Analysis of Electric Potential Distribution on Ceramic Disc Insulators under Dry Conditions using ANSYS

Sulthan Mohyuddin
Associate Professor
Department of Electrical and Electronics Engineering
Srinivas Institute of Technology, Mangaluru

Abstract— Power line insulators are used to support the high voltage current carrying conductors. Outdoor insulators are subjected to a variety of stresses, including mechanical, electrical and environmental stresses. These stresses are acting unison. The exact nature and magnitude of these stresses varies significantly and depends on the details of insulator design, application and location. In the present work, the electric field and potential distribution in the vicinity of standard normal type ceramic insulator (i.e. 120KN) under dry and clean conditions are presented. For modeling and finite element analysis of insulators, CATIA, HYPERMESH and ANSYS software's were used. The field and potential distribution in the vicinity of insulator by applying normal voltage (i.e. 11kV) were observed and highly stressed regions were identified. The field and potential distributions were also observed by changing the distances of the path of the first and third ribs of the insulators keeping the creepage length constant (L).

Key words: Outdoor Insulator, EPD, Ceramic Insulator, Finite Element Method, Dry and Clean insulator

I. INTRODUCTION

The reliability of the power networks and apparatus is very important for the performance of an electric power system. In recent years, extra high voltage power lines have been widely used to transmit the electric energy from the power stations to the end users. Insulators are among the key devices of the electric power transmission systems. They are used to support, separate or contain conductors at high voltage. The insulators need to withstand not only regular voltages and over voltages, such as lightning and switching events, but also various environmental stresses such as rain, snow and pollution.

Pollution flashover is one of the main problems that endanger the reliability of an electric power system. The presence of contamination on the insulator surface, combined with highly humid and wet conditions such as fog, dew or rain, is particularly responsible for many insulator pollution flashovers. With higher and higher voltages, the problem of insulator pollution flashover increases and the penalties increase sharply due to direct and indirect lost revenue and the damage to the equipment. Therefore, more and more attention must be paid to improve the pollution performance of insulators.

II. NECESSITY OF STUDY OF POTENTIAL DISTRIBUTION ALONG CERAMIC INSULATOR

The electric potential distribution of ceramic insulator is generally the more nonlinear in many times. The reason is that there are intermediate metal parts for a ceramic insulator. The electric field strength on ceramic insulators and associate hardware need to be controlled for three reasons. Two kinds of methods have been used to study the electric field strength distribution along ceramic insulators. These methods can be classified as experimental methods and numerical analysis methods. For experimental methods, capacitive probes, flux meters, dipole antennas and electro-optical quartz sensors can be used as electric field strength measuring devices to study the electric field strength distribution along ceramic insulators under dry or wet conditions. A commercial available insulator tester designed by Positron Power Division can be used for the on-line measurement of the electric field strength distribution along ceramic insulators, at some distance from the insulator.

The domain methods include the finite difference method (FDM) and finite element method (FEM), which apply mainly for domains with bounded boundaries. The boundary method include the charge simulation method (CSM), and the boundary element method (BEM) which apply for domains with open boundaries and have no restrictions in regards the geometry of the domain.

III. DESCRIPTION OF EXISTING PROBLEMS

Although the EFPD along the ceramic insulators has been widely studied for a long time, the results of these studies cannot be applied directly to the real power line insulators. The limitations of the previous studies are: The analysis of the EFPD along ceramic insulators usually assumes single phase energization. However, a real power line means three phase energization, and the presence of the other two phases may have some influence on the EFPD along a ceramic insulator.

