Abstract: In high voltage transmission porcelain materials are important one. To mount the transmission line on a transmission tower we need an insulation material. Many literatures deal about the silicon and rubber-based insulators. In this paper the porcelain is modelled as FEM model using the PDE tool and electric potential distribution is analyzed. The PDE tool come in handy to draw the shape of the insulator. In this paper the straight shed and alternate shed insulators are analyzed with the MATLAB PDE tool and results are analyzed. then using some random water droplets in the insulator, the impact is observed.

Keywords: Porcelain Insulator, Partial Differential Equation, Finite Element Method, Potential Distribution Analysis

I. INTRODUCTION

To operate the power system in a protected environment then the power system is operated in reliable way. To ensure that power system protection is one of the important methods [1,3]. The power system usually has the generators, transmission and distribution. While transmitting the high voltage has to be transmitted. While transmitting high voltages the towers need a proper insulator. Usually the towers are used here with ceramic insulators. But as the power transmission is done on outdoors the contamination is more. The major problem is pollution on insulators [2, 5]. The dry insulators have no problem in performance. But if the insulators are contaminated while it is placed near the road ways then there will be dust and water droplets. If so then the current leakage may happen due to the water droplets [4]. This leakage current may create flashover due to arcing [7]. This makes the interruption of transmitting the power. Determining the electric field around the insulator with water droplets are important [6]. This analysis may show whether the insulators are in safe region even with random water droplets. Many literatures are used to understand the concept which are listed in [8-26]. In this paper the porcelain insulator is added with water drop. Then it is discussed with straight shed and alternate shed insulators. The electric field and potential field is analyzed with Partial Differential Equation (PDE) tool in MATLAB.

II. STATEMENT OF THE PDE PROBLEM

The power system requires a detailed simulation study before it is implemented. There are many simulation studies available to design the power system parameters like electrical quantities such as Voltage rating, current rating, power rating of the devices. And also studying the impact of fault like security studies. But any of these described studies not including the physical parameters and environmental parameters. So, there is a problem in power system reliability when the transmission system insulators are placed in the out space. It has many impacts like due to rain, dust and temperature effects. To analyse these effects, we go for Partial Differential Equation modelling of the devices which can analyse the electromagnetic effects with temperature change. By calculating the potential distribution, the electric field can be calculated. The field can be obtained by minus gradient of electric potential distribution.

$$E = - \nabla V$$  \hspace{1cm} (1)

Using maxwell’s equation

$$\nabla E = \nabla (\nabla V) = \frac{\rho}{\varepsilon}$$  \hspace{1cm} (2)

where, $\rho$ - resistivity \( \text{N} \text{m} \)

$\varepsilon$ - dielectric constant of the material ($\varepsilon = \varepsilon_r \varepsilon_0$)

$\varepsilon_0$ - dielectric space constant ($8.854 \times 10^{-12} \text{F/m}$)

$\varepsilon_r$ - relative dielectric material constant

Substituting equation (1) in (2) Poisson’s equation is obtained as

$$\varepsilon_r \nabla (\nabla V) = - \rho$$  \hspace{1cm} (3)

Substitute $\rho = 0$ the equation (3) shows

$$\varepsilon_r \nabla (\nabla V) = 0$$  \hspace{1cm} (4)

Cartesian system coordinates can be shown as equation $F(u)$

$$F(u) = \frac{1}{2} \int \varepsilon_r \left( \varepsilon_x \left( \frac{dx^2}{dy^2} \right) + \varepsilon_y \left( \frac{dy^2}{dx^2} \right) \right) dx dy$$  \hspace{1cm} (5)

where, $\varepsilon_x$ and $\varepsilon_y$ are x and y components of the dielectric constant, $u$ is the electric potential.

