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FINITE ELEMENT MODELING FOR ELECTRIC FIELD AND VOLTAGE DISTRIBUTION ALONG THE CAP AND PIN INSULATORS UNDER POLLUTION

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Abstract

The knowledge of the behavior of both the electric potential and electric field is one of the main factors needed when designing an insulator. Using AutoCAD software a 2D cap and pin 1512L insulator model was created in the clean state and under pollution from one to five insulators separately making a chain of insulators for a total of 10 models. Later they are imported to COMSOL Multiphysics 5.6 software, simulations of the 1512L insulator were made to see the effect the pollution has and the differences that occur on the distribution with the addition of more insulators in the chain. The potential distribution starts to develop a pattern after a certain number of insulators in the chain while the pollution induces high value spikes in the field distribution. Finite-element-analysis for numerical simulation of the pollution effect in outdoor insulators: a review and a novel method.

Keywords: 1512L, electric field, electrical potential, COMSOL Multiphysics, pollution

1. INTRODUCTION

The transport of the electrical energy takes a lot of technical and economic factors to study. Insulators play a vital role in transmission lines so the design and concept of such devices must be carefully studied [1]. The insulators must not only hold and operate on the service voltage but also under various constraints presented by the environment.

Pollution is one of the constraints that affect the insulator's normal operation. Under wet conditions this problem only escalates and because of that, leakage current occurs which will eventually lead to a flashover breaking down the transmission line [2]. Additionally high values of electric field may lead to partial discharge and premature aging of insulation [3]. Therefore, the knowledge of the distribution of the electric field and electric potential is a necessity to understand the impact the pollution has on the insulator. Calculating them can be done using different methods such as the Charge Simulation Method, Boundary Element Method, the Finite Difference Method or the Finite Element Method [2-12]. The finite element method is one of the most used methods by researchers to calculate the distributions of the electric potential and electric field. N.A. Othman et al [11] reported that the contaminants significantly effects the voltage and electric field distributions after simulating a cap and pin insulator under contaminations and without them. This effect although not the same exact effect has also been reported by Arshad et el [12] after simulating a polymeric insulator in clean, dry surface and light, medium, heavy and very heavy pollution.

In this paper, 2D models of the cap and pin 1512L insulator were made in the form of a single insulator and a chain with up to 5 insulators with and without the presence of pollution. Using COMSOL Multiphysics 5.6 the simulations of the models were made to see the change that happen to the distribution of the electric field and electric potential under these circumstances.

The paper is structured as follows: Section 2, design of the model using AutoCAD is presented, Section 3 gives the boundary conditions provided for the insulators. Section 4 shows the generated mesh is the free triangular mesh (the default meshing option) which is usually appropriate for intricate problems. Section 5presents the results of simulation using COMSOL Multiphysics software and in section 6the conclusion and prospects of further work are given.

2. DESIGN OF THE MODEL

Using AutoCAD software a 2D model of the cap and pin 1512L insulator was made. The pollution is modeled in a uniform shape and stationed on the pin side on the glass as seen in figure 1. In electrostatics the calculation of the distributions of the electric potential and electric field depends on the relative permittivity of the different materials, see table 1.

Table 1. Properties of the materials

Material	Relative permittivity
Iron	10^6
Glass	4.2
Cement	5.9
Air	1.0006
Pollution	80

The dielectric constant chosen for the pollution is that of distilled water. In designing insulators, the first priority is to design a shape for the insulating material that counters various pollution environments. The places where the field values are high are potentially arc-starting places in other words they are the places that the arcs start at. In comsol for the electrostatic physics only the relative permittivity is needed to calculate the potential and field distributions and so the relative permittivity will be studied.

The electric potential allows the calculation of the electric field through the following equation:[13-14]

$$\vec{E} = -\nabla V \tag{1}$$

Maxwell's equation:

$$\nabla . D = \rho \tag{2}$$

$$D = \varepsilon E \tag{3}$$

$$\nabla . \varepsilon \vec{E} = \rho \tag{4}$$

We get Poisson's equation as follows:

$$\nabla \varepsilon \nabla V = -\rho \tag{5}$$

Neglecting the space charges, we get Laplace's equation in the form:

$$\nabla \varepsilon \nabla V = 0 \tag{6}$$

The Finite Element Method (FEM) is the most popular and flexible numerical method for determining approximate solutions of partial differential equations.

A commercially available FEM package is COMSOL Multiphysics, which can solve problems in 1D, 2D, and 3D. The main steps of the finite element simulation are shown in Figure 2.