IV. MATHEMATICAL MODEL

Calculation of electric fields requires solution of Laplace's eqn. and Poisson's equation eqn. with boundary conditions satisfied. This can be done either by analytical or numerical methods.

$$\nabla^2 \varphi = -\rho/\varepsilon_0 \qquad (1.1)$$

$$\nabla^2 \varphi = 0 \qquad (1.2)$$

In eqns. the operator ∇^2 is called the laplacian and is a vector with properties

$$\nabla.\nabla = \nabla^2 = \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} + \frac{\partial^2}{\partial z^2} \qquad (1.3)$$

Governing Equations and the potential Ve within an element is first approximated and then interrelated to the potential distributions in various elements such that the potential is continuous across inter-element boundaries. The approximate solution for the whole region then become

$$V(x,y) = \sum_{e=1}^{N} Ve(x,y) \qquad (1.4)$$

Where N is the number of elements into which the solution region is divided.

The most common form of approximation for the voltage V within an element is a polynomial approximation.

$$Ve\,(x, y) = a + bx + cy \qquad (1.5)$$

For the triangular element and for the quadrilateral element the equation becomes

Ve (x, y) = a + bx + cy + dxy

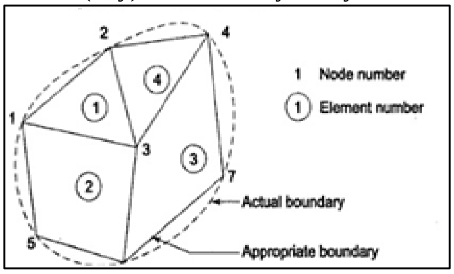

Fig. 1: Typical triangular element

The potential Ve in general is not zero within the element e but it is zero outside the element in view of the fact that the quadrilateral elements are non-confirming elements. Consider a typical triangular element shown in Fig.1. The potentials Ve1, Ve2 and Ve3 at nodes 1, 2, and 3 are obtained from Eq., as

$$\begin{bmatrix} Ve1 \\ Ve2 \\ Ve3 \end{bmatrix} = \begin{bmatrix} 1 & x_1 & y_1 \\ 1 & x_2 & y_2 \\ 1 & x_3 & y_3 \end{bmatrix} \begin{bmatrix} a \\ b \\ c \end{bmatrix}$$

The coefficients a, b and c are determined from the above equation as

$$\begin{bmatrix} a \\ b \\ c \end{bmatrix} = \begin{bmatrix} 1 & x_1 & y_1 \\ 1 & x_2 & y_2 \\ 1 & x_3 & y_3 \end{bmatrix}^{-1} \begin{bmatrix} Ve1 \\ Ve2 \\ Ve3 \end{bmatrix}$$

Substituting this equation in Eq., we get

Ve = [1 x y] 1/2A (1.6)

$$Ve = \sum_{i=1}^{N} \alpha_i\ (x, y) Ve \quad (1.7)$$

And A is the area of the element *e*, that is,

$$2A = \begin{vmatrix} 1 & x_1 & y_1 \\ 1 & x_2 & y_2 \\ 1 & x_3 & y_3 \end{vmatrix}$$

$= (x_1 y_2 - x_2 y_1) + (x_3 y_1 - x_1 y_3) + (x_2\, y_3 - x_3 y_2)$ Or A = ½[$(x_2 - x_1)\ (y_3 - y_1)$ - $(x_3 - x_1)\ (y_2 - y_1)$] (1.8)

The value of a positive if the nodes are numbered counterclockwise (starting from any node) as shown by the arrow in Fig.1. It may be noted that eq. gives the potential at any point (x, y) within the element provided that the potentials at the vertices are known. These are called the element shape functions. They have the following properties:

$$\alpha_1\ ((x_1, y_1) = \begin{bmatrix} 1 \\ 0 \end{bmatrix} \begin{bmatrix} i = j \\ i \neq j \end{bmatrix}$$

$$\text{Ve} = \sum_{i=1}^{3} \alpha_i(x, y) = 1 \quad (1.9)$$

The energy per unit length associated with the element is given by the following equation:

$$W_e = 1/2\ \varepsilon [Ve]^T [C^{(e)}][Ve] \quad (1.11)$$

Where, T denotes the transpose of the matrix

$$[Ve] = \begin{bmatrix} Ve1 \\ Ve2 \\ Ve3 \end{bmatrix}$$

$$\text{And} \quad [C^{(e)}] = \begin{bmatrix} C_{11}^{(e)} & C_{12}^{(e)} & C_{13}^{(e)} \\ C_{21}^{(e)} & C_{22}^{(e)} & C_{23}^{(e)} \\ C_{31}^{(e)} & C_{32}^{(e)} & C_{33}^{(e)} \end{bmatrix}$$

