Study on Effect of Size and Location of Void on Electric Field and Potential Distributions in Stator Bar Insulation with finite-element-model

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Abstract: Insulations are the most important part of high voltage equipment such as cables and machines. Therefore the study of the condition and mechanism of failure of high voltage insulations is important. In this paper the electric field and potential distribution in the insulation of stator bar are studied. In particular, the effects of the size and location of the void in the insulation are investigated. COMSOL software was used to carry out the simulation based on the finite element method (FEM). A 2D modeling of stator bar insulation was used in this work. The results show the electric field is affected by the size and location of the void in the insulation, in terms of the field strength and uniformity. The results of this work to help improve the understanding of the electric field response due to the size and location of void within the stator bar insulation.

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1. Introduction

Insulators are the most important part of high voltage equipments such as cable, machines and etcetera. Based on last researchers, the main reason for errors and problems in machines is insulation. Fault and Errors in insulations almost will make some severe damage to machines and equipments. [1-4] The cavity can occur in the insulation during the construction, installation and operation. Operational stress that occurs in insulations is including thermal, mechanical and electrical effects that will change the chemical and physical properties of insulations, so it could make destruction. The most important reasons of faults in insulations are the existence of void in insulation. PDs are small electrical discharges that occur in high value of electrical field owing to condition around the fault area in insulations [2, 4-7]. Internal discharges also happen in insulation due to the high stress of electrical field with help of voids, breaks or blobs. Electrical permittivity of air filled void is lower than a dielectric insulator. Therefore this will make a high tension area and a weak point in insulator.

Polyesters and epoxy resin are special thermosetting polymers that have wide usage in machine insulation [1, 4, 8-10]. Regarding the bond of oxygen atoms in carbon chains of atom building and fixed dipole mode of Polyester resins, their permittivity and water absorption will increase.

Epoxy resin has higher properties; they are non-polar, powerful mechanical properties, highly resistant and will compound with many materials.

But, they are more expensive than polyester resins and they need more control in the production process. These days epoxy resins are the best insulators for high voltage stator insulators.

The study of electric field and potential distribution in dielectric insulation with void is important for evaluating of partial discharge and breakdown failure in insulation.

Modeling of electrical field in insulation with void is under investigation. Davies and Chen studied the models of voids inside the dielectric [1, 2]. There is also research done to model or simulate various insulation ageing phenomena in order to improve the condition monitoring of the device. A lot of work had carried out simulation work on cable and polymers [1, 3, 12- 14]. However, little data are available on the machine winding materials. This paper studies the electrical field and voltage distribution in machine stator bar insulator. It is focused on the changes and the effects of electric field in insulators by FEM (finite element method). The effect of void size and its place in stator bar insulator is submitted. The results will make more deep understanding of modeling stator insulator and insulated electrical field interaction.

2. Electrostatic Model

Electric field distribution in insulator by 2D field models is explained. This model is modeled in a non-degraded system and is as a base for analysis. Also, an air filled void model will use for investigating the effect of void on the stator bar insulator.

The mathematical equation of electric field distribution in the insulation is used for modeling the electric field regards to the model of the insulation system.

Equation 1 shows the relation between electric field (E) and electric potential (V). As it can be seen electric field is equal to the negative gradient of electric potential.

$$E = -\nabla V \qquad (1)$$

This relation between electrical field (E) and electrical displacement (D) for insulators, regarding relative permittivity ε of the insulator and free space is submitted in equation 2.

$$D = \varepsilon E \qquad (2)$$

$$\varepsilon = \varepsilon_0 \varepsilon r \qquad (3)$$

where ε_0 is is the permittivity of free space that it is 8.854 187 817 × 10−12 farads per meter ($F.m^{-1}$)
from equation 2 and 3 the equation 4 is earned

$$D = \varepsilon_0 \varepsilon r E \qquad (4)$$

The relation between electric replacement D and charge density ρ is represented in Gauss' Law equation 5.

$$\nabla . D = \rho \qquad (5)$$

The flux can be related to electric charge follow by equation 5

$$\nabla . J = Qj = - \partial\rho/\partial t \qquad (6)$$

Where J is flux and Q is the electric charge

$$J = \sigma E + \partial D/\partial t + Je \qquad (7)$$

Equations 5 and 6 give equation 8

$$\nabla (J + \partial D/\partial t) = 0 \qquad (8)$$

Therefore substituting equations 2, 7 and 1 into equation 8 will earn equation 9

$$-\nabla (\sigma + (\partial \varepsilon/\partial t) \nabla V = 0 \qquad (9)$$

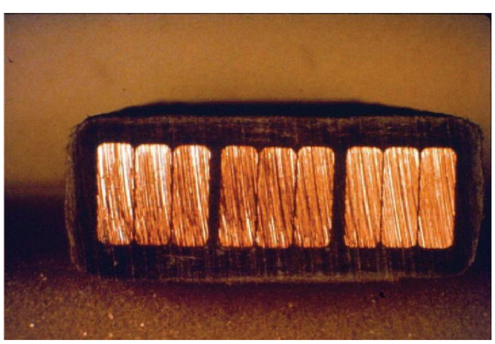


Figure 1. Cross-section of a three-turn coil made with an epoxy mica paper insulation system [3].

