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Analysis of Electric Field on Insulator for Different Pollution Condition

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ABSTRACT

This paper presents the simulation results of electric field and potential distributions along the surface of various insulators such as porcelain, polymeric and glass insulators, under clean and various contamination conditions with/without water droplets, salt, dust etc. The objective of this work is to compare the effect of contamination on potential and electric field distributions along the insulator surface. Numerical analysis of electric field distribution is obtained using Finite Element Method (FEM) which is implemented using ANSOFTMAXWELL. To model polluted environments, deposit of pollution is modeled as a thin layer with appropriate conductivity. Different pollution levels were simulated keeping the pollution layer thickness constant the field is compared with coating of salt over the insulator. The simulation results show that electric field distributions are obviously depended on contamination conditions.

Keywords: Electric field, Insulator and Conductivity.

1. INTRODUCTION

Pollution reduces the electrical strength of the insulator; it combines with moisture and lessens superficial resistance up to 20 %.Polluters such as steam, industrial mist, cement, and plaster in industrial regions as well as salt in coastal region are transferred by fog or wind and form a film on insulator surface that convert a conductive layer to pass leakage current. This phenomenon makes the insulator instable, increase electrical flashover probability and finally reduces T&D system's reliability significantly. This process increases the leakage currents, which decreases the withstand voltage of the insulator, that finally result in flashovers and undesirable outages. Flashovers on high voltage insulators due to natural and industrial pollutants adversely affect performance and reliability of overhead lines in polluted areas. So it is necessary to study the effect of pollutants on electric field distribution.

Types of Pollution:

The level and the type of pollution of a region are associated with the sources of pollution, as well as with weather factors of the place.

A. Industrial Pollution:

The industrial pollution of the insulators appears with the industries development and by the contaminants generated and expelled to the atmosphere. There are diverse types of industrials pollutants: metallurgical, chemical substances, dust, smoke, cement, etc. These substances will settle by the action of the wind, weight, electric fields…, on the insulators creating a contaminant layer. This layer settled on the insulators is formed slowly during a period that can last months or years. During this period will alternate dry epochs with humid epochs.

B. Marine Pollution:

The insulators exposed to coastal or marine environments, can become to be conductors due to the formation of a conductive layer on its surface. This layer will be formed on account of the salted dew of the mornings in these zones close to the coasts. When dried with the heat produced in the same insulator or with the environment temperature, is going to deposit in the insulator the evaporated salt that had absorbed before. The particles placed in the insulators are not dangerous in dry weather but, the problem arises when the environmental weather is humid, because the layer can become conductor. The conductivity of this layer will depend on the kind of salt that form it. The weather conditions vary considerably from the coastal areas to the interior areas and they play a very important role in the contaminants deposition rate and in the operation of the insulator. The problem of the pollution depends mainly on the environment.

C. Desert Pollution:

In some zones, the insulators of the electric lines are often subject to the deposition of contaminants substances of the deserts. This can cause a serious reduction in the efficacy of the insulator, having as a result the flashover and the electricity supply lack. Also the storms of sand must be kept in mind. The type of environmental conditions will affect considerably to the insulators. The predominant elements in this type of pollution are: the sand and the widespread, salty dust in a dry atmosphere. The desert climate is characterized for sand storms and hurricanes that contain particles that move to a high speed. These particles strike to the surface of the insulator causing the material erosion. The storms of sand are an important factor that causes a decrease of reliability in electrical lines.

2. MATHEMATICAL MODELING

A. Electric field and potential distributions calculation:

One simple way for electric field calculation is to calculate electric potential distribution. Then, electric field distribution is directly obtained by minus gradient of electric potential distribution. In electrostatic field problem, electric field distribution can be written as follows

$E = \nabla V$ (1)

From Maxwell's equation

$\nabla E = \nabla(-\nabla V) = \rho/\varepsilon$ (2)

Where

ρ - Resistivity of a material

ε - Dielectric constant of a material

($\varepsilon = \varepsilon 0 \varepsilon r$)

$\varepsilon 0$ - Dielectric constant in free space

εr - Relative dielectric constant of a material

Placing equation (1) into equation (2) Poisson's equation is obtained.

$\varepsilon . \nabla(\nabla V) = -\rho$ (3)

Without space charge ρ = 0, Poisson's equation becomes Laplace's equation.