The matrix given above is normally called as element coefficient matrix. The matrix element $C_{ij}^{(e)}$ of the coefficient matrix is considered as the coupling between nodes *i* and *j*, as shown in Fig.2

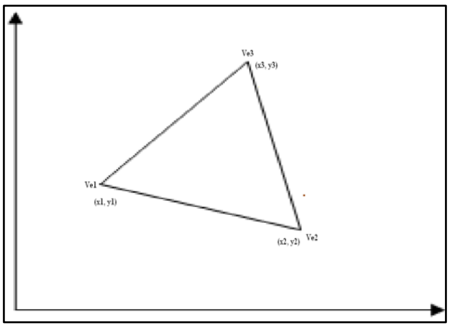

Fig. 2: Nodes of elements coefficient matrix

It is of practical interest to know the electric field strength distribution for a full scale insulator during field conditions under three phase energization. A typical 120kN ceramic insulator is used for this study. The insulator is made of ceramic with a relative permittivity of 6.3 and an pin and cap with a relative permittivity of 1000. The insulator is equipped with metal fittings at both line and ground ends.

The disc type porcelain insulator with different parts as shown below in Fig.3

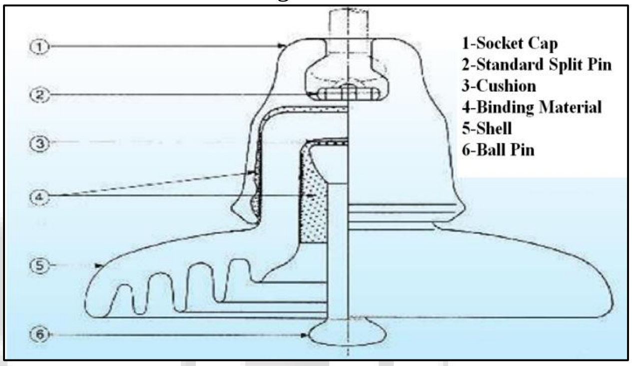

Fig. 3: Disc type porcelain insulator with different parts

Insulators used for high-voltage power transmission are made from glass, porcelain, or composite polymer materials. Porcelain insulators are made from clay, quartz or alumina and feldspar, and are covered with a smooth glaze to shed water. Insulators made from porcelain rich in alumina are used where high mechanical strength is a criterion. Porcelain has a dielectric strength of about 4–10 kV/mm.

A standard normal type porcelain/ceramic insulator was selected to simulate electric field and potential distributions in this study. The basic design of a ceramic insulator is as follows, for this study, standard normal type ceramic/porcelain insulator chosen. A schematic of the ceramic insulator disc is shown in Fig.3.

The design of cap and pin type ceramic insulator essentially consists of a malleable/ductile iron cap, malleable/forged iron pin and a ceramic/porcelain shell. The cap and pin of the insulator is fixed to the ceramic shell with the help of a Portland cement. A bituminous coating is applied to the pin to prevent corrosion. The dimension of insulator used are given for each model in the CATIA models as shown in Fig.4

Altair Hyper View is a complete post-processing and visualization environment for finite-element analysis (FEA), multi-body system simulation, video and engineering data. Hyper View can visualize data interactively, as well as capture, standardize and automate post-processing activities.

