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Simulation Studies of Composite Insulators used in High Voltage Transmission

[1] Rohit P R, [2] Rahul P R, [3] Keka Mukhopadhyaya
[1][2][3] Department of Electrical & Electronics Engineering, CMR Institute of Technology, Bengaluru

Abstract: **The aim of the paper is to accurately study the electric field and potential distribution across the silicone composite insulator used in high voltage transmission systems. For simulation study, finite element method based SOLIDWORKS along with EMS software is used. Silicone composite insulators are being increasingly used for outdoor applications as they have better characteristics than porcelain and glass types. They have better contamination performance due to their hydrophobic surface. They are lighter and possess higher impact strength. Several methods have been developed for the computation of electric fields and potential along an insulator. The electric field and potential distribution around and inside the insulator when it is stressed by power frequency is examined using SOLIDWORKS along with EMS, which is a suite of programs for 2D and 3D electrostatic field analysis. The software package uses the finite element method to solve the partial differential equations that describe the behaviour of the fields. In this paper, the electric field analysis and potential field analysis is carried out for 66kV, 132kV, 220kV and 400kV composite long rod insulators and using corona ring can decrease the electric field stress. The electric field distribution within and around the high voltage insulator is a very important aspect of the design of insulators. The knowledge of the electric field distribution and other electrostatic parameters are useful for detection of defects in the insulators.**

Keywords: Composite Insulators, SOLIDWORKS, EMS, Finite element analysis, Electrostatic simulation.

1. INTRODUCTION

The generation and consumption of electric power are seldom in close vicinity. The bulk of electric power is transmitted through overhead lines from the generating sites to the distribution level. Most of these lines span over several thousands of kilometers. In order to minimize losses, power is transmitted at higher voltages in the order of several hundred kilovolts. The high voltage line conductor has to be physically attached to the tower support structure which is at ground potential. For the purpose of electrically isolating these line conductors from the support structure as well as providing mechanical support to them, insulators are used.

Higher voltage rating puts the insulators under a huge amount of electrical stress. In addition to that, the high voltage insulators used in outdoor applications are degraded by various environmental factors including precipitation, winds, temperature variations and pollution. Under wet and polluted conditions, the electric field along their length gets intensified which might lead to flashover. Flashover of insulators in service could give way to interruptions in power supply which affects the reliability of these bulk systems. Also, interruptions could incur heavy monetary losses to many customers and industries. Therefore, insulation performance forms a small but extremely significant part of the whole picture. Research on its functionality and design is of utmost significance [1].

A composite insulator consists of a core material, end fitting, and a rubber insulating housing.

The core is of FRP (Fiber Reinforced Plastic) to distribute the tensile load. The reinforcing fibers used in FRP are glass (E or ECR – Epoxy corrosion resistant) and epoxy resin is used for the matrix. The portions of the end-fitting to transmit tension to the cable and towers are of forged steel, malleable cast iron, aluminium etc. The rubber housing provides electrical insulation. It covers the FRP Rod thereby protecting it from corrosion due to atmospheric exposure. Composite insulators are also known as polymeric or non-ceramic insulators.

Silicone rubber has superior electrical characteristics and weather resistance properties over a wide range of temperatures, for use in the housing. It is resistant to oxidation, has low surface energy, and resists degradation from ultraviolet radiation. These properties make silicone rubber a good choice for electrical insulators.

The advantages of Composite Insulators are:

- Superior Handling of Mechanical Shock Loads hence convenient to handle, transport and erect.
- Low weight (< 80 % of conventional porcelain) and easy handling.
- Resistance to vandal damage.
- Superior Dielectric Strength
- High Power arc resistance due to high thermal withstand ability.

