ELECTRIC FIELD ANALYSIS OF 9-TONNE RAILWAY INSULATOR BY FINITE ELEMENT METHOD

Dissertation

A Project report Submitted in partial fulfilment of the Requirements for the award of the Degree of

MASTER OF

TECHNOLOGY IN

HIGH VOLTAGE ENGINEERING

By

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CERTIFICATE

This is to certify that Thesis/Dissertation entitled "ELECTRIC FIELD ANALYSIS OF 9-TONNE RAILWAY INSULATOR BY FINITE ELEMENT METHOD " that is being submitted by **KOTHAPALLI MOUNIKA** bearing **Roll. No: 18021D0803** in partial fulfilment of the requirement for the award of the degree of the **Master of Technology in HIGH VOLTAGE ENGINEERING,** to the Jawaharlal Nehru Technological University Kakinada is a record of bona fide work carried out by him under my guidance and supervision.

The contents of this thesis, in full or in parts, have not been submitted to any other Institute or University for the award of any degree or diploma.

Project Guide

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ABSTRACT

High voltage insulators in electrical power system provide electrical isolation between conductor and tower and also provide mechanical support to the conductors. Porcelain, glass and silicone rubber are the common materials which will be used for the insulating material. Insulators for railway traction applications are a category apart from the regular insulators as they demand extremely stringent performance and safety requirements. The Indian railways network is a vast system of approximately 67,000 route km of which about 33,000 route km are already electrified using either silicone rubber or porcelain insulators. Indian railways network typically uses three major types of insulators using composite and porcelain material they are: Stay Arm, Bracket tube and 9 Tonne insulators.

For better performance and better safety requirements of railway insulators additional care need to be taken for analysing the electrical stress and field distribution. For analysing electrical field intensity numerical methods are the best solution. In this work, 9tonne railway polymer insulator is designed and electric field intensity is analysed with the help of FEM-M-2D software package. This software analyses the field intensity with the help of Finite Element Method. In this work, two pollution zone insulators are considered(i.e., polluted zone: 1050 mm creepage distance and very heavy polluted zone: 1600 mm creepage distance). Polluted and very heavy polluted zone insulators are designed with FEMM-2D software package and various pollution performances are also analysed for both type of insulators.

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND STUDY

Railway insulators have developed rapidly since early this century, beginning with simple glass and porcelain insulators. These materials have outstanding insulating properties and weather resistance, but have the disadvantages of being heavy, easily fractured, and subject to degradation of their withstand voltage properties when polluted.

The development and use of polymeric insulators started during the 1960s. By the mid-1970s a number of new insulating materials had been developed, and the concept of a composite structure was advanced. Since the 1980s, greater use has been made of Silicone Rubber (SiR) due to its weather resistance, which is virtually permanent, and its strong hydrophobic properties, where water on the polymeric surface tends to form discrete droplets. This property helps to minimise the leakage current, the probability of dry band formation and lead to an explosive increase in the use of composite insulators.

Railway insulators have a very high resistivity as well as a low conductivity. Their atoms possess tight bound electrons which don't actually move across the material. Since the electrons are always static as well as not roaming freely, the current can't pass through it at all. Apart from the protecting the loss of a current, the insulators also make the electric current even more efficient by simply concentrating flow of the current.

The insulators which are meant for the applications in rail way traction need very high performance, high safety as well as high strength. These types of insulators are mainly manufactured in accordance with the demand and specification setup by RDSO, which is the main governing body. These types of insulators are mainly used in the 25KV railway traction systems, meeting the demand of electrification o f railway lines in India. The roofline insulator is used in locomotives mostly.

An ideal design of an insulator should increase the weather resistance of the material. It has to be able to reduce pollution accumulation and water condensation on the surface that could increase surface conductivity. Moreover, resistance to weather and vandals depend on the mechanical and electrical properties of the material. Today, modern polymeric insulators are used to replace glass and porcelain insulators and are extensively used in traction. Insulators have a major role to isolate the conductor from the support and also used as a support of the conductor itself . Polymeric insulators have many advantages over the ceramic and glass insulators such good performance in contaminated environment, light weight, easy handling, maintenance free, and considerably low cost. Because of these properties it is gaining popularity worldwide and replacing the conventional ceramic and glass insulators.

Fig.1.1Iinsulator on railway system

The use of Polymeric/Silicone Rubber base insulators have several advantages over the conventional ceramic insulators eg: light weight, unbreakable, hydrophobic, resistant to ozone & UV radiations, resistant to earth quake shocks , self dealing properties & resistant to vandalism.

A typical polymeric insulator consists of a Glass Fibre Reinforced (GFR), resin-bonded rod onto which metal end fittings are attached. To protect the core from environmental stresses, it is covered with housing materials which are Ethylene Propylene Rubber (EPR), Ethylene Propylene Diene Methylene (EPDM) or SiR.

The importance of polymeric insulators is the electrical stress, under both normal operating and transient overvoltage conditions. The high field regions especially near the high voltage conductor and the earth terminal, initiate corona and discharges on the surface that can lead to premature degradation and more seriously failure of the insulator. One of the main factors contributing to the development of discharges on insulator surfaces is the electric field distribution on the insulator surface. Considering these consequences, field control is greatly demanded to achieve stress relief on polymeric insulator.

1.2 PROBLEM STATEMENT

Due to their wide role in railway system, insulators are subject to electrical, mechanical and environment stresses. The performance of traction insulators primarily depends on the local environmental conditions like high temperature ambient and a wide range of surface pollution that cause degradation over a period of time. Degradation leads to partial arcing which grow more severe and can generate combustion that ignites flammable debris, smoke including fires resulting in the service interruptions and safety risks of the traction system. The presence of pollutants covering the insulator surface could reduce the hydrophobicity of the polymeric material, by promoting the formation of a continuous conductive film.

To the model designed in this paper, an adequate length of three types of pollution contaminations known as salt, cement, and urea is applied uniformly and non uniformly on the weather sheds near HV and ground terminals. And the wet insulator response with the presence of pollutants covering the insulator surface.

1.3 OBJECTIVES

Over the last few decades, polymeric insulators started to gain popularity amongst electric power utilities around the world. The main objective of this project is optimizing the electric field distribution along the leakage path of the 765kV single V suspension polymeric insulator graded with three types of grading materials such as ZnO, Al2O3, and SiC under contaminated surface conditions.

The specific objectives of this project are below:

1) To evaluate electric field distribution around 25kV 9-Tonne polymeric railway insulator.
2) To examine the effects of various pollution contaminations on field distributions. Three major types of contaminations such as salt, urea, cement are considered for this study.
3) To examine the effects of various pollutant contaminations on wet and dry polymer insulator.
4) To find a severe pollution contamination on 9-Tonne polymer insulator.

1.4 SCOPE OF THE PROJECT

The Determination of electric field on the insulator surface is important to predict high stress region on the insulator. This project focuses on:

1) To analyse electrical field stress near the high voltage and ground terminal, along the leakage path of railway insulator using Finite Element Method (FEM) package.
2) To analyse electrical field distribution under various pollution contaminations and water molecules of polymeric insulator.
3) To carry out a model of 25kV 9-Tonne polymeric insulators two-dimensional (2D) design.

1.5 ORGANIZATION OF THE THESIS

This report is divided into eight chapters:

CHAPTER 1 provides the introduction of the project which includes background study, objective of the project and organization of the thesis.

CHAPTER 2 provides a literature review on polymeric 9-Tonne insulator phenomena and different test for railway insulators and RDSO specifications. Different stresses which deteriorate the performance of insulator are discussed in this chapter.

CHAPTER 3 presents the EFA of 25kV 9-Tonne polymer insulator . Simulation results of both insulators (polluted and very heavy polluted zone) will be compared in this chapter.

CHAPTER 4. Presents the results of EFA of 25kV 9-Tonne polymeric insulator under various contamination conditions and compared with dry clean condition.

CHAPTER 5 Presents the results of EFA of 25kV 9-Tonne polymeric insulator under water molecules condition.

CHAPTER 6 Presents the results of EFA of polluted zone 25kV 9-Tonne polymeric insulator under various contaminations with wet insulator and compared with wet insulator without contamination.

CHAPTER 7 Presents the results of EFA of very heavy polluted zone 25kV 9-Tonne polymeric insulator under various contaminations with wet insulator and compared with wet insulator without contamination

CHAPTER 8 presents general conclusions based on the findings in this study, and outlines some recommendations for future investigation.

CHAPTER 2

A REVIEW ON RALWAY INSULATORS

2.1 RAILWAY INSULATORS

Railway insulators have a very high resistivity as well as a low conductivity. Their atoms possess tight bound electrons which don’t actually move across the material. Since the electrons are always static as well as not roaming freely, the current can’t pass through it at all. Apart from protecting the loss of a current, the insulators also make the electric current even more efficient by simply concentrating flow of the current.

Insulators for railway traction applications are a category apart from the regular insulators as they demand extremely stringent performance and safety requirements. Modern insulators has set the standards in design, manufacture, testing and supply of insulators for railway traction application. These types of the insulators are mainly manufactured in accordance with the demand and specification are setup by RDSO, which is the main governing body. These types of insulators are mainly used in the 25KV railway traction systems and meeting the demand of the electrification of railway lines in India. The roofline insulator is used in locomotives mostly.

We provide different kinds of railway insulators like:

- Stay arm and bracket insulator for supporting conductor to pole.
- 9 tonne, sectioning insulators for end termination and traction line operation and substation of Railway.
- Roofline, Post insulator for locomotive.

These insulators are mainly developed to not just meet but also exceed demand laid by RDSO, main governing body for electrical traction insulator application. The insulator manufactured is subject to acceptance as well as routine tests according to the standards of RDSO. The size of the sample is increased mainly for proving the consistency in the performance of the product.

The insulator apart from undergoing the regular test is even subjected to different tests such as

- Flexural strength of the test specimen

- Investigation of Scanning Electron Microscope or SEM
- Analysis of Energy Dispersive X-Ray or EDX
- Check on the modulus of elasticity
- Tests of power arc

These type of tests and strict control of the process of manufacturing as well as stringent adherence to the quality control has helped in making the modern day railway insulators in being different from their counterparts.

2.2 TESTS

2.2.1 Type Test

Suitability for long-term use of Silicone composite insulators shall be assessed by type tests. The manufacturer shall furnish all the data sheets pertaining to the electrical and mechanical properties of rubber compound, bonding agent or any other required during manufacturing process to RDSO at the time of product design approval. In no case, insulator manufacturer shall change the make, grade, type or composition of the rubber compound without repeating the type tests related to electrical and material properties. Type tests shall be repeated, when ever the design or the material of the insulator is changed/modified or at the time of renewal of vendor approval/registration. (whichever is higher shall be taken). These tests need not be repeated, if the material of the sleeve/housing and core (glass fiber) are same batch for other types of insulator offered for prototype tests.

(ii) The electrical tests shall be carried out on 3 samples of one type of insulator only, in case the design of insulator (excluding end fittings) is same for all the types offered for prototype testing.

(iii) The Tests mentioned shall be conducted on any one type of insulator only. They shall be repeated with a time span gap of every 5 to 6 years or till any change in design/material (Polymer compound) of the insulators offered for prototype tests whichever is earlier.

(iv) The Tests mentioned shall be carried out on any one type of insulator (preferably on 9-Tonne insulators) in case the design of insulator (excluding end fittings) is same for all the types offered for prototype testing. Also the power arc test shall be carried out on any one type of insulator preferably Sectioning insulator out of Post, Operating & Sectioning insulator. They shall be repeated with a time span gap of every 5 to6 years or till any change in design of the insulators offered for prototype tests whichever is earlier.

(v) The galvanization test shall be conducted on three samples of each type of metal fittings of the insulators broken during mechanical load and performance test. This test shall be conducted on hooks in case of stay arm insulator.

2.2.2 Acceptance Criteria of Type Test

A single batch of insulators offered for type tests, shall pass all the tests as stipulated above. In case any insulators /test specimen sample fails in the type test, manufacturer shall brought out in black & white, the reason of such failure & corrective action taken . The bulk manufacture of the insulator shall be taken up, only after approval of the original tracings of drawings , if any, necessitated during the type tests and clear written approval of the results of the tests on the prototype is communicated by the Purchaser /Director General(T), Research Designs and standards organization to the manufacturer. All facilities shall be made available to conduct such test- without any charges. The renewal of prototype approval shall be accorded for a period of three years only or as per RDSO policy. In addition, a quality audit shall be done minimum every six month for checking quality of the manufacturing process. Prior to giving call to Director General (Traction Installation) Research Designs and Standards Organization, Lucknow for testing of the prototype (at least 15 days in advance), manufacturer shall submit a detailed test schedule consisting of schematic circuit diagrams for each of the tests and the number of days required to complete all the tests. Once the schedule, is approved, the tests shall invariably be done accordingly. However, during the process of type testing or even later, RDSO reserves the right to conduct any additional test , besides those specified herein, on any insulator so as to test the insulator to his satisfaction or for gain additional information and knowledge. The following documents shall be furnished by the manufacturer at the time of type/acceptance test for Silicone compound & FRP rod.

1) Name and trade mark of manufacturer.

2)Product data sheet/Test certificate.

3) Any other information required by the purchaser.

2.2.3 Routine Test

These tests are for the purpose of eliminating insulators with manufacturing defects. They are conducted by manufacturer on every insulator offered for acceptance. Which shall pass the tests. The manufacturer shall maintain the detailed record of the number of insulators tested, rejected and other essential data, for purpose of examination during tests, assessment, audit visits. Routine visual examination, the visual examination shall be conducted as per IEC 61109. Routine mechanical load test, all insulators except for sectioning insulator shall be subjected to axial tensile load of 70% of the value specified for the one minute. In case of sectioning insulator, the tensile load shall be applied 80 mm eccentric as indicated in. If any insulator cracks or its metal fittings loosen or deform or crack, it shall be rejected. Every insulator passing the routine mechanical load test shall be affixed with a clear label or stamp on the end fitting indicating that it has passed routine mechanical load test.

