ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 5, May 2016

Electric Field and Potential Distribution along Porcelain Insulator under Polluted Conditions using Finite Element Method

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ABSTRACT:The paper presents finite element studies carried out on a porcelain insulator used in SF_6 live tank circuit breaker. Electric potential and field distributions were studied in clean as well as polluted conditions. All simulations were performed using the software Finite element method magnetics (FEMM) which uses finite element method (FEM) at its backend process. To model polluted environments, uniform deposit of pollution is modeled as a thin layer with appropriate conductivity. Different pollution levels were simulated keeping the pollution layer thickness constant.

KEYWORDS: Electric Field Intensity, Electrostatic, Finite Element Method (FEM), Live Tank Circuit Breaker, Sulfur Hexafluoride (SF_6).

I.INTRODUCTION

With the increase in voltage levels for transmission system, high voltage equipments' insulation has gained tremendous importance. The basic property of insulating materials is to resist voltage or electric field intensity. While designing high voltage equipments, knowledge of electric field strength distribution along high voltage insulator plays an important role [1]. Knowledge of electric field strength is useful to check the behavior of an insulating material when it is subjected to high electric field stress.

The efficiency of electrical system is centered mainly on the uptime of the service. To maintain continuity in the service, pollution performance of the high voltage insulators must be known. Ceramic/Porcelain insulators find its applications in high voltage apparatus like circuit breakers and transformers etc. These insulators are exposed to pollutants which can either be soluble or non-soluble in nature.

2-D axisymmetric electrostatics and current flow simulations of Porcelain interrupter insulator were carried out in FEMM software. Electric field plots and distributions were of main concern in the output. A thin pollution layer was also modeled over the insulator surface to see potential and stress distribution along porcelain insulator under polluted conditions.

II.ELECTROSTATIC PROBLEMS

The branch of engineering which deals with charges at rest is called electrostatics. Word 'Electrostatic' means electricity at rest. Assuming steady state conditions typical electrostatics problem which is governed by the well-known Gauss's and Poisson's equations [2], [3], [4]:

$$E = -\nabla V \quad \dots (1)$$

$$-\epsilon_0 \nabla^2 V = \rho \quad \dots (2)$$

where, $E$is the electric field intensity, $V$is the applied voltage, $\rho$is the space charge density and $\epsilon_0$is the dielectric permittivity of air. The electric field should satisfy the charge conservation law:

$$\nabla . j = 0 \quad \dots (3)$$

Where, $j$is the current density. The latter is defined as:

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$$j = \rho.u = \rho.\mu.E \ldots (4)$$

where, u is the ion drift velocity and μ is the ion mobility. Above equations can be combined to obtain:

$$\nabla\{(\nabla^2 V)(\nabla V)\} \quad \ldots (5)$$

Physical problems are reduced to the mathematical problem of solving (5) considering boundary conditions. Numerically computed results of voltage distribution at each node are provided by Finite element model. Equation (1) gives electric field strength around user defined domain. Boundary conditions and precision are important parameters in such numerical analysis as far as accuracy of the results is concerned

III.FINITE ELEMENT METHOD

The FEM solves Maxwell's equations in the differential form. The basic concept of this method is "divide and combine". It relies on converting the problem area of complicated form over continuous region into one in which the region is divided into small elements. This process is called meshing. The field in the region of interest is divided into triangular elements for two dimensional representation and tetrahedron for three dimensional representation. It is a flexible method that is well suited to problems with complicated geometry.

IV.USE OF FINITE ELEMENT METHOD MAGNETICS

In this paper, electric potential and field distribution along porcelain insulator is examined using software FEMM which is a suite of programs for solving low frequency electromagnetic problems on 2-D planar and axisymmetric domains [5]. Electrostatics and electric current flow interface is used to examine electric potential and field distributions in clean and polluted conditions respectively.

V. SIMULATED INSULATOR

The simulated insulator is used as the housing for the breaking unit of 420 kV SF_6 live tank circuit breaker. Figure 1 shows full section of dual break SF_6 live tank circuit breaker out of which one section was simulated in the software. Top flange was applied with high voltage (1kV) and bottom flange was at ground. Electric field values obtained were then extrapolated to the voltage value of 855 kV which is the voltage experienced across one section of breaking unit during lightning impulse voltage.

