Study on Leakage current characteristics and Numerical Analysis of Pollution layer on Polymer Insulator

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***Abstract-**Among the new insulating materials widely used in high voltage outdoor insulation systems, silicon rubber materials also called polymeric materials are very important; during the last 20 years, they have been applied for manufacturing outdoor insulators. These materials are organic; therefore, they are prone to decomposition under different environmental conditions. Polymeric insulators exhibit good performance under polluted conditions due to the unique property of hydrophobicity. However, pollutants in combination with moisture cause the formation of wet conducting films and thus allow the flow of leakage currents. The appearance of dry bands causes arcs on the insulator surface. Such arcs elongate and bridge the electrodes resulting in flashover. In this regard, it is to be understood that whether hydrophobicity transfer occurs on a polluted polymer insulator for different pollution severity. In this paper, the electric field distribution of 33kV polymeric insulators has been carried out for various pollution severities using Solid works. The electric field and potential distribution have been investigated for non-uniform and uniform deposition of the pollution layer. The simulations show that the voltage distribution is uniformly distributed and gradually decreases from the high voltage end to the low voltage end for a non-polluted insulator and the contaminated insulator, the voltage distribution is different, a large portion of voltage is shared by the sheds on the high voltage side; the voltage is also high and magnitude towards the low voltage end of the insulator.*

To understand the correlation between insulator condition and its leakage current phenomenon, various equivalent circuits representing insulator under different conditions has been investigated. This paper presents the proposed equivalent circuit models of two main conditions of an insulator, i.e. clean, and polluted. In general, the model consists of a capacitor(s) and a nonlinear resistor(s). By using the models, the leakage current simulations have been done using MATLAB SIMULINK software package. The simulations show that leakage current increases for polluted insulators compared to clean insulators.

Key Words: Polymer Insulator, pollution severity, equivalent circuit, leakage current, MATLAB SIMULINK, SOLID WORKS

1. INTRODUCTION

There has constantly been a necessity for electrical insulation since the period electric power was discovered. The power system comprises of generation, transmission, and distribution system. Outdoor insulators are an integral part of the transmission system and its performance is the critical factor governing the system reliability. When these insulators are used in a contaminated environment such as marine, industrial, agricultural, traction, pollutants get deposited on these insulators. This results in a flashover and ultimately failure of the insulator. Ceramic or glass insulators have been used in outdoor insulators for many years. It is being replaced by composites insulators because of lightweight, low cost, improved resistance to vandalism, and excellent hydrophobicity. Polymeric insulators being organic under environmental electrical stresses undergoes surface degradation, loss of hydrophobicity thus affecting its electrical properties. A polymer is a large molecule made up of chains or rings of linked repeating subunits, which are called monomers. Polymer Insulator (composite) is an electrical device consisting of an insulation section made of polymer materials and metal fittings. Ex: Silicon rubber

Fig 1: Polymer insulator

2. LITERATURE REVIEW

Silicone rubber insulator is widely used in the high voltage insulation system including outdoor and indoor applications. During its service life, insulators are exposed to atmospheric conditions. The pollutants from industries play a major contributor to polymer insulator behavior.

One of them is environmental pollution, where pollutants stick to the insulator surface. The polluted condition may produce leakage currents or even electrical discharges.