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- Excellent Pollution Performance (Durable & Hydrophobicity).
- Flame resistant
- Shatter resistance
- Aerofoil design offering minimum wind resistance.
- Low Leakage current and Power loss due to its high surface resistivity.
- Wide range of service Temperatures (from –50 C to 100 C).
- Interchangeability – can easily replace existing Porcelain Insulators.
- Better aesthetics.
- Low maintenance.
- UV resistant [2].

There are several key benefits of using 3D CAD design and CAD 3D modeling in Civil, Electrical, Mechanical and Architectural industry. Key benefits include simplicity, automation and interactive analysis.

Using SOLIDWORKS along with EMS can greatly improve design quality because it is far more comprehensive process than 2D design. Hence, many human errors that can occur with conventional 2D design methods are avoided. The designer who uses 2D method has to hold much of the information mentally. With 3D environment he/she can visualize whole structure or product with real-life simulation and can avoid errors. Reducing human errors minimizes the need for re-work, improves overall design quality and saves costs [3].

With 2D views, projections might show a specific member in several different views while other members might be completely omitted to maintain drawing precision. This results in poor field distribution estimation. With 3D design simulation material estimation process becomes simple because items are represented as they occur in the design. As long as a CAD 3D design is created as a true to life model, designer gets quantities with exact accuracy.

EMS (Electro-Magnetic Simulation) is a 3D-field simulator for electromagnetic and electromechanical applications and an add-in to SOLIDWORKS and licensed by EMWorks.

These applications include: bushing, insulators, circuit breakers, power generators, transformers, electric motors, capacitors, magnetic levitation devices, synchronous machines, DC machines, permanent magnet motors, actuators, solenoids, etc.
EMS is based on the powerful finite element method (FEM), which solves the physical equations directly without any simplifications or assumptions.
It is designed to help us gain physical insight into the performance of our designs through the computation of important parameters such as: torques, forces, fields, currents, inductances, capacitances, flux linkages, current losses, electrical stresses, etc.
EMS shortens time to market by saving time and effort in searching for the optimum design.

ANALYSIS TECHNIQUES

Simulation is the cost-effective and less time consuming method to find the field distribution of insulators.

This paper presents the graphs and three-dimensional electrostatic simulation of composite insulators used in high voltage transmission systems.

Calculation of the electric field within and around the high voltage insulator under different conditions can be calculated or measured that will be helpful in improving the insulator design through proper electric field grading techniques as it is an indication for flashover propagation.
Several numerical methods such as finite difference (FD), finite element (FE), charge simulation method (CSM), finite integration technique (FIT) and boundary element method (BEM) can be used to study the electric field and voltage distributions along insulators Numerical methods are highly recommended for initial design stages of composite insulators used in high voltage systems in order to avoid the high cost of running laboratory tests.

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.

Here, we make use of numerical methods for solving the problems.

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The choice is narrowed down to Finite Element method for the following reasons:

- Finite Element Method (FEM) has the ability to handle complex geometry with relative ease.
- The material properties in adjacent elements do not have to be the same. This allows application to composite insulators.
- Irregularly shaped boundaries can be approximated using elements with straight sides or matched exactly using elements with curved boundaries. Hence, it can handle complex restraints.
- It can handle a wide variety of engineering problems.
- It can handle complex loading.
- FEA is a good choice for analyzing the problems over complicated domains when the domain changes, when the desired precision varies over the entire domain, or when the solution lacks smoothness [5].
- FEM is commercially available in packages like SOLIDWORKS, Ansys, Coulomb, Nastran etc.

The following steps describe the FEM:

1. Discretization of the solution domain into smaller regions or elements.
2. Deriving governing equations for a typical element.
3. Assembling all elements into the solution region.
4. Solving the system equations obtained.

FEM is very flexible and can be applied to the most complicated geometries. It is capable of giving highly accurate results and the accuracy of results depends on the number of elements considered in the geometry. 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. There could also be large localized errors with no means to check the accuracy of the results [4].