The above equations are used by COMSOL software for calculating the electric field and charge density by finite element method [4, 7-8, 15].

3. Geometry and Model

Figure 1 shows the Cross-section of a three-turn coil made with an epoxy mica paper insulation system [3, 16]. Based on figure1, a stator bar is modeled for analyzing the behavior of electrical field and electrical potential distribution inside a cavity. Figure 2 shows the common construction of stator bar. The dimension of the geometry is taken from the common stator bar for 11kV machine. The conductor is copper which is 4mm×9mm.The overall dimension of the stator bar geometry is 45mm×13mm.This model has dielectric epoxy resin of 50 mm x 10 mm. The FEM simulation was carried out in 2D. Figure 3 shows the model geometry and the generated mesh of the simulation. The size of mesh is extremely fine especially at boundary regions. In addition, the mesh inside the cavity has 1200 rectangular elements in order to have better observation for electric potential distribution and electric field in the cavity.

The electrical properties of the material those are used for modeling the stator bar are given in table 1.

Table 1. Electrical properties of materials

Material	Conductivity (S/m) , σ	Relative permittivity , εr	Resistivity (Ω.m), ρ
Copper	5.96×10^{7}	1	1.68×10^{-8}
Air	8×10^{-15}	1.0005898	1.3×10^{16}
Epoxy mica	3×10^{-12}	5-7	3.3×10^{11}

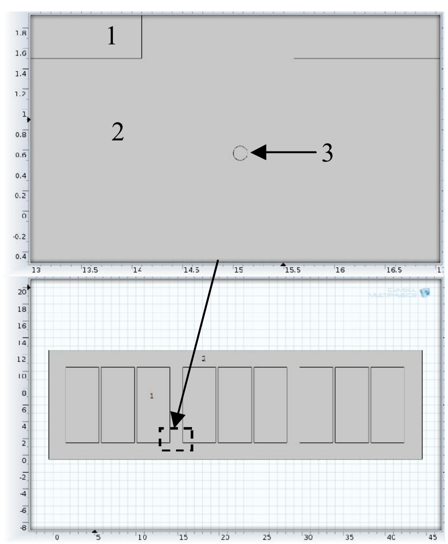


Figure 2. Geometry of stator bar indicating the (1) conductor, (2) insulation, (3) cavity

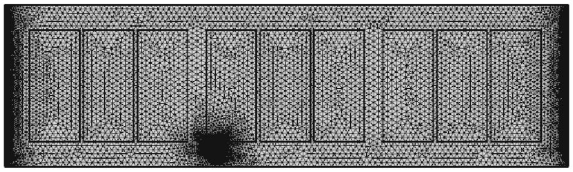


Figure 3. FEM generated mesh indicating concentrations of elements around key regions

4. Simulation Results

Figure 4 shows the distribution of electric potential in the insulating material of the stator bar. The values shown are at the θ=90° (peak value) of the sinusoidal applied voltage.

From this figure, it can be seen the electrical potential is high around the conductor boundaries and is low around the ground boundaries. The lines of same potential field are parallel with ground line.

Figure 5 shows the distribution of electric field in the insulating material of the stator bar. The values shown are at the θ=90° (peak value) of the sinusoidal applied voltage, or at 0.005 sec instant. From this figure, it can be seen the electrical field is zero in conductor but it is high around the conductor boundaries and is low around the ground boundaries. It can also be clearly seen that electric field is higher at the sharp corners of the stator bar.

Figure 6 and figure 7 are show the potential and electric field distributions in the region around the cavity for the cases of with and without the cavity.

The uniformity of electric field in stator bar

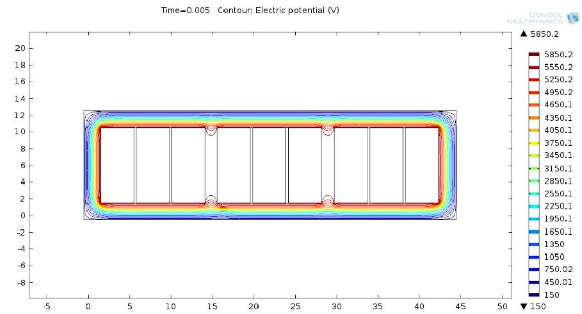


Figure 4. The electric potential distribution in the stator bar at θ = 90°. (peak value).

insulator at the time 0.005 second while the electric potential of conductor is maximum. Also the effect of the air filled cavity on uniformity of electric field is shown in figure 5 (b). The radius of the inserted void is 0.05mm.

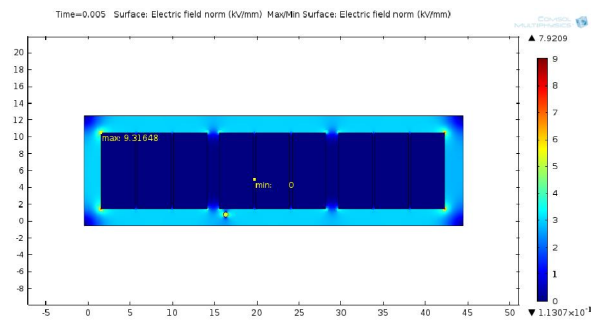
