

# INVESTIGATING THE EFFECTS OF DISC INSULATOR TYPE AND CORONA RING ON VOLTAGE DISTRIBUTION OVER 230-KV INSULATOR STRING USING 3-D FEM

Ebrahim Akbari, Mohammad Mirzaie

<sup>1</sup>Dept. of Elec. and Comp. Eng., Babol Univ. of Tech., Babol, Iran  
[e.akbari@stu.nit.ac.ir](mailto:e.akbari@stu.nit.ac.ir), [mirzaie@nit.ac.ir](mailto:mirzaie@nit.ac.ir)

## ABSTRACT

*The voltage distribution of insulator strings, which are very common in the suspension of overhead transmission systems, is greatly uneven. So the calculation of the voltage distribution along them is a very important factor in the design of the insulators. Also, no remarkable endeavour regarding the impact of insulator material and profile upon the electric field and voltage distribution has been made so far. In this paper several 230-kV insulator strings with different porcelain and glass units were simulated and their voltage distributions were compared, to investigate the effect of insulator types on this quantity. Also the effect of corona ring on potential distribution over insulator strings with different insulator types was investigated. Reported results show the dependency of voltage distribution to insulator material and profile.*

**KEYWORDS:** *Porcelain and Glass Disc Insulator Strings, Voltage Distribution, Finite Element Method*

## I. INTRODUCTION

Insulator strings are widely used in power systems for the dual task of mechanically supporting and electrically isolating the live phase conductors from the support tower. This is due to their high mechanical strength, easy installation and operation, and low cost. The number of units of an insulator string depends on several factors such as operation voltage, mechanical strength, sea level (of alignment), lightning strength, and contamination level of the environment [1]. Due to the coupling capacitance between disc insulators and conductors around them, the potential distribution of insulator string is uneven greatly. The voltage and electric field on the insulators near wires is three to five times greater than others, which may easily lead to corona, insulators' surface deterioration and even flashover. And these problems will seriously affect the operation safety of transmission lines [2]. So the calculation of the electric field and voltage distribution in and around high voltage insulators is a very important factor in the design of the insulators. Furthermore, the knowledge of the electric field is useful for the detection of defects in insulators [3].

Several circuit methods for calculating potential distribution were studied in [4]. Also Izgi et al [5] used circuit method for calculating voltage distribution over insulator string depending on atmospheric conditions such as wind and contamination; but these methods could not analyse electric field distribution. Methods based on field theoretical approach were reviewed in [6], which indicated its advantages in the analysis of electrical insulation problems. However, the electric field evaluation of a practical insulator is so complex that an analytical method is very difficult, if not possible, to compute the exact solutions. Numerical methods are thus often adopted in engineering applications to derive acceptable solutions. Wei et al [7] applied charge simulation method (CSM) to calculate potential and electric field distribution along insulator strings, but they simplified the problem which could not include the influence of conductors or towers. A finite difference method (FDM) to calculate the electric field in and around polluted insulators with asymmetric boundary conditions has been proposed by Morales et al [8]. Zhao et al [9] applied boundary element method (BEM) in

calculating the potential and electric field distribution along insulators. Their method considered the effects of conductors, grading devices and transmission towers. But computational requirements were high.

Finite element method (FEM) was applied in calculating potential and/or electric field distribution along insulators in [10]- [12]. In [10] a two-dimensional (2-D) FEM was used for simulation of electric field distribution on ceramic insulators. In [11] Ashouri et al used FEM-based software, Maxwell 3-D for investigating the wind effect on the potential distribution of an insulator string. Reddy et al [12] used FEM-based software to study the potential and electric field distribution of different types of porcelain disc insulators; but their method was two-dimensional (2-D) and could not consider the supporting structures, conductors and other accessories.

In this paper several insulator strings with different disc insulators was simulated using a three-dimensional (3-D) electric field program based on finite element method. The potential distributions along insulators was calculated and compared for different insulator types. The effects of tower and conductor existence were considered and also the effect of corona ring, for reduction of maximum electric field and improving voltage distribution, was investigated.