First, in the model specification stage, a model of the actual problem must be built, the simulation of which requires potential and electric field calculations, i.e. we must find out the partial differential equations that must be solved under given boundary conditions. In our work the geometry of the problem must be defined by a CAD software tool. After selecting potentials, the weak formulation of these partial differential equations must be worked out as well.

It is depending on the problem, in our cases electrostatic problem, mathematical model of the arrangement should be adequate to calculate electric potential and field quantities in the given accuracy.

The next step is the preprocessing task. Here we have to give the values of different parameters, such as the material properties.

We must add the characteristics of the material to each of the shapes. The boundary conditions and the parameters of the model are added after. Modelling with COMSOL Multiphysics is summarized in this flowchart presented in figure 2.

3. DISCRETIZATION IN FINITE ELEMENTS

This section presents the various network possibilities simulated to allow a better adaptation of the computational network to the corresponding problem. Although the automatically generated mesh is more than enough.

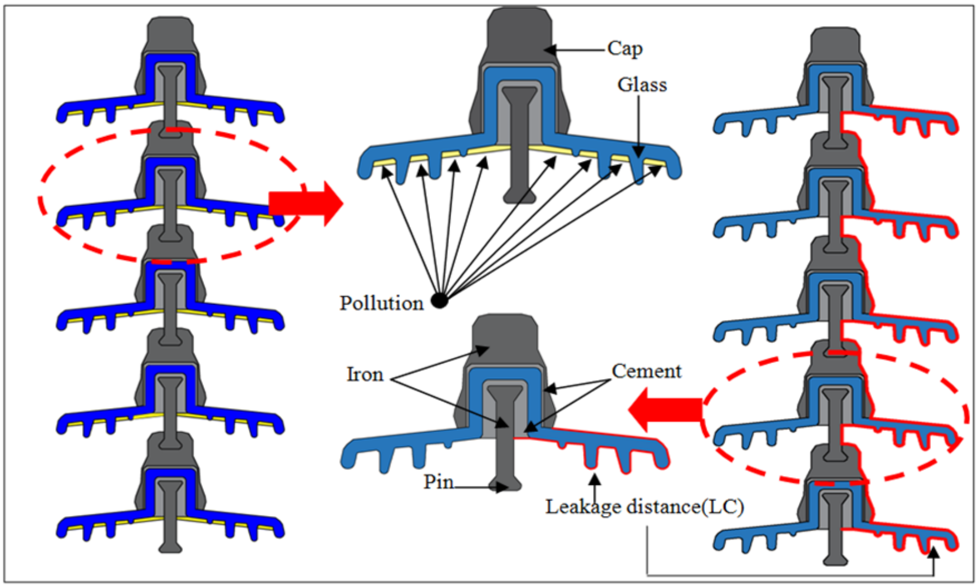


Fig. 1. Insulator with and without pollution

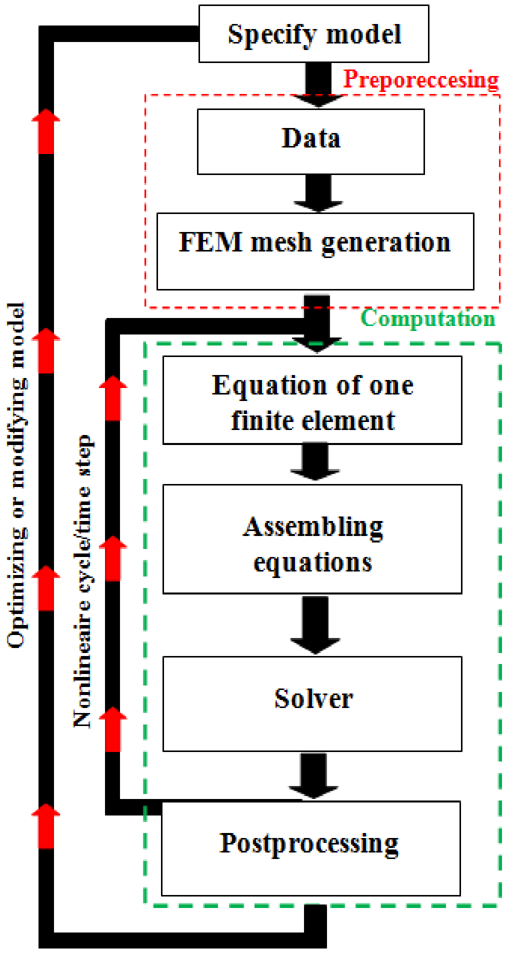
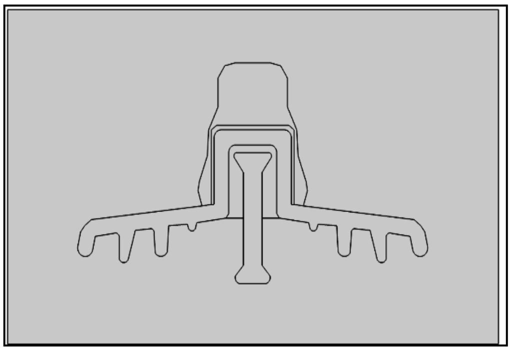