2.2.4 Acceptance Test

These tests are for the purpose of verifying mechanical characteristics as well as the required properties of the FRP rod housing material of insulator and other characteristics as considered necessary, to ensure quality of manufacturing and the material used. The sample size shall be 1.5% of the quantity offered subject to a minimum of 6 picked up at random. The following tests shall constitute part of the acceptance tests, to be conducted on the insulators selected in random from the lot offered for acceptance. Only after passing the visual examination, other acceptance tests shall be conducted on the offered insulators. No failure should take place in the tests. If any insulator fails in the retest, or in the first testing of tests, the entire lot shall be rejected & each insulator of the lot shall be destroyed. The specific gravity, tear strength & hardness (Shore A) test shall be carried out on specimen taken out from the insulator offered for acceptance test and minimum three test slab from same rubber compound shall be prepare for conducting tests at manufacturer premises during inspection by the inspecting authority. For the purpose of conforming / co-relating the composition of the test slabs with that at the insulators material, the acceptance test results of both (insulator & test slab) shall not be more than the limit given below:

a) Hardness (Shore A) : Test results shall be within ± 2.

b) Tear strength : Test results shall be within ± 0.30.

c) Specific gravity :Test results shall be within ± 0.02

Formation of lot, All the insulators of the same type and design manufactured under identical conditions of production shall be offered for acceptance. Batch of insulators shall be the complete number of insulators manufactured from one type of silicone rubber / FRP rod, during the month, which shall be marked on the insulator offered for testing.

2.3 POLLUTION ON INSULATORS

In recent years, the demand of electric power has enlarged considerably. To satisfy this demand, electrical companies have to improve the efficiency of their transmission lines. Also, with the liberation of electrical markets, the individual clients will have the possibility to choose the supplier companies that provide them a better quality of service.

The efficiency of the system is based mainly on the continuity of the service, avoiding faults that suppose economic losses for companies and users. To maintain this continuity, one of the main problems that have been found is the effect produced by pollution in the insulators of electric lines. This pollution is the one of the main causes of flashover in the insulators. The insulator begins to fail when the pollutants that exist in the air settle in the surface of the insulator and combine with the humidity of the fog, rain, or dew. The mixture of pollutants, plus the humidity form a layer that become conductor and allow passing currents that will facilitate the conditions of short circuit. This is due to a decrease of the resistance of the insulator surface. Unless there is a natural cleaning or an adequate maintenance, the electrical activity will be affected by a possible flashover in the insulator.

In other words, the pollution degrades the insulators and affects severely to their electric characteristics, being one of the main causes of mis-operation of the insulators. Therefore, the electric companies should prevent the interruptions of the service, produced by insulators contaminated.

Most of the methods of pollution control are based mainly in:

- Analysing the severity of the pollution, that is to say, to establish “zones of pollution”.
- Controlling the situation of pollution on the insulators, to determine when a cleaning or maintenance of the insulators are needed for prevent problems due to pollution.
- Comparing the behaviour of different designs of insulators (form, length) and/or of the materials of the insulator that are going to work under contaminated environments.

- The probability of appearance of fault situation depends on the type of material of the insulator, the weather of the zone, the type and level of pollution, as well as the working voltage of the insulator. Other problems related to pollution are: corrosion and erosion of the insulator. Also in polymeric insulators, the phenomenon of dry bands, and the effect of pyrolysis, must be kept of analysing the operation of the insulator.

2.3.1 Types of Pollution

The level and the type of pollution of a region are associated with the sources of pollution, as well as with factors of the place. Table 2.1, shows the pollutants and the sources that produce them. Independently of the existing pollution type, the normal phases in which a flashover can appear in the insulator by pollution are:

- The pollution is placed on the surface of the insulator and a contamination layer appears. The pollution can be caused by a great variety of sources, (sea salt, industries, ashes....).The wind is the main bearer of the particles, having a secondary role the gravity and the electric field.
- By the action of rain, fog, etc. ...., the layer on the surface is damped and enlarges the conductivity.
- The contaminant layer dries. Thus, there is an increase of conductivity and leakage current.
- Dry bands are formed as a consequence of the warming-up of the layer on the insulator surface. ‘
- Partial arches appear through the dry bands.
- Partial discharges are produced, these discharges produce audible noise.
- Finally, the total discharge is produced.

Contaminant	**Source of pollution**
Salt	Coastal Areas Salt Industries High ways with deposit of snow where salt is used to melt the snow
Cement	Cement plant Construction sites Rock quarries
Earth	Plowed fields Earth moving on construction projects

Fertilizers	Fertilizer fields Frequent use of fertilizers in cultivated fields
Metallic	Mining handling process Mineral handling process
Coal	Coal mining Coal handling plants/thermal plants Coal burning/brick kilns areas
Volcanic ash	Volcanic activity areas
Defecation	Roosts of bird areas
Chemical	Wide variety of chemical/ process industries, oil refineries...........
Smog	Automobile emissions at highways crossing Diesel engine emissions at railway crossing/yards
Smoke	Wild fire Industrial burning Agriculture burning

Table 2.1 Contaminants and their sources

So that the flashover can be produced these phases have not be happen consecutively but that several phases can occur at the same time. When the contamination layer is dampened, the resistance diminishes and the current of filtration that passes through this is increased. With this increase, the temperature of the contaminant layer is elevated, and that diminish still more the resistance. The resistance will diminish until the temperature reaches the boiling point, beginning to lose humidity. From this point the layer resistance begins to enlarge little by until its total drying. Then will reach the maximum value of resistance. This phenomenon is lot more feasible in narrow parts of the insulator where the density of current is higher. The increase of the resistance makes the current diminish, but its formation implies that most tensions applied to the insulator appear through it, by being still humid the remainder of the layer. An increase of pollution produces the increase in the leakage current and then the flashover of the insulator is more probable. But if we could distribute the pollution over the entire insulator, the voltage would be forced to be more linear, so we could avoid the electric concentration in any point of the insulator and the probability of flashover would diminish.

In some locations very close to large sources of pollution, the entire insulator is covered with the contaminant, but this situation is an exception more than a rule. Because of it, the most typical guideline is a not uniform distribution. The surfaces exposed or protected of the insulator are affected on different ways by the forces that are responsible for placing the contaminant and to clean the surface. Thus in many cases the most exposed areas are more contaminated than the areas protected, but there are cases where the contrary is also certain.

2.3.2 Methods for Reducing the Effect of Pollution

To avoid the effect of pollution on the insulators there are three alternatives. Those are correct selection of the insulator type, maintenance of the insulators and elimination of the source of pollution. The effect of pollution will depend on the region and on the efficiency of the maintenance plans the correct selection of the insulator type.

2.4 NUMERICAL FIELD ANALYSIS TECHNIQUES

Numerical methods are used to determine the electric field distribution for complex geometries, where it is cumbersome and expensive to use analytical techniques or run laboratory tests. All electromagnetic field problems can be expressed in terms of partial differential equations with the help of Maxwell's equations. Along with these set of equations, certain boundary conditions are described in order to completely describe the electric field for the system under consideration.

The Maxwell's equations are as follows:

In free space, Maxwell's equations and the constitutive equations are:

$$\nabla \times H = \frac{\partial D}{\partial t} + J \qquad (2.1)$$

$$\nabla \times E = -\frac{\partial B}{\partial t} \qquad (2.2)$$

$$\nabla . B = 0 \qquad (2.3)$$

$$\nabla . D = \rho \qquad (2.4)$$

$$B = \mu H \qquad (2.5)$$

$$D = \mu E \qquad (2.6)$$

In the presence of conducting materials, the principle of charge conservation is expressed by the relation:

$$\nabla . J + \frac{\partial \rho}{\partial t} = 0 \qquad (2.7)$$

The variables used are described below:

H=vector of magnetic field strength.

E=vector of electric field strength.

B=vector of magnetic flux density.

D=vector of electric flux density.

J=conduction current density.

ε =permittivity of free space.

μ =permeability of free space.

At the interface of different materials the integral form of Maxwell's equations is reduced to

$$n.(B_1 - B_2) = 0 \qquad (2.8)$$

$$n.(D_1 - D_2) = \sigma \qquad (2.9)$$

$$n \times (E_1 - E_2) = 0 \qquad (2.10)$$

$$n \times (H_1 - H_2) = K \qquad (2.11)$$

$$n \times (J_1 - J_2) = -\frac{\partial \sigma}{\partial t} \qquad (2.12)$$

Where

N=unit normal vector to the interface of surfaces 1 and 2

$B_1, D_1, E_1, H_1, J_1 =$ Field vectors on surface 1

$B_2, D_2, E_2, H_2, J_2 =$ Field vectors on surface 2

K=Density of surface currents

σ =Density of surface charges

By using Green's function, these partial differential equations can be transformed into differential or integral equations. The purpose of numerical methods is to transfer an operator equation, differential or integral into a matrix equation. These are solved iteratively till the solution converges with a certain predefined tolerance limit. There are two different categories of numerical methods. The domain methods and the boundary methods. Domain methods make use of differential equations whereas boundary methods make use of integral equations in their solving. The different domain methods are Finite Element Method (FEM) and Finite Difference Method (FDM); while the boundary methods include Charge Simulation Method (CSM) and Boundary Element Method (BEM). This method employs integral equations and the principle of weighted residuals for calculations. Volume integral is transformed into surface integral, thereby reducing the dimension of the problem by an order of one. The various numerical techniques mentioned above are discussed briefly in the sections that follow.

2.4.1 Charge Simulation Method

Charge simulation method has been used for many high voltage problems.it falls under the category of boundary methods. This method works by replacing the distributed charge of conductors as well as the polarization charges on dielectric interfaces by a large number of fictitious discrete charges. The magnitudes of these charges are calculated such that their integrated effect satisfies the boundary conditions exactly at a selected number of points on the boundary.an advantage is that it can be applied to three dimensional field problems without axial symmetry.

The basic principle of the CSM is very simple. If several discrete charges of any type (point, line or ring, for instance) are present in a region, the electrostatic potential at the i^{th} contour point can be found by summation of the potentials resulting from the individual fictitious charges (j) as long as the point does not reside on any one of the charges. Let Q_j be a number of n individual charges and V_i be the potential at any point within the space. According to superposition principle

$$V_i = \sum_{j=1}^{n} P_{ij} Q_j \tag{2.13}$$

Where P_{ij} , are the 'potential' coefficients which can be evaluated analytically for any types of charges by solving Laplace's or Poisson's equations. As soon as the fictitious charges are determined, the potential and the field intensity at any point outside the electrodes can be calculated. As soon as an adequate charge system has been developed, the potential and field at any point outside the electrodes can be calculated. Whereas the potential is found and the field stress is calculated by superposition of magnitudes of various directional components. For example, for Cartesian coordinate system, the net field **E,** at i_{th} contour point, is given by

$$E_i = [\sum_{j=1}^{n} \frac{\partial P_{ij}}{\partial x} Q_j] a_x + [\sum_{j=1}^{n} \frac{\partial P_{ij}}{\partial y} Q_j] a_y + [\sum_{j=1}^{n} \frac{\partial P_{ij}}{\partial z} Q_j] a_z \qquad (2.14)$$

or

$$E_i = [\sum_{j=1}^{n} (f_{ij})_x Q_j] a_x + [\sum_{j=1}^{n} (f_{ij})_y Q_j] a_y + [\sum_{j=1}^{n} (f_{ij})_z Q_j] a_z \qquad (2.15)$$

Where $(f_{ij})_x$, $(f_{ij})_y$ and $(f_{ij})_z$ are the 'field intensity' or field coefficients; a_x, a_y and a_z are unit vectors in the x, y and z directions, respectively.

CSM has proved quite useful for estimation of electric field intensity for two and three dimensional fields both with and without axial symmetry. It is a simple method and is found computationally efficient and provides accurate results. The simplicity with which CSM takes care of curved and rounded surfaces of electrodes or interfaces of composite dielectric medium makes it a suitable method for field estimation. The computation time is much less as compared to FDM and FEM.

However, it is difficult to apply this methods for thin electrodes *e.g.* foils, plates or coatings as some minimum gap distance between the location of a charge and electrode contours is required. Also, it is found difficult to apply this method for electrodes with highly irregular and complicated boundaries with sharp edges etc.

2.4.2 Finite Difference Method

This method is an approximation for solving partial differential equations. This can be applied to linear, non-linear, time dependent and time independent equations. The basis of this technique is the replacement of a continuous domain representing the entire space surrounding the high-voltage electrodes with a rectangular or polar grid of discrete "nodes" at which the value of unknown potential is to be computed. Thus we replace the derivatives describing Laplace's equation with "divided-difference" approximations obtained as functions of the nodal values. Methods like Taylor's series are used to transform the differential operator into difference operator. According to Laplace's equations, the potential at any node in a mesh is given by

$$\frac{\partial^2 V}{\partial r^2}+\frac{1}{r}\frac{\partial V}{\partial r}+\frac{\partial^2 V}{\partial z^2}=0 \tag{2.16}$$

The finite difference form this equation is given by

$$V_{r,z}=K_1V_{r+1,z}+K_2V_{r-1,z}+K_3V_{r,z+1}+K_4V_{r,z-1} \tag{2.17}$$

Where the coefficients K_1, K_2, K_3, K_4 depend on the model geometry and mesh configurations. The application of this method is relatively easy.

The method is found suitable only for two-dimensional symmetrical field where a direct solution is possible. In order to work for irregular three-dimensional field so that these nodes are fixed upon boundaries becomes extremely difficult. Also to solve for such fields as very large number of $V(x, y)$ values of potential are required which needs very large computer memory and computation time and hence this method is normally not recommended for a solution of such electrostatic problems.

