Risk assessment of pollution on a 66kV composite insulator using ANSYS

Ms. N H M Netravati[1], Mrs. Sunitha N.S[2], Dr.Shivakumara Aradhya R.S.[3], Dr. K.N Ravi[4]

M.Tech. student[1], Assistant Professor[2], Professor[3]
[1,2,3]Department of Electrical & Electronics Engineering, Acharya Institute of Technology, VTU, Belgaum
Professor & HOD[4]
[4]Dept of Electrical & Electronics Engineering, Saptagiri Institute of Technology, VTU, Belgaum

Abstract: In practice, insulators are subjected to various atmospheric conditions and they affect surface characteristics of the composite insulators. One of the major causes of insulation failure in high voltage power lines is leakage current on polluted insulator's surface. In order to study the impact of contamination level on electric field distribution of composite insulator, simulations had been implemented using ANSYS. The project uses a 66kV composite insulator manufactured by BHEL-EPD Bangalore. The insulator is simulated using the finite element technique. The electric field and potential distribution along the insulator surface for different pollution severities like light, medium, heavy and very heavy pollution are investigated. These different pollution severities are achieved by varying the layer conductivity uniformly on the insulator surface. From the simulation results, it can be seen that electric field strength is excessive at the junction of metal end fittings and insulator housing and minimal along the sheds of the insulator. Also the electric field stress increases as the pollution severity increases. Also the simulation is carried out to study the effect of dry band formation at different height along the insulator surface. Results exhibit that the electric field stress reduces as the position of dry band is varied from high voltage (HV) end to ground end indicating that for dry band close to the HV end will have higher probability of flashover. The results obtained may help designers in industry and researchers for assessing outdoor polymeric insulators and thereby selection of insulators for various contaminated environments.

Keywords: leakage current, pollution layer, electric field stress, electric potential, dry band, pollution severity.

1. Introduction

There has constantly been a necessity for electrical insulation since the period electric power was discovered. Requirement for electric power is rising with the increase in its consumption in private and industrial sectors. Finding the suitable insulation becomes more difficult as the voltage level gets higher. The insulation level of the system is determined by factors like insulators withstand ability and switching and lightening impulse voltage in contaminated environments. The system's reliability considerably depends upon the weather and environmental conditions that cause flashover of the contaminated surface of insulators resulting in transmission line tripping at operating voltage, possibly leading to blackouts. Flashovers are mainly caused by adverse environmental conditions. Fog, drizzle and pre-monsoon showers on the surface of insulator form a wet conducting layer for the conducting current to flow. Pollution severity and the contamination salinity determine the magnitude of leakage current that affects the conductivity of the contamination layers. Increased heat on the surface leads to increased conductivity and leakage current. The heating dries up the surface conducting path and thus "dry bands" are formed. These in turn bridges partial arcs. Glows of highest potential gradient occur across these dry bands when the potential discharges increase with streamer discharges. These discharges produce audible noise. Finally, the partial flashover which occurs in series leads to complete flashover of the insulator. In this regard, it is to be understood that the importance of pollution performance for the right choice of insulators design for various polluted conditions. This can be used as a remedial measure to reduce flashovers.

There are numerous investigations available in literatures on the examination of the influence of pollution severities on the porcelain and glass insulators. But very few studies are available on the polymeric insulator performance under polluted conditions. As flashover of the polluted insulator occurs even at the operating voltage of the system thus necessitates the investigation. At high voltages, the electric field stress can be sufficiently high to harm the insulator, hence by conducting the simulation studies for the insulators, the stress for which the insulator operates safely can be known well in advance. This helps to decide the need for a grading device to reduce the electric stress to acceptable levels. Research also shows that due to dry band formation, dry band arcing takes place at 30kV/cm. Finally, the partial flashover which occurs in series leads to complete flashover of the insulator.