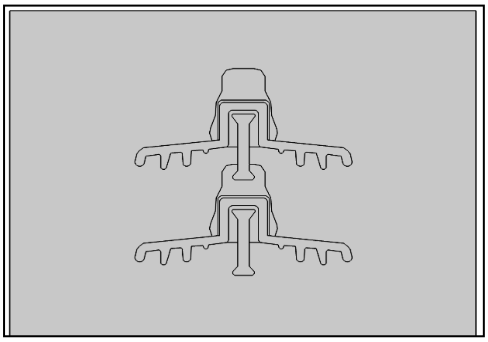
Fig. 2. Flowchart steps of simulation by FEM

Two boundaries are defined for the models, which are always going to be the pin as the point where the electric potential is going to be located and with each insulator added to the chain a value of 25 kV of voltage will be added. The second boundary is the cap of the last insulator as the ground. Table 2 shows the number of element in the mesh for each and every model created.

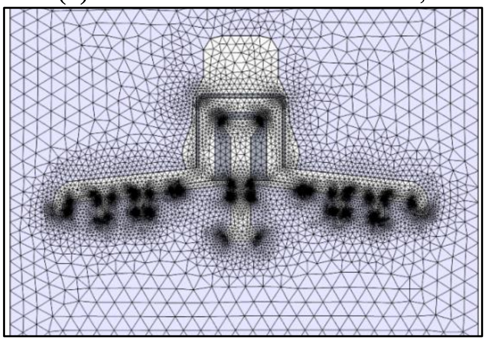
For example, one insulator number of mesh elements equal to 18350 elements without pollution, and equal to 22459 with pollution.