The author Mohammad Amin et al., has developed a new methodology which explains that water droplets induced discharges are the main reason for the hydrophobicity degradation of polymer insulators. [1].The accelerated aging test shows that the silicone rubber (SiR) insulators' performance under polluted conditions can be analyzed with the state of the hydrophobicity on their surface. [2].The authors Mahdi Izadi et al. explains about, how the deposition of moss effects on the electrical performance of polymer insulators, and behavior of contaminated polymer insulator towards lightning. [3].The author Arshad A et al. explains the effect of dry band location on electric field distribution along a polymeric insulator under contaminated conditions.[4]. The authors E Jayaprakash et al. explain the analysis of the electric field on polymer insulator for different pollution conditions. The electric field stresses are highest in the areas near the top and bottom of the insulators. [5]. Experimental study of pollution and simulation on insulators using COMSOL under AC voltage shows that the flashover voltage of outdoor polymer insulator decreases according to the conductivity of the polluted environment. [6].The authors Refaieed Mostafa, et al. studied the optimal design of the insulator shed diameter spacing and metal end fitting diameter to reduce the maximum value of the electric field strength.[7]. Investigation of electric field and potential distribution around the composite insulator for several configurations were done using FEM analysis. [8].The usage of COMSOL software was accomplished by simulating a polymer rod type insulator under dry and clean conditions and several types of pollution conditions with the presence of dry band areas and water droplets [9].The authors S.Z.Moussavi, et al. explains that A deposition of pollutants with higher conductivity creates higher field values and may cause an easier flashover. [10].The authors Suwarno Harjo et al. proposed the models and computer simulation of leakage current waveforms that were done using APT/EMPT under various conditions and applied voltages. The results indicated that the simulated leakage current waveforms were similar to those obtained from the experiment. This revealed the validity of the proposed model. [11].The authorsWaluyo et al. simulated the equivalent circuit of insulators for three conditions, i.e. clean, polluted, and polluted with dry-band discharge. From the results obtained it is seen that on a clean insulator, the high capacitance will create oscillations, whereas, on polluted insulators, the current waveforms will be distorted [12].

3. SOFTWARE REQUIREMENTS

3.1 MATLAB

MATLAB is a multi-paradigm numerical computing environment and programming language developed by Math Works. MATLAB allows matrix manipulations, plotting of functions and data, implementation of algorithms, creation of user interfaces, and interfacing with programs written in other languages.

Using MATLAB, we can

- Analyze data
- Develop algorithms
- Create models and applications

3.2 SIMULINK

SIMULINK is a MATLAB-based graphical programming environment for modeling, simulating, and analyzing multidomain dynamical systems.SIMULINK is widely used in automatic control and digital signal processing for multidomain simulation and model-based design. Some of the advantages of SIMULINK are:

- SIMULINK is similar to hardware implementation.
- It is very easy to read as it is like a block diagram
- Simulation is done over time so the state of the whole system in each time-slot is available.

3.3 SOLIDWORKS

SOLIDWORKS is a 3-D computer-aided design (CAD) tool used for various modeling, mapping and sketching purposes. Views are automatically generated from the solid model, and notes, dimensions, and tolerances can then be easily added to the drawing as needed. SOLIDWORKS Simulation is a virtual testing environment to analyze the design, evaluate its performance, and make decisions to improve product quality.

4. SIMULATION USING MATLAB SIMULINK

4.1 Equivalent Circuit Models of Outdoor Insulators

During operation, an outdoor high voltage insulator may come under various stresses. One of them is environmental pollution, where pollutants stick to the insulator surface. The polluted condition may produce leakage currents or even electrical discharges. Their waveforms are normally non-pure sinusoidal. To understand the correlation between the insulator's condition and its leakage current phenomenon, we have investigated equivalent circuits for representing insulators under different conditions. Equivalent circuit models of two main conditions of insulators, i.e. clean and polluted insulators are analyzed[12]. In general, the model consists of a capacitor(s) and a nonlinear resistor(s). By using the models, the leakage current simulations have been done using MATLAB SIMULINK software package.

4.1.1 Clean Insulator

Fig 2 shows the equivalent circuit of a clean insulator consisting of a linear resistor and capacitor. These elements are connected in parallel and purely depend on the internal insulator characteristics and the applied voltages. It is understandable, that in high voltage engineering a capacitive effect of high voltage apparatus, as the case of an insulator, will appear dominantly.