There are two kinds of discharges on the surface of polymer insulators during use. They are arc discharge and corona (partial) discharge. When the insulator surface gets wet due to rain, dry bands are formed which leads to arc discharge. Corona discharge happens at the intersection of air, polymeric material and water droplet due to the difference in permittivity. Moreover, after the hydrophobic loss, the leakage current flows through the contaminated layer. Measured conductive current can give details of the condition of the whole surface of the insulator. The state of the insulator surface and its electrical performances are specific in exclusive areas due to varied environmental stresses and irregular profiles.

The electric potential and electric field distribution is disturbed because of the discharge of leakage current, Dry bands may form which can initiate flashover. In order to assess electric field distribution on the contaminated insulator surface, different numerical techniques can be utilized. To avoid dry corona release, it is recommended that the most extreme electric field stress at any point on the surface should not go beyond 2.28kV/mm; likewise the greatest electric field stress for watered polymeric insulator will have to be around 0.5-0.7 kV/mm. figuring out the simulation of the electrical field and potential distribution alongside a polymeric insulator is essential especially for the design of the triple intersection; sheath, air and metallic end fittings. The electric field stress close to this intersection must be less than the dry corona release range. The majority of the past work is centered on electric field increase under water droplet but very few papers are accessible on the numerical simulation study of polymeric insulators once hydrophobic properties are deteriorated [1]

Research has persistently shown that the magnitude of leakage current is reliable in predicting the insulator surface discharge and ultimately its failure. Thus, the probability distribution of leakage current can be used to assess the insulator failure risk. Based on this, the cumulative probability of leakage current can be produced. The electric utility might set a critical probability of the leakage current beyond which insulator failure becomes more obvious [2].

In case the pollution could be dispersed over the whole insulator, the voltage could be stiff to be more linear avoiding the electric concentration at each and every point on the insulator thus reducing the likelihood of flashover [3].

Since it is ambiguous to understand the real pollution performance of polymeric insulators, research work has to be continued by carrying out simulation studies. In the present study, the parameters that influence the electric field stress, leakage current, impact of dry band position are studied in detail using ANSYS 2D E-MAG software.

2. Simulation procedure

i. Establishment of model

The project uses a 66kV BHEL EPD silicon rubber insulator. The SOLID EDGE program is used to create the insulator model. The important key point's co-ordinates are obtained from the Solid Edge CAED model and they have been used in ANSYS to develop the insulator model. ANSYS E-MAG software is used to simulate the electric field distribution alongside the surface of silicon composite insulators. Since polymeric insulator structure is axis-symmetric; the electric field distribution can also be simulated by two-dimensional area. The insulator shed profile constitution is shown in fig 1.

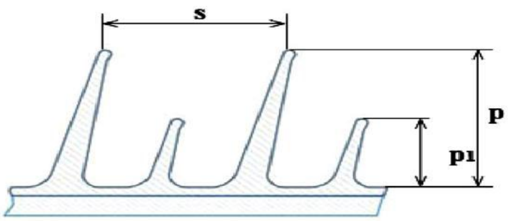


Fig.1 Insulator shed profile

Table 1 shed profile details

Dimension	Symbol	Value (mm)
Distance between two larger sheds	S	50
Length of larger shed	P	55
Length of smaller shed	P1	40
Diameter of inner shed	–	108
Diameter of outer shed	–	138

ii. Material properties

The three primary parts of the polymeric insulators are metal end-fittings, fiber rod, and silicon rubber. Material properties used for insulator [3] are listed in table 2. Forged steel material is used to construct the metal end-fittings. A fiberglass rod gives crucial mechanical support.