MODELLING OF ELECTRIC FIELD

Electrostatic analysis belongs to the low-frequency electromagnetic domain or regime. In this domain, displacement currents are neglected. In addition, the fields depend on position only. With these conditions, the first two of Maxwell's equations become:

$$V\ X\ E=0 \qquad (1)$$

Where E is the electric field where*V* is the divergence operator.

$$V.D=r \qquad (2)$$

Where D is the electric flux density and *r* is the volume charge density.
Along with the constitutive relation:

$$D=\varepsilon E \qquad (3)$$

By introducing an electric scalar potential, □, and expressing the electric field as:

$$E= -V\Phi \qquad (4)$$

Where ε and Φ are the permittivity and charge densities respectively.
The famous Poisson's equation

$$V.(\ \varepsilon V\Phi)=r \qquad (5)$$

is obtained. The electrostatic analysis solves the Poisson equation [7].

BOUNDARY CONDITIONS

The boundary conditions applied here are that electric field at the ground level is set as zero. In contrast, the boundary conditions at the conductor surfaces are practically different for different voltages. The electrostatic assumption that EMS Electrostatic analysis assumes is that no current flows in any material. Objects are either perfect conductors or perfect insulators. For conducting objects, the electric charges are condensed on their surfaces, which force the field inside the conductors to be zero. Insulators are considered as perfect insulators with no current flowing inside them.

It is important to bear in mind the above electrostatic assumptions. Therefore, thick conductors can either be left as mesh voids or fully meshed. In the case where a thick conductor is kept as a mesh void, the boundary conditions are applied on the surface of the conductor to simulate their presence. However, if the thick conductors are actually meshed, the boundary conditions are applied on the component itself.

Conductors can have a zero thickness. In such cases, conductors are specified by a perfect conducting surface. The only material property required is the permittivity of materials (see Table I).The electric conductivity is not required because it is considered either infinite in conducting objects or zero in insulators [6].

Table 1: Permittivity of materials

Material	Permittivity (F/m)
Fiber Reinforced Plastic	7
Silicone Rubber	4
Metal End Fitting	1000
Air	1

Table 2: Specifications of Insulators

Insulator Type	No. of sheds	Applied Voltage in kV	Voltage per phase in kV
66kV	18	66	38.105
132kV	30	132	76.210
220kV	36	220	127.017
400kV	44	400	230.940

SIMULATION STUDIES

Figures 1 to 4 show the 3D electric field plots for 66, 132, 220 and 400kV Composite Long Rod Insulators respectively.