Fig 2: Proposed model of clean insulator equivalent circuit

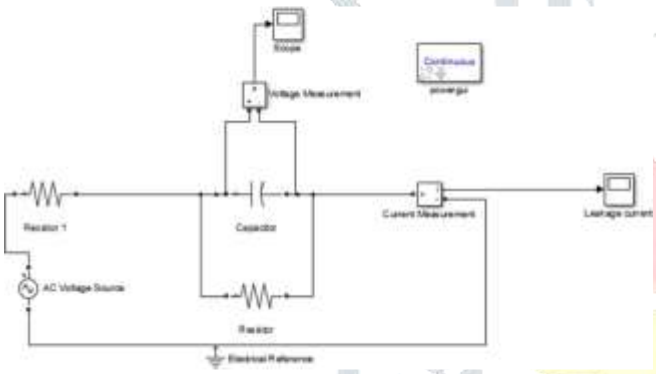

Fig 3: Model of a clean insulator in MATLAB SIMULINK

The simulation was carried out for a sinusoidal voltage of 50 Hz, 11kV. For comparison, two values of capacitance, i.e. 0.1 pF and 50 pF are assumed, whereas the resistance value is assumed as 4421 MΩ. These values were so chosen, to obtain the leakage current of the order of microamperes. The output waveforms are shown below in Fig 4. The figure (4.a) shows a typical leakage current waveform on a clean insulator with relatively low capacitance, 0.1pF. The graph represents a pure waveform, while the figure (4.b) shows the waveform with relatively high capacitance, 50pF. It is shown that the current waveform experiences an oscillation. The circuit tends to indicate a resonant behavior, due to stored energy in the capacitor. Its amplitude increases as a consequence of the decrease of the total equivalent impedance. Thus there is an increase in leakage current as the capacitance increases. The values of leakage currents for both the capacitances are shown in Fig 4.

Fig 4a: Capacitance of 50Pf

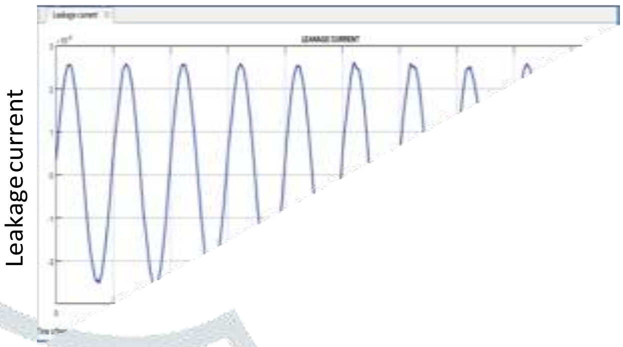

Fig 4b: Capacitance of 0.1pF

Fig 4: Typical leakage current waveforms on a clean insulator with different capacitances

4.1.2 Polluted Insulator

Fig 5 shows a proposed polluted insulator equivalent circuit. The presented circuit is a modification of the clean insulator, by adding a non-linear resistor in parallel, as a representation of the contaminated and moistened surface. In this contaminated condition, it can be categorized into two levels, i.e. light and heavily contaminated and moistened surfaces. Less moist and contaminants on insulator surface, with a certain applied voltage, will tend to produce short burst currents, while the heavy ones would rather yield in long burst currents. [12]

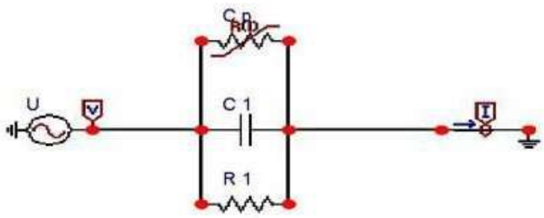

Fig 5: Proposed model of polluted insulator equivalent circuit

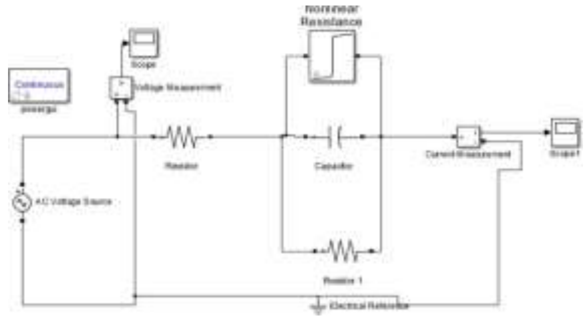

Fig 6: Model of the polluted insulator in MATLAB SIMULINK

The simulation was carried out and the plot obtained is shown fig 6. The value of leakage current obtained is about 2.49A, which is shown in Fig 7.