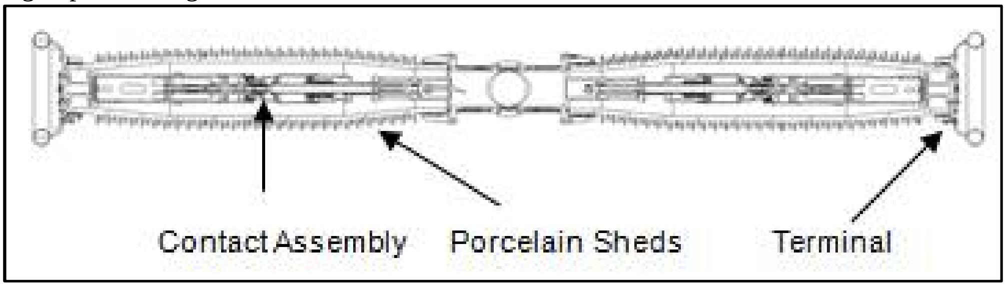

Fig. 1 Section of SF_6 interrupter

VI. SIMULATION AND RESULTS (CLEAN AND DRY CONDITION)

Insulator was modeled in CAD based software and then imported to FEMM. Results of clean and dry condition were then compared with the simulation results for polluted condition. Figure 2 illustrate density plot and for potential and electric field. It was observed that equipotential lines were more crowded near energized flange and between contact gap. This led to higher values of electric fields at these regions compared to rest of the region along creepage distance.

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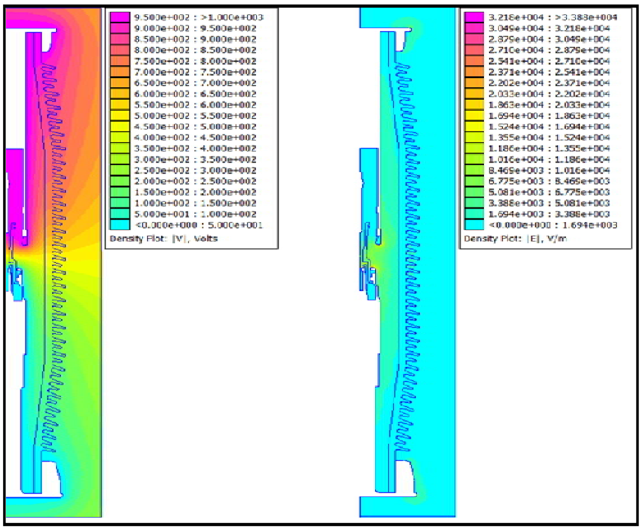

(a) (b)

Fig. 2 Density plots (a) Potential (b) Electric field

Figure 3 shows the curve of potential distribution along the surface of insulator. For all curves presented in the paper, X-axis is marked in terms of per unit of creepage distance.

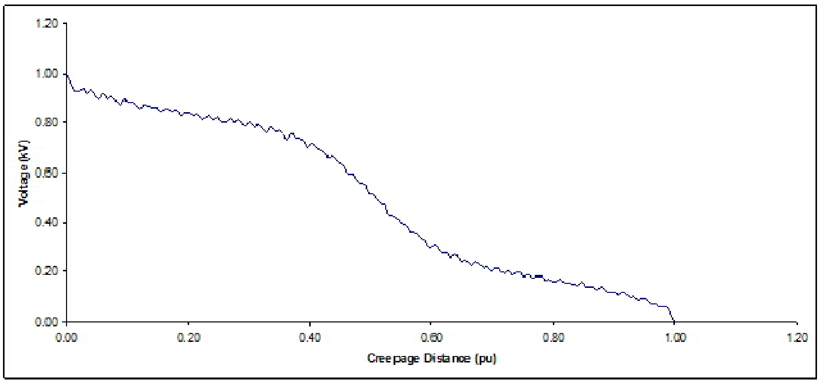

Fig .3 Potential curve for clean and dry condition

Figure 4 shows the curve of electrical field distribution along the surface of insulator in clean and dry condition.

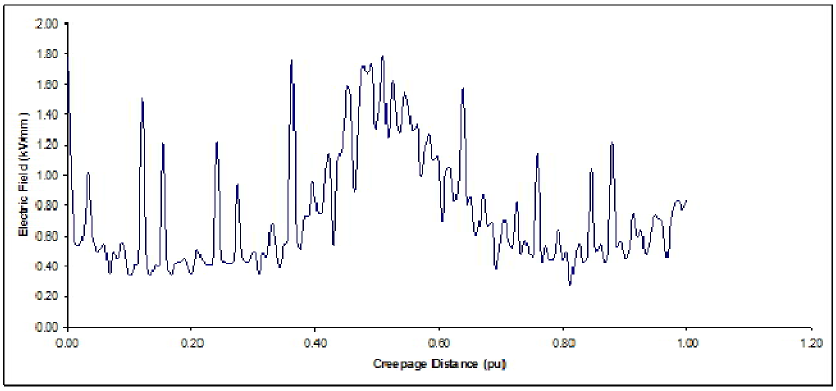

Fig .4Electric field curve for clean and dry condition

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From above curves, it was noticed that voltage distribution was maximum near the energized flange and minimum at the grounded flange. Also, electric field intensity was maximum near the energized flange and along contact gap than that of near grounded flange. Maximum value of 1.78 kV/mm was observed along creepage distance of the insulator.