## II. PARAMETERS OF INSULATORS, GRADING RING, TOWER AND CONDUCTORS

The investigations were carried out on three types of porcelain disc insulators and three types of glass disc insulators, which were denominated by Type A-F, respectively. Technical parameters of the insulators are introduced in Figure 1 and given in Table 1, in which H is the configuration height, D is the diameter, L is the leakage distance and  $F_{min}$  is minimum mechanical failing load. Also profiles of different insulator types are shown in Figure 2. The length of the conductor, which was used for the simulation of the model, was chosen to be equal to the insulator string length. Tower height was 5000 mm and cross-arm length was 3175 mm and finally one of the common types of corona rings in 230-kV power transmission lines was selected for the investigations, whose profile and dimensions are shown in Figure 3. The ring centre is 35 mm away from string axis.

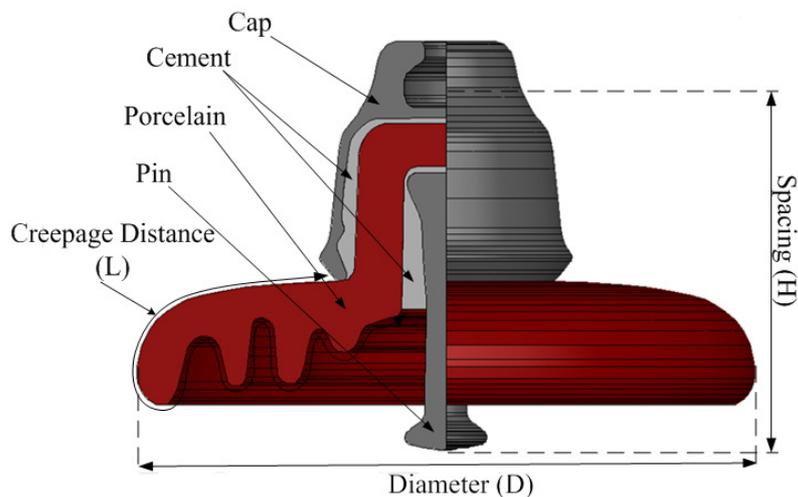
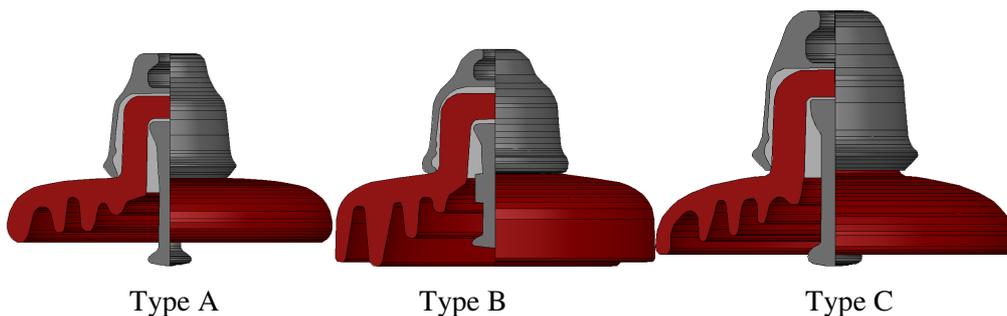


Figure 1. Dimension parameters and material types of one of the simulated insulators