Table 2 Lists of material properties

Material	Relative Permittivity	Conductivity (S/m)
Silicone Rubber	3	1E+014
Forged Steel	1E+005	5.7E+007
Fiber Core	7.1	1E-013
Air Background	1	1E-050

iii. Boundary conditions

In order to excite the insulator, the potential voltage of (66*√2)/√3=53.88kV i.e. peak phase voltage is applied toward one side and ground potential at the other side. The insulator is provided with ground and support clearance as per the standards.

iv. Conversion of salt content expressed in esc (mg of salt/g of sand) into pollution layer electrical conductivity(s/m)

For the simulation studies, the sand grains of 1-2mm diameter are considered with the salinity of 0.5-1.5mg salt/g sand which gives a uniform pollution layer for different conductivities [1]. To change over the substance (mg of salt/g of sand) - into contamination layer electrical conductivity (S/m), the solution salinity was initially obtained from expression

$$S_a = ESC * Q * 10^{-3} \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where S_a is the solution salinity, Q is the quantity of sand accumulated on insulator surface with a certain amount of water.

Salinity is then interrelated to electrical conductivity of such solution is obtained

$$S_a = (5.7 * \sigma_{20})1.03 \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

σ_{20} Is the conductivity at a temperature of 20°C in (S/m). Using the concept of lattice geometry, the quantity Q can be represented as:

$$Q = \rho * \left(\frac{\lambda}{1-\lambda}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

λ –Lattice arrangement density, which is proportional to the actual amount of particles that occupies a given space; ρ is the specific gravity of wet sand (1.92 g/ml).

The parameter λ was computed to fall in the range from 0.523 to 0.740. The above values give a realistic Q value = 2.1 g/ml.
By using the above equations, the analogous electrical conductivity was calculated and listed in table 3.

Once the model is established, the electro-static (for without pollution) and electric conduction (for polluted insulator) are carried out and the obtained results are discussed in the next section.

3 Simulation results and discussion

I. Electric field distribution in silicon rubber composite insulator without pollution

At first, the simulation was conducted for the insulator without any pollution severities. The Electric field and Potential distribution over a typical 66kV composite insulator are shown in fig 2 and 3 respectively wherein Voltage gradually reduces from high voltage end to the ground electrode.

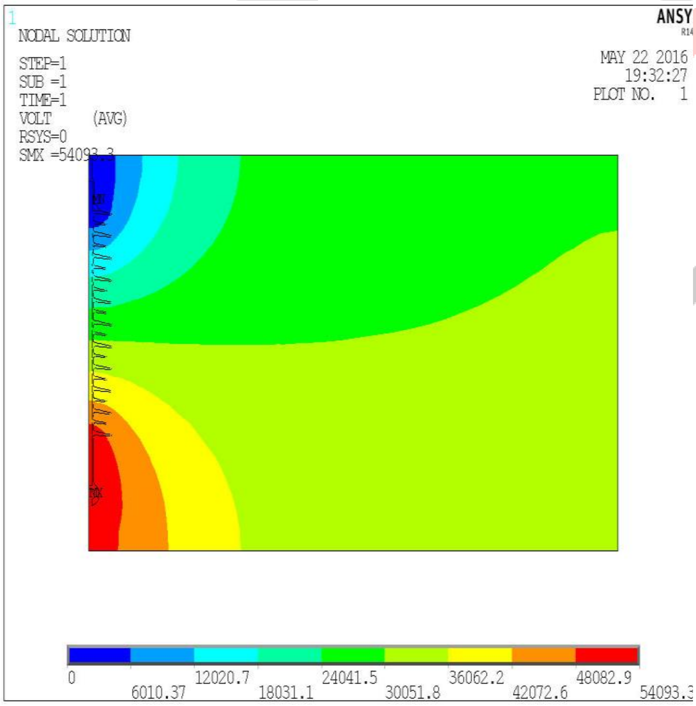


Fig 2 Potential distribution

At the point, when insulators have high resistivity its surface is dry and henceforth, there is less probability for a drift of leakage current. Hence, electric field stress on the non polluted insulator surface has little impact on the leakage current and arc initiation.