In the condition of isometric permittivity distribution by substituting $\varepsilon = \varepsilon_r = \varepsilon_x$, $\varepsilon_y$, Equation (5) can be reformed as

$$F(u) = \frac{1}{2} \int \left( \frac{dx^2}{dy^2} \right) + \left( \frac{dy^2}{dx^2} \right) dx \ dy$$  \hspace{1cm} (6)

$$F(u) = \frac{1}{2} \int \omega \varepsilon_0 (\varepsilon - j \omega \tan \delta) \left[ \left( \frac{dx^2}{dy^2} \right) + \left( \frac{dy^2}{dx^2} \right) \right] dx \ dy$$  \hspace{1cm} (7)

$\omega$ - angular frequency,

$\varepsilon_0$ - permittivity of free space

$\tan \delta$ – tangent of dielectric loss angle

$u^*$ – complex potential

A linear variation of electric potential is assumed as shows below,
FEM Based Electric Potential Distribution Analysis of Porcelain Insulator using MATLAB PDE tool

\[ u_e(x, y) = \alpha_{e1} + x\alpha_{e2} + y\alpha_{e3} \quad (e = 1, 2, 3, ..., n_p) \]  

where \( u_e(x, y) \) is the electric potential of an arbitrary point, \( \alpha_{e1}, \alpha_{e2}, \alpha_{e3} \) are the computational coefficients.

Here \( n_p \) is the total number of knots in the network.

III. RESULTS AND DISCUSSIONS

The simulation is carried out for the two straight shed porcelain insulators and with alternate shed insulator. The dimensions are taken from the standard insulator size. Here to draw the porcelain insulator in 2D, PDE tool in MATLAB is used. The polygon tool in the PDE is helpful to draw the entire shape of the insulator. Then the draw mode is switched to boundary mode. Here the values of boundary are set using Dirichlet boundary equation. Then drawing formula is set in the PDE tool to get the exact shape. When double clicking on the boundary the values of the boundaries can be changed. The simulation is carried out for triangularization and electric potential distribution contour graph. This analysis is done for,

- straight shed without water drops
- straight shed with water droplets
- alternate shed without water drops
- alternate shed with water drops

![Figure 1 triangularization of straight shed insulator without water droplet](image1)

![Figure 2 triangularization of straight shed insulator with water drops on left side of sheds](image2)

![Figure 3 triangularization of alternate shed insulator without waterdrops](image3)

![Figure 4 triangularization of water drops on the left side of first shed in alternate shed](image4)

![Figure 5 potential distribution of straight shed insulator without water drops](image5)
The triangularization is affected due to the random water drops. Then the Figure 11 shows the triangularization of alternate shed insulator without waterdrops. Here also the edges of the insulators are dense in triangles. Then the Figure 12 shows the triangularization of water drops on the left side of first shed in alternate shed. Here also the triangularization is getting affected by water drops. The Figure 13 shows the potential distribution of straight shed insulator without water drops. The potential distribution shows the high potential in red. Medium voltage in yellow then low voltage in blue. Near to the insulator lower end it is red and it has more potential effect. Moving toward the peak of the insulator it is becoming as blue. Then the Figure 14 shows the potential distribution of straight shed insulator with water drops. It can be shown that the water drops affect the potential distribution. The Figure 15 shows the Potential distribution of alternate shed insulator without water drops. Then the Figure 16 shows the potential distribution of alternate shed insulator with water drops. In alternate shed also the potential gets affected by not severe like in the straight shed.

IV. CONCLUSION

For the testing the laboratory conditions water drops are added in the simulation with an ideal model. For the wet and dry conditions, the insulator surface is considered as tangential. The denser colored area is identified as the polluted region of the insulator. From the graphs the property of the insulator can be identified before the practical implementation.