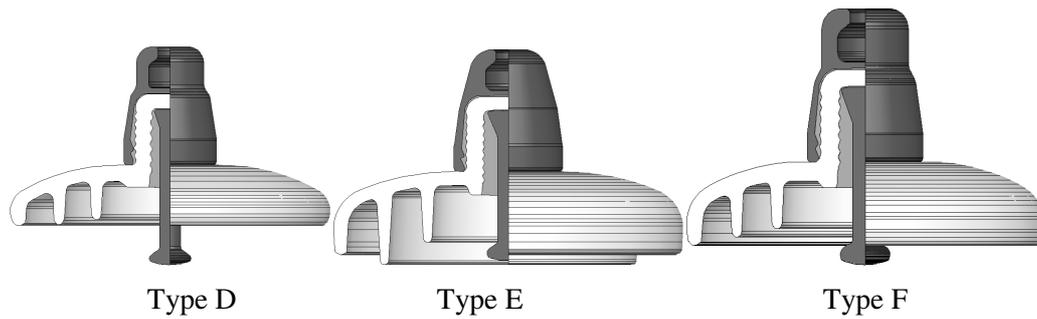


Figure 2. Profiles of the simulated insulators

Table 1. Technical parameters of the simulated insulators

No.	Type	Manufacturer	Material	H (mm)	D (mm)	L (mm)	Fmin (kN)
A	0207	Iran Insulator Co.	Porcelain	146	255	295	120
B	0215	Iran Insulator Co.	Porcelain	146	255	440	120
C	0206	Iran Insulator Co.	Porcelain	170	280	370	160
D	U120B	Pars Maghareh Co.	Glass	146	255	320	120
E	U120BP	Pars Maghareh Co.	Glass	146	280	442	120
F	U160BL	Pars Maghareh Co.	Glass	170	280	370	160

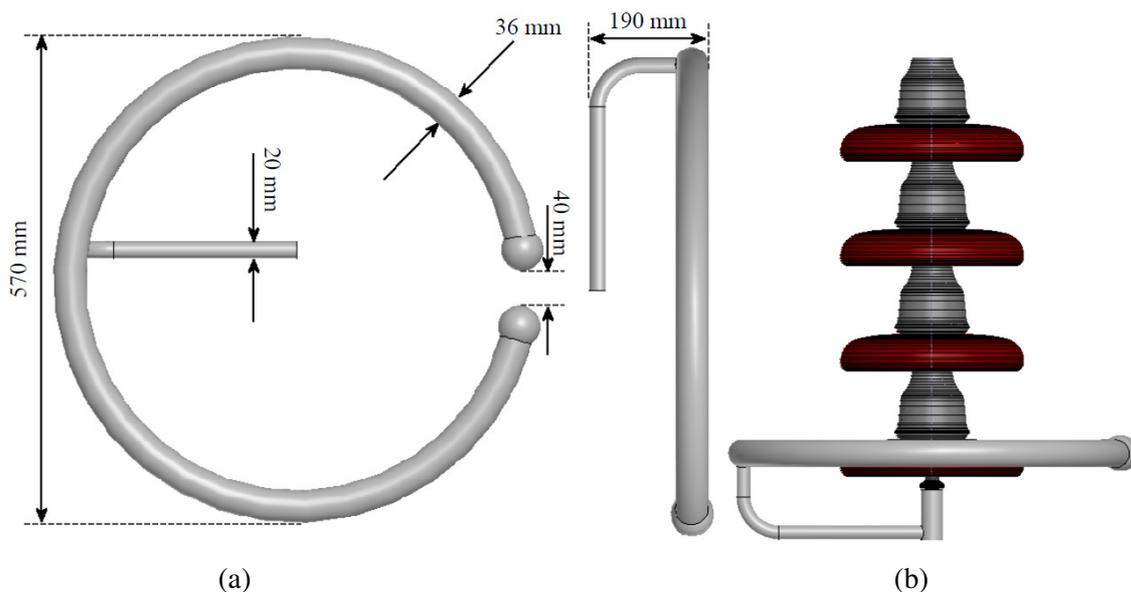


Figure 3. Schema of simulated corona ring (a) profile and dimensions (b) installation configuration

### III. NUMERICAL SIMULATION PROCEDURE

Finite element method (FEM) was introduced in 1960, and initially applied in electrical engineering in 1965. Now FEM is being widely used in electrical engineering as a main numerical calculation method for quantifying and optimizing the performance of an insulator under electro-magnetic fields [12].

The finite element method for any problem consists of, basically, discretizing the solution domain into a finite number of elements, deriving governing equations for a typical element, assembling of all elements in the solution domain, and solving the system of equations.

High voltage apparatus, including outdoor insulators, lie in the domain of the electrostatics application modes. The 'statics' implies that the time rate of change is slow, and that wavelengths are very large compared to the size of the domain of interest, in this case an outdoor insulator [13].