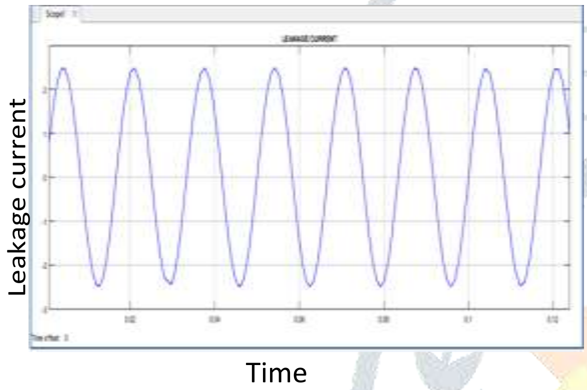

Fig 7: Leakage current waveform of polluted insulator for the capacitance of 50Pf

4.2 RESULTS AND DISCUSSION

Two electrical equivalent circuit models of outdoor insulators have been simulated using MATLAB SIMULINK software package. The two kinds of circuit models are clean and polluted insulators. The values of Leakage Current obtained for the two conditions are shown in Table 1. It can be observed that for clean insulators the value of leakage current in the case of 50pF is found to be 173.38µA and for 0.1pF the value is 2.6 µA, which means as the capacitance increase the leakage current also increases. For a polluted insulator, the leakage current is found to be 2.49A.

Table 1: Values of Leakage Current for the two conditions

CONDITIONS	CAPACITANCE VALUE	VALUE OF LEAKAGE CURRENT
Clean Insulator	50pF 0.1pF	173.38 µA 2.6 µA
Polluted Insulator	50pF	2.49A

5. SIMULATION USING SOLID WORKS

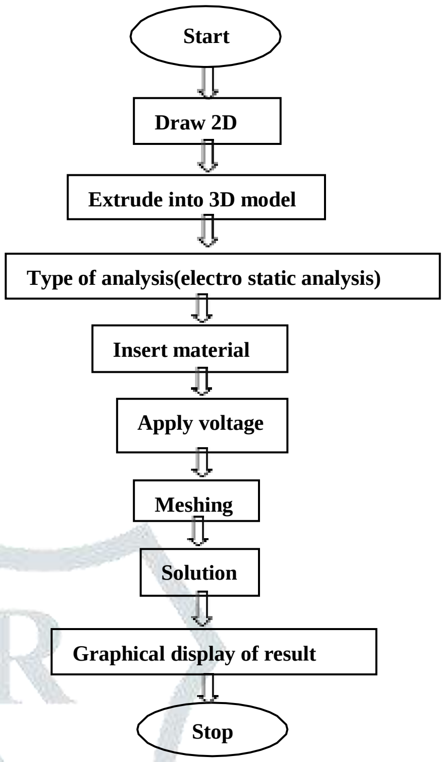

Fig 8. Flowchart for simulation Process

The flow chart for the simulation using SOLID WORKS is shown in fig 8. The first step is to draw the 2D model which is then converted into the 3D model. An electrostatic analysis was carried out and the material is assigned to the geometry. A high voltage of about 33kV rms is applied to the insulator. The solution and graphical display of the result are obtained and analyzed.

To know the performance characteristics of polymer insulator following conditions were considered

- Non-polluted condition. (clean insulator)
- Uniform deposition of pollution layer

5.1 Non-polluted condition of polymer insulator:

The surface potential and electric field distribution for the 33kV polymer insulator under normal conditions are presented in fig 8. In this condition, approximately 0V has appeared on each disc of the insulator. Figures (8.a) and (8.b) illustrate the potential and the electric field distribution around and inside the insulator when there is no pollution. The voltage distribution is uniformly distributed and gradually decreases from the high voltage end to the low voltage end for a clean insulator.