REFERENCES

1. J. S. T. Looms. Insulators for High Voltages. London, United Kingdom: Peter Peregrinus Ltd, 1988, pp. 2-12.
2. S. Chakravorti and H. Steinbigler, “Boundary element studies on insulator shape and electric field around HV insulators with or without pollution,” IEEE Transactions on Dielectrics and Electrical Insulation, vol.7, no.2, pp.169-176, Apr 2000.
3. R. S. Gorur, E. A. Cherney, and J. T. Burnham, Outdoor Insulators, Ravi S. Gorur, Inc., Phoenix, Arizona, USA, 1999.
4. CIGRE Taskforce 33.04.01: “Polluted insulators: review of current knowledge,” CIGRE technical brochure 158, June 2000.
5. A. S. Krzma, M. Albano, and A. Haddad, “Comparative performance of 11kV silicone rubber insulators using artificial pollution tests,” in 2015 50th International Universities Power Engineering Conference (UPEC),Stoke On Trent, United Kingdom, pp. 1–6, 2015.
6. J. L. Rasolonjahanary, L. Krahenbuhl, and A. Nicolas, “Computation of electric fields and potential on polluted insulators using a boundary element method,” IEEE Transactions on Magnetics, vol.28, no.2, pp.1473-1476, Mar 1992.
7. A. S. Krzma, M. Albano, and A. Haddad, “Flashover influence of fog rate on the characteristics of polluted silicone rubber insulators,” in 2017 52th International Universities Power Engineering Conference (UPEC), Crete, Greece, pp. 1–6, 2017.
8. IEC 60507:2013, ‘Artificial pollution test on high-voltage ceramic and glass insulators to be used on a.c. systems’, 3rd edition.
9. M. Albano, A. S. Krzma, R. T. Waters, H. Griffiths, and A. Haddad, “Artificial pollution layer characterization on conventional and textured silicone-rubber insulators,” in The 19th International Symposium on High Voltage Engineering (ISH), Pilsen, Czech Republic, 2015.
10. M. Talbat: “Influence of Transverse Electric Fields on Electrical Tree Initiation in Solid Insulation”, IEEE CIEIDP 2010, pp. 313–316, USA, October 17-20, 2010.
FEM Based Electric Potential Distribution Analysis of Porcelain Insulator using MATLAB PDE tool

11. M. Talaat: "A Simulation Model of Fluid Flow and Streamlines Induced by Non-Uniform Electric Field" IEEE, 14th MEPCON’10, pp. 371-375, Egypt, December 19-21, 2010.

12. A. El-Zein, M. Talaat and M.M. El Bayh: "A Numerical Model of Electrical Tree Growth in Solid Insulation" IEEE TDEI, Vol. 16, No. 6; pp. 1724-1734, December 2009.

13. A. El-Zein, M. Talaat and M.M. El Bayh; "A New Method to Predict the Electrical Tree Growth in Solid Insulation" Proceedings of the 16th ISH 2009, paper D-15, pp. 1-6, 2009.

14. A. El-Zein and M. Talaat: “A New Model of Investigating the Electric Field in Dielectric Liquid for Streamer Initiation” J. Elec. Eng. (JEE) Vol. 10, No. 2, pp. 47-51, 2010.

15. B. Marungsri, H. Shinokubo, R. Matsuoka and S. Kumagai: “Effect of Specimen Configuration on Deterioration of Silicon Rubber for Polymer Insulators in Salt Fog Ageing Test”, IEEE TDEI Vol. 13, No. 1; pp.129-138, February 2006.

16. B. Marungsri, W. Ouchantuek, A. Oonsivilai and Kulworawanchomp, “Analysis of Electric Field and Potential Distributions along Surface of Silicon Rubber Insulators under Contamination Conditions Using Finite Element Method" World Academy of Science, Engineering and Technology 53, pp. 1353- 1363, 2009.

17. William H. Hayt, Jr., Engineering Electromagnetics, 5th edition, McGraw-Hill Book Company, pp. 71-99, 1989.

18. [18] C. N. Kim, J. B. Jang, X. Y. Huang, P. K. Jiang and H. Kim: “Finite element analysis of electric field distribution in water treed XLPE cable insulation (1): The influence of geometrical configuration of water electrode for accelerated water treeing test”, J. of Polymer Testing, Vol. 26, pp. 482 – 488, 2007.

19. Kevin R.J. Ellwood, J. Braslaw: “A Finiteelement model for an electrostatic bell sprayer”, Journal of Electrostastics, Vol. 45, pp. 1-23, 1998.