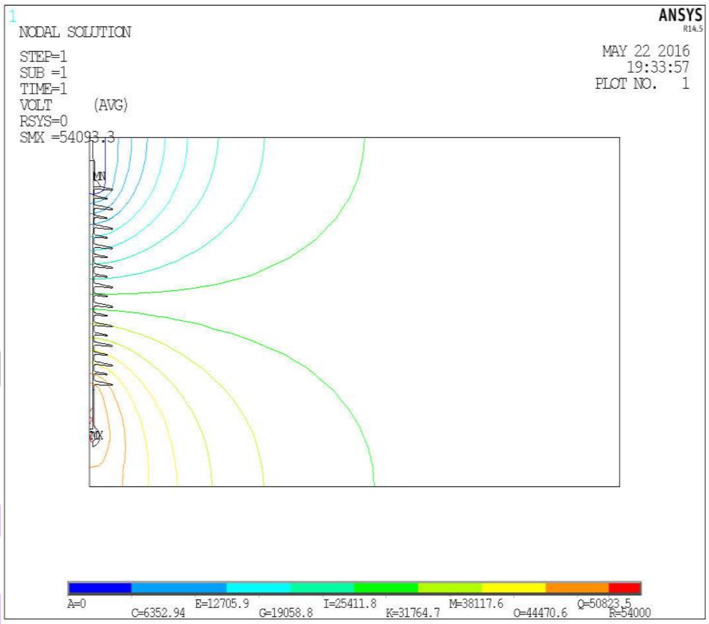


Fig. 3 Equipotential lines along a standard 66kV composite insulator

Fig 4 represents the U-shape electric-field scattering along the insulator surface. Electric field stress is more at the intersection of metal end fittings and at the base of shed areas, while lower electric field is in the middle. From the simulation, the highest electric stress on the non polluted insulator is found to be 0.2707kV/mm. The threshold level of electric field strength for the corona discharge to be initiated on the surface of a cleaned insulator is 2.28kV/mm.

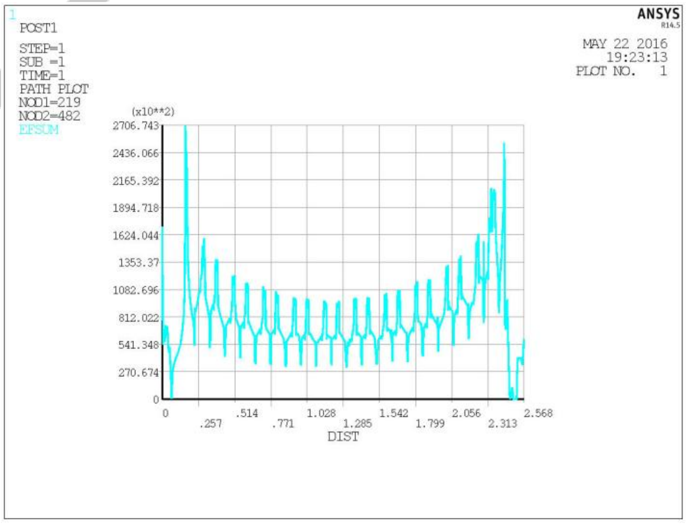


Fig 4 Electric field graph

From the obtained results it can be concluded that corona inception is not possible in case of a clean and dry insulator. Taking into account these outcomes it can be inferred that corona beginning is unrealistic for the dry insulator surface.