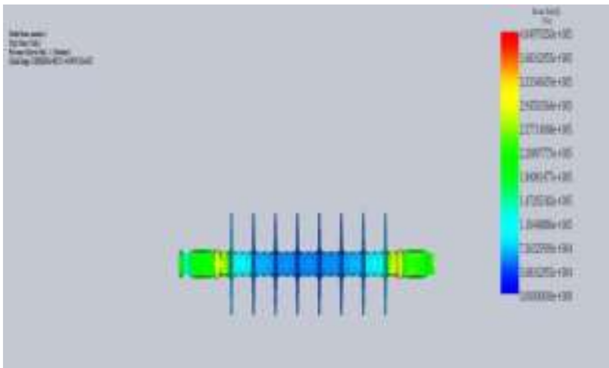

Fig 9a: Potential Distribution

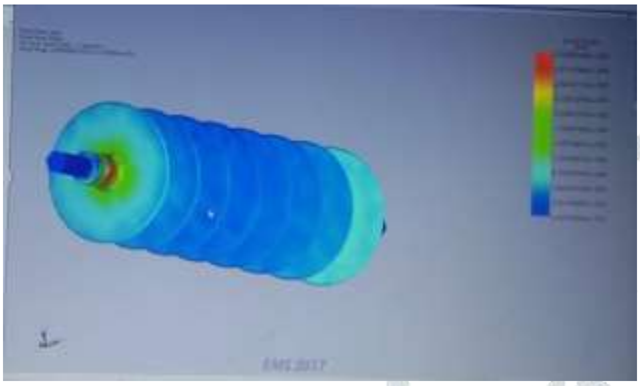

Fig 9b: Electric Field Distribution

Fig 9: Field distribution in insulator under healthy condition

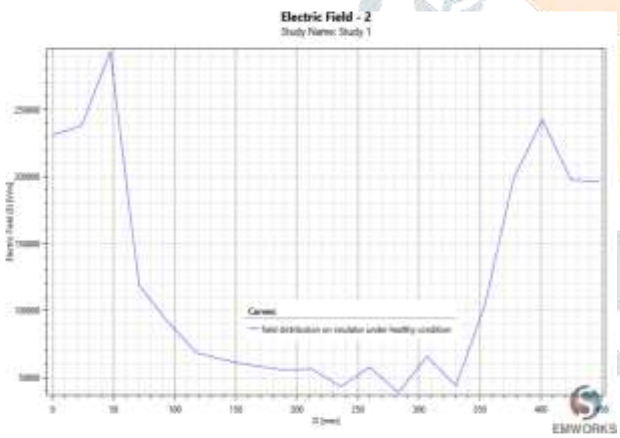

Fig 10: Electric field graph

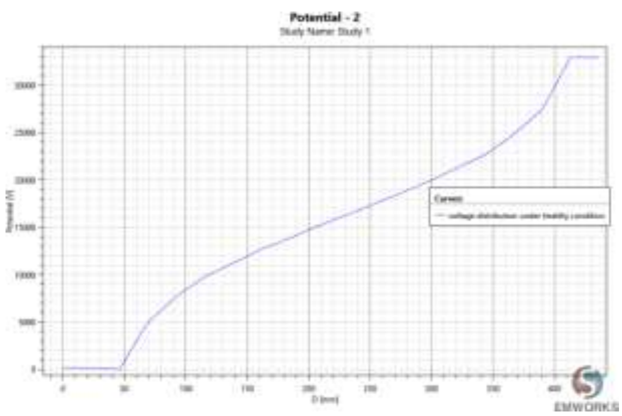

Fig 11: Potential Graph

5.2 Uniform deposition of pollution layer on polymer insulator

5.2.1 Pollution layer of 0.5mm

To simulate the pollution, a thin film of a pollutant 0.5mm has been added on the surface of the insulator as shown in fig 13. Potential on each disc of the insulator is found to be appx.6-24kV. The pattern of field distribution is presented in fig 14. Graphs of potential and electric fields are presented in fig 15-16

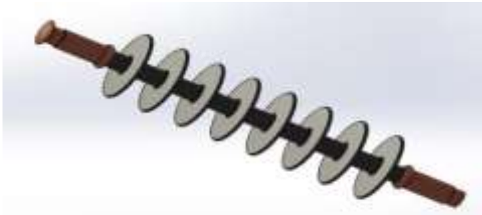

Fig 12: Model View.