2.4.3 Boundary Element Method

The boundary element method (BEM) is a relatively new technique for solving Laplace's and Poisson's equations (and other partial differential equations).it uses the area charge elements to replace real charges. The discretization of the real charges is generally carried out by boundary elements having three or four nodes, which uses linear shape functions to approximate the internal charge distribution. If the outer surface geometry is not covered, then suitable intermediate points can be added. The evaluation of the resulting potential functions of the boundary elements is done by numerical integration. In this way, the number of elements and thus the number of unknowns of the resulting linear equations is greatly reduced compared with domain approaches such as finite element and final difference methods. The boundary approach also makes it possible to handle problems with infinite domain.
Boundary element formulation calls for the scalar electric potential due to surface charge density, which is written as

$$\varphi(\xi)=1/(2\alpha\pi\varepsilon_0)\int_\gamma \rho_s(x)\phi^l(\xi,x)dP(x) \tag{2.18}$$

Where, ϕ^l denotes the fundamental solution of the potential problem, α =1 or 2 for two or three dimensional problems respectively, and $\rho_s(x)$ denotes the surface charge density. The above equation is source formulation of BEM. This equation can be solved using the standard point allocation procedure for discretized image charges that lie within the conducted boundaries. The allocation approach has been recognised as the charge simulation. The electric field is then given by

$$\varphi(\xi) = 1/(2\alpha\pi\varepsilon_0)\int_{\gamma} \rho_s(x)\nabla\phi^l(\xi, x)dP(x) \tag{2.19}$$

By solving the system of equations, the unknown values of the charge density can be found. Once the charge distribution is known potential and electric field values can be calculated throughout the domain using the above equations.

The main disadvantage of this method is the programming complexity and need for large amount of computational time to execute an improper integral. Sometimes the integrals can produce a singular matrix.so care must be taken to avoid such a situation or to handle it appropriately.

2.4.4 Finite Element Method

FEM is a numerical approach to solving the partial differential equations (PDE), which represent a physical system. The finite element solution is suitable for small domain problems with limited and closed boundary conditions. FEM includes accurate electric field calculation, enhanced design and faster response.it has the ability to deal with complex 2D domains.it is more suitable to take boundary conditions into account. The finite element method is most widely used in numerical solution of electric field problems.it is flexible and can be applied to the most complicated geometries.it is capable of giving accurate results and the accuracy depends on the number of elements considered in the geometry.

Three levels of analysis programmes were used for pre-processing, solving and post processing. The levels involve different activities as illustrated in Figure 2.9.

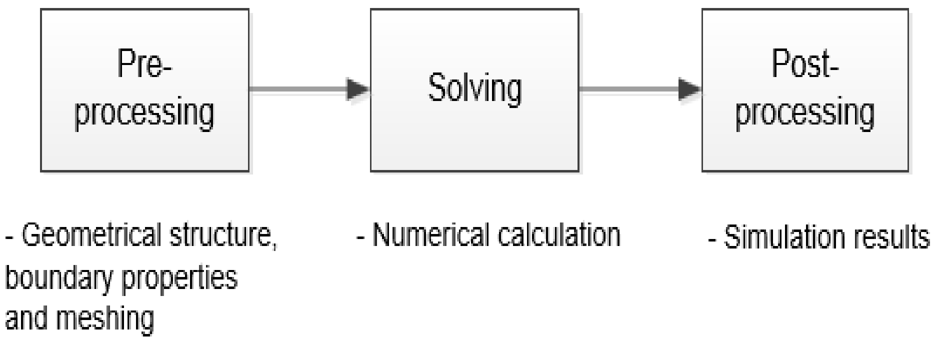


Fig 2.1: Three levels of FEM analysis

Diagram in Figure 3.1 is an illustration of the consecutive stages of pre-processing, numerical solving and post processing. At the pre-processing stage, physical problems such as geometrical structure, material and boundary properties are presented which enables modelling to take place, after which the modelled space is meshed. The meshing of the elements is the starting point for transforming the geometry into small units and simple forms using the finite element method. Numerical solving is particularly dependent on the physical interface. The final stage is post processing which enables users to generate graphical plots depending on post processing parameters. The main disadvantage of this method is that the entire domain space is divided into elements.in case of unbounded regions; the number of elements considered becomes extremely large which in turn increases computation burden.

It is important to undertake an appropriate physical study before carrying out the simulation process. In order to investigate the electrical field distribution along the insulator, the physical platform was set in Electrostatic and stationary studies.

CHAPTER 3

ELECTRIC FIELD ANALYSIS (EFA) OF 25kV 9-TONNE POLYMER INSULATOR

3.1 9-TONNE POLYMER INSULATOR

Insulators for railway traction applications are a category apart from the regular insulators as they demand extremely stringent performance and safety requirements. Modern insulators has set the standards in the design, manufacture, testing and supply of insulators for railway traction application. We manufacture various categories of 25kV railway insulators addressing every need for the electrification of railway lines. The shortest distance along the contours of the external surfaces of the insulating part of the insulator i.e., distance between those parts which normally have the operating voltage between them.

The insulator tube which is normally, though not exclusively, used as a strain insulator for anchoring of conductors, is known as 9-Tonne insulator. It is also used in a vertical position to support 25 kV feeder wire.

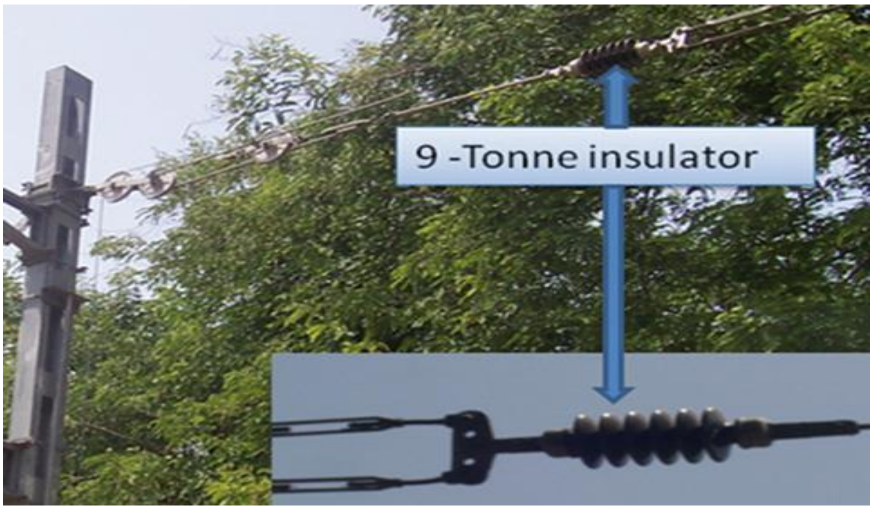


Fig.3.1 Railway 9-Tonne insulator

1050 mm Creepage Distance Insulator i.e., 20 mm/kV

These insulators shall be used in light and medium polluted areas, where Salt Deposit Density (SDD) is in the range of 0.1 to 0.3 mg/sq.cm.

1600 mm Creepage Distance Insulator i.e., 31 mm/kV

These insulators shall be used in heavily /very heavily polluted zones, where SDD is more than 0.3 mg/sq.cm.

Note:-IEC Publication 60815 & IS: 13134 prescribe four levels from the point of view of pollution i.e. light to very heavy pollution. For the purpose of standardization, and in order to avoid multiplicity of types of insulators to suit each type of pollution, only 1050 & 1600 mm insulators shall be used in the zones defined above on Indian Railways.

3.2 BASIC COMPONENTS

Silicone composite insulator shall have following basic components and shall be manufacture according to process given in following paras

3.2.1 Shed and Sheath Materials

Composite insulator's shed & sheath shall be made of High Temperature Vulcanising (HTV) type silicone rubber, having silicone content between 40-50 % by weight. ATH (Alumina Tri hydrate) should be used as filler. The filler should be properly mixed with silicone compound to ensure the uniform distribution. Thickness of sheath should be minimum 3mm & shall have excellent Hydrophobic and anti-tracking properties. The material should conform to the tests specified in this specification. The material preferably shall be such that it should not attract rats/birds/squirrels/monkeys and other rodents at storage location or on the line. The thickness of shed at edge should not be less then the 2mm to minimize the external damage. Manufacturer should indicate the solvent etc. to be used for cleaning silicone rubber sheds along with method of cleaning.

3.2.2 Core/Rod

Core of the composite insulator should be manufactured from the Boron free, Electrically Corrosion Resistant (ECR) grade fiber glass reinforced plastic (FRP) rod having at least 70% fibers by weight. It should be void free and should have high resistance to acid corrosion.

3.2.3 End Fittings

The end fittings shall be made of spheroidal graphite cast iron to Grade: 400/15 of IS: 1865-1991 or forged steel fittings to BS 970 (Part-II). Approval of the type test of the insulator implies employment of metal fitting of the particular make, material & design used during type test and the same shall be approved. In event of insulator manufacturer resort to change in make, material or design of metal fitting, in house prototype tests (mechanical tests) shall be required to be repeated. In addition to above, RDSO may carry out the checks of incoming metal fittings. Both the metal fittings of one insulator should be of the same material & make.

3.3 EFA OF POLLUTED ZONE INSULATOR

The electric field distribution in and around the insulator is necessary for the optimal design of the insulator. The accurate computation of electric field distribution can be computed using Finite element method (FEM). For this insulator dimensions are very useful. Insulator dimensions are tabulated in table 3.2.

Table 3.1: Geometrical configurations-25kV polymer 9-Tonne insulator

S. No	Particulars	Dimension
1	FRP Length	450
2	Total Length	600
3	FRP Diameter	32
4	Core Diameter	38
5	Pitch	60
6	Big Shed diameter	120
7	Small Shed diameter	90

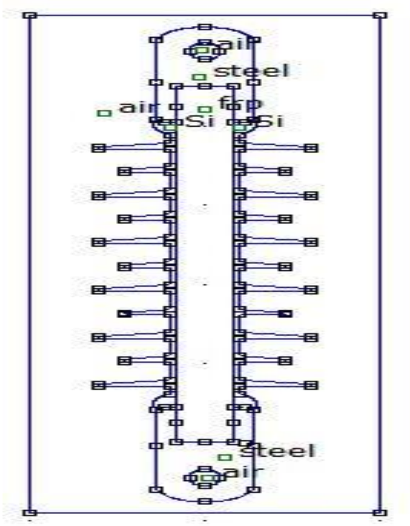


Fig 3.2: 25kV 9-Tonne polymer insulator

3.3.1 ASSIGNING MATERIALS

As per the geometrical configurations, insulator is designed by using FEMM 2D package. After designing, insulator materials like steel, Si and FRP are assigned to the model with the help of relative permittivity values. Insulator material properties are given in Table 3.2

Table 3.2: Material Properties

S. No	**Material**	**Relative permittivity**
1	FRP	5
2	Si	3
3	Steel	1
4	Air	1

3.3.2 ASSIGNING BOUNDARY ELEMENTS

The boundaries in the model need to be split into individual sections, referred to as boundary elements. The distribution, number and shape of these elements are the key factors that determine the accuracy of the solution. FEM generally uses 2D elements for analysis purpose.

3.3.3 ASSIGNING BOUNDARY CONDITIONS

- The rated line-to-ground voltage as 100kV to the high voltage end fitting.
- Zero volts to the grounded end fitting

Air is assigned as a surrounding medium. After assigning boundary elements 2D triangular elements are generated throughout the model. This 2D triangular element gives field results at each every point of the insulator. Insulator model with 2D triangular meshes. By running the model electric field results are taken at critical regions of the insulator.

3.3.4 EFI RESULTS

2D triangular elements and EFA result of polluted zone are shown in fig 3.6 and EFA result is tabulated in table 3.3.

Table 3.3: EFA result of 25kV polluted zone polymer insulator

S. No	Particulars	Electric Field Intensity(EFI) (kV/mm)
1	Creepage distance (CD)	0.217
2	Triple Point	0.284
3	First Shed	0.116
4	Inside FRP	0.311
5	Inside Si	0.144

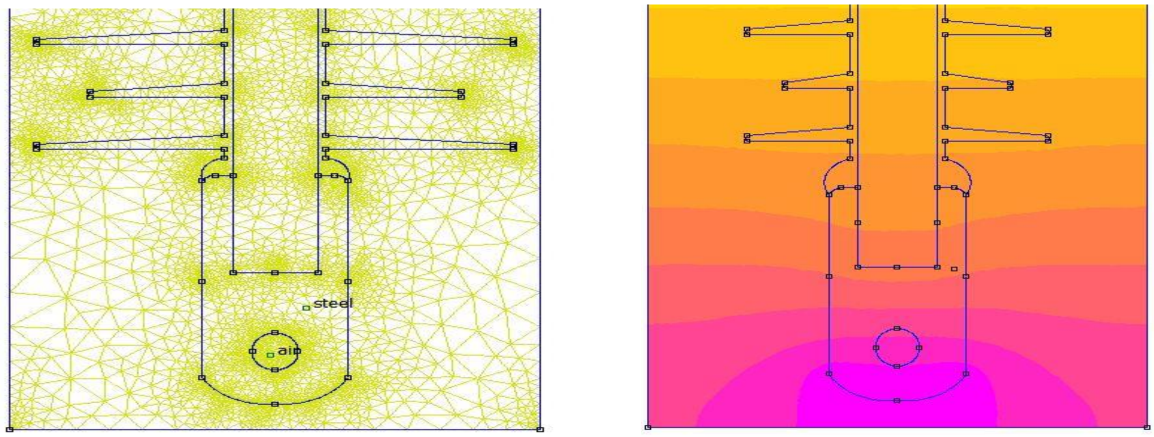
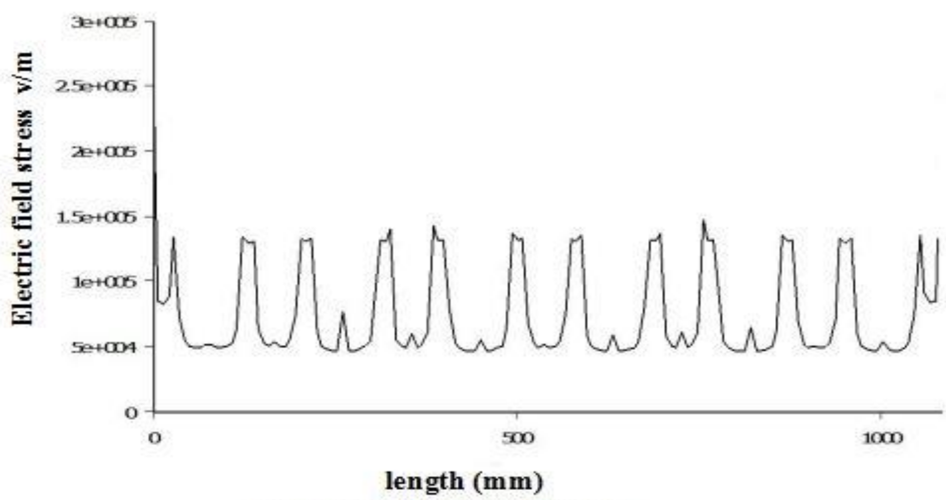
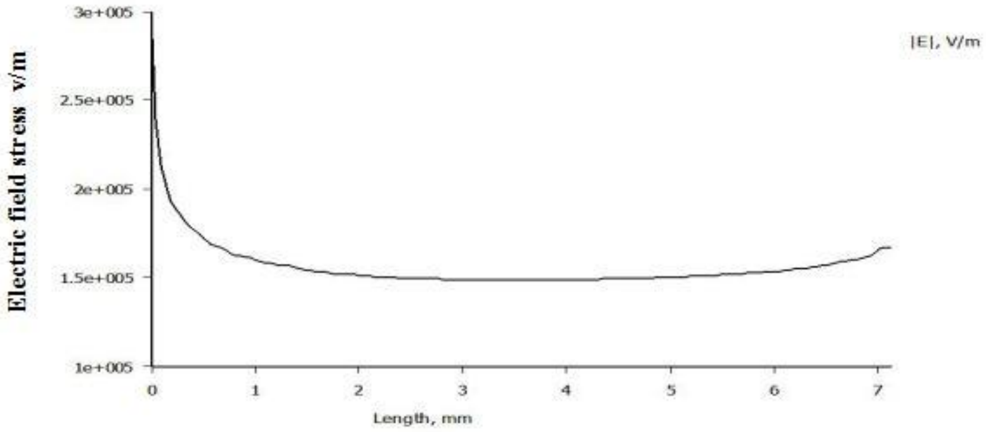