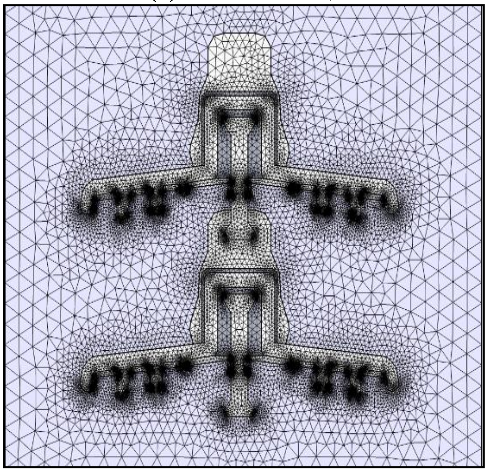
(a) One insulator in the software,



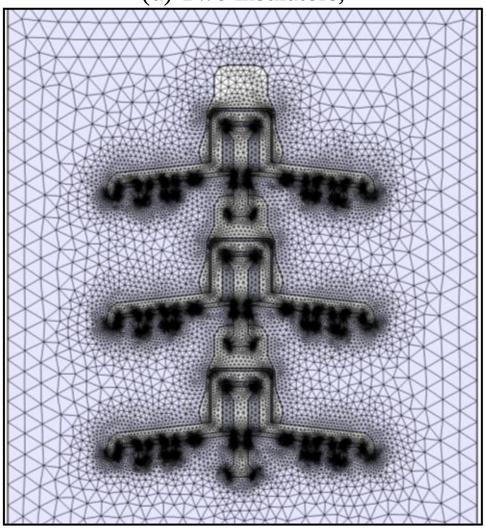
(b) Two insulators in the software,



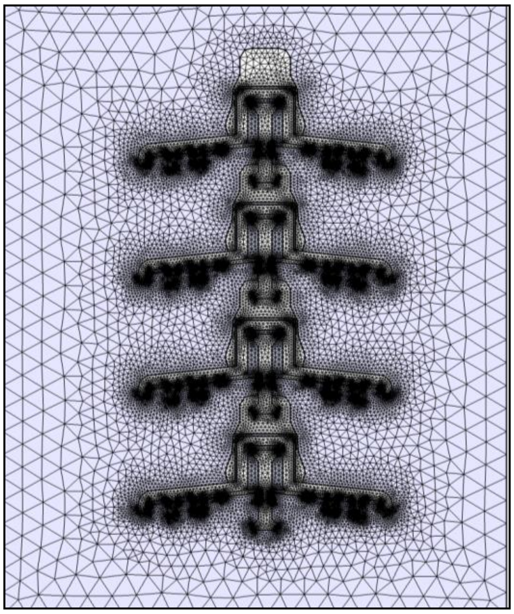
(c) One insulator,



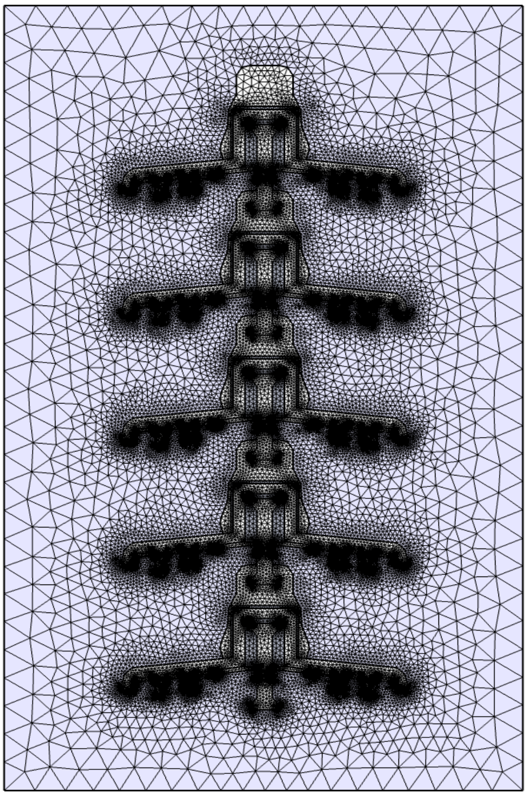
(d) Two insulators,



(e) Three insulators,



(f) Four insulators,



(e) Five insulators.

Fig. 3. COMSOL model of a cap and pin insulators, geometry are meshed by triangles

4. RESULTS AND DISCUSSION

This section shows the electric field stress and potential distributions for all samples under contamination conditions. Calculating electric field and potential at a surface distance from HV to ground electrode.

The contour plot for the electric potential distribution in the insulator and around it is drawn for all the cases studied and the same is done for the electric field with the addition of the streamline plot that shows the direction of the field lines. Additionally the potential and field distributions along the leakage distance presented in figure 1 is plotted to see the differences presented in the case of the clean and polluted insulator in the different cases studied.

Table 2. Number of mesh elements in each model

		Without pollution	With pollution
One insulator	Triangle	18350	22459
	Edge	1004	1312
	Vortex	213	229
Two insulators	Triangle	37276	43504
	Edge	1936	2532
	Vortex	422	454
Three insulators	Triangle	45644	64920
	Edge	2869	3742
	Vortex	631	679
Four insulators	Triangle	73426	86425
	Edge	3769	4957
	Vortex	840	904
Five insulators	Triangle	90114	107024
	Edge	4695	6161
	Vortex	1049	1129

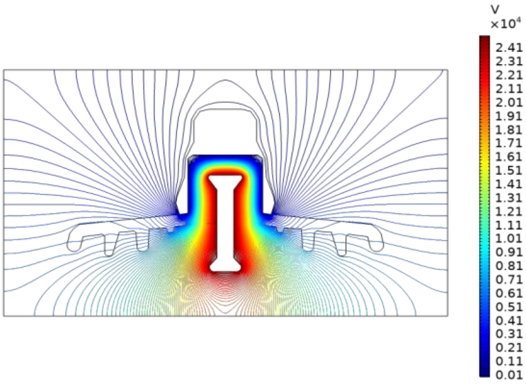
4.1. Electric potential (EP) distribution

Figure 4 shows the potential distribution and equipotential lines for different cases of the insulators string surface in the clean state for five cases.