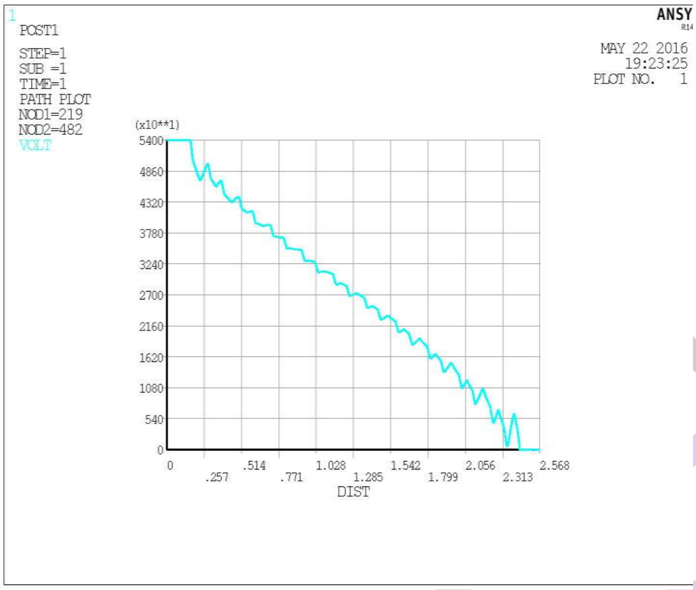


Fig 5 Electric potential graph

Fig 5 shows the graphical representation of electric potential drop over the insulator surface. It was observed that voltage gradually reduces from positive to the ground electrode.

II. Electric field distribution in silicone rubber composite insulator with pollution

At the point when the surface of a contaminated insulator gets wet because of icy fog, snow, or rain, contamination contaminants liquefy in water forming a leakage current because of potential difference on the alongside of the insulator. The magnitude of current flowing through the insulator surface relies upon the surface area and the conductivity of the contamination pollutants. For investigation, a uniform contamination layer of 1.5mm thickness was taken into account.

Sample insulator sector

Since it is complex to analyze the leakage current distribution along the whole insulator, part of the insulator was chosen, where the boundary conditions (potential and electric field) were set around that division. The insulator division has one longer shed and the other smaller shed with an overall creepage length of 215 mm. The leakage current density on the insulator surface was computed for different conductivities.

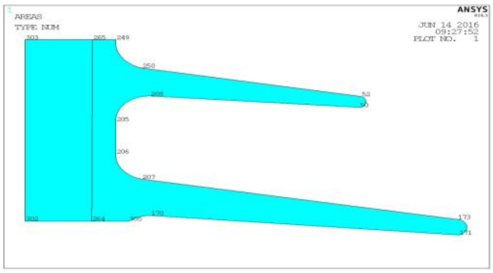


Fig 6 sample insulator section

By carrying out the simulation of the entire insulator model, the insulator section shown in fig. 6 was set to the subsequent boundary conditions. The electric potential on the two ends of the sample sector as obtained from the global analysis – were found to be 44751.7V and 40962.3V. The subsequent electric field and electric potential over the clean insulator surface are shown in fig 7 and 8 respectively where the maximum electric field was 0.150kV/mm.