Fig 3.3 **(**a) and (b) 2D triangular meshes of 25kV polymer insulator and EFI contours

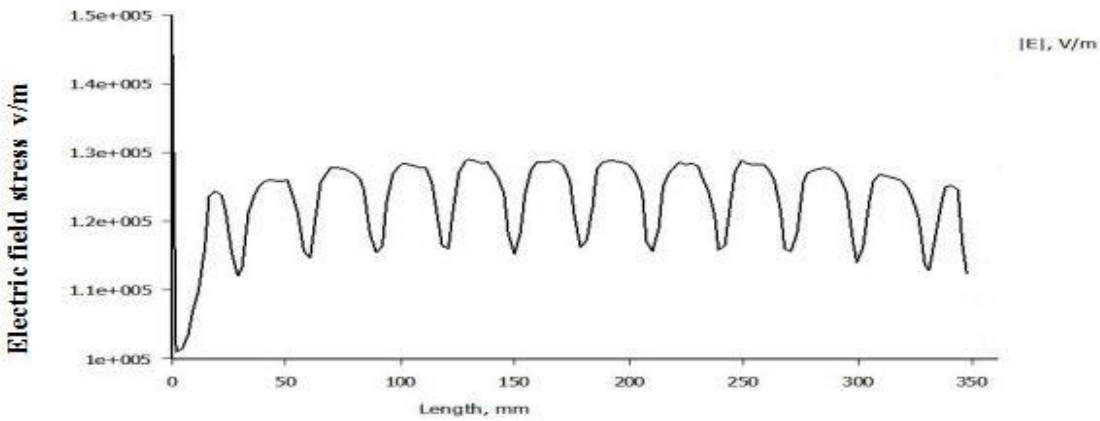


a)electric field stress along CD



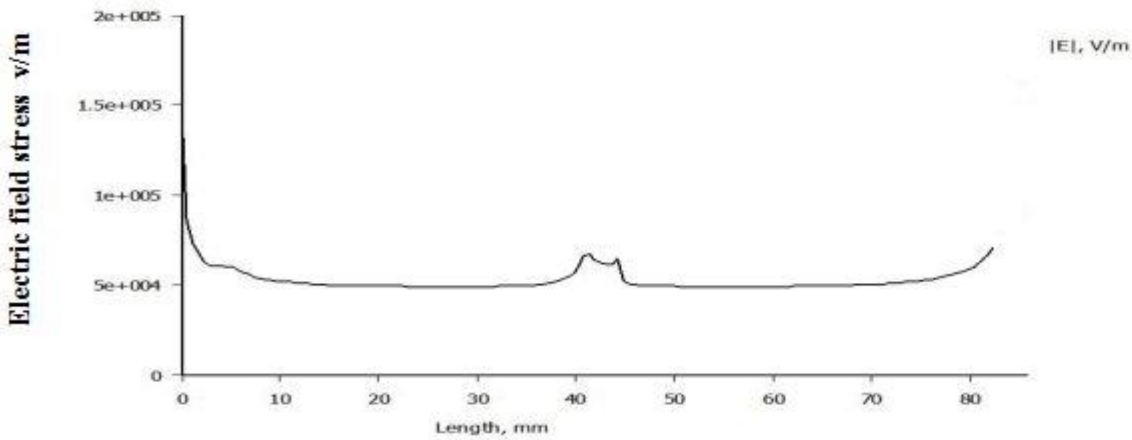
length (mm)

b)electric field stress at Triple point



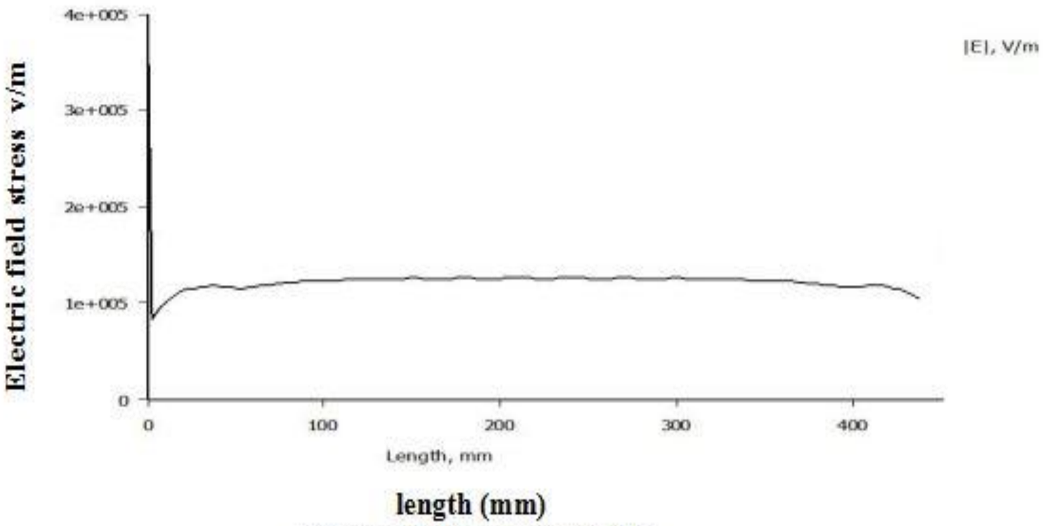
length (mm)

d)electric field stress inside si



length (mm)

c)electric field stress at first shed



e)electric field stress inside frp

Fig 3.4(a to e):EFI results under clean condition

3.4 EFA OF VERY HEAVY POLLUTED ZONE INSULATOR

The electric field distribution in and around the insulator is necessary for the optimal design of the insulator. The accurate computation of electric field distribution can be computed using Finite element method (FEM).For this insulator dimensions are very useful. Insulator dimensions are tabulated in table 3.4.

Table 3.4: Geometrical configurations-25kV polymer insulator

S. No	Particulars	Dimension
1	FRP Length	450
2	Total Length	600
3	FRP Diameter	32
4	Core Diameter	38
5	Pitch	60
6	Big Shed diameter	180
7	Small Shed diameter	140

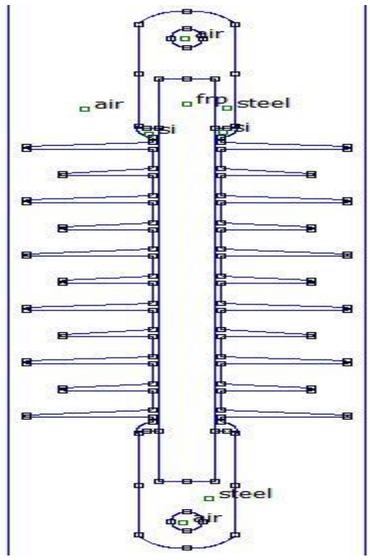


Fig 3.5: 25kV 9-Tonne polymer insulator

3.4.1 ASSIGNING MATERIALS

As per the geometrical configurations, insulator is designed by using FEMM 2D package. After designing, insulator materials like SiR, FRP and steel are assigned to the model with the help of relative permittivity values. Insulator material properties are given in Table 3.5.

Table 3.5: Material Properties

S. No	Material	Relative permittivity
1	Silicon rubber	3
2	FRP core	5
3	Steel	1
4	Air	1

3.4.2ASSIGNING BOUNDARY ELEMENTS

The boundaries in the model need to be split into individual sections, referred to as boundary elements. The distribution, number and shape of these elements are the key factors that determine the accuracy of the solution. FEM generally uses 2D elements for analysis purpose.

3.4.3 ASSIGNING BOUNDARY CONDITIONS

- The rated line-to-ground voltage as 100kV to the high voltage end fitting.
- Zero volts to the grounded end fitting

Air is assigned as a surrounding medium. After assigning boundary elements 2D triangular elements are generated throughout the model.

3.4.4 EFI RESULTS

2D triangular elements and EFA result without grading ring are shown in fig 3.8 and EFA result is tabulated in table 3.6.

Table 3.6: EFA result of 25kV very heavy polluted zone polymer insulator

S. No	**Particulars**	**EFI (kV/mm)**
1	Creepage distance(CD)	0.207
2	Triple Point	0.231
3	First Shed	0.130
4	Inside FRP	0.312
5	Inside Si	0.145

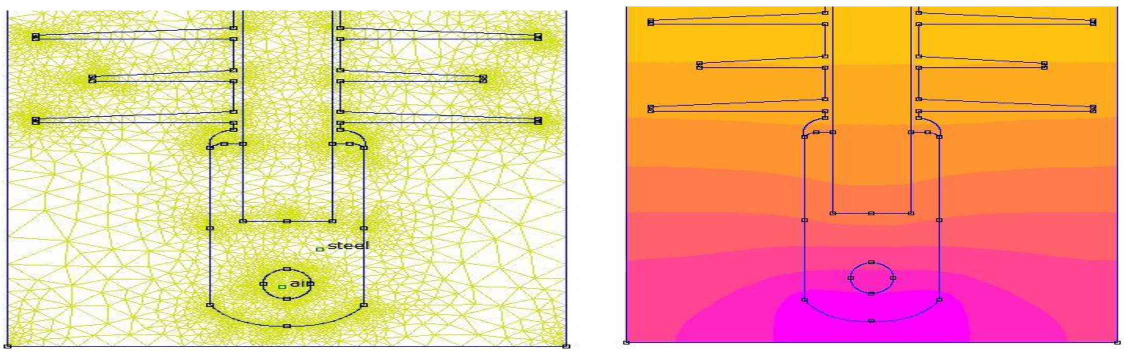
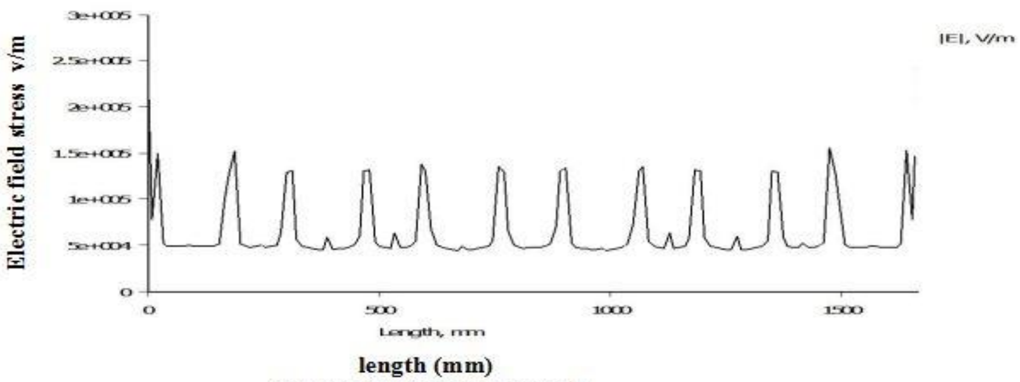
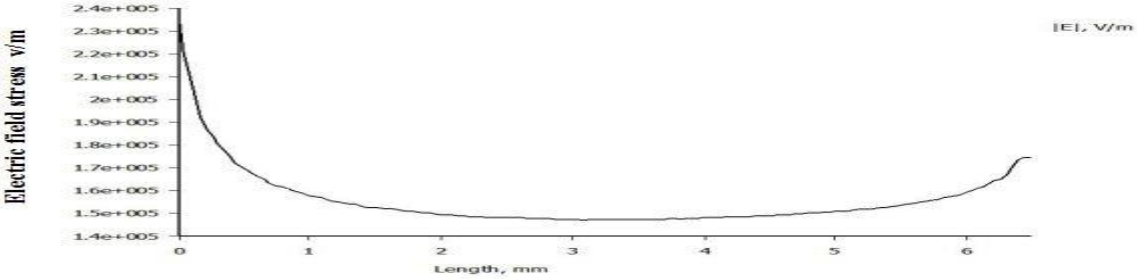


