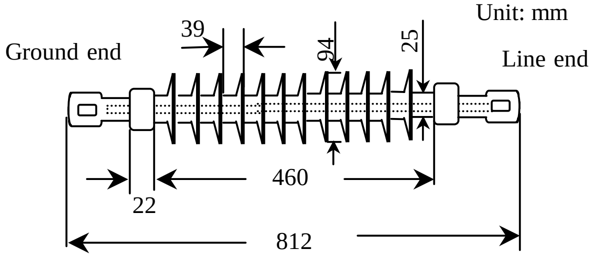


Figure 1. Simplified dimensions of a typical 34.5 kV non-ceramic insulator used in the calculations.

The insulator is equipped with metal end fittings. It is made of silicon rubber weather sheds with a relative permittivity of 4.3 and fiberglass rod with a relative permittivity of 7.2. There are 12 weathersheds on the housing. The insulator is surrounded by air with a relative permittivity of 1.0. The top metallic end fitting is taken as the ground electrode and for the purposes of calculations the bottom electrode is connected to a steady voltage source of 100 V. The insulator is positioned vertically, but shown horizontally in Figure 1 for convenience.

## EFFECTS OF THE SIMPLIFICATION OF INSULATORS ON THE ELECTRIC FIELD AND POTENTIAL DISTRIBUTIONS

There are various shapes of non-ceramic insulators. One of the typical 34.5 kV non-ceramic insulators is assumed to have 12 sheds and a length of about 0.8 m. For comparison purposes, a typical 500 kV insulator has 100 sheds and a length of 4.2 m. In order to reduce the EFPD calculation time when analyzing long insulators, the simplification of the insulator is necessary. To decide which feature of the geometry can be omitted with the least influence on the EFPD along the insulators, the 34.5 kV non-ceramic power line insulator shown by Figure 1 is used for the calculations.

Non-ceramic insulators have four main components. They are the fiberglass rod, silicone rubber sheath on the rod, silicone rubber weather sheds, and metal end fittings. Four models are used for the step-by-step comparison process. They are: (a) two electrodes only, (b) two electrodes and the fiberglass rod, (c) two electrodes, rod and sheath on the rod without weather sheds, and (d) the "full" 34.5 kV insulator.

The instantaneous voltage applied at the line end is 100 V. The voltage at the ground end is 0 V. The equipotential contours around the four simplified models are shown in Figure 2. Each number shown along the perimeters of the four contour plots means centimeters. Case (a) shows that about 20% of the insulation distance sustain about 70% of the applied voltage. The presence of the rod slightly changes the potential distribution, see Case (b). The distribution of the equipotential contours for Case (c) is very close to Case (d). However, the presence of the weather sheds changes the equipotential contours. Comparing Cases (c) and (d), the maximum difference between potentials at the same point along the center line of the insulator is only 1% of the applied voltage. This indicates that the simplification introduced by Case (c) is acceptable for the center line EFPD of Case (d). However, the electric field strength magnitudes for Cases (c) and (d) along the paths defined on the surface of the sheaths are shown in Figure 3.

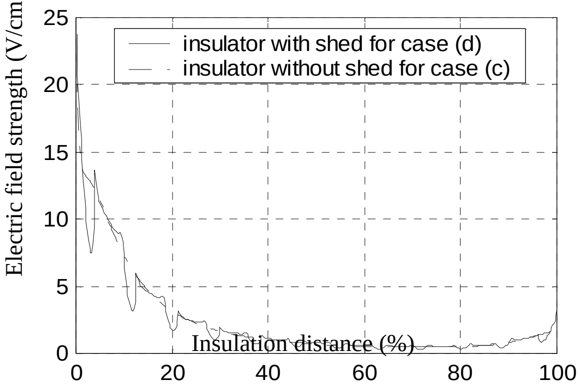
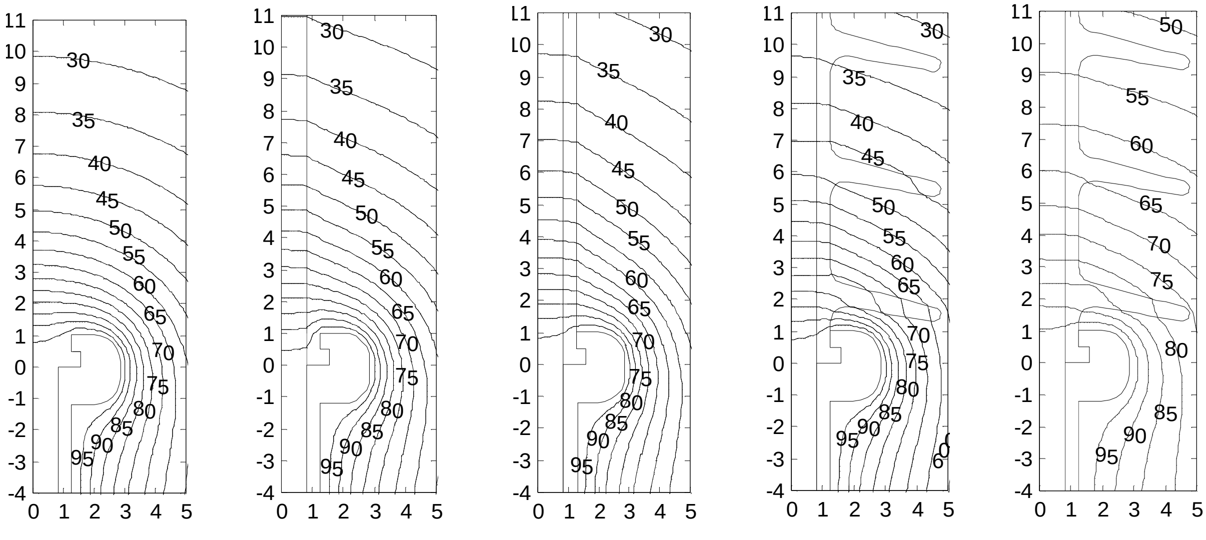