$\varepsilon . \nabla(\nabla V) = 0$ (4)

B. FEM analysis of the electric field distribution:

The finite element method is one of numerical analysis methods based on the variation approach and has been widely used in electric and magnetic field analyses since the late 1970s. Supposing that the domain under consideration does not contain any space and surface charges, two-dimensional functional F (u) in the Cartesian system of coordinates can be formed as follows:

$F(u) = 1/2 \int_D [\varepsilon x (du/dx)^2 + \varepsilon y (du/dy)^2]\, dxdy$ (5)

Where εx and εy are x- and y-components of dielectric constant in the Cartesian system of coordinates and u is the electric potential. In case of isotropic permittivity distribution (ε = ε x = ε y), equation (5) can be reformed as

$F(u) = 1/2 \int_D \varepsilon [(du/dx)^2 + (du/dy)^2]\, dxdy$ (6)

If the effect of dielectric loss on the electric field distribution is considered, the complex functional F (u) should be taken into account as

$\overset{x}{F}(u) = 1/2 \int_D \omega\, \varepsilon 0 (\varepsilon - j\varepsilon + g\delta) [(du/dx)^{x2} + (du/dy)^{x2}]\, dxdy$ (7)

Where ω is angular frequency, ε0 is the permittivity of free Space (8.85 ×10-12 F/m), tg δ is tangent of the dielectric loss angle, and u* is the complex potential.

Inside each sub-domain De, a linear variation of the electric potential is assumed as described in (8)

$u(x, y) = \alpha_e 1 + \alpha_e 2\, x + \alpha_e 3\, y;$ (8)
$(e = 1, 2, 3, \ldots n_e)$

Where u_e (x, y) is the electric potential of any arbitrary point inside each sub-domain D_e, $\alpha_e 1$, $\alpha_e 2$ and $\alpha_e 3$ represent the computational coefficients for a triangle element e, ne is the total number of triangle elements.

The calculation of the electric potential at every knot in the total network composed of many triangle elements was carried out by minimizing the functional F(u), that is,

$\partial F(u_i) / \partial u_i = 0; \quad (i = 1, 2, 3, \ldots np)$ (9)

Where np stands for the total number of knots in the network. Then a compact matrix expression

$[Sji]\{ui\} = \{Tj\}; \quad i, j = 1, 2, \ldots np$ (10)

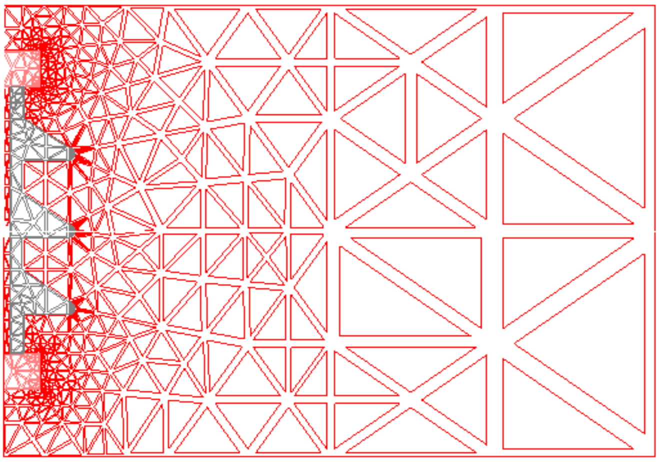
Where [Sji] is the matrix of coefficients, {ui} is the vector of unknown potentials at the knots and {Tj} is the vector of free terms. After it is successfully formed, the unknown potentials can be accordingly solved.

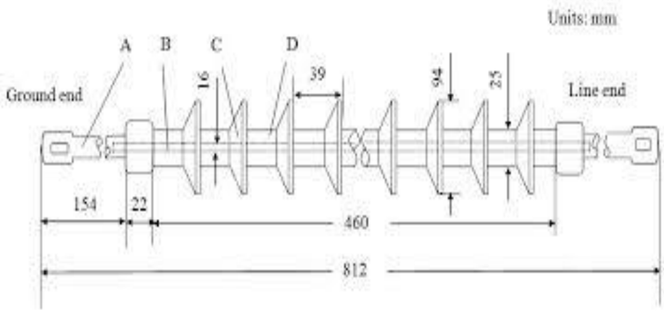
3. SIMULATION AND RESULTS

FEM based ANSOFT software is used to analyze the electric field over the insulator different pollution condition. Various pollutants like salt, dust and water droplet are coated over the insulator surface and field analysis is done. Field results are compared, based on the results optimal design of insulator must be done.

Mesh Analysis:

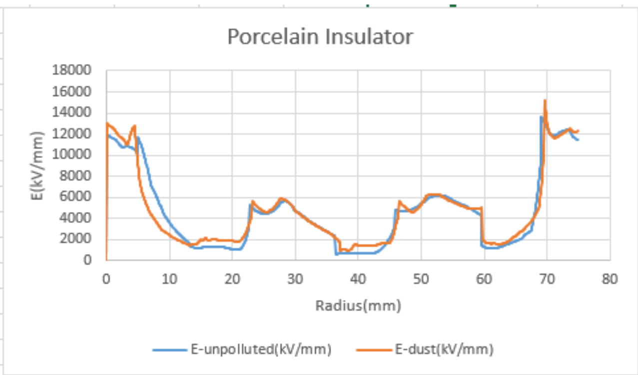
The number of meshes is found to be very high near the high voltage and low voltage electrode. Triple junction point has largest number of meshes and the number of meshes is found to decrease as we move away from the insulator. Larger number of meshes imply greater accuracy.