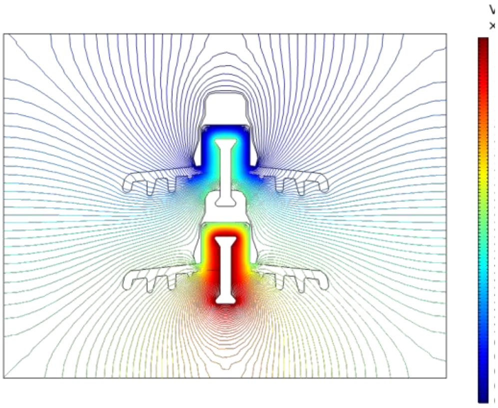
According to these results, the contour lines are absent in the cap and the pin of each insulator in the chains and that is due to the fact that the electric potential faces no obstruction in the metal parts of the chain. Contrary to that the greatest changes happen on the glass surface and both the parts of the cement, the reason is due to the fact that the concentration of the electric potential is through the shortest distance of the chain, in other words through the center of the chain. However, due to existence of the different materials obstructing it a lot of variation in the values of the potential exists. With each insulator added to the chain the potential drops accordingly in a way that the contour lines color changes in these obstructing materials descendingly indicating a drop with each distance from the potential pin to the ground cap.

Now, the variation of the electric potential as a function of the leakage distance for different element of the insulators string (five cases) is presented in the figure below.

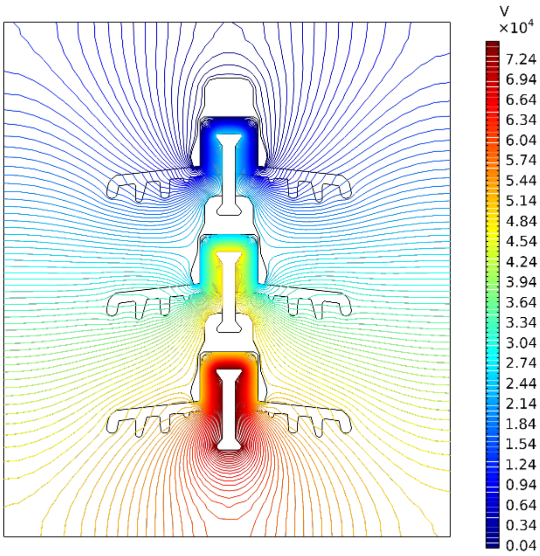
From figure 5, we can see that the value of the potential in the presence of pollution is very high compared to its absence in all cases. Looking at figure 5(a) to 5(e), we can see that as the number of insulator in the chain increase at the end of the chain the potential drops to the values found from the clean state of the chain. It is also obvious looking at figure5(a) to 5(c), that the electric potential starts to develop according to a pattern, so predicting the potential around the chain with six insulators is possible.



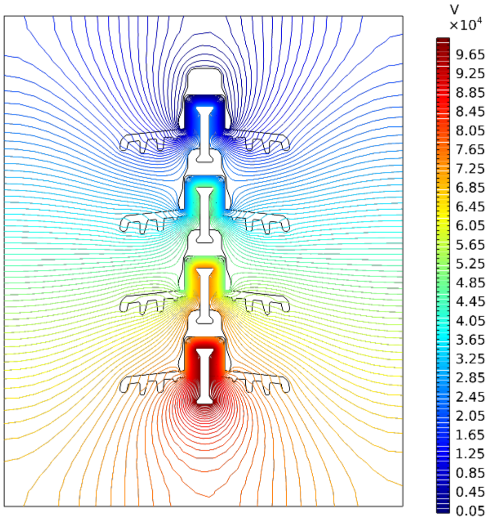
(a) One insulator,



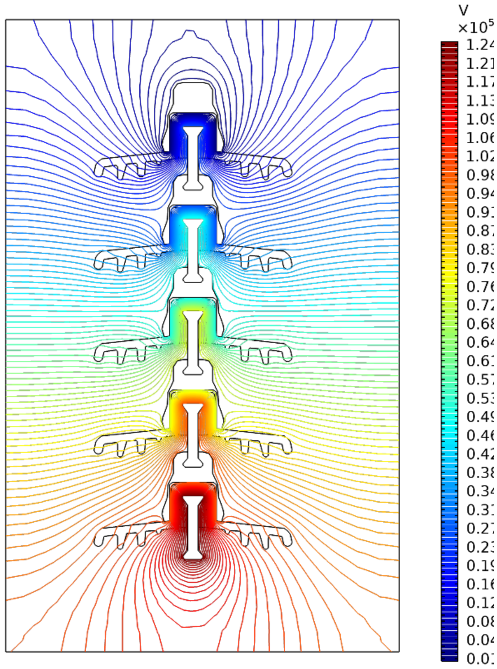
(b) Two insulators,



(d) Three insulators,



(e) Four insulators,



(f) Five insulators.

Fig. 4. Potential distribution and equipotential lines for insulators string in the clean state for five cases

It can be seen that the presence of pollution in this form does not distort the shape of the distribution by much, only its value from the side in which it is stationed on (pin side in this case).