The boundary problem of the 3-D electrostatic-field FEM is expressed as (1) with  $\phi$  being the electric potential [13].

$$\left\{ \begin{array}{l} \frac{\partial^2 \phi}{\partial x^2} + \frac{\partial^2 \phi}{\partial y^2} + \frac{\partial^2 \phi}{\partial z^2} = 0 \quad \text{B1} \\ \phi|_{S_0} = \phi_0 \quad \text{B2} \\ \phi_1 = \phi_2, \epsilon_1 \frac{\partial \phi_1}{\partial n} = \epsilon_2 \frac{\partial \phi_2}{\partial n} \quad \text{B3} \\ \iint_{S_i} \epsilon \frac{\partial \phi}{\partial n} dS = 0, \phi|_{S_i} = \phi_i \quad \text{B4} \end{array} \right. \quad (1)$$

where boundary condition B1 is true in the whole region, B2 is known potential boundary, B3 is the boundary condition on the interface of different mediums and B4 is floating potential boundary.  $\phi_0$  is on the high voltage terminal, conductor and corona ring, and 0 V on the lower voltage terminal and iron tower. Cap and pins with unknown potentials must be set as floating potential boundaries. For high voltage insulator string problems considering effects of tower and conductor, there is no symmetry plane. The numerical analysis method was introduced in [10,11] with more detail.

The model simulated in FEM, which consists of the insulator string, the transmission line and also simplified tower, is shown in Figure 4(a).

#### IV. POTENTIAL DISTRIBUTION OVER INSULATOR STRING

As mentioned before voltage and electric field distribution of insulator string is uneven because of the effects of stray capacitive currents. This phenomenon can lead to corona discharge on insulator surface and therefore should be considered before insulator usage. The equipotential contours around a 230-kV insulator string consisting of 13 insulator units are shown in Figure 4(b). The uniformity degree of voltage distribution depends on insulator unit capacitance, the number of units, cross-arm length and corona ring parameters.

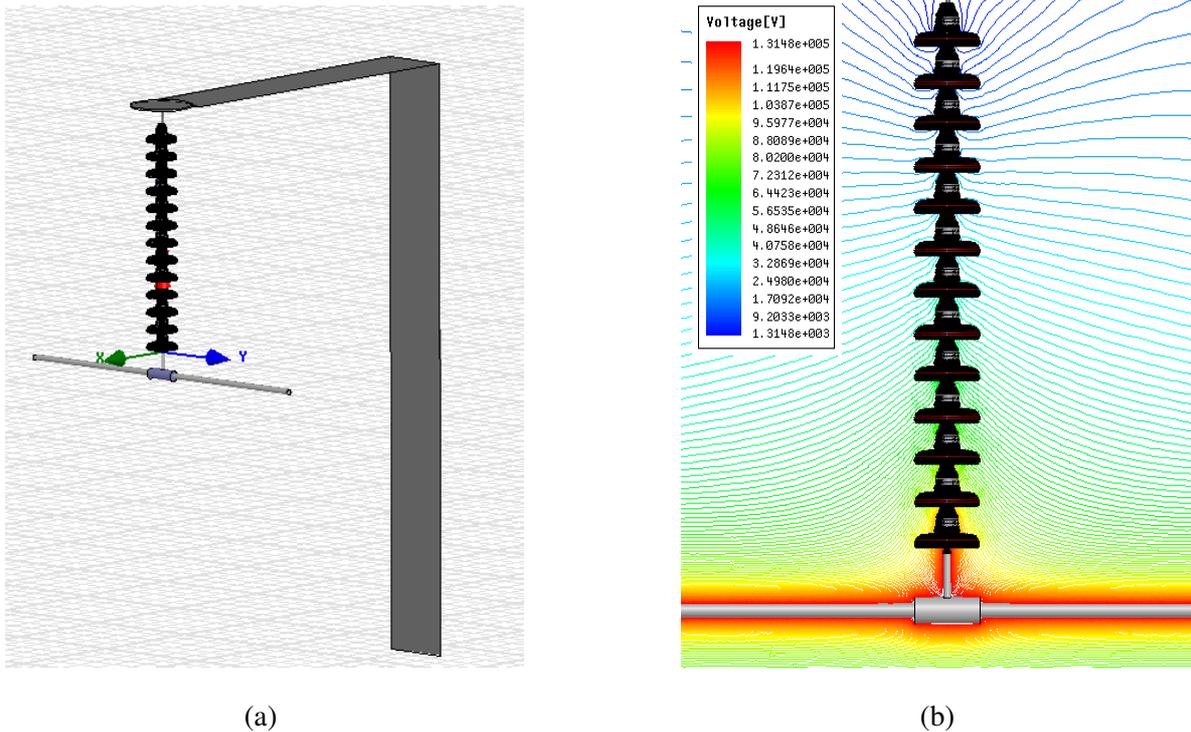
String efficiency ( $\eta$ ) is used to determine the level of uniformity of voltage distribution of insulator string. The formula is:

$$\eta = \frac{U}{n \cdot U_{\max}} * 100 \quad (2)$$

where  $U$  is phase-neutral voltage over insulator string,  $U_{\max}$  is the maximum voltage drop on a single disc in insulator string,  $n$  is the number of insulator units, and  $\eta$  is the percentage of string efficiency. For better studying of voltage distributions all values of voltages was normalized as following:

$$\%U_i = \frac{U_i}{(230/\sqrt{3})} * 100 \quad (3)$$

where  $U_i$  is the voltage of  $i$ -th unit in kV and  $\%U_i$  is the normalized voltage of the same unit in %. In this paper, insulator units are enumerated from energized side to grounded side of the string.



**Figure 4.** (a) The model of tower, conductor, and insulator string used for simulation (b) the equipotential contours around a 230-kV insulator string

## V. SIMULATION RESULTS

Insulator strings consist of several disc insulator units connected series to each other. To investigate the effect of insulator type and profile on potential distribution, simulation of insulator strings in different conditions has been carried out by software based on FEM and results were presented.

### 5.1. Effects of Transmission Tower and Conductor

In order to investigate tower and conductor effects on voltage distribution, a string of 13 insulator units of type A was simulated with and without tower and conductor, and results of normalized voltage distribution were presented in Figure 5. As can be seen, the difference between two curves is too high. Thus hereafter a model of tower and conductor with pre-mentioned dimensions (section 2) is included in all simulations.

### 5.2. Effects of Types of Insulator Units

Normalized voltage distribution and efficiency for insulator strings with 13 units of types A-F is given in Figures 6(a) and 6(b), respectively. It is obvious from figures that, the type of insulator is a determining factor for voltage distribution. Also it is comprehended that, glass insulators which have greater capacitance values yield higher string efficiency.

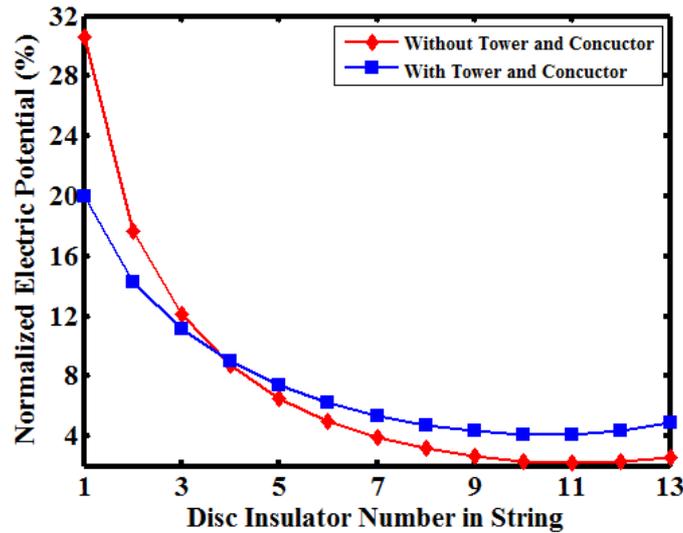


Figure 5. Comparison of normalized electric potential distribution for simulations with and without tower and conductor