VII.POLLUTION CONDITION

Surface of outdoor insulators may get polluted uniformly or non-uniformly during service [6], [7]. To observe behavior of potential and stress distributions along insulator, thin conductive pollution layer of 0.5 mm was added over the insulator surface uniformly. Figure 5 shows the pollution layer uniformly spread over entire creepage distance of an insulator surface.

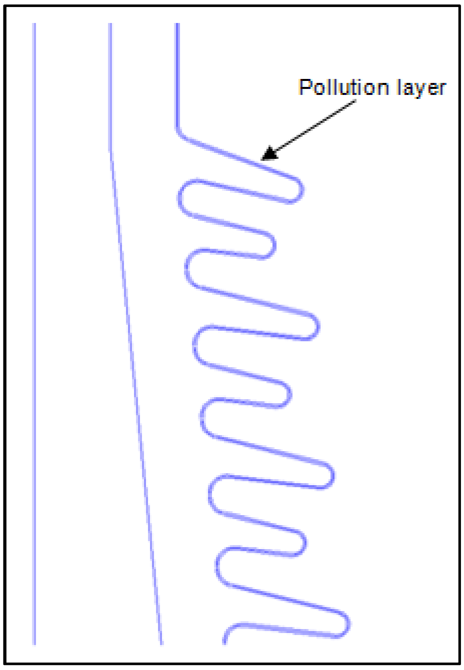

Fig .5 Uniform layer modeled over insulating surface

Figure 6 shows potential distribution trend for polluted environment. It was seen that distribution of potential between the flanges became uniform and smooth, compared to that in clean and dry condition.

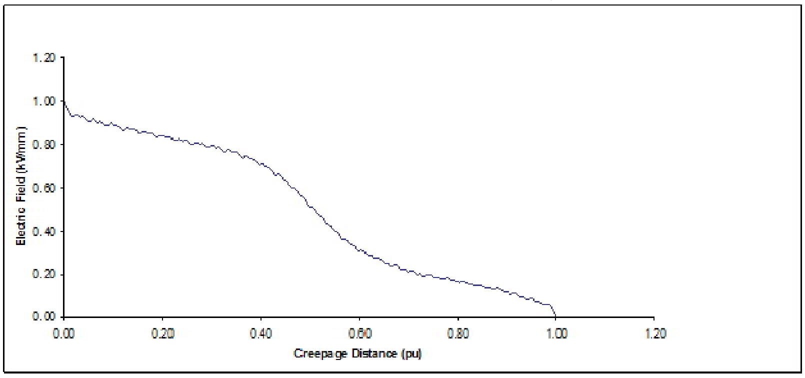

Fig .6 Potential curve for polluted condition

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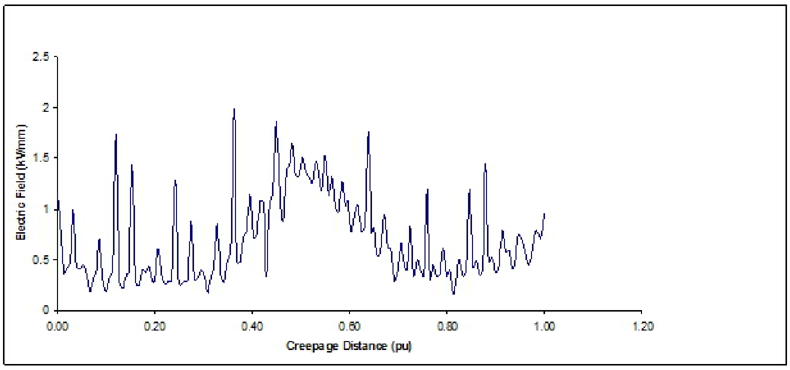

Fig .7 Electric field curve for polluted condition

Figure 7 shows electric field trend along creepage distance for polluted environment. It was seen that field values near energized flange and along sheds adjacent to open contact gap were higher than that of near grounded flange. Also maximum value of electric field intensity for polluted condition exceeds to that of clean condition.

VIII.VARIATION OF POLLUTION CONDUCTIVITY

In this section, simulation results for different pollution levels were compared to observe its effect on voltage and electric field distribution. Figure 8 shows curve of voltage distribution for the polluted insulator surface condition.