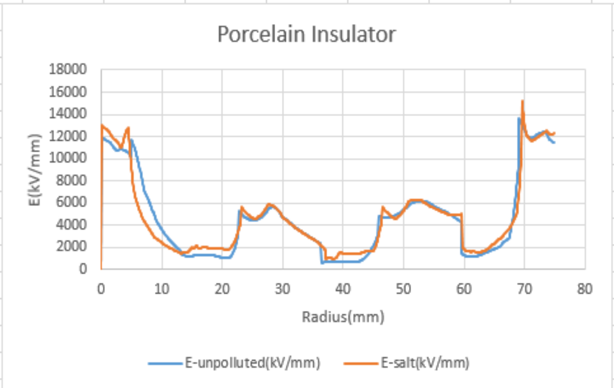
Standard Dimension for Insulator

Porcelain Insulator with Dust Pollutant:

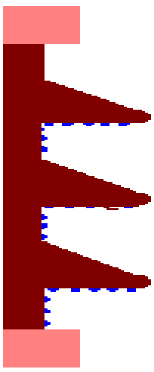


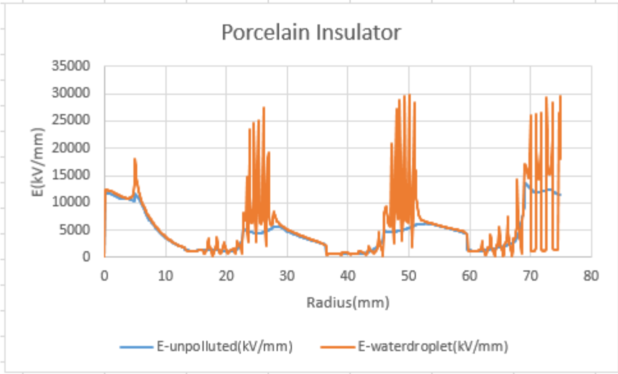
In actual power system porcelain insulators are used in practice for low voltage application as they are economical. Here porcelain insulator coated with layer of dust is simulated to obtain the field distribution. Due to dust pollution field in the high voltage electrode has increased by 12.73 % and field near low voltage electrode is increased by 15.64 %.

Porcelain Insulator with Salt Pollutant:
Porcelain insulator with salt pollutant is widely found near seashores. Since salt has greater conductivity, it leads to quicker flashover because of increase in electric field. Due to dust pollution field in the high voltage electrode has increased by 8.8 % and field near low voltage electrode is increased by 28.1 %.



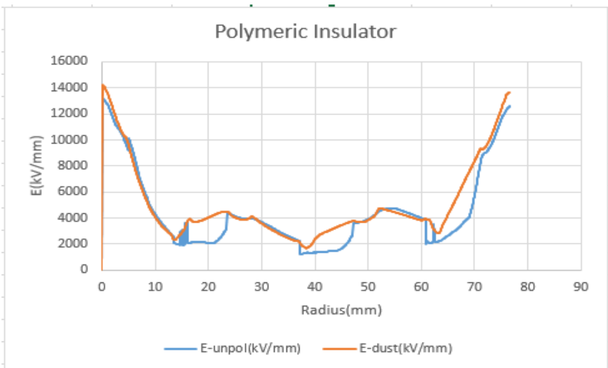
Porcelain Insulator with Water Droplet over the Insulator Surface:



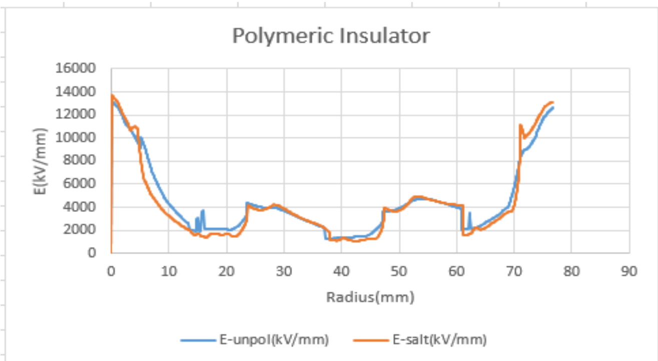


Electric field analysis is done when the porcelain insulator is coated with small water droplets over the surface to find the field distribution after rain. Because of presence of water droplets over the insulator surface, the field disstribution is found to have raised tremendously.