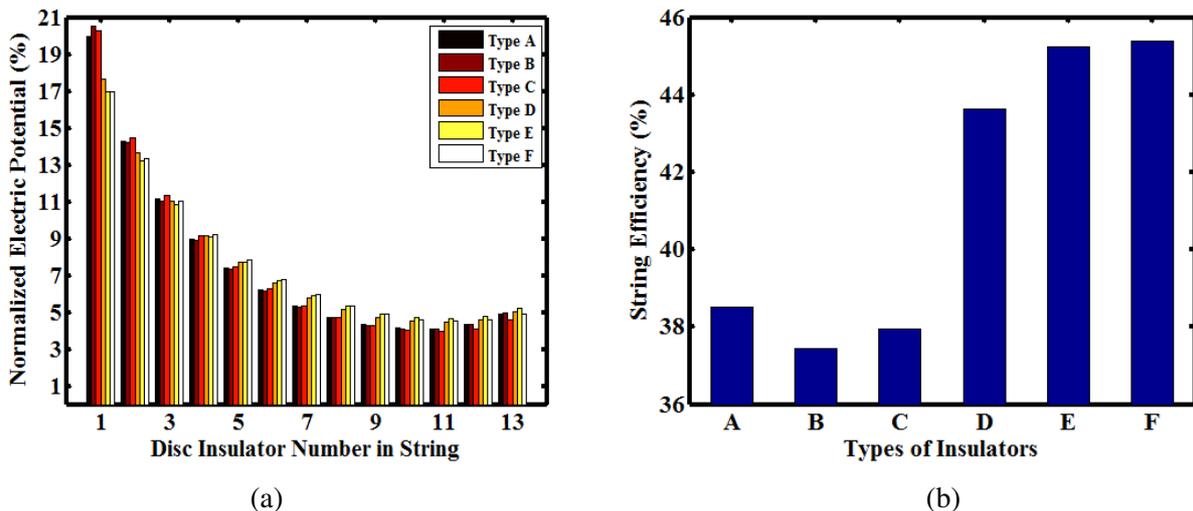


Figure 6. Simulation results for different insulator strings: (a) normalized electric potential distribution and (b) string efficiency

### 5.3. Effects of Corona Ring

To investigate the effects of corona ring existence on voltage distribution and string efficiency, the introduced corona ring was added in all of the simulations of section 5.2 and new results were given in Figure 7(a) and 7(b), respectively. Comparing Figure 7(b) and 6(b), and considering dimensions and materials of insulators from Table 1, it can be deduced that the degree of improvement of voltage distribution using corona ring depends on insulator material and profile, as well as the corona ring configuration parameters.

### 5.4. Effects of Number of Units in the Insulator String

In order to study the effects of number of units on potential distribution and efficiency of an insulator string, a string consisting of one of the introduced insulator units (type A) was simulated for various number of insulator units ( $n=13, 14, 15, 16$ ) and results were presented in Figure 8(a) and 8(b), respectively. It is obvious that, increasing the number of insulators in the string reduces the maximum voltage drop along insulator units slightly; but owing to the increasing of  $n$ , efficiency of the string would fall due to (2).

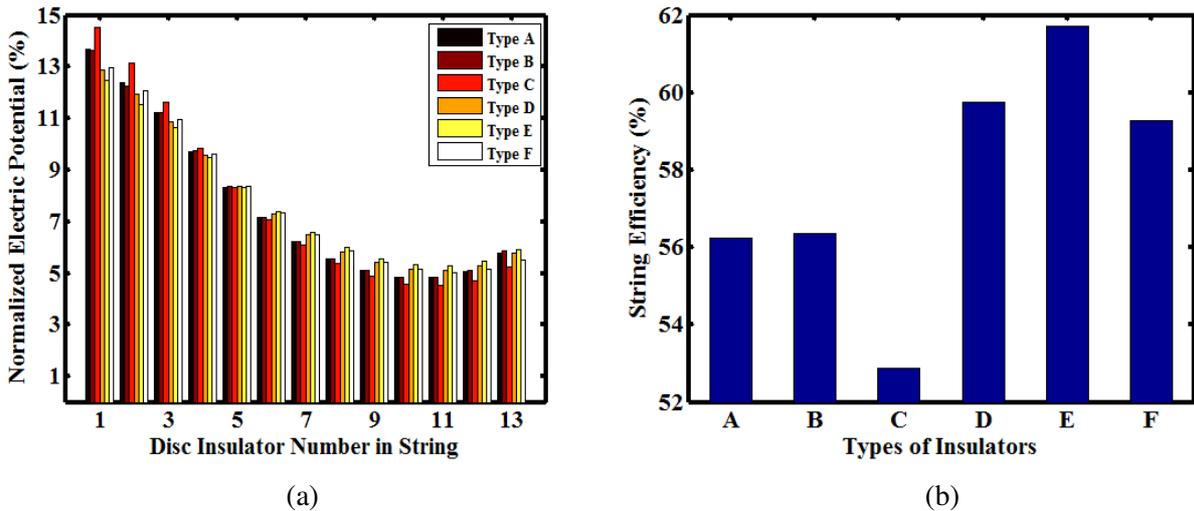


Figure 7. Effects of corona ring for different insulator strings: (a) normalized electric potential distribution and (b) string efficiency