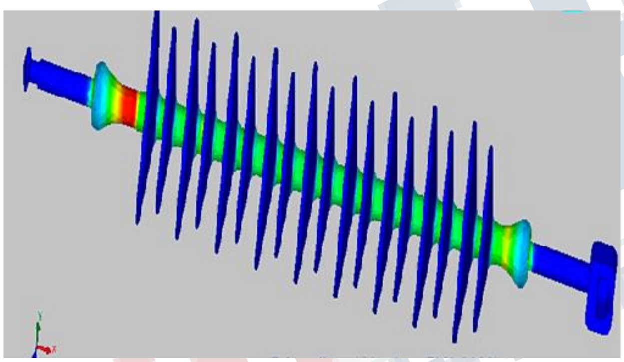

Fig 1: 3D Electric Field Plot for 66kV Composite Long Rod Insulator

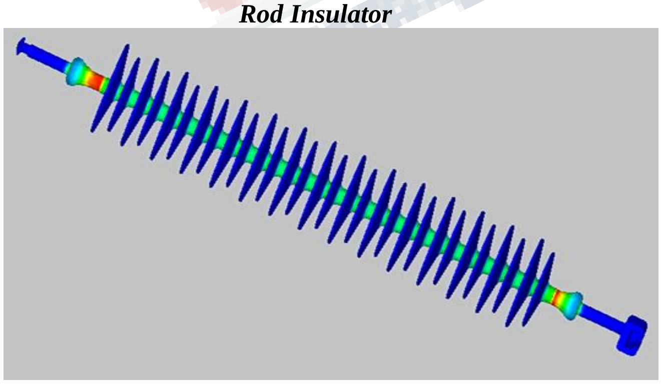

Fig 2: 3D Electric field plot for 132kV Composite Long Rod Insulator

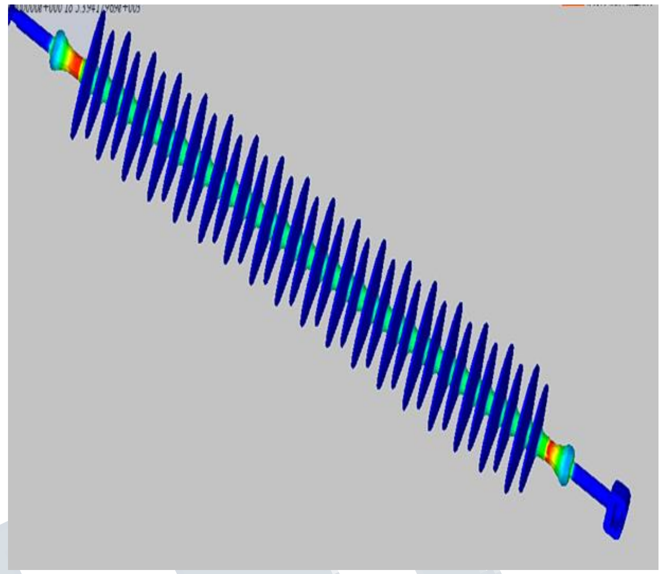

Fig 3: 3D Electric field plot for 220kV Composite Long Rod Insulator

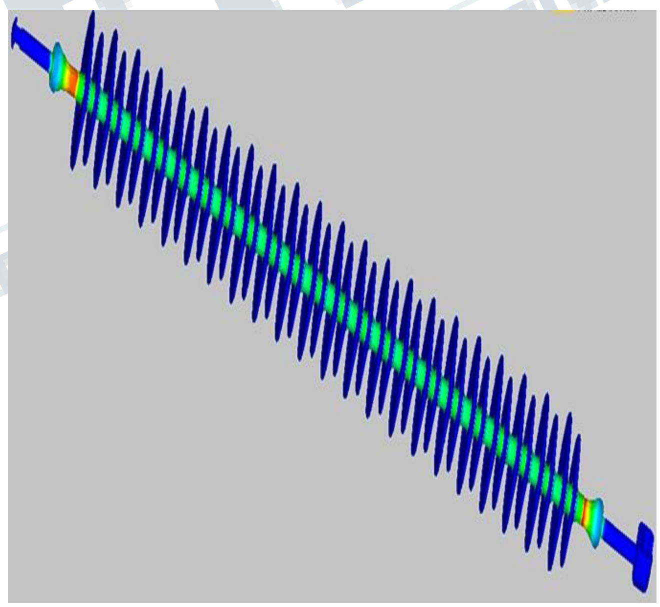

Fig 4: 3D Electric field plot for 400kV Composite Long Rod Insulator

Figures 5 to 8 graphically represent the electric field distribution along the insulators.