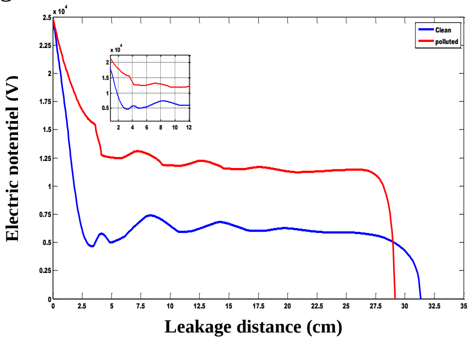
4.1. Electric field (EF) distribution

The performances of the insulators installed in polluted regions represent the factors of first importance in the architecture, the sizing, the quality and the reliability.

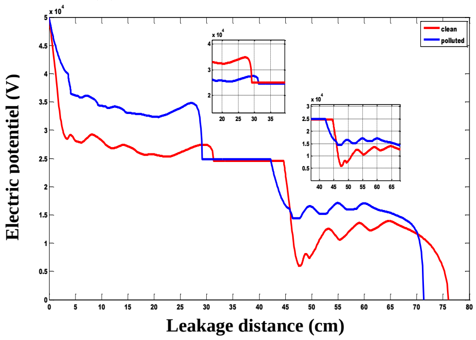
High-voltage insulation, In order to monitor the quality of insulation of a structure, it is imperative to really know the mechanisms leading to bypass under pollution.

Figure 6 shows the electric field distribution and equipotential lines for different cases of the insulators string surface in the clean state for five cases, with electric field vectors.

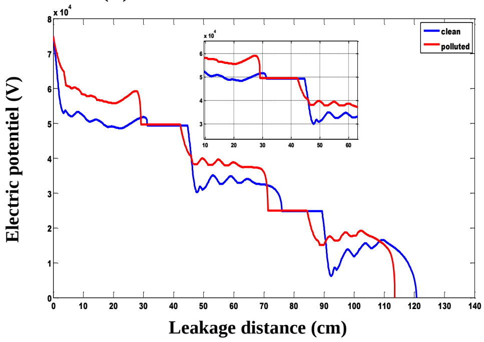
The figures of the contour and streamline above show that the electric field is concentrated around the upper side of the pin and the lower side of the cap where it touches the glass. While the streamlines show the occasional break of the line when entering the glass.



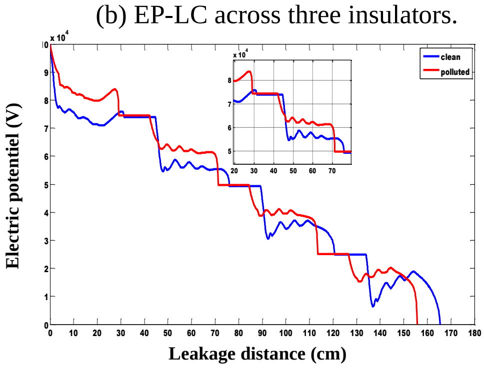
(a)EP-LC across one insulator.



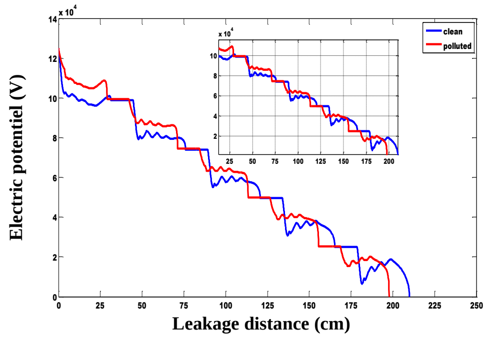
(b) EP-LC across two insulators.



(b) EP-LC across three insulators.



(c) EP-LC across four insulators.

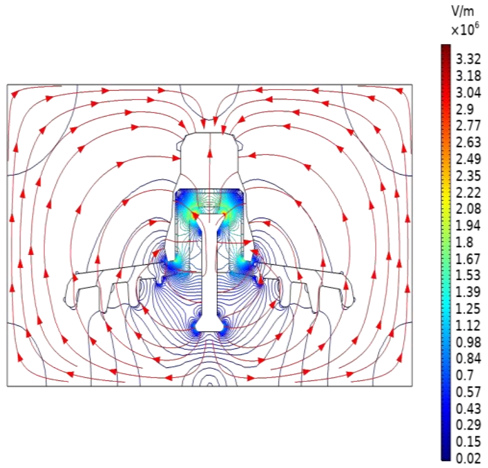


(c) EP-LC across five insulators.