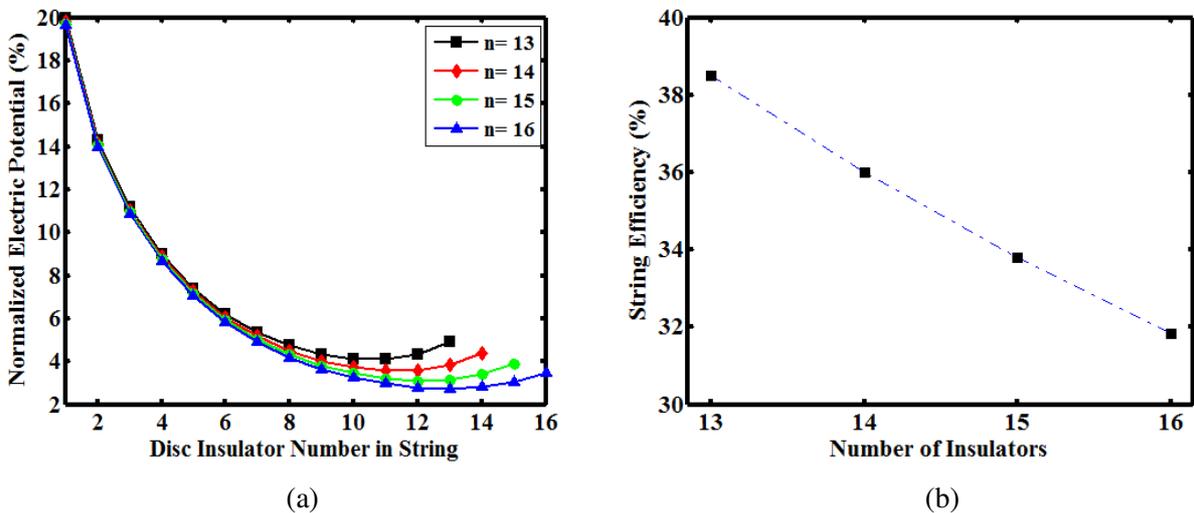


Figure 8. Effects of number of units for a string consisting units of type A and without corona ring: (a) normalized electric potential distribution and (b) string efficiency

## VI. CONCLUSIONS

An attempt was done to understand the effect of disc insulator type and corona ring on the voltage distribution of insulator strings.

According to the results, distribution of voltage over insulator strings depends on insulator material and profile. Between them, the type of insulator material has a determining effect on voltage distribution and insulator strings with insulator units of type glass have more even voltage distribution than strings composed of porcelain insulator units. Nevertheless, profile of insulator units can affect the voltage distribution over insulator string, to some extent.

Furthermore, it was concluded that, the degree of improvement of voltage distribution using corona ring depends on insulator material and profile, as well as the corona ring configuration parameters and same corona ring yields different degree of improvement of voltage distribution over insulator string, for different types of insulator units. Hence for each particular type of insulator unit, corona ring parameters should be optimized separately to give the maximum value of string efficiency.

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## Authors

**Ebrahim Akbari** was born in Amol, Iran, on March, 1984. He received the B.E. degree in electrical engineering from Birjand University, Birjand, Iran, in 2009. He is currently working toward M.Tech. degree from Babol University of Technology, Babol, Iran. His research interests are High Voltage Engineering, Finite Element Method, Artificial Intelligence and Power System Operation.



**Mohammad Mirzaie** received his PhD degree in Electrical Engineering from Iran University of Science and Technology, Tehran, Iran. Currently he is working as an Associate Professor in the Electrical Engineering Department, Babol University of Technology, Babol, Iran. His research interests are High Voltage Engineering, Life Assessments and Diagnostics in High Voltage Equipment and Reliability in Components.