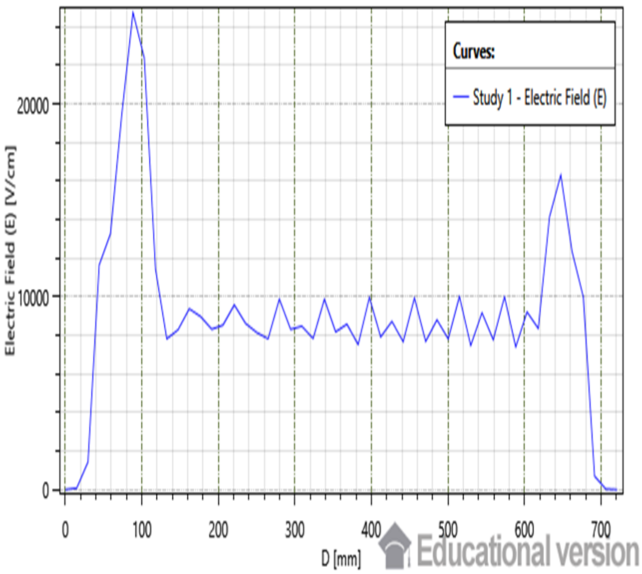

Fig 5: Electric Field distribution for 66kV Composite Long Rod Insulator

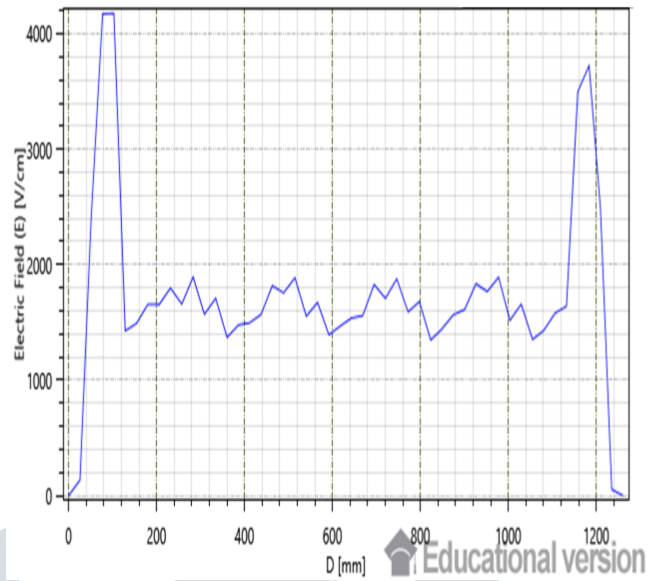

Fig 7: Electric Field distribution for 220kV Composite Long Rod Insulator

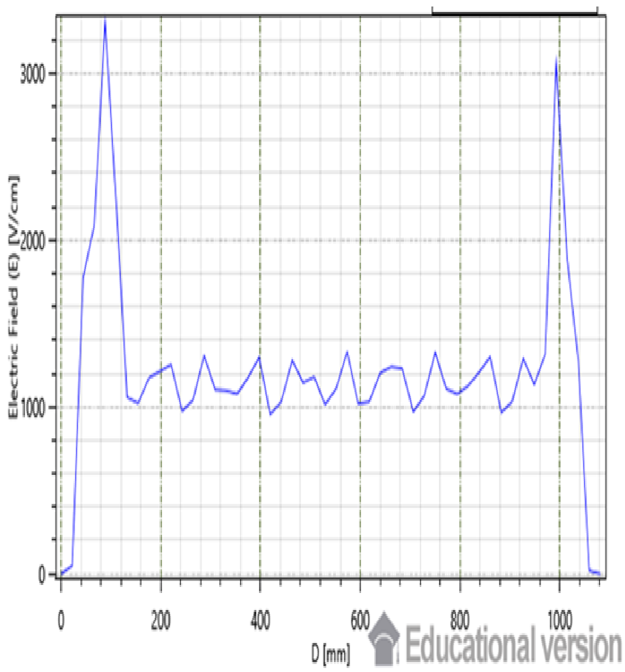

Fig 6: Electric Field distribution for 132kV Composite Long Rod Insulator

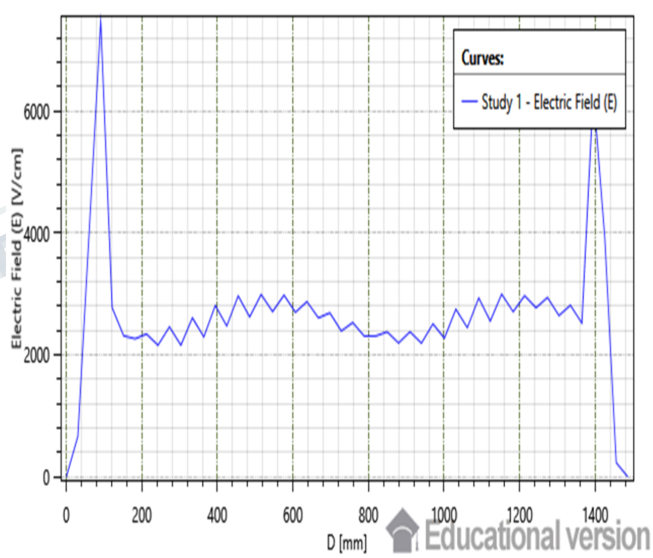

Fig 8: Electric Field distribution for 400kV Composite Long Rod Insulator

The maximum electric field stress of silicone rubber composite insulators must be in the range of 26 to 36kV/mm as per IEC standards [7].

The observations from the above plots are represented in Table 3 as shown.

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Table 3: Observations from plots

Insulator Type	Applied Voltage (kV)	Accepted Maximum voltage before breakdown (kV)	Maximum electric field stress at triple point junction (kV/cm)
66kV	66	72.5	2.7348
132kV	132	147	3.7964
220kV	220	245	5.3941
400kV	400	425	8.8192

Figures 9 to 12 show the 3D potential plots for 66, 132, 220 and 400kV Composite Long Rod Insulators respectively.