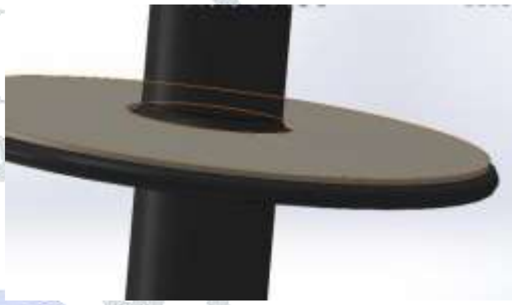

Fig 13: Dust Deposition of 0.5mm on each Disc

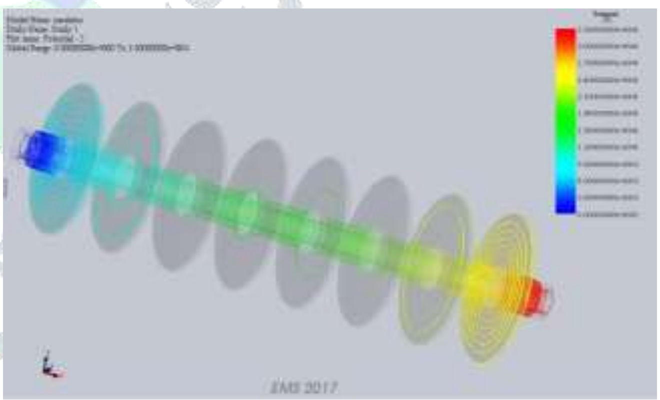

Fig 14: Field distribution on Insulator

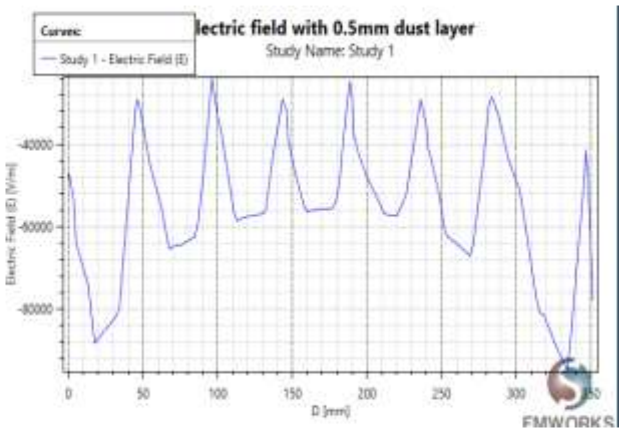

Fig 15: Electric Field Graph

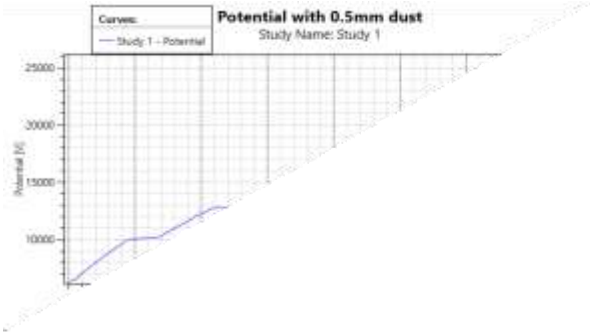

Fig 16: Potential Graph

5.2.2 Pollution layer of 1mm

For a uniform pollution layer of 1mm applied on polymer insulator the Potential on each disc of an insulator is found to be appx.7-25 kV. Fig 17 shows the field distribution pattern on the surface of the insulator. Fig18 and Fig 19 represents graphs of potential and electric field respectively.