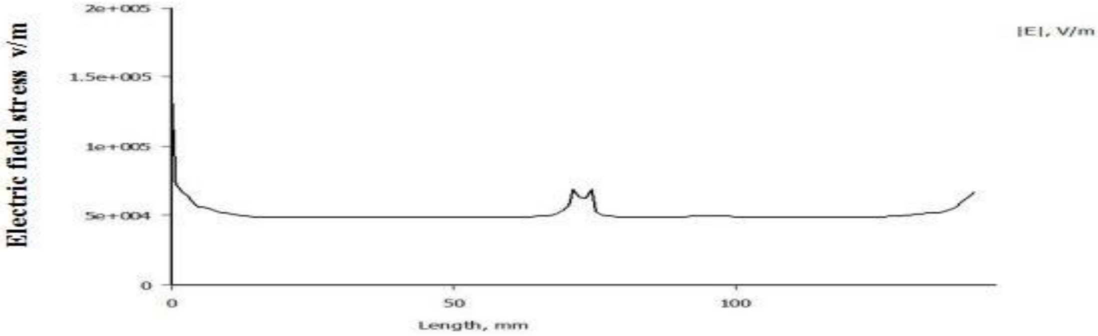
Fig 3.6 (a) and (b) 2D triangular meshes of 25kV polymer insulator and EFA result



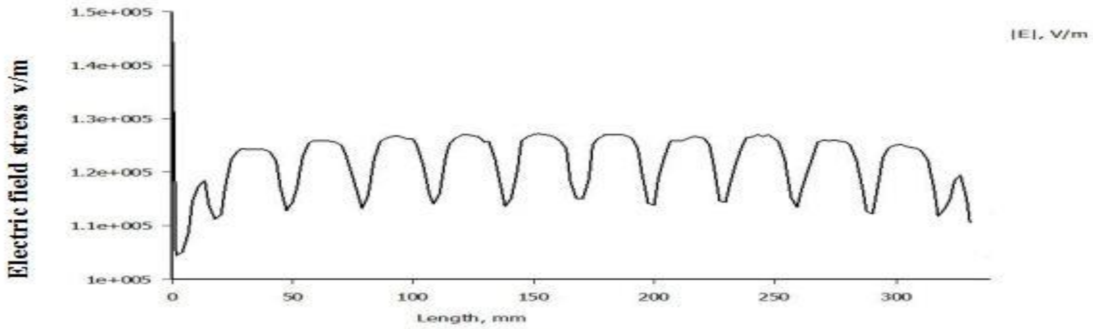
a)electric field stress along CD



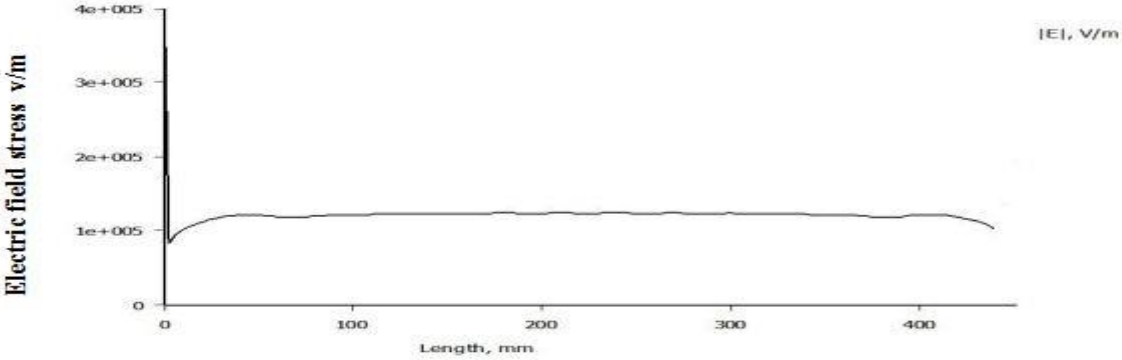
length (mm)
b)electric field stress at Triple point



length (mm)
c)electric field stress at first shed



length (mm)
d)electric field stress inside si



length (mm)
e)electric field stress inside frp

Fig 3.7(a to e): EFI results under clean condition

3.5 EFI RESULTS COMPARISON

The comparison of EFA result for 25kV polluted and very heavy polluted zone 9-Tonne polymer insulator is shows in fig 3.8

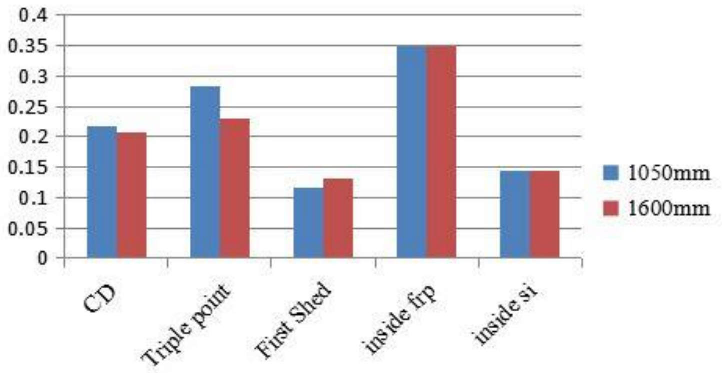


Fig 3.8: EFI result for polluted and very heavy polluted zone insulator

CHAPTER 4

EFA OF 25kV POLYMER INSULATOR PERFORMANCE UNDER VARIOUS CONTAMINATIONS

4.1 INTRODUCTION

Many factors that may raise the level of electric field along the insulators such as atmospheric conditions, pollution contaminations, rain. This pollution is the one of the main causes of flashover in the insulators. The insulator begins to fail when the pollutants that exist in the air settle in the surface of the insulator and combine with the humidity of the fog, rain, or dew. It is known that the performance of outdoor insulators is greatly affected by the severity and type of pollution on their surface. Due to the accumulation of the pollution, electric field along the insulators become dangerously high. Therefore the study of pollution effect is of great importance. Here, we considered three types of pollution contaminations include salt with relative permittivity of 6.1, urea with relative permittivity of 3.5 and cement with relative permittivity of 2.7. These are major pollution contaminations since the insulators are installed near the coastal and industrial regions. The various pollution contaminations are considered on the weather sheds near HV and ground terminals of both sides of the string. This can be handled easily by the simulation software used in this work. Three types of major pollution contaminations considered for this study are summarized in table 4.1.

Table 4.1**.** Type of pollution and their corresponding relative permittivity.

S .No	Materials	Relative Permittivity
1	Cement	2.7
2	Salt	6.1
3	Urea	3.5

As can be clearly observed, field distributions on insulator string become deteriorate when compared to the without pollution. Here the main considerations are CD and at HV end because the pollution is applied on the weather sheds along the insulator string. Electrical performance of the insulator string. With salt, urea, cement pollution contaminations are summarized in table 4.2, 4.3, 4.4.

4.2 CEMENT CONTAMINATION

4.2.1 Polluted Zone

Cement is applied on the weather sheds of insulator string near the HV and ground terminals which can be easily handled in FEM software. Considering the contamination on the insulator to be even and uneven with 1mm and 0.5 thickness for better understand.

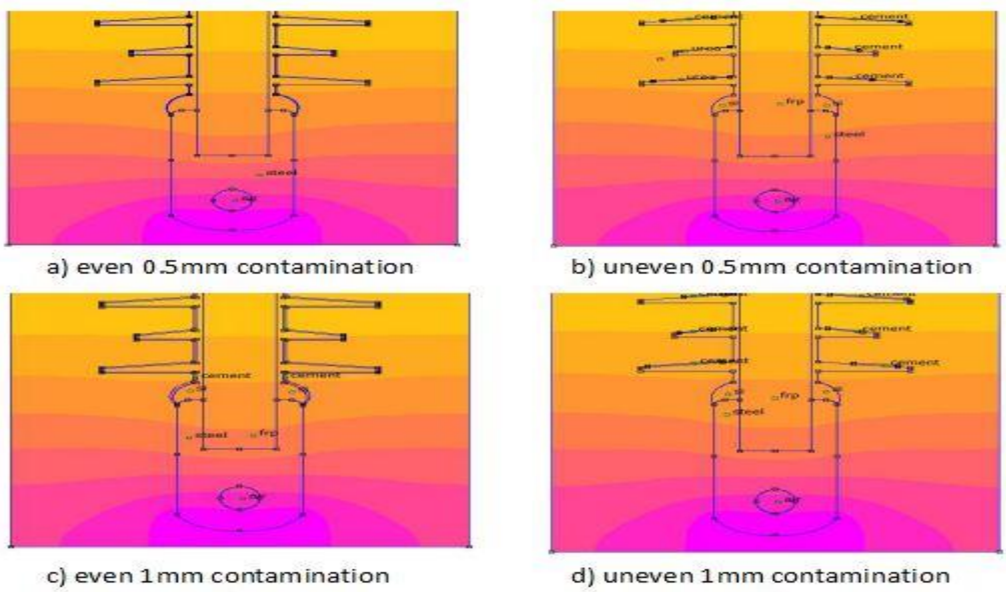


Fig 4.1. EFI contours of cement polluted polymeric insulator

As can be clearly observed, when compared to without pollution, Peak magnitudes in high field regions particularly at first shed is increased by 17% and along the leakage distance is increased by 13% under 1mm thickness cement pollution contamination shown in table 4.2. and the electric stress are increases with increase the thickness of the contamination.The electric field stress at various parts of insulator string under cement contamination condition is investigated by simulation, as shown in from fig 4.2(a to e) to fig 4.5(a to e).

Table 4.2. EFA result of polymer insulator with cement contamination

S. No	**Particulars**	**Polluted zone Electric Field (KV/mm)**				**Electric Field without pollution (KV/mm)**
		0.5mm Evenctmn	1mm Evenctmn	0.5mm Unevenctmn	1mm Unevenctm	
1	CD	0.241	0.244	0.229	0.232	0.217
2	Triple Point	0.184	0.172	0.276	0.270	0.284
3	First Shed	0.136	0.136	0.142	0.142	0.116

4	Inside SiR	0.144	0.146	0.146	0.147	0.144
5	Inside FRP	0.348	0.324	0.324	0.324	0.311

As can be clearly observed, when compared to without pollution, Peak magnitudes in high field regions particularly at first shed is increased by 22% and along the leakage distance is increased by 12% under 1mm thickness cement pollution contamination shown in table 4.3.

4.2.2 Very Heavy Polluted Zone

Cement is applied on the weather sheds of insulator string near the HV and ground terminals which can be easily handled in FEM software. Considering the contamination on the insulator to be even and uneven with 1mm and 0.5 thickness for better understand. Simulation result of cement polluted model is shown in fig from fig 4.7(a to e) to fig 4.10(a to e).

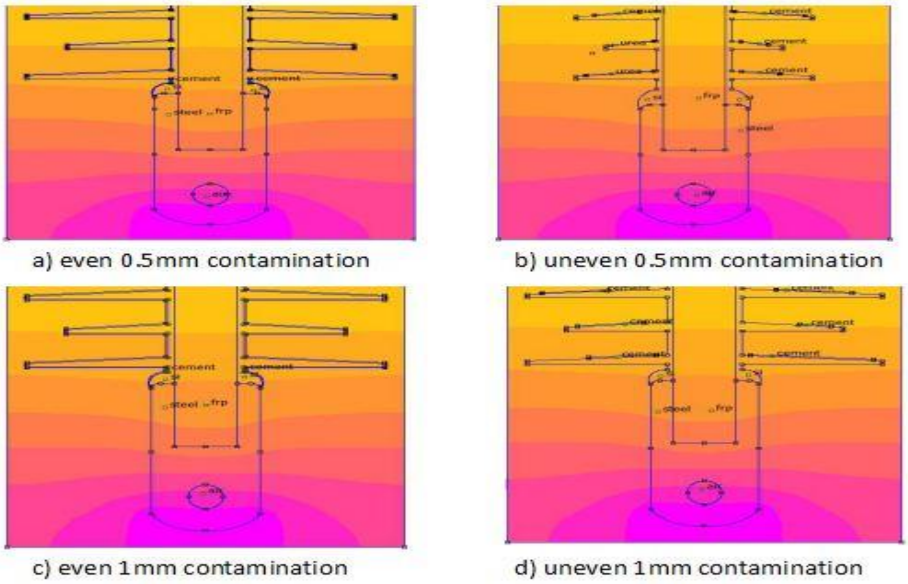


Fig 4.2. EFI contours of cement polluted insulator

Table 4.3. EFA result of polymer insulator with cement contamination

S. No	Particulars	Very High Polluted zone Electric Field (KV/mm)				Electric Field without pollution (KV/mm)
		0.5mm Evenctmn	1mm Evenctmn	0.5mm Unevenctmn	1mm Unevenctm	
1	CD	0.224	0.226	0.218	0.220	0.207
2	Triple Point	0.185	0.146	0.238	0.239	0.231
3	First Shed	0.144	0.144	0.145	0.145	0.130
4	Inside SiR	0.145	0.152	0.147	0.147	0.145

5	Inside FRP	0.326	0.326	0.324	0.324	0.312

As can be clearly observed, when compared to without pollution, Peak magnitudes in high field regions particularly at first shed is increased by 10% and along the leakage distance is increased by 9% under 1mm thickness cement pollution contamination shown in table 4.3.

4.3 UREA CONTAMINATION

4.3.1 Polluted Zone

The electric field stress at various parts of insulator string under urea contamination condition is investigated by simulation, as shown in from fig 4.11(a to e) to fig 4.14(a to e).

Table 4.4. EFA result of polymer insulator with urea contamination

S. No	**Particulars**	**Polluted zone Electric Field (KV/mm)**				**Electric Field without pollution (KV/mm)**
		0.5mm Evenctmn	1mm Evenctmn	0.5mm Unevenctmn	1mm Unevenctm	
1	CD	0.266	0.276	0.253	0.259	0.217
2	Triple Point	0.164	0.150	0.278	0.270	0.284
3	First Shed	0.132	0.139	0.142	0.142	0.116
4	Inside SiR	0.145	0.146	0.147	0.147	0.144
5	Inside FRP	0.324	0.324	0.324	0.324	0.311

As can be clearly observed, when compared to without pollution, Peak magnitudes in high field regions particularly at first shed is increased by 18% and along the leakage distance is increased by 27% under 1mm thickness urea pollution contamination shown in table 5.3.

4.3.2 Very Heavy Polluted zone

The electric field stress at various parts of insulator string under urea contamination condition is investigated by simulation, as shown in from fig 4.15(a to e) to fig 4.18(a to e).