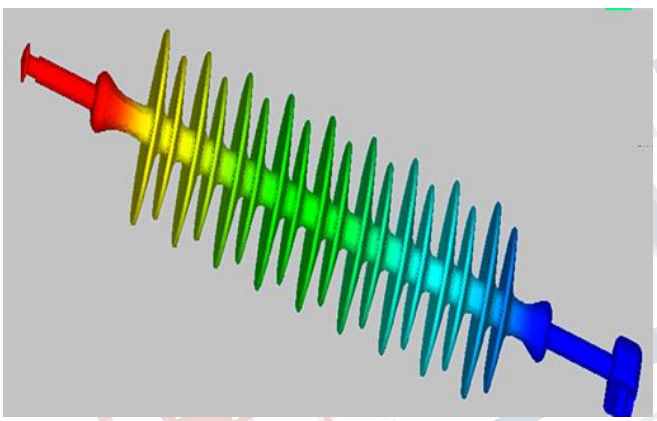

Fig 9: 3D Potential plot for 66kV Composite Long Rod Insulator

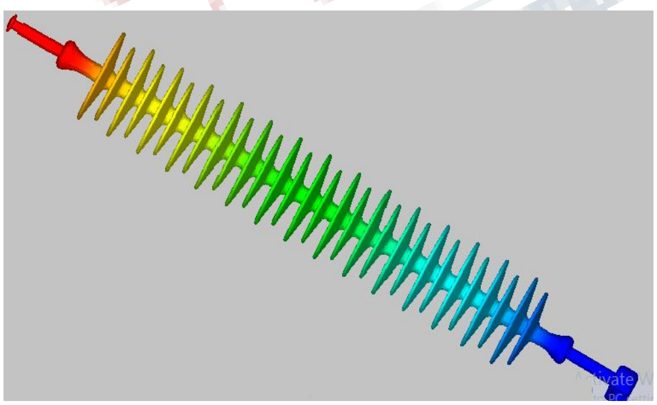

Fig 10: 3D Potential plot for 132kV Composite Long Rod Insulator

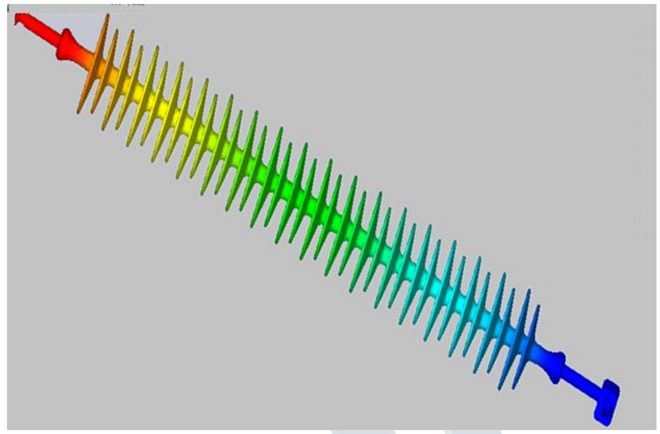

Fig 11: 3D Potential plot for 220kV Composite Long Rod Insulator

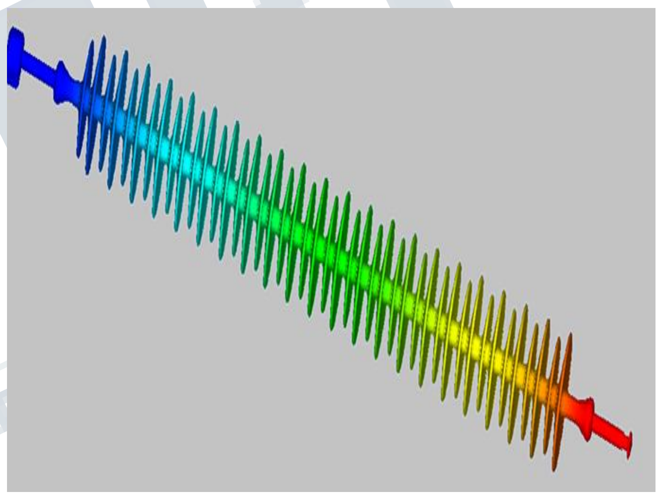

Fig 12: 3D Potential plot for 400kV Composite Long Rod Insulator

RESULTS & DISCUSSION

- From the above table we can observe that the values of maximum electric field stress obtained are within permissible limits.
- Maximum stress is observed at the triple point junction. The maximum electric field value occurs at the triple point. Triple point is a point where, insulating housing material, energized end fitting and air are located. When we apply more voltage, stresses will be higher at that point.

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- Comparing the values obtained we can say that by adding a Corona Ring (usually for 220kV and 400kV and above), the potential distribution along the insulator can be improved and the field stress can be reduced. This protects the insulator and extends its lifespan.
- The Corona Ring reduces the stress at the sheds and the triple junction.
- It can be observed that the electric field stress distribution is non-linear when rating is lower. With the addition of corona ring the potential and electric stress can be reduced considerably.
- The reduction of voltage from metal end to ground end can be observed.
-

CONCLUSION

This paper was aimed at analysis of composite insulators used in transmission systems with the aid of numerical analysis techniques. This technique can be used to investigate the various factors that affect the electric field and voltage distribution along composite insulators without the need of performing physical laboratory experiments which could prove to be very expensive and exhaustive.

The electric field calculations along composite insulators showed that the maximum electric field value depends on the system voltage. The field magnitude is greater for systems at higher voltages. The maximum field value was found to occur at the junction of the metallic energized end fitting-rubber housing-air.

Field mitigating techniques like corona rings installed on composite insulators at different voltage ratings help in mitigating the electric field to appreciable levels. Corona rings are highly recommended even for system voltages (220 kV and 400 kV and above). For composite insulators used in UHV systems, an additional field mitigating device might be necessary.

Some of the future works that can be carried out based on this paper are:

- Electric field mitigation techniques used in wet conditions may be developed using 3D simulation.
- The effect of water droplets on shed and sheath region of composite insulators may be investigated and the electric field value for corona inception may be established. The effects of their volume, and angle of contact and water conductivity might be varied to study their effect on electric field magnitudes. These could help in performance analysis of composite insulators under wet conditions.

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