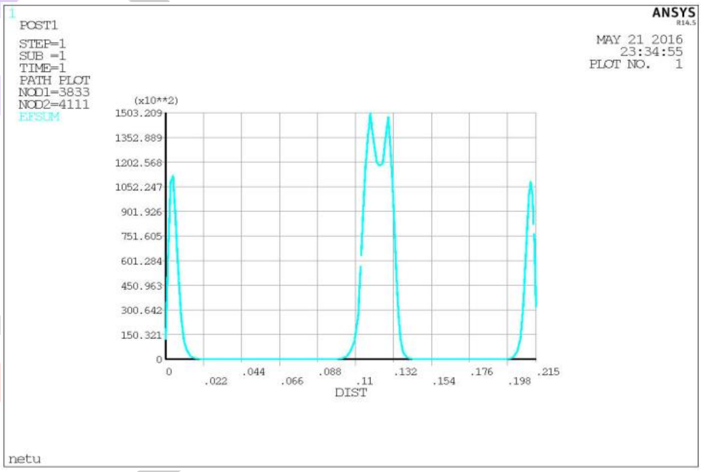


Fig 7 Electric field distribution on clean sample sector

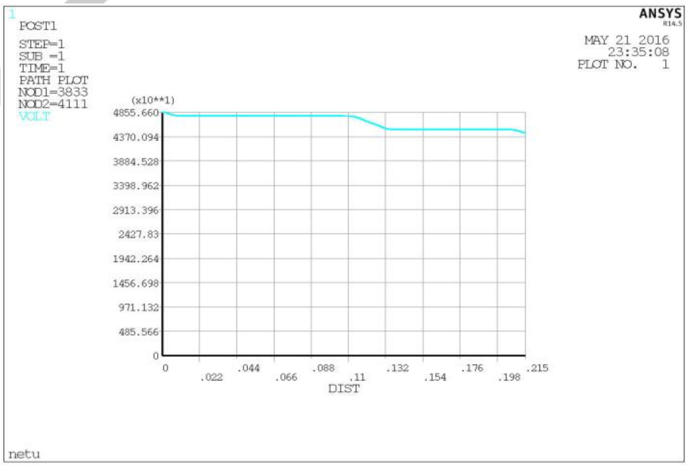


Fig 8 Potential distribution on clean sample sector

So as to study the electric field distribution over the surface of the polymeric insulators electric field and potential simulations were done at various contamination severity ranges.

Table 3 maximum electric field stress for different layer conductivities

Sl. No	Layer conductivity	Maximum electric field stress
1	284.9µS/cm	0.165kV/mm.
2	558.4µS/cm	0.399kV/mm
3	827.8µS/cm	0.402kV/mm

The simulation results showed that the electric field stress increases as the pollution severity increases and pollution severity had almost no impact on the distribution of electric potential over the insulator surface.

III. Interdependence of leakage current on layer conductivity

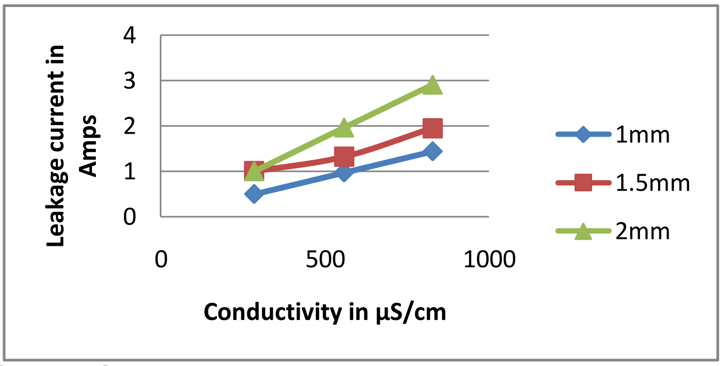
The magnitude of the leakage current on a polluted insulator depends on the pollution severity and its contamination salinity, which subsequently affects the conductivity of the contamination layer.

The conductivity values from the table 4 were readily utilizes in contaminated insulator simulation in looking for the measurements of tangential electric field along composite insulator, which drives the leakage current. The impacts of those conductivities in every polluted layer on the leakage current density on insulator surface were noted.

Table 4 leakage current (A) through different thickness layer with different conductivities

Layer thickness / Conductivity (µS/cm)	Leakage current (Amps)		
	1mm	1.5mm	2mm
284.9	0.494533	0.969293	1.4355
558.4	1	1.319	1.9483
827.8	1.00271	1.96533	2.90926

Fig 9 shows the variation of leakage current for different



layer conductivities.

Fig 10 shows the impact on the surface distribution of leakage current density of various conductivities in a 1, 1.5 and 2mm polluted layers. Surface integration was numerically carried out to produce surface leakage currents in the above instances.