Figure 3. Electric field strength magnitude along the insulation distance at the surface of the sheath for Cases (c) and (d).



(a) (b) (c) (d) (e)

Figure 2. Equipotential contours around the four computational models.

Of course there is a change in the EFPD in the vicinity of the weather sheds shown by Case (d). However, the electric field strength outside the weather sheds still has a good correspondence in Cases (c) and (d). For example, the maximum electric field strength for Case (c) is 22.9 V/cm and for Case (d) is 23.8 V/cm. The difference between them is only 4%, which means that the electric field distribution of the insulator with weather sheds can be estimated through the simplified insulator model without weather sheds.

## EFFECTS OF CONDUCTORS

The effects of the power line conductor on the EFPD have been studied by adding a 3m long single conductor section just below the insulator. The insulator is suspended from the center of a 1.6 x 0.4 m ground plane. The equipotential contours around the insulator together with this conductor are shown in Figure 2(e). It can be seen that now 20% of the insulation distance sustain about 47% of the applied voltage. The electric field strength distribution around the insulator is shown in Fig. 4.

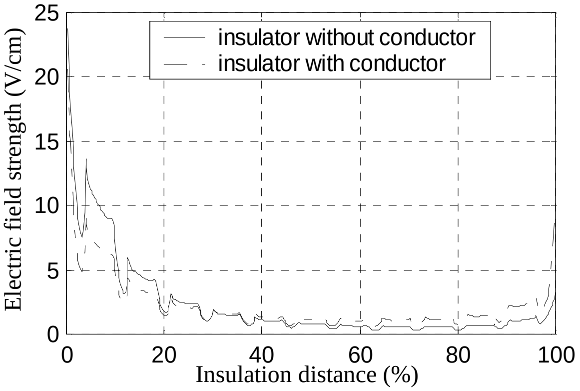


Figure 4. Electric field strength magnitude along the insulation distance at the surface of the sheath.

The maximum value of the electric field strength at the line end of the insulator with the presence of the 3 m long conductor section is 20.6 V/cm and at the ground end is 8.7 V/cm. The conductor section at the line end reduces the electric field strength at the line end, but increases the electric field strength near the ground end.

## TOWER TO BE MODELED

The simplified geometry and major dimensions of a 765 kV power line tower and conductors are shown in Figure 5. All dimensions shown are in centimeters.

The power line conductors and the tower have been modeled three-dimensionally. The bundle conductors (with four subconductors) have been modeled as smooth conductors, positioned parallel to the ground. The length of each conductor considered is 60m. The two ground wires have been ignored in the calculations. The insulator used for the calculation has a simplified geometry, without weather sheds. The diameter of the fiberglass rod together with the polymer sheath is 1.3 cm. The length of the insulator is 5.7m. The corona ring diameter is 50 cm; the diameter of the tube used for the corona ring is 10cm.

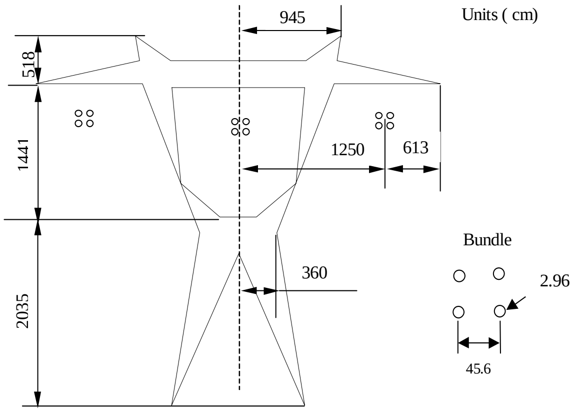


Figure 5. 765 kV power line tower and conductors, simplified geometry and major dimensions.