20. M. C. Arklove and J. C. G. Wheeler, “Salt – Fog Testing of Composite Insulators”, 7th Int. Conf. on Dielectric Material, Measurements and Applications, Conf. Pub. No. 430, September 1996, pp. 296 – 302.

21. B. Marungsri, H. Shinokubo, R. Matsuoka and S. Kumagai, “Effect of Specimen Configuration on Deterioration of Silicone Rubber for Polymer Insulators in Salt Fog Ageing Test”, IEEE Trans. on DEI, Vol.13, No. 1, February 2006, pp. 129 – 138.

22. CIGRE TF 33.04.01. Polluted insulators: a review of current knowledge, CIGRE, 2000.

23. K. Chrzan, Z. Pohl, T. Kowalak, “Hypsogrophic Properties of Pollutants on HV Insulators”, IEEE Transactions on Electrical Insulation, Vol. 24, No. 1, pp. 107-112, 1989

24. N. Mavrikakis, E. Koudoumas, K. Siderakis, D. Pylarinos, E. Thalassinakis, O. Kokkinaki, A. Klini, C. Kalpouzos, M. Polychronaki, D. Anglos, “Insulators’ pollution problem: Experience from the coastal transmission system of Crete”, 52nd International Universities’ Power Engineering Conference (UPEC 2017), Heraklion, Crete, August 29- September 1, 2017.

25. K. Siderakis, D. Pylarinos, E. Thalassinakis, I. Vitellas, E. Pyrgioti, “Pollution maintenance techniques in coastal high voltage installations”, Engineering Technology and Applied Science Research, Vol. 1, No. 1, pp. 1-7, 2011.

26. D. Pylarinos, K. Siderakis, E. Thalassinakis, "Comparative Investigation of Silicone Rubber Composite and RTV Coated Glass Insulators Installed in Coastal Overhead Transmission Lines", IEEE Electrical Insulation Magazine, Vol. 31, No. 2, pp. 23-29, 2015

AUTHORS PROFILE

B. Mallikarjuna obtained B.E Degree from Gulbarga University and M.E Degree from Bangalore University during the year 1992 and 1997 respectively. He is working as the Assistant Professor at RNS Institute of Technology, Bengaluru and having teaching experience of 25 years. His area of interest is High voltage Engineering.

K.N.Ravi born in Salem, India during the year 1956. Received BE degree in Electrical Engineering from Bangalore University during 1978. He received ME degree in Electrical Engineering with specialization in High Voltage from Indian institute of Science during 1981. He obtained Phd degree from Indian Institute of Science during the year 1995 for the thesis “Pollution ageing studies of Insulators under DC voltages”. He received Badkas medal during 1996 for best thesis. Joined CPRI during 1982 and was working in High Voltage Division till July 2007. His areas of interest are Design of external insulation from the point of view pollution for AC and DC voltages, Pollution Performances of DC insulators, lightning arrester and polymeric insulators. Presently working as Prof and Head, Dept of Electrical and Electronics Engineering, Sapthagiri College of Engineering, Bengaluru. He has published more than 50 papers in national and international conferences.

V.Muralidhara obtained B.E., M.E. Degree from Mysore University, Mysore during the year 1975 and 1978 respectively. He worked as a lecturer at PESCE, Mandya from 1976 to 1981 and Joined Bangalore Institute of Technology (BIT) Bangalore during 1981 and presently working as Professor, Dept of Electrical and Electronics Engineering, BNMI Institute of Technology, Bengaluru. He published papers in International and National Journals / conferences and having 40 years of teaching experience. His area of interest is HV Engineering and Quality analysis of DC insulators

N.Vasudev obtained B.E, M.E, PhD Degree from the University of Bangalore, Mysore and Bangalore during the year 1982, 1986 and 1999 respectively. He worked as lecturer at RV College Of Engineering during 1982 to 1984. He joined CPRI High voltage Division during the year 1987 as an Engineering Officer. At present he is the Head of HV Division. His areas of interest are design of external insulation from the point of view of pollution. Ageing studies on polymeric AC and DC insulators under polluted conditions. He has more than 50 publications at National and International forums. He is an IEEE member.