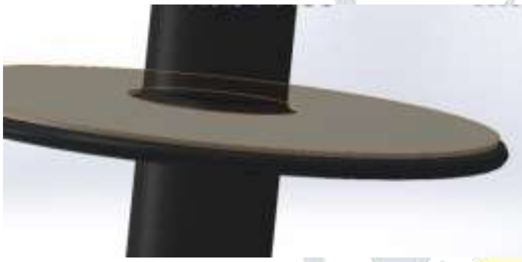

Fig 17: Dust Deposition of 1mm on each Disc

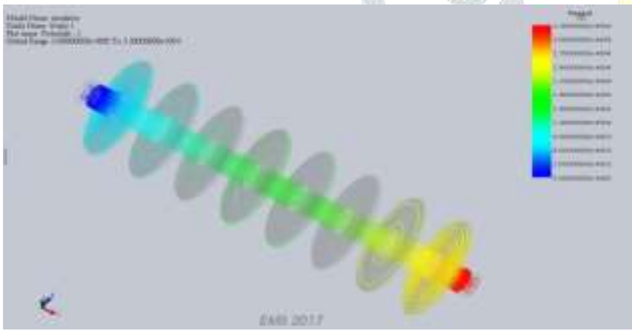

Fig 18: Field distribution on insulator.

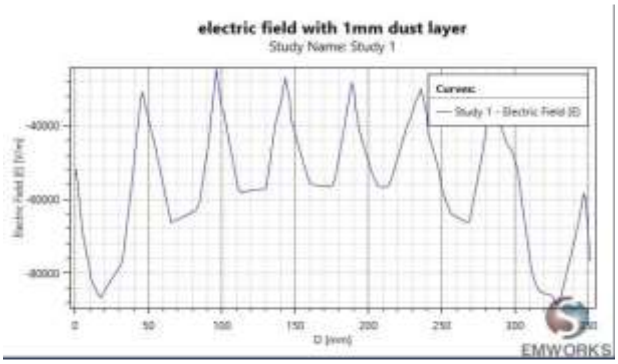

Fig 19: Electric field graph

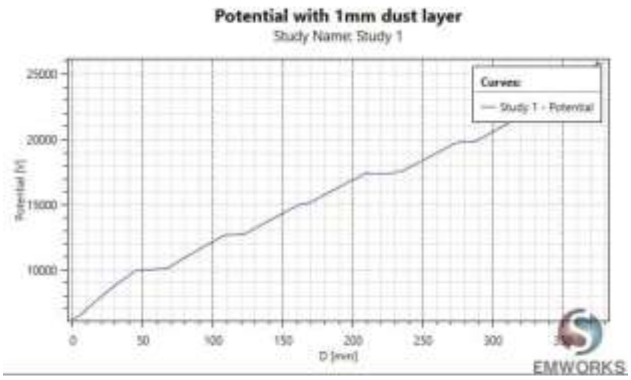

Fig 2: Potential Graph

5.3 RESULT AND DISCUSSION

The distribution of voltage and electric field on a clean and contaminated insulator was carried out using the SOLIDWORKS Polymeric insulator was taken as the main insulator model. From the simulation results, it was noted that the voltage distribution is uniformly distributed and gradually decreases from the high voltage end to the low voltage end for a non-polluted insulator. For the contaminated insulator, the voltage distribution is different, a large portion of voltage is shared by the sheds on the high voltage side; the voltage is also high and magnitude towards the low voltage end of the insulator. It can be said that pollutants have the effect of increasing voltage magnitude along the insulator surface contamination affect voltage and electric field distribution. The effects in distribution may lead to premature aging or poor performance of the insulator.

6. CONCLUSION

i. The effect of leakage current on clean insulator and polluted insulator was analyzed using their equivalent circuit in MATLAB SIMULINK.. From simulation results, it is found that the leakage current for a polluted insulator is more as compared to a clean insulator. Also as the capacitance increases leakage current increases.

ii. The electrical performance of a 33kV HV polymeric insulator was studied during this project. The Electric Field Distribution for the clean and polluted condition was studied using SOLID WORKS. Under contamination conditions, higher electric field distribution and more nonlinear potential distribution are obtained than the clean insulator. It can be said that pollutants have the effect of increasing voltage magnitude along the insulator surface.

These results could help in the design and choice of insulators in highly polluted areas. It was noted that contamination affects voltage and electric field distribution which results in increased leakage current. The effects in distribution may lead to premature aging or poor performance of the insulator. By understanding the behavior of polymer insulators for various polluted conditions, its installation and maintenance also will become easy.

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