Table 4.5. EFA result of polymer insulator with urea contamination

S. No	**Particulars**	**Very Heavy Polluted zone Electric Field (KV/mm)**				**Electric Field without pollution (KV/mm)**
		0.5mm Evenctmn	1mm Evenctmn	0.5mm Unevenctmn	1mm Unevenctm	
1	CD	0.235	0.252	0.224	0.227	0.207

2	Triple Point	0.172	0.159	0.239	0.238	0.231
3	First Shed	0.140	0.144	0.142	0.144	0.130
4	Inside SiR	0.145	0.146	0.146	0.147	0.145
5	Inside FRP	0.324	0.324	0.324	0.324	0.312

As can be clearly observed, when compared to without pollution, Peak magnitudes in high field regions particularly at first shed is increased by 11% and along the leakage distance is increased by 22% under 1mm thickness urea pollution contamination shown in table 5.3.

4.4 SALT CONTAMINATION

4.4.1 Polluted zone

Similarly salt is the most severe pollution if insulator string is installed near the industrial regions. The electric field stress at various parts of insulator string under salt contamination condition is investigated by simulation, as shown in from fig 4.19(a to e) to fig 4.22(a to e).

Table 4.6. EFA result of polymer insulator with salt contamination

S. No	**Particulars**	**Polluted zone Electric Field (KV/mm)**				**Electric Field without pollution (KV/mm)**
		0.5mm Evenctmn	1mm Evenctmn	0.5mm Unevenctmn	1mm Unevenctm	
1	CD	0.328	0.360	0.258	0.261	0.217
2	Triple Point	0.129	0.112	0.273	0.274	0.284
3	First Shed	0.130	0.141	0.148	0.146	0.116
4	Inside SiR	0.149	0.151	0.151	0.151	0.144
5	Inside FRP	0.348	0.356	0.350	0.352	0.311

As can be clearly observed, when compared to without pollution, Peak magnitudes in high field regions particularly at first shed is increased by 22% and along the leakage distance is increased by 66% under 1mm thickness salt pollution contamination shown in table 4.6.

4.4.2 Very Heavy Polluted zone

The electric field stress at various parts of insulator string under urea contamination condition is investigated by simulation, as shown in from fig 4.23(a to e) to fig 4.26(a to e).

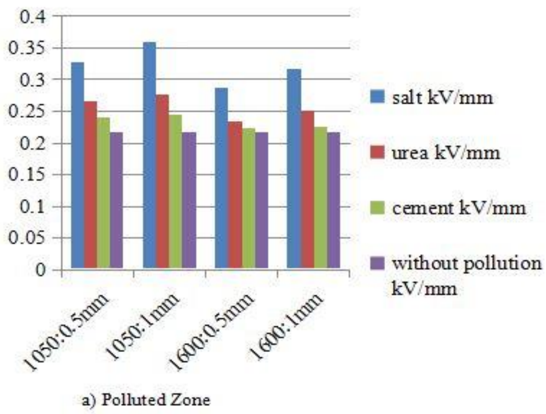
Table 4.7. EFA result of polymer insulator with salt contamination

S. No	Particulars	Polluted zone Electric Field (KV/mm)				Electric Field without pollution (KV/mm)
		0.5mm Evenctmn	1mm Evenctmn	0.5mm Unevenctmn	1mm Unevenctm	
1	CD	0.288	0.316	0.230	0.234	0.207
2	Triple Point	0.146	0.131	0.233	0.233	0.231
3	First Shed	0.142	0.148	0.149	0.149	0.130
4	Inside SiR	0.151	0.152	0.151	0.151	0.145
5	Inside FRP	0.352	0.356	0.348	0.348	0.312

As can be clearly observed, when compared to without pollution, Peak magnitudes in high field regions particularly at first shed is increased by 14% and along the leakage distance is increased by 53% under 1mm thickness salt pollution contamination shown in table 4.7.

4.5 EFA RESULTS COMPARISON

The comparison of EFA result for 25kV 9-toone polymeric insulator and without pollution for both polluted and very heavy polluted zone are shown in fig5.5a & b. In the case of polluted zone compared to without pollution, the field is increased by 66%, 27%, 12%due to salt, urea, cement along leakage distance and 22%,18%, 22% at the first shed. And in the case of polluted zone compared to without pollution, the field is increased by 53%, 22%, 9%due to salt, urea, cement along leakage distance and 14%,11%, 10% at the first shed. By increasing the thickness of the contamination on insulator, the field also increases about 10%,7%,1% due to salt, urea, cement approximately. Field at the triple point (the point at three mediums exists) varies highly with even and uneven contamination on the insulator.



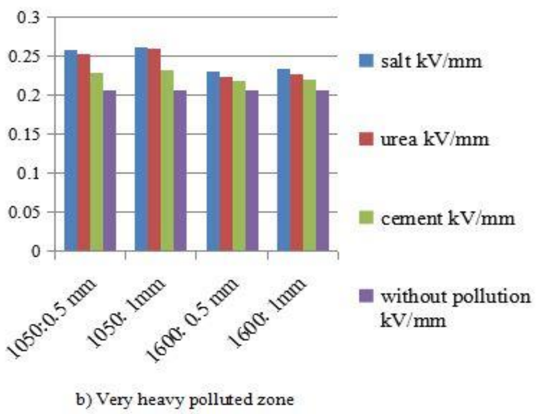


Fig 4.3. Comparison of EFI result of 25kV insulator with and without pollution

CHAPTER 5

EFA OF 25KV POLYMERIC INSULATOR UNDER WATER MOLECULES

5.1 INTRODUCTION

Hydrophobicity of any material is its resistance t o flow of water on its surface. A material is highly hydrophobicity, if it resists to flowing water dropped on it and is least hydrophobic if dropped water flows in form of paths on its surface. The aquaphobic surface is water repellent in contrast with a hydrophilic surface that is easily wetted. Hydrophobicity of a material can be explained using the contact angle on the material surface (θc) that liquid drop makes when it comes into the contact with a solid surface, this angle is a measure of the surface moister. The material which is easily wettable allows water to touch a large surface area and hence makes a contact angle of less than 90°,hydrophobic material allows less water surface contact and thus makes a contact angle greater than 90° as shown in Fig. 1.

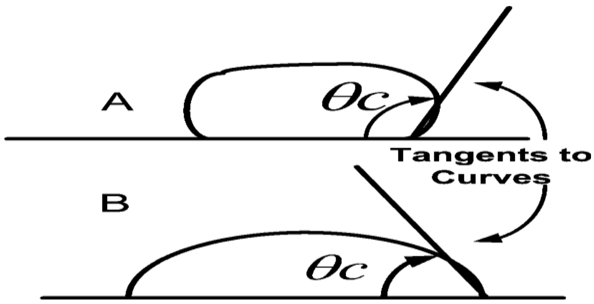


Fig 5.1. shape of a liquid Droplet on a (A) Hydrophobic surface and (B) Less Hydrophobic surface.

Contact angle is also a measure of the surface contamination. The surface hydrophobic of insulation material is often quantitatively evaluated by the value of contact angle formed between water droplet & material surface, which direct representation of the tension between interfaces of water and the material atoms. The shape of the liquid droplet depends on the type of the solid material and physical and chemical state of its surface. It is clear from the Fig. 1 that the smaller is the contact angle , the more wettable is the surface and vice versa. Surfaces are assumed to be hydrophobic when the contact angle is less than 35° for contact angles greater than 90, surface is imagine to be hydrophobic and the surfaces characterized by the contact angles from 35° to 90°are partially wettable . It is also noted that the term hydrophobicity represents resistance to water, it is generally used to represent resistance to any liquid.

The loss of hydrophobicity causes reduction in electrical insulation and pollution withstand performance and it also influences the aging process of SIR insulators. The most obvious drawback of hydrophobicity is reduction in electrical insulator is increase in surface leakage current activity and as a result, the increased dryness of the surface. This fact is known as a major insulation performance factor for ceramic insulators, but for a polymeric or nonceramic insulators hydrophobicity loss or reduction causes other serious effects.

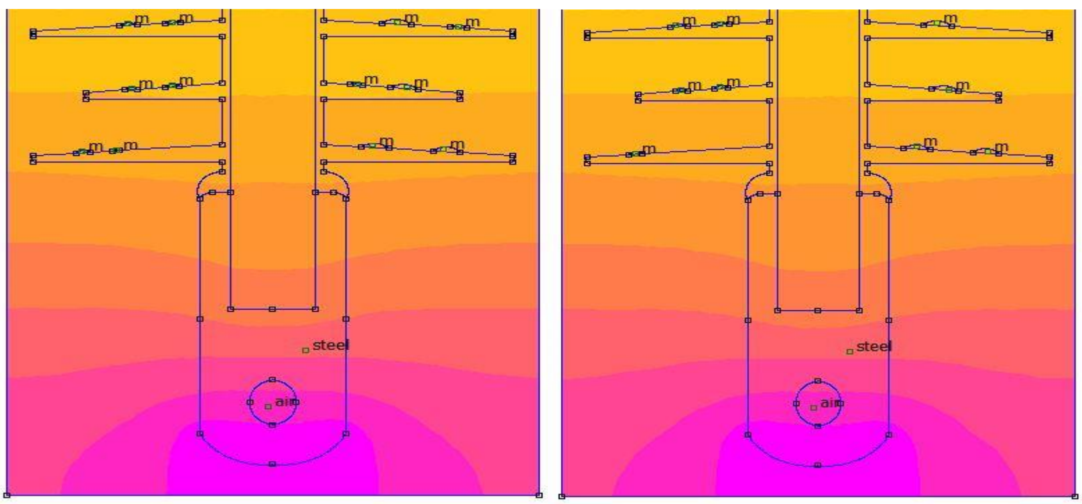
Table 5.1. Pollutant permittivity value

S .No	Materials	Relative Permittivity
1	water	81

As can be clearly observed, field distributions on insulator string become deteriorate when compared to the clean insulator. Here the main considerations are CD and at HV end because the water molecules are applied on the weather sheds along the insulator string. Electrical performance of the insulator string with water molecules are summarized in table 5.2 and 5.3.

5.2 POLLUTED ZONE

The electric field stress at various parts of insulator string under wet condition is investigated by simulation, considering equal and unequal water molecules for better understand.



b) Equal water molecules a) Unequal water molecules

Fig 5.2. FEM analysis results under wet condition

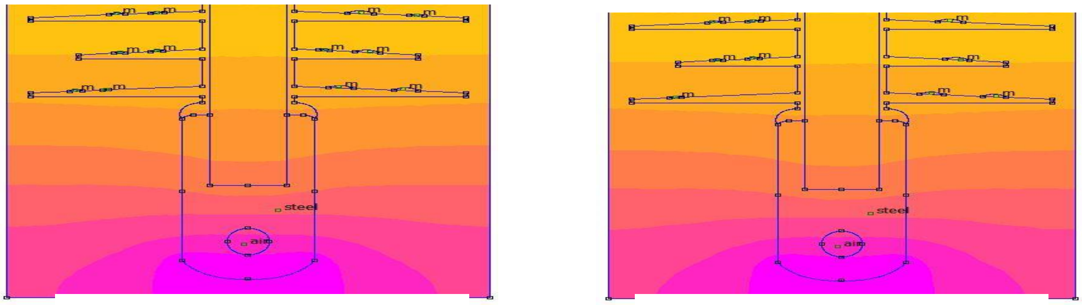
Table 5.2.EFA results under wet condition.

S. No	Particulars	Electric Field (KV/mm)		Reference Values (KV/mm)
		Equal Water Molecules	Unequal Water Molecules	
1	CD	0.225	0.232	0.217
2	Triple Point	0.268	0.270	0.284
3	First Shed	0.144	0.146	0.116
4	Inside Si	0.154	0.152	0.144
5	Inside FRP	0.344	0.344	0.311

As can be clearly observed, when compared to without water molecules, Peak magnitudes in high field regions particularly at first shed is increased by 7% and along the leakage distance is increased by % under unequal water molecules shown in table 5.2.

5.3 VERY HEAVY POLLUTED ZONE

The electric field stress at various parts of insulator string under wet condition is investigated by simulation, considering equal and unequal water molecules for better understand as shown in fig 5.3(a) and fig5.3 (b) respectively.



a) equal water molecules　　b) Unequal water molecules

Fig 5.3. FEM analysis results under wet condition

Table 5.3. EFA results under wet condition.

S. No	Particulars	Electric Field (KV/mm)		Reference Values (KV/mm)
		Equal Water Molecules	Unequal Water Molecules	
1	CD	0.223	0.228	0.207
2	Triple Point	0.248	0.236	0.231
3	First Shed	0.144	0.146	0.130
4	Inside Si	0.155	0.152	0.145

5	Inside FRP	0.348	0.352	0.348

As can be clearly observed, when compared to without pollution, Peak magnitudes in high field regions particularly at first shed is increased by 12% and along the leakage distance is increased by 10% under unequal water molecules shown in table 5.3.

5.4 EFA RESULTS COMPARISON

The comparison of EFA result for 25kV 9-tonne polymeric insulator with and without water molecules on insulator is shown in fig5.5 (a & b). At Polluted zone compared to without water, the field is increased by 4% ,7% due to equal and unequal water molecules along leakage distance and 24%,26% at first shed. At Very Heavy Polluted zone compared to without water, the field is increased by 8% , 10% due to equal and unequal water molecules along leakage distance and 11%, 13% at first shed.