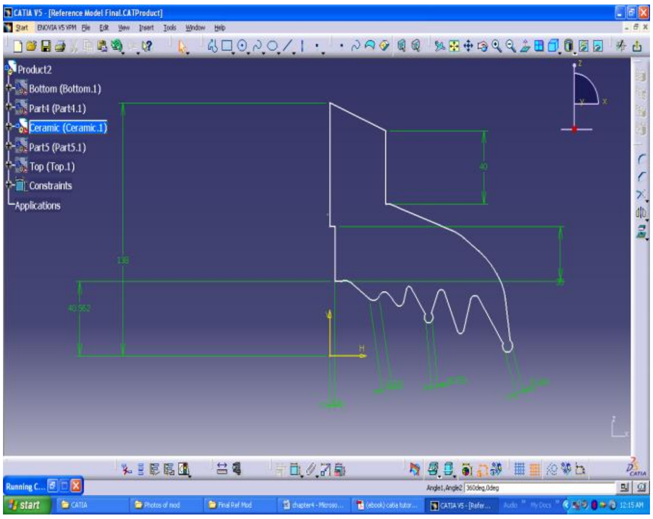

Fig. 4: Dimension of insulator in CATIA

The model of insulator after importing in the HYPERMESH is as shown in Fig.5.

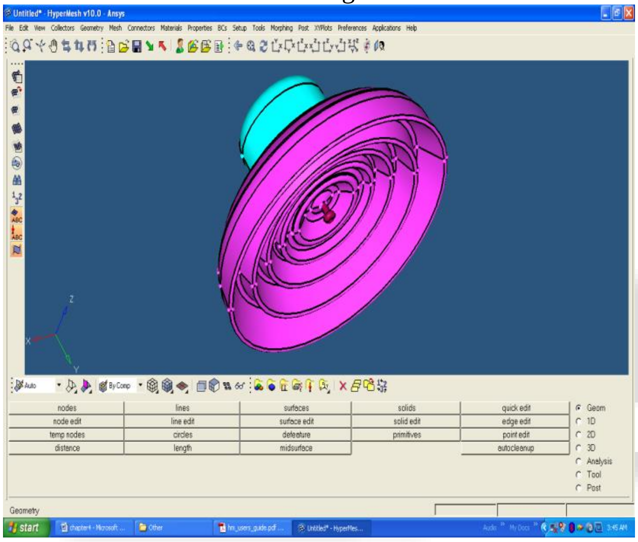

Fig. 5: Model of insulator after importing in the HYPERMESH

Sl. No	CATIA M0 parts No.	HYPER MESH Mo parts color	Material model no	Relative permittivity
1	Part1 (Cap of insulator)	Orange	Material model 1 (ground end)	10000
2	Part2 (Binding cement)	Blue	Material model 2 (Cement part)	100
3	Part3 (Ceramic surface)	Yellow	Material model 3 (Disc part)	6.3
4	Part4 (Pin of insulator)	Aqua accent 5	Material model 4 (Pin part)	10000
5	Part5 (air part)	Red accent 2	Material model 5 (air part)	1

Table 1: Details of materials used for Insulator

For doing HYPERMESH, we should cut the model as half part and then quarter part, for doing so we have to select the nodes and fixed points. After doing the above properties and the meshing the model is as shown below in Fig.6.

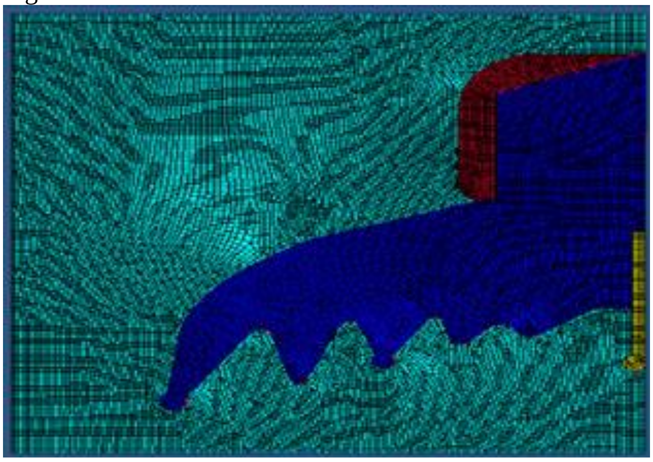

Fig. 6: Meshing Model of Insulator

In the present work as it is difficult to create 3-D model i.e., model of ceramic insulator in ANSYS, so a model is developed in CATIA software tool, and quarter of the model (2-D) is taken and meshed the 2-D model using HYPERMESH tool (both tools are explained in above section CATIA and HYPERMESH) and then it is imported to ANSYS for further analysis in this we are finding electric field distribution and electric potential distribution around ceramic insulator.