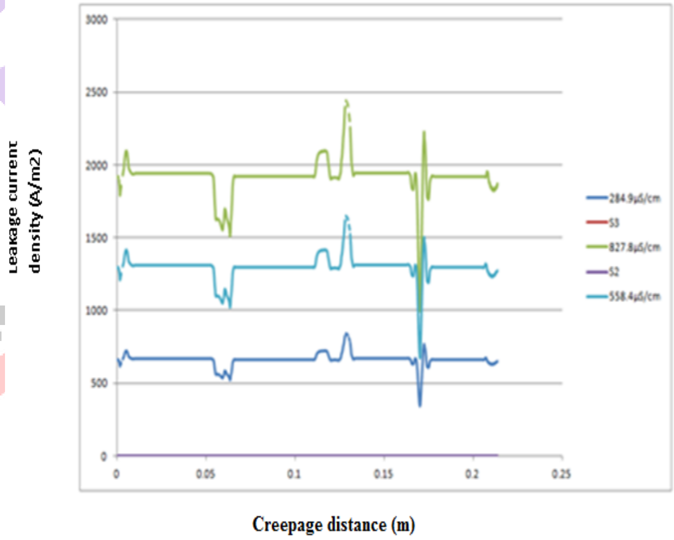


Fig 10 Leakage current density through 1.5mm layer with different conductivities

From the obtained results (Fig 9) we can conclude that as the pollution severity of the layer increases it leads to increased leakage current flow on the insulator surface.

IV. Impact of dry bands on electric field distribution

Dry band (6mm*1.5mm) are formed with the conductivity of 12092 ohm-m at different heights of the insulator in order to study the variation in the electric field stress and potential distribution over the insulator surface.

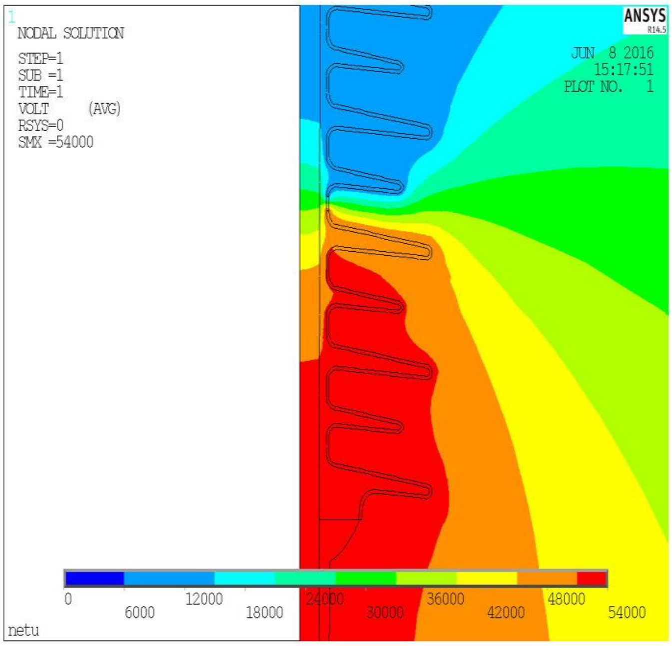


Fig 11 potential plot

From fig 11 it can be seen that the formation of dry band at 25% of insulator height promotes a redistribution of electric potential on insulators over the surface.

As non-uniform resistance exists on the contaminated insulator surface, the dry band with a lower resistance gets to be dried speedily which in turn increases the resistance on account of which maximum heat is released.

When dry band is formed at 25% of the insulator height from high voltage end, it can be observed that there is a huge voltage drop across the dry band and increased field strength of 69.34kV/cm.