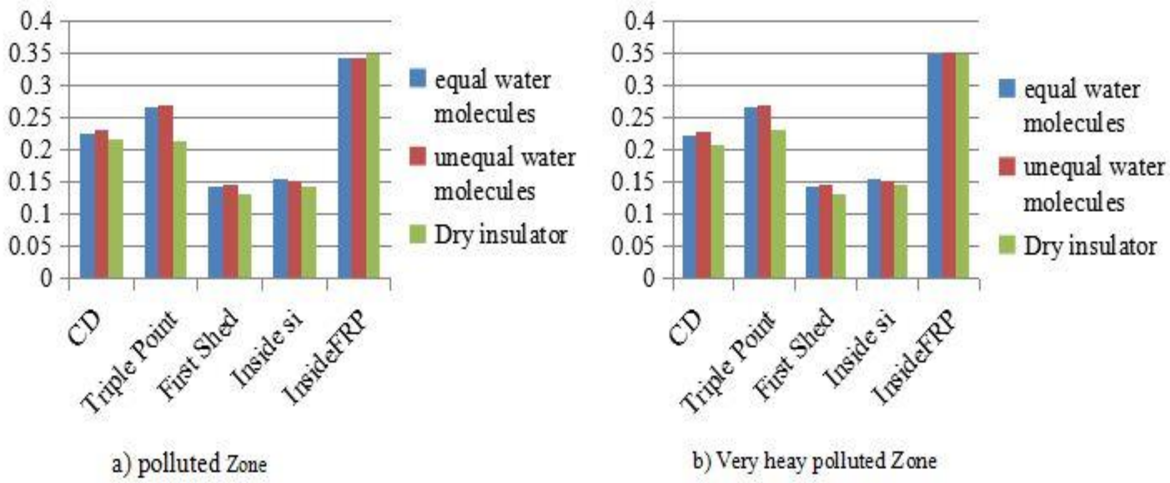


Fig 5.4. comparison of EFA result of 25kV 9-tonne insulator with and without water on insulator

CHAPTER 6

EFA OF POLLUTED ZONE 25KV INSULATOR WITH WATER MOLECULES AND UNDER VARIOUS CONTAMINATIONS

6.1 INTRODUCTION

Pollution layers, as they deposit on the surfaces of insulators reduce hydrophobicity to extent depending on the chemical structure of the pollution. This fact is even used for pollution tests of composite insulators. It has also been observed that growth of mold under humid conditions can reduce the hydrophobic behavior. LMW in the bulk of silicone rubber tends to adsorb on much higher surface energy. The adsorption process of LMW is therefore the essence of the hydrophilic to hydrophobic change of deposited pollutants on the surface. Adsorption of materials with some surface energy is the inherent necessity of the energy minimization in system.

Fig 6.1: Insulator with both contamination and water droplets

The larger difference of surface energy exists, the more prominent adsorption process occurs. Actually, in wetting condition, adsorption layer of LMW always cannot completely bypass the influence of pollutants. In addition, before the pollutants deposits on the surface of si rubber it has already reached an energy balance status by adsorbing water molecules in the environment, which will necessarily lessen or delay adsorption of LMW to pollution layer. For inorganic salts deposited on surface, LMW adsorption is nearly stopped because of the strong affinity of these salts with water, which completely obviates possibility of hydrophobic recovery. This statement and the results reported in support the fact that the hydrophobicity transfer process is mostly dependent on the chemical properties of pollutants and, more specifically and their affinity with the water. However, inorganic pollutants cannot gain hydrophobicity even after a long rest time if they don't have any dynamic LMW chains.

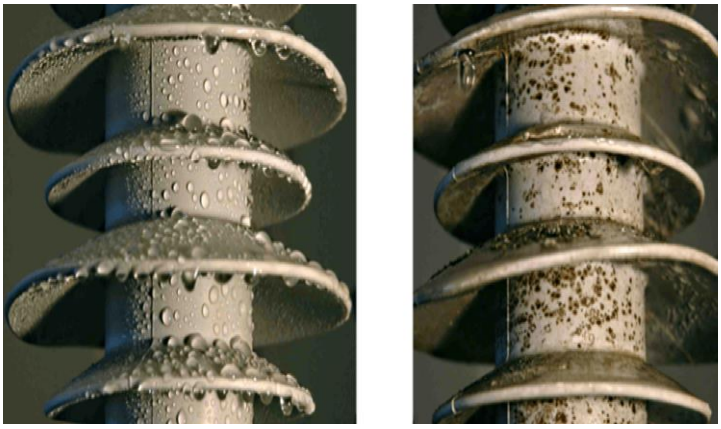


Fig 6.2: Water molecules and their effect on polymer insulator

6.2 SALT CONTAMINATION

6.2.1 Equal Water Molecules

The electric field stress at various parts of insulator string under wet condition with salt pollution contamination is investigated by simulation, considering even and uneven salt contamination of thickness 0.5mm and 1mm for better understand.

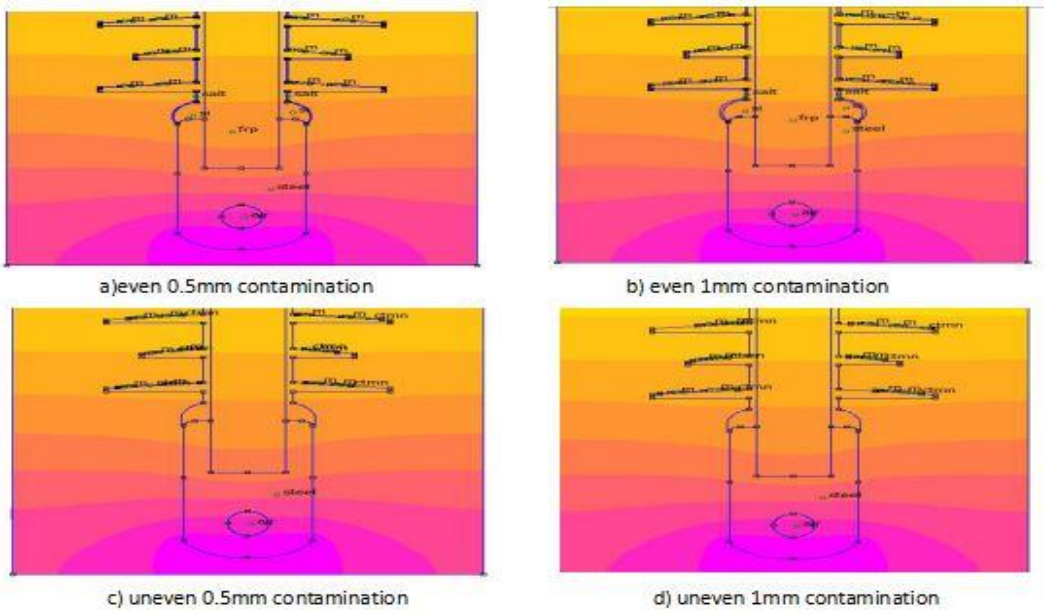


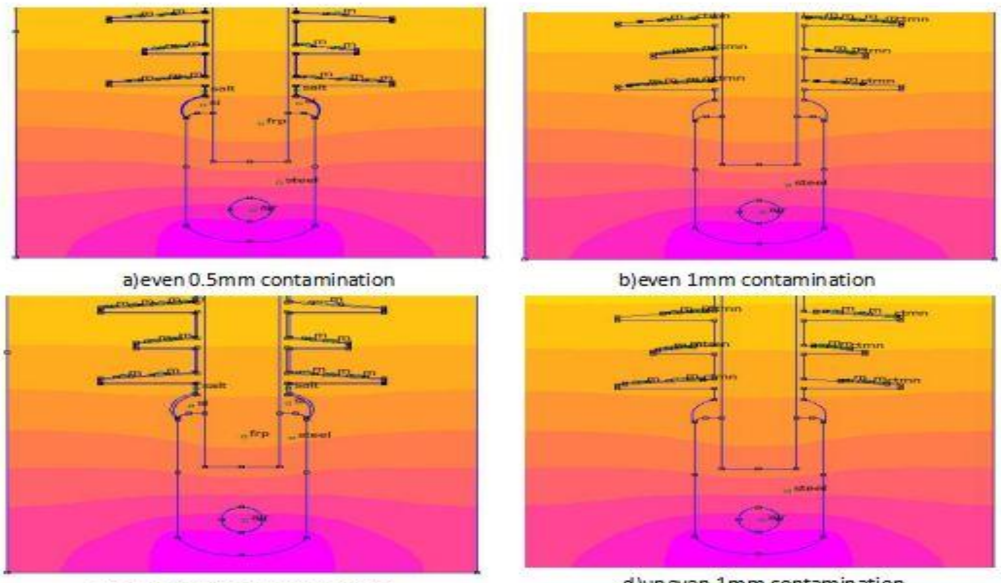
fig 6.3: EFI contours of wet polymeric insulator with salt contamination

Table 6.1. EFA results of wet condition with salt contamination.

S. No	Particulars	Electric Field (KV/mm)				Reference Values (kV/mm)
		0.5mm Even ctmn	1mm Even ctmn	0.5mm Uneven ctmn	1mm Uneven ctmn	
1	CD	0.334	0.363	0.308	0.314	0.225
2	Triple Point	0.129	0.115	0.273	0.273	0.268
3	First Shed	0.166	0.175	0.168	0.167	0.144

6.2.2 Unequal water molecules

The electric field stress at various parts of insulator string under unequal wet condition with salt pollution contamination is investigated by simulation, considering even and uneven salt contamination of thickness 0.5mm and 1mm for better understand.



a)even 0.5mm contamination

b)even 1mm contamination

c)uneven 0.5mm contamination

d)uneven 1mm contamination

fig 6.4: EFI contours of unequal wet polymeric insulator with salt contamination

Table 6.2. EFA results of unequal wet condition with salt contamination.

S. No	Particulars	Electric Field (KV/mm)				Reference Values (kV/mm)
		0.5mm Even ctmn	1mm Even ctmn	0.5mm Uneven ctmn	1mm Uneven ctmn	

1	CD	0.312	0.336	0.302	0.312	0.232
2	Triple Point	0.127	0.116	0.260	0.274	0.270
3	First Shed	0.166	0.174	0.166	0.167	0.146

6.3 UREA CONTAMINATION

6.3.1 Equal Water Molecules

The electric field stress at various parts of insulator string under wet condition with urea pollution contamination is investigated by simulation, considering even and uneven urea contamination of thickness 0.5mm and 1mm for better understand.

Table 6.3. EFA results of wet condition with urea contamination.

S. No	**Particulars**	**Electric Field (KV/mm)**				**Reference Values (kV/mm)**
		0.5mm Even ctmn	1mm Even ctmn	0.5mm Uneven ctmn	1mm Uneven ctmn	
1	CD	0.268	0.278	0.260	0.264	0.225
2	Triple Point	0.165	0.150	0.269	0.268	0.268
3	First Shed	0.157	0.180	0.160	0.159	0.144

6.3.2 Unequal Water Molecules

The electric field stress at various parts of insulator string under unequal wet condition with urea pollution contamination is investigated by simulation, considering even and uneven urea contamination of thickness 0.5mm and 1mm for better understand.

Table 6.4. EFA results of unequal wet condition with urea contamination.

S. No	**Particulars**	**Electric Field (KV/mm)**				**Reference Values (kV/mm)**
		0.5mm Even ctmn	1mm Even ctmn	0.5mm Uneven ctmn	1mm Uneven ctmn	
1	CD	0.256	0.262	0.254	0.259	0.232
2	Triple Point	0.164	0.150	0.258	0.270	0.270
3	First Shed	0.156	0.160	0.160	0.159	0.146

6.4 CEMENT CONTAMINATION

6.4.1 Equal Water Molecules

The electric field stress at various parts of insulator string under wet condition with cement pollution contamination is investigated by simulation, considering even and uneven cement contamination of thickness 0.5mm and 1mm for better understand.

Table 6.5. EFA results of wet condition with cement contamination.

S. No	Particulars	Electric Field (KV/mm)				Reference Values (kV/mm)
		0.5mm Even ctmn	1mm Even ctmn	0.5mm Uneven ctmn	1mm Uneven ctmn	
1	CD	0.245	0.245	0.253	0.259	0.225
2	Triple Point	0.185	0.171	0.268	0.270	0.268
3	First Shed	0.158	0.159	0.160	0.159	0.144

6.4.2 Unequal Water Molecules

The electric field stress at various parts of insulator string under unequal wet condition with cement pollution contamination is investigated by simulation, considering even and uneven cement contamination of thickness 0.5mm and 1mm for better understand.

Table 6.6. EFA results of unequal wet condition with cement contamination.

S. No	Particulars	Electric Field (KV/mm)				Reference Values (kV/mm)
		0.5mm Even ctmn	1mm Even ctmn	0.5mm Uneven ctmn	1mm Uneven ctmn	
1	CD	0.235	0.240	0.252	0.261	0.232
2	Triple Point	0.180	0.171	0.258	0.270	0.270
3	First Shed	0.156	0.156	0.154	0.159	0.146

6.5 EFA RESULTS COMPARISON

The comparison of EFA result for 25kV polluted zone polymeric insulator with and without contamination with water molecules for equal and unequal are shown in from fig.6.17 a & b.

Compared to without contamination, the field is increased by 61%, 24%,15% and 45%, 13%, 11% due to salt, urea, cement for equal and unequal water molecules along leakage distance respectively.

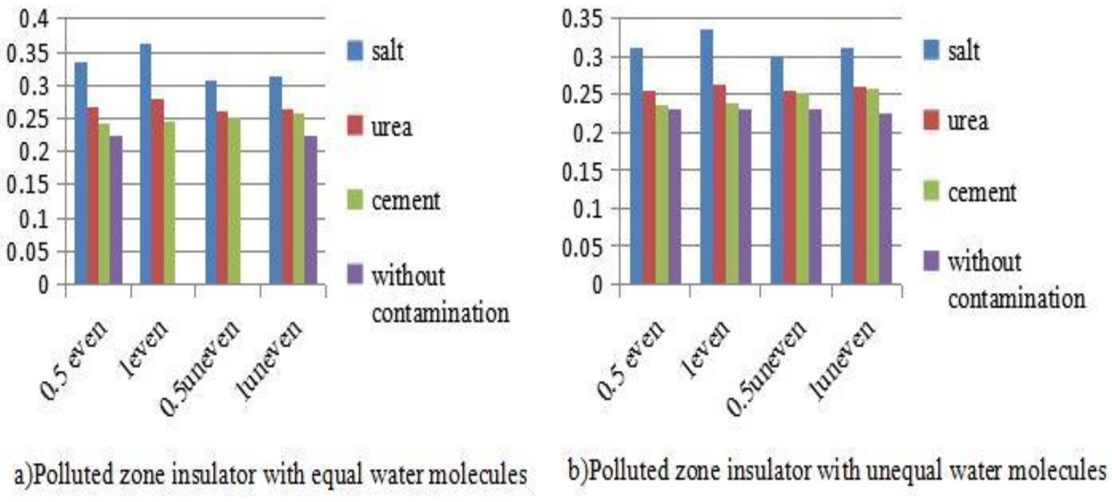


Fig 6.5: comparison of EFI result of 25kV insulator

CHAPTER 7

EFA OF VERY HEAVY POLLUTED ZONE 25KV POLYMERIC INSULATOR WITH WATER MOLECULES AND UNDER VARIOUS CONTAMINATIONS

7.1 INTRODUCTION

The discharges over the surface in wet conditions cause the major loss of hydrophobicity of silicon insulators. In case of silicon rubber insulators, the water induced discharges occur more frequently than corona discharge under normal humidity and thus become an important long term aging factor. So more attention should be given to study water induced discharges and their effect.