Applying load and giving permittivity to the standard disc type insulator. The results from the simulations were given in figures.

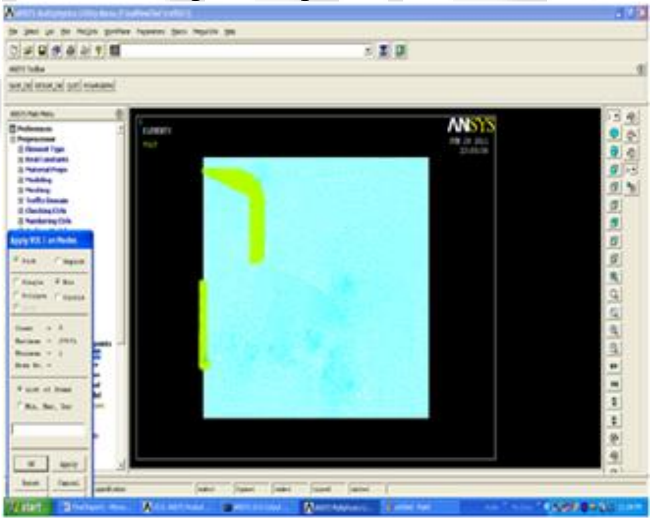

Fig. 7: Model of Insulator in ANSYS

V. Simulation Results and Discussions

In the present work, a standard ceramic insulator with dry and clean conditions has been simulated using finite element analysis software ANSYS for the estimation and evaluation of potential and field distributions. The contour plots of potential and field distributions of standard ceramic insulators are shown in Fig.8. Potential distribution of standard normal type ceramic insulator

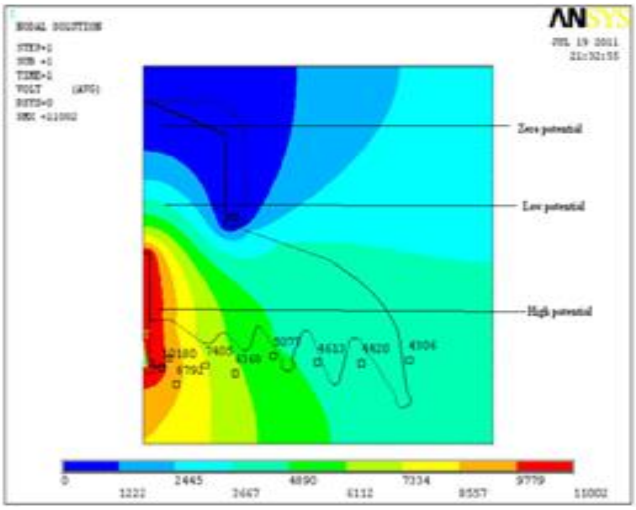

Fig. 8: Potential distribution in ANSYS

The potential distribution plots for the clean and dry insulators were also shown in figures. These figures show that the voltage is fairly evenly distributed over the insulator surface from live end to dead end.

The electric potential line plots on the insulator with dry and clean condition were shown in figures. These figures show that the electrical stresses were the highest in the regions adjacent to the live end fitting. The stresses on the insulator material surface do not exceed about 1.7V/cm. The maximum electrical field stresses calculated was 14.8V/cm.