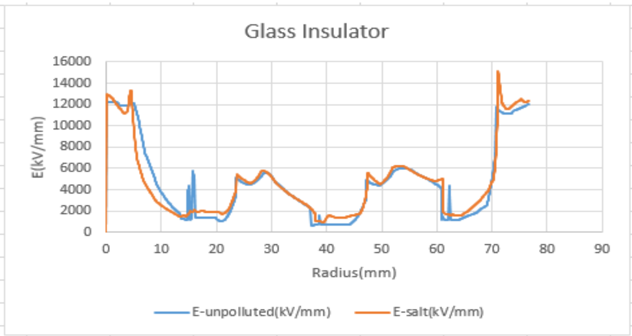
Polymeric Insulator with Dust Pollution:
Polymeric insulators are used in practice for high voltage application. Here polymeric insulators are coated with layer of dust is simulated to obtain the field distribution. Due to dust pollution field in the high voltage electrode has increased by 6.6 % and field near low voltage electrode is increased by 8.0 %.

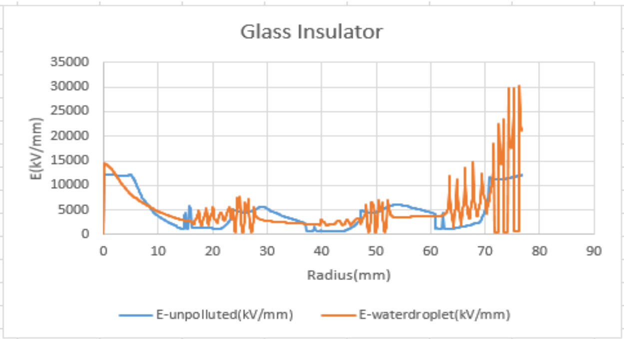


Polymeric Insulator with Salt Pollution:
Polymeric insulator with salt pollutant is found near seashores. Since salt has greater conductivity, it leads to quicker flashover because of increase in electric field. Due to dust pollution field in the high voltage electrode has increased by 3.6 % and field near low voltage electrode is increased by 4.0 %.

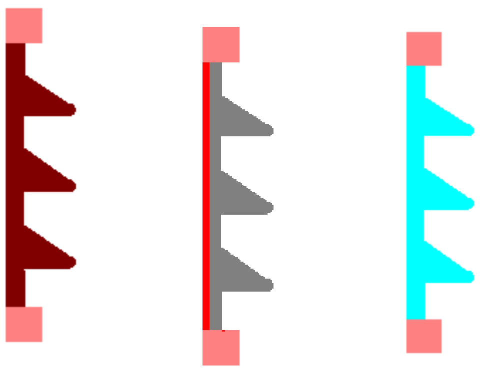


Following figs shos the field result of glass insultor with salt, dust amd water droplets over the insulator surface.



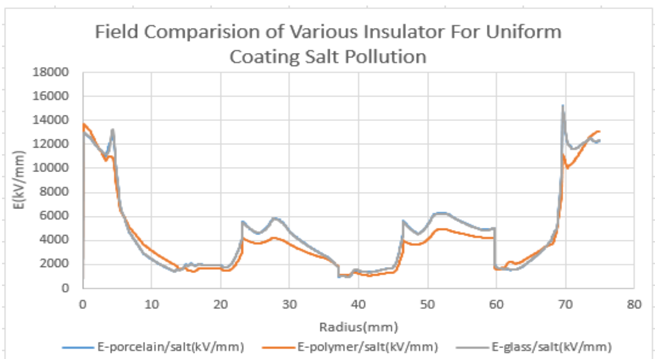


4. TYPES OF INSULATION MATERIALS AND THEIR FIELDS



(Porcelain) (Polymer) (Glass)

Field Comparision Of Different Types Of Insulating Materials:



From above result polymeric insulator is better than other insulators such as glass and porcelain. The field on the polymeric insulator is very less when compared to others except starting point. Maximum electric field is near the high voltage electrode in case of polymeric insulator. In case of porcelain and glass insulator maximum electric field is near the low voltage electrode. Then glass insulator has better field distribution than the porcelain insulator.

5. CONCLUSION

This report presents simulation results which contribute to a better understanding of the behavior of various pollutants on the insulating surface under electric field stress. Based on the model created in the simulation software, the simulation results for electric potential and field plots over the clean insulator, uniformly polluted insulators are shown in different figures. The results indicate that the electrical field stresses are highest in the areas near the top and bottom of the insulator. The plots shows that the electric field between various types of insulator with different pollution conditions.

From the results obtained the polymeric insulator is better than other insulators in clean and polluted case. Because field distribution on polymeric insulator is very less when compared to others insulators like porcelain and glass insulators. It has also been observed that the field distribution on the polluted insulator is greater than the field distribution on the polluted insulator.

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