7.2 SALT CONTAMINATION

7.2.1 Equal Water Molecules

The electric field stress at various parts of insulator string under wet condition with salt pollution contamination is investigated by simulation, considering even and uneven salt contamination of thickness 0.5mm and 1mm for better understand.

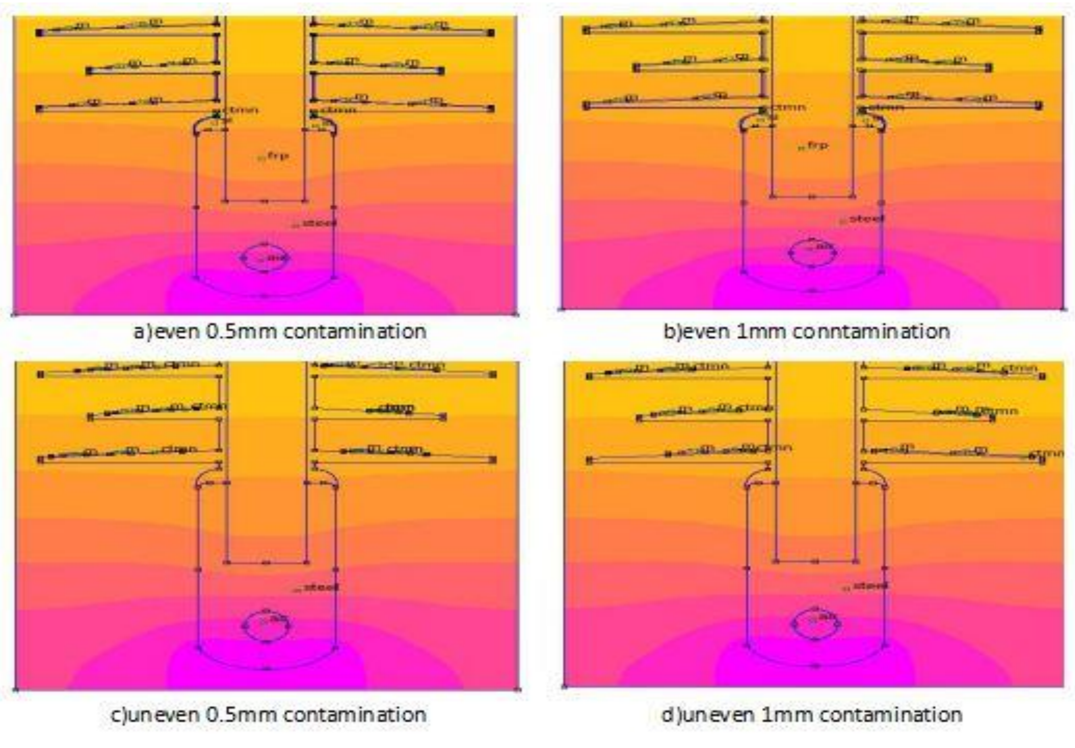


fig 7.1: EFI contours of equal wet polymeric insulator with salt contamination

Table 7.1. EFI results of equal wet condition with salt contamination.

S. No	Particulars	Electric Field (KV/mm)				Reference Values (kV/mm)
		0.5mm Even ctmn	1mm Even ctmn	0.5mm Uneven ctmn	1mm Uneven ctmn	
1	CD	0.300	0.339	0.296	0.307	0.223
2	Triple Point	0.149	0.133	0.246	0.243	0.249
3	First Shed	0.140	0.142	0.154	0.156	0.144

7.2.2 Unequal Water Molecules

The electric field stress at various parts of insulator string under wet condition with salt pollution contamination is investigated by simulation, considering even and uneven salt contamination of thickness 0.5mm and 1mm for better understand.

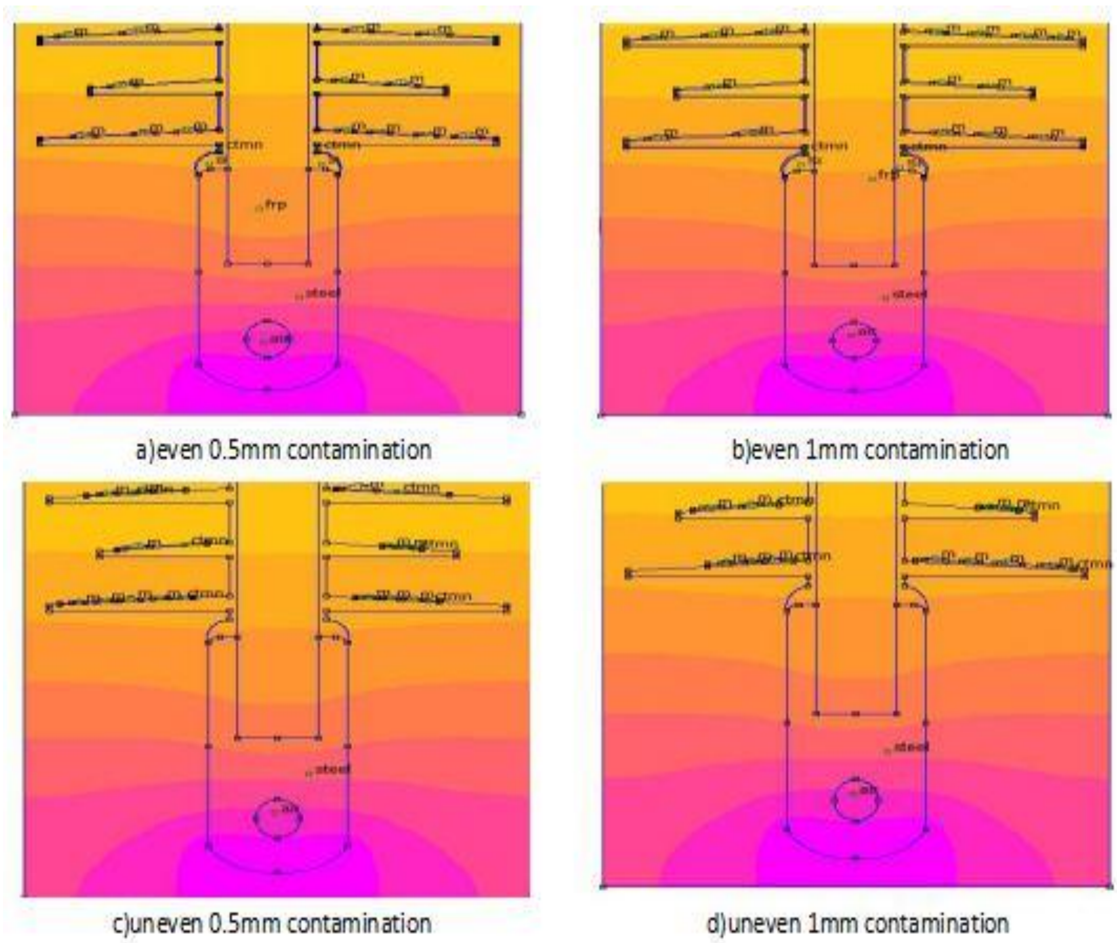


fig 7.2: EFI contours of unequal wet polymeric insulator with salt contamination

Table 7.2. EFI results of unequal wet condition with salt contamination.

S. No	Particulars	Electric Field (KV/mm)				Reference Values (kV/mm)
		0.5mm Even ctmn	1mm Even ctmn	0.5mm Uneven ctmn	1mm Uneven ctmn	
1	CD	0.292	0.334	0.283	0.298	0.232
2	Triple Point	0.149	0.132	0.250	0.244	0.270
3	First Shed	0.145	0.142	0.154	0.155	0.146

7.3 UREA CONTAMINATION

7.3.1 Equal water molecules

The electric field stress at various parts of insulator string under wet condition with salt pollution contamination is investigated by simulation, considering even and uneven salt contamination of thickness 0.5mm and 1mm for better understand.

Table 7.3. EFA results of equal wet condition with urea contamination.

S. No	Particulars	Electric Field (KV/mm)				Reference Values (kV/mm)
		0.5mm Even ctmn	1mm Even ctmn	0.5mm Uneven ctmn	1mm Uneven ctmn	
1	CD	0.246	0.256	0.246	0.232	0.223
2	Triple Point	0.174	0.161	0.244	0.241	0.249
3	First Shed	0.136	0.140	0.142	0.148	0.144

7.3.2 Unequal Water Molecules

The electric field stress at various parts of insulator string under wet condition with salt pollution contamination is investigated by simulation, considering even and uneven salt contamination of thickness 0.5mm and 1mm for better understand.

Table 7.4. EFA results of unequal wet condition with urea contamination.

S. No	Particulars	Electric Field (KV/mm)				Reference Values (kV/mm)
		0.5mm Even ctmn	1mm Even ctmn	0.5mm Uneven ctmn	1mm Uneven ctmn	
1	CD	0.248	0.258	0.247	0.253	0.232
2	Triple Point	0.173	0.162	0.243	0.243	0.270
3	First Shed	0.142	0.138	0.168	0.148	0.146

7.4 CEMENT CONTAMINATION

7.4.1 Equal water molecules

The electric field stress at various parts of insulator string under wet condition with cement pollution contamination is investigated by simulation, considering even and uneven cement contamination of thickness 0.5mm and 1mm for better understand.

Table 7.5. EFA results of unequal wet condition with cement contamination.

S. No	Particulars	Electric Field (KV/mm)				Reference Values (kV/mm)
		0.5mm Even ctmn	1mm Even ctmn	0.5mm Uneven ctmn	1mm Uneven ctmn	
1	CD	0.226	0.231	0.229	0.232	0.223
2	Triple Point	0.186	0.177	0.224	0.241	0.249
3	First Shed	0.140	0.141	0.147	0.148	0.144

7.4.2 Unequal Water Molecules

The electric field stress at various parts of insulator string under wet condition with cement pollution contamination is investigated by simulation, considering even and uneven cement contamination of thickness 0.5mm and 1mm for better understand.

Table 7.6. EFA results of unequal wet condition with cement contamination.

S. No	Particulars	Electric Field (KV/mm)				Reference Values (kV/mm)
		0.5mm Even ctmn	1mm Even ctmn	0.5mm Uneven ctmn	1mm Uneven ctmn	
1	CD	0.225	0.228	0.231	0.234	0.232
2	Triple Point	0.186	0.179	0.253	0.243	0.270
3	First Shed	0.145	0.140	0.155	0.150	0.146

7.5 EFA Result Comparison

The comparison of EFA result for 25kV polluted zone polymeric insulator with and without contamination with water molecules for equal and unequal are shown in from fig.6.17 a & b. Compared to without contamination, the field is increased by 52%, 15%,4% and 42%, 13%, 3% due to salt, urea, cement for equal and unequal water molecules along leakage distance respectively.

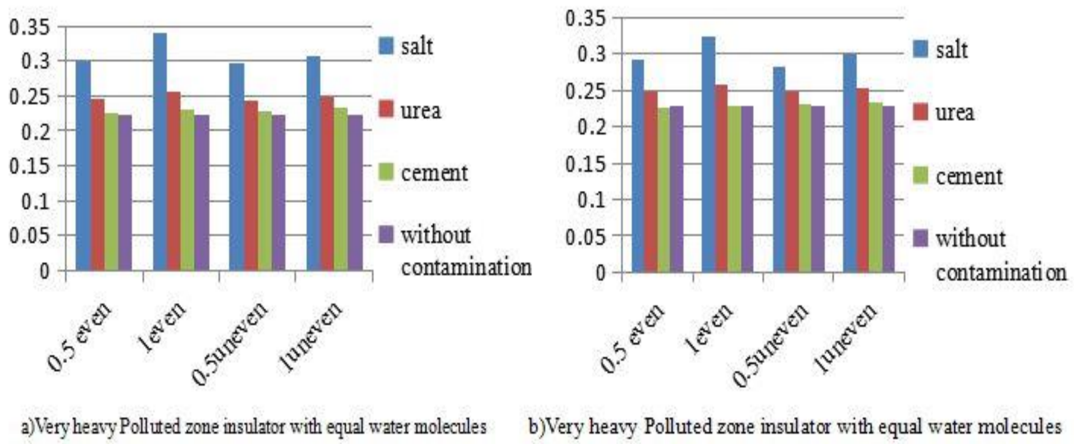


Fig 7.3. comparison of EFI result

CHAPTER 8

CONCLUSION

An approach is proposed to find the most severe pollution contaminant in the environment for 25kV 9-Tonne polymer insulator. This method consists of various pollution which is mostly observing on the railway insulators and water molecules.

A number of simulations were carried out to know the electrical performance of railway insulators. Based on the simulation results it was concluded that electric field is greatly influenced by the pollution layer conductivity and thickness of the contamination. Models of clean and three mostly observing contaminations are considered in this study. In these contaminations, salt has the highest electrical stress and which are observed along leakage distance of the polymer insulator. Salt is the most severe pollution contamination on polymer insulator. The highest EFI observed in this study at salt 1mm thickness layer between 0.5mm and 1mm. As the pollution layer conductivity and thickness increases, EFI increases and the obtained results prove that the stress increases with increase in pollution severity. When comes to water molecules on polymer insulator i.e. wet insulator, the stress level on the polymer insulator greatly depend on the parameters such as droplets location on the insulating surface, distance between droplets, droplets volume and the number of droplets. The severity of electric field stresses greatly increase, if the pollution contamination on insulator is combined with water molecules. Hence the salt pollution contaminant on the wet insulator is the most severe contaminant compared to salt contaminant without water molecules.

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