VI. CONCLUSION

In this study, the electric field and potential distributions in the vicinity of ceramic disc/suspension insulators under dry and clean conditions were presented. A three dimensional electric field analysis program ANSYS is based on finite element method has been used for calculations of EFPD. A 11kV standard 120KN porcelain disc insulator was selected to simulate EFPD in this study. The design off cap and pin type ceramic insulators essentially consists of a malleable/ductile iron cap, malleable/forged iron pin and a ceramic/porcelain shell. The cap and pin of the insulators is fixed to the ceramic shell with the help of a Portland cement. The third dimensional model of standard single disc type insulator. Simulation have been carried out on this standard single disc type of insulator and other two simulations were also done on it by varying its air distances (i.e. width of rib) of first and third ribs.

Based on these discussions the following conclusions were drawn.

- The potential distribution for all the three cases remains unaltered.
- The underside corrugations do not affect the potential distribution.
- There is clearly field intensification by a factor of 9.

REFERENCES

[1] H.Sedigh Nezhad A.Gholami A.Jalilian M.T. Hassanzadeh, ”Performance Improvement of Insulator string in polluted conditions”, IEE transaction on power delivery 2007.

[2] I. F. Gonos F. V. Topalis I. A. Stathopulos, “A model for the determination of the Dielectric strength of non-uniformly polluted insulators”, Department of Electrical and Computer Engineering, Electric Power Division, Zografou, GR 157 80 Athens, GREECE.

[3] X. Liang, S. Wang, J. Fan, and Z. Guan, “Development of Composite Insulators in China,” IEEE Transactions on Dielectrics and Electrical. Insulation, Vol. 6, No. 5, October 1999, pp. 586-594.

[4] G. H. Vaillancourt, S. Carignan, and C. Jean, “Experience with the Detection of Faulty Composite Insulators on High-Voltage Power Lines by the Electric Field Measurement Method,” IEEE Transactions on Power Delivery, Vol. 13, No. 2, April 1998, pp. 661-666.

[5] D. H. Shaffner, D. L. Ruff, and G. H. Vaillancourt, “Experience with a Composite Insulator Testing Instrument Based on the Electric Field Method,” Proceedings of the 9th International Conference on Operation and Live-Line Maintenance, 2000 IEEE ESMO, pp. 318-327.

[6] A. J. Philips, D. J. Childs, and H. M. Schneider, “Water Drop Corona Effects on Full-Scale 500 kV Non-Ceramic Insulators,” IEEE Transactions on Power Delivery, Vol. 14, No.1, Jan. 1999, pp. 258-265.

[7] A.G.E. Sutjipto, Jufriadi, R. Muhida, Afzeri, and E.Y. Adesta, “Modeling Electric Field Distribution on Insulator under Electron Bombardment in Vacuum”, Dept. of Manufacturing and Materials Engineering, International Islamic University Malaysia.

[8] Evgeny Sorkin and Tsvi Piran,”Effects of Pair Creation on Charged Gravitational Collapse”, The Racah Institute of Physics, The Hebrew University, Jerusalem, Israel, 91904

[9] M. T. Gencoglu, y and M. Cebeci” Computation of AC flashover voltage of polluted HV insulators using a dynamic arc model”, Department of Electrical and Electronics Engineering, Faculty of Engineering, Firat University, Elazig, Turkey

[10] I. F. Gonos F. V. Topalis I. A. Stathopulos, “A model for the determination of the dielectric strength of non-uniformly polluted insulators”, Department of Electrical and Computer Engineering, Electric Power Division, Zografou, GR 157 80 Athens, GREECE

[11] M. T. Gencoglu,y and M. Cebeci, ”Computation of AC flashover voltage of polluted HV insulators using a dynamic arc model”, Department of Electrical and Electronics Engineering, Faculty of Engineering, Firat University, Elazig, Turkey

[12] Felix Amarh,”Electric Transmission Line Flashover Prediction System”, George G. Karady Salt River Chair Professor Arizona State University Department of Electrical Engineering

[13] Andrew benwell,” Flashover prevention on polystyrene high voltage insulators in a vacuum”, Dr. Scott Kovaleski, Thesis Supervisor December 2007