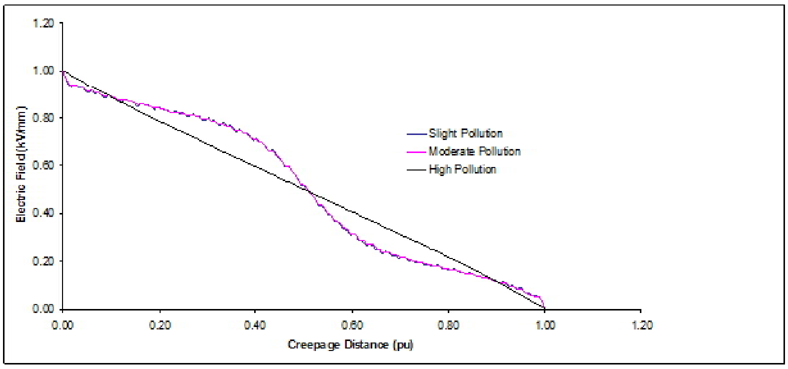

Fig .8 Potential curves for different polluted conditions

Pollution levels were increased from slightly polluted environment to highly polluted environment. Figure 9 shows curve of electric field distribution for the polluted insulator surface condition.

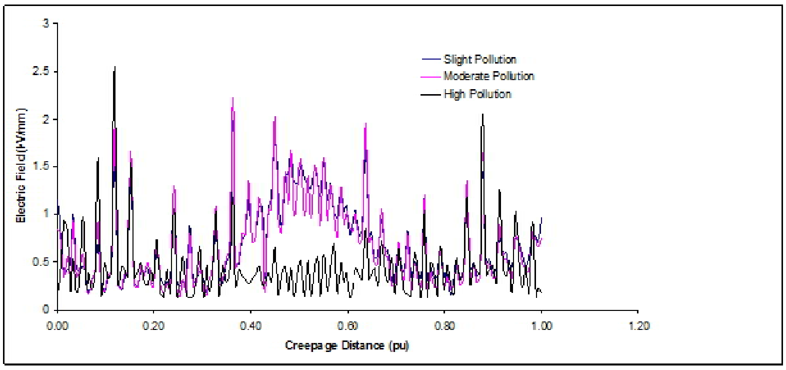

Fig .9 Electric Field curves for different polluted conditions

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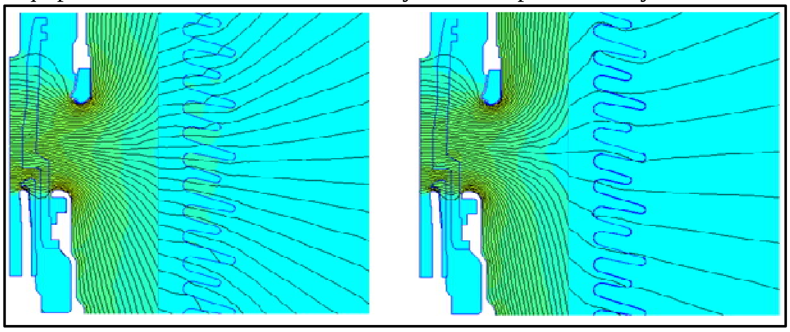
It was noticed that voltage distribution became more and more uniform with increase in conductivity levels. Also maximum value of electric field intensity increases with the increase in conductivity. Table 1 summarizes maximum values of electric field attained in different environmental conditions.

Table 1 Peak values of electric field

Condition	**Maximum value of electric field (kV/mm)**
Clean and dry	1.78
Slight pollution	1.99
Moderate pollution	2.23
High pollution	2.55

IX.ELECTRIC FIELD INTENSITY ALONG SHEDS ADJACENT TO CONTACT GAP

In case of polluted environment, it was seen that electric field intensity along sheds adjacent to contact gap was smaller than that of clean and dry condition. This is due to the fact that equipotential lines under polluted environment are spread more widely along pollution layer which is resistive in nature. Leakage current flows along pollution layer which is driven by electric field. This current causes surface heating resulting in formation of dry bands. Figure 10 shows redistribution on equipotential lines which is caused by resistive pollution layer.



(a) (b)

Fig .10 (a) Clean and Dry condition (b) Pollution condition

IX.CONCLUSION

Electrostatic analysis of Interrupter Insulator was carried out using Finite Element Method software for clean and pollutedcondition. It was seen that pollution layer over insulating surface results in linearising the potential distribution along insulating surface. Also maximum value of electric field increases with the increase in pollution conductivity which makes porcelain insulator susceptible to flashover.

ACKNOWLEDGEMENT

Tejas Khare wishes to thank Crompton Greaves Limited for providing continual guidance for his masters project.

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