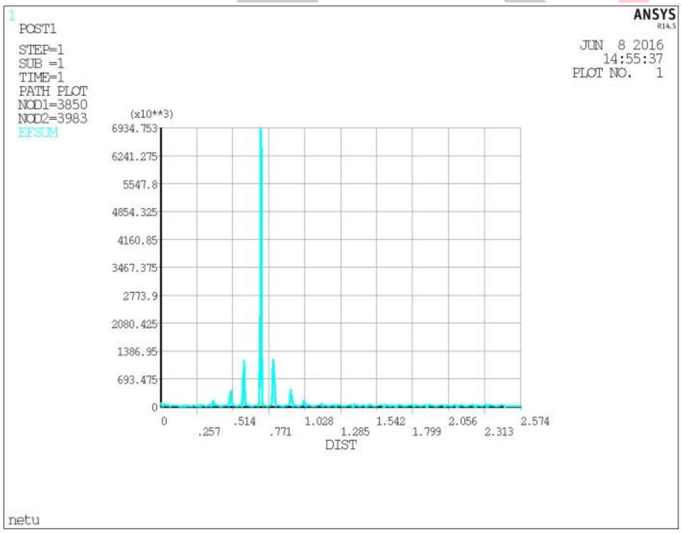


Fig 12 Electric field distribution

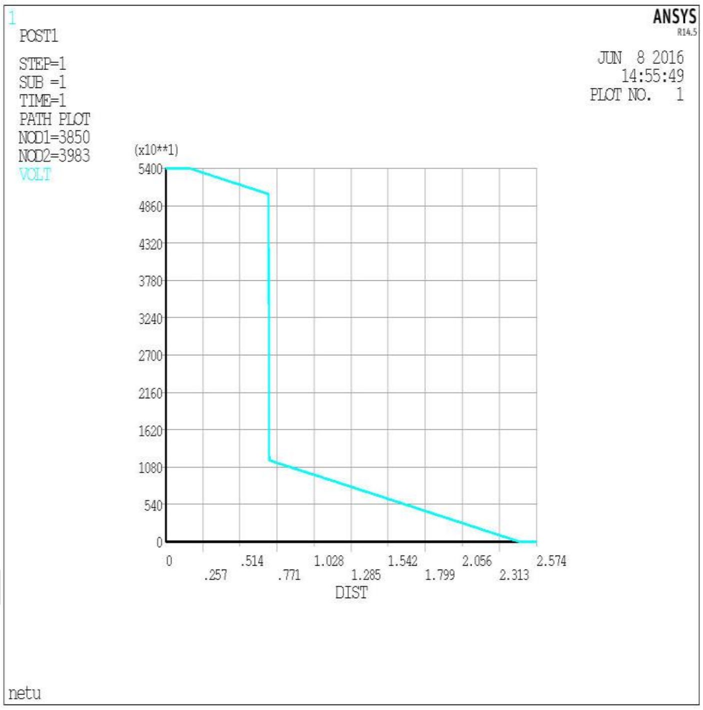


Fig 13 Electric potential distribution

From the obtained results, it can be concluded that formation of dry bands has distorted the potential distribution on the insulator surface which in turn increases the field strength of dry bands. It is observed that the dry band which is at 25% of the insulator height from high voltage end has more electric field stress compared to the dry band which is positioned at 75% of height. Hence dry band formed at near the high voltage end has more electric stress than the dry band which is near to ground end and will have higher probability of flashover

Table 5 maximum field stress for different dry band positions

Position of the dry band from HV end	**Maximum field stress in kV/cm**
At 25% of insulator height	69.3
At 50% of insulator height	66.9
At 75% of insulator height	66.7

Maximum electric field stress exceeding 30kV/cm (max) leads to dry arcing [1].From table 5 it is observed that maximum electric field stress is exceeding 30kV/cm (max) thus there is likely to cause dry arcing.

Conclusion

The simulation results shows that the electric field stress is high at the intersection of metal end fittings and at the base of shed areas, while the lower electric field is in the middle. And also the electric field stress increases as the pollution severity increases. It was observed pollution severity had almost no impact on the distribution of electric potential over the insulator surface.

From the obtained results, it can be concluded that as the pollution severity of the layer increases it leads to increased leakage current flow on the insulator surface.

The creation of dry band at different heights forms a redistribution of electric potential on insulator along the surface. And also it was observed that there is a huge voltage drop across the dry band thus increasing the field strength. From the simulation results, it can be concluded that the dry band which is near to high voltage end has more electric field stress compared to the dry band near to ground end.

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