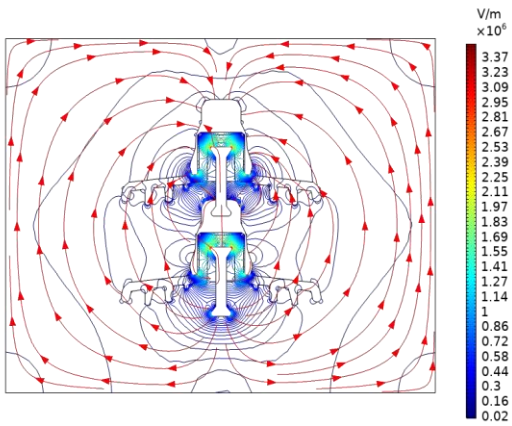
Fig. 5. Electric potential-leakage distanceacross five insulators

Despite the change in the number of the insulators, the same distribution occurs in the electric field whether the contour or the streamline plots.Just like the potential, thegreatest changes in the field happen around the center of each insulator between the pin and the cap.

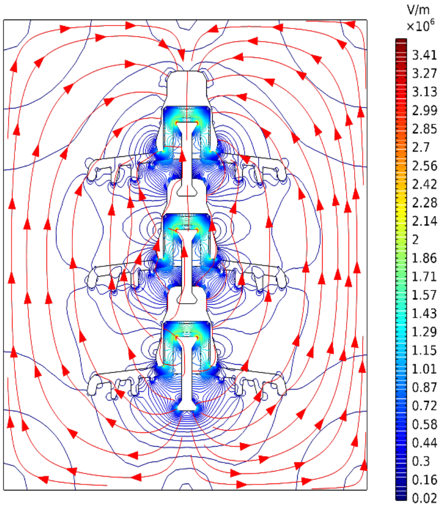
Suitable for high voltage outdoor transmission line applications, the electric field distribution along an insulator is studied under contaminated conditions to assess the effect of contamination on the electric field stress along the insulator surface and the potential for corona and dryband arcing.