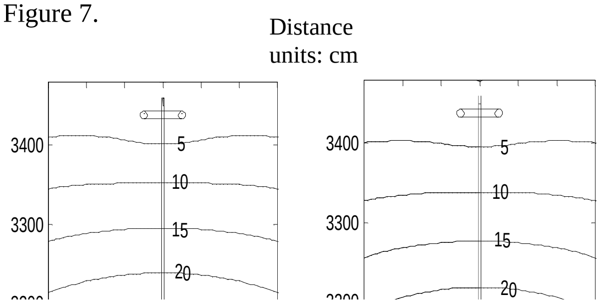
## EFFECTS OF OTHER TWO PHASES OF THE THREE PHASE SYSTEM

The effects of the other two phases of the three phase system have been investigated for both an I-string and a V-string type of insulator configuration. The center phase conductor is inside the tower window. In terms of EFPD that is the worst case.

In order to evaluate the effects of the three phase energization, two cases have been considered. In the first case, only the center phase at the tower is considered. In the second case, the instantaneous voltages applied to the three phase conductor system are: $V_{left}$ = -50 V, $V_{center}$ = 100 V, $V_{right}$ = -50 V. The resulting equipotential contours for a 765 kV I-string are shown in Figure 6.

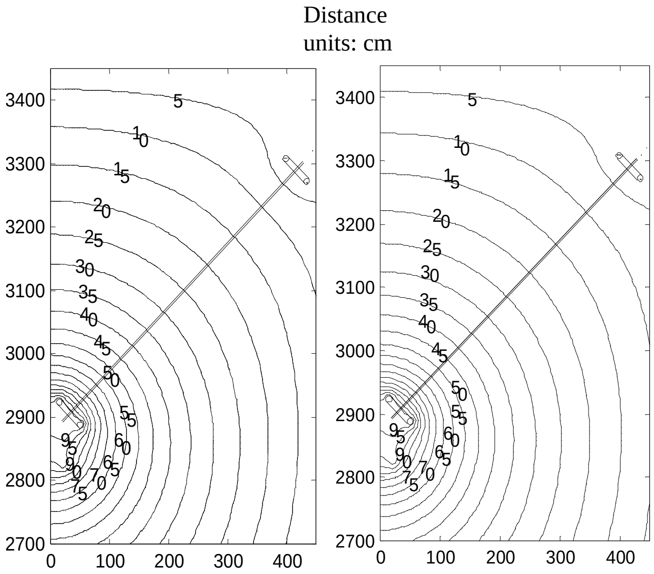
Figure 6 shows that the EFPD at the ground end and the middle section of the insulator is changed by the presence of the other two phases. The potential distribution at the line end changes less than at the middle section of the insulator. The reason for that is that the line end of the insulator is of course much closer to its conductor and the corona ring there than to the other two phases. The maximum electric field strength at the triple junction point of the energized metal fitting, the weather shed, and air is 2.368 V/cm for single phase and 2.76 V/cm for three phase energization, for the voltage system assumed.

The resulting equipotential contours for a V-string are shown in Figure 7.



(a) Single phase (b) Three phase

Figure 6. Equipotential contours for I-string under (a) single phase and (b) three phase energization.



(a) Single phase (b) Three phase

Figure 7. Equipotential contours for V-string under (a) single phase and (b) three phase energization.

Figure 7 shows that the trend of the EFPD of the V-string is similar to that of the I-string. The potential distribution at the ground end and the middle section of the insulator is changed by the presence of the other two phases. The potential distribution at the line end also changes somewhat. The maximum electric field strength at the triple junction point (defined above) is 2.27 V/cm for single phase and is 2.41 V/cm for three phase energization, for the voltage system assumed.

## CONCLUSIONS

The electric field strength and potential distributions around non-ceramic insulators have been studied using the COULOMB software.

- For a typical 34.5 kV non-ceramic insulator, four simplified computational models representing the performance of the insulators have been studied. The results show that the weather sheds of the insulator can be omitted without significantly compromising the accuracy when calculating the potential distribution along the insulator.
- The presence of the conductor attached to the insulator has significant effects on both the potential and electric field distributions.
- The effects of the presence of the other two phases of the three phase system on the potential distribution along the center phase insulator have been calculated. The maximum electric field strength at the triple junction point of the energized metal fitting, the weather shed, and air is about 16% higher for an I-string and 6% higher for a V-string under three phase energization compared to the single phase case.

## ACKNOWLEDGMENT

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## REFERENCES

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