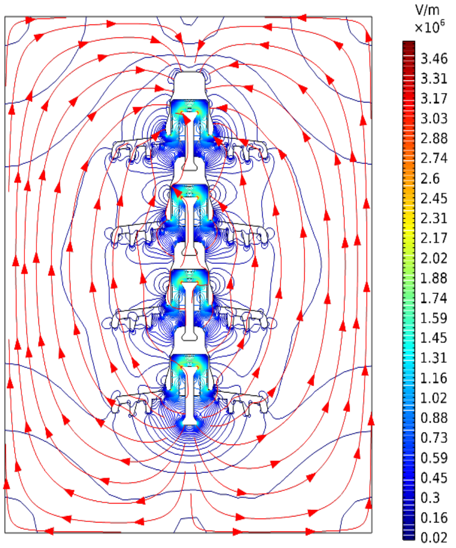
(a) One insulator,



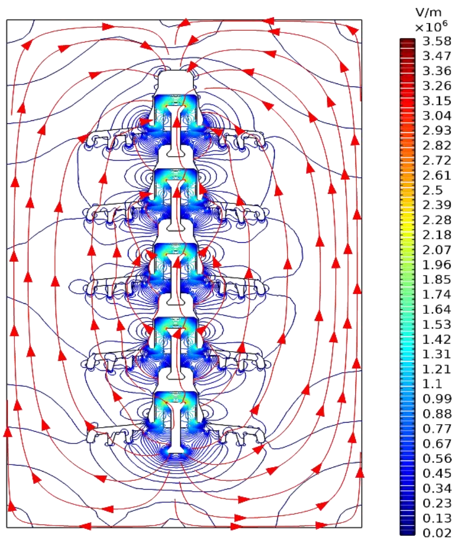
(b) Two insulators,



(d) Three insulators,



(e) Four insulators,

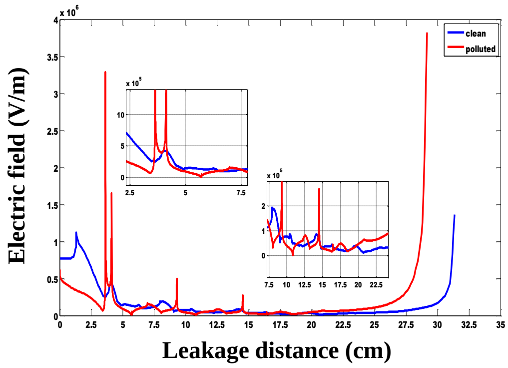


(a) Five insulators

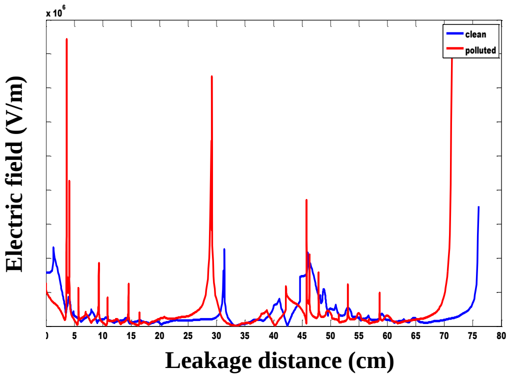
Fig. 6. Electric field distribution and equipotential lines for insulators string in the clean state for five cases

Looking at figure 7, we can see that the pollution causes the value at the start to drop and induces high value spikes of the electric field along the leakage distance and contrary to the start it causes the value at the end to rise significantly. Adding more insulators to the chain, the value at the end stays relatively the same compared the clean state.

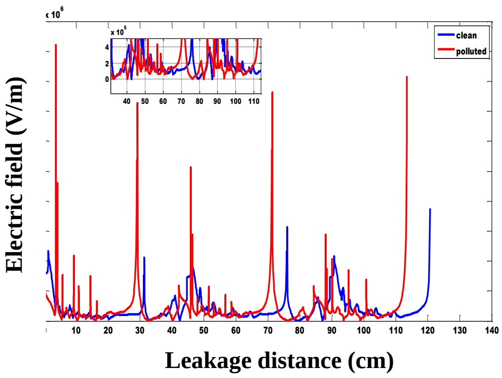
Spikes are created at the start of every insulator in the chain with every spike having a higher value than the one before it. The values at the start of the chain and the end of the chain on the pin side are always the spots where the electric field has the highest value.



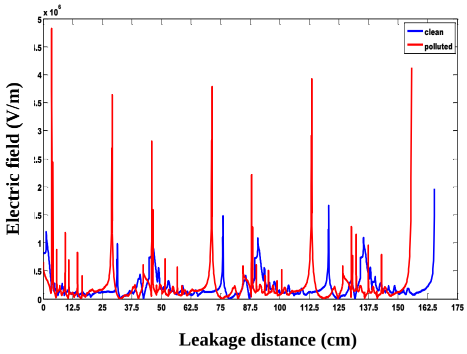
(a) EP-LC across one insulator



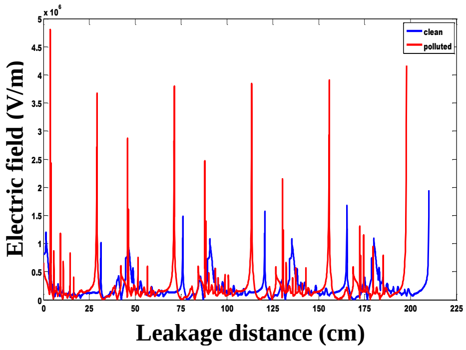
(b) EP-LC across two insulators



(c) EP-LC across three insulators



(d) EP-LC across four insulators



(e) EP-LC across four insulators

Fig. 7. Electric field-leakage distance a cross five insulators

The places where the field values are high are the highly likely places where the arcs start at. Similar to the composite insulator, cap and pin insulator will have the arcs start between the glass (sheds in the case of the composite insulator). The arcs in our insulator can also start at the cap side from the cap to the glass creating a route to the pin.

6. CONCLUSION

From these simulations, a clear observation can be taken and that is that after two insulators the electric potential and electric field start taking a certain pattern, which helps to predict its behavior under uniform pollution. It can also be seen that the presence of pollution in this form does not distort the shape of the electric potential distribution only its value on the pin side while the value of the potential stays the same on the metal parts of the insulator starting from the cap of the first one. The same cannot be said for the electric field distribution since the presence of the pollution even though in a uniform shape, it induces high value spikes that leads to various problems that lead to premature aging and ultimately flashover.

One of the solutions would be increasing the length of the pin of the insulator in other words increasing the length between the insulators in a chain. Another is to add a somewhat similar shape to the glass on the cap side like on the pin side.

Author contributions: *rresearch concept and design, O.G.; Collection and/or assembly of data, O.G., H.B.; Data analysis and interpretation, O.G., H.B.; Writing the article, O.G.; Critical revision of the article, H.B., L.B.; Final approval of the article, O.G., H.B., L.B.*

Declaration of competing interest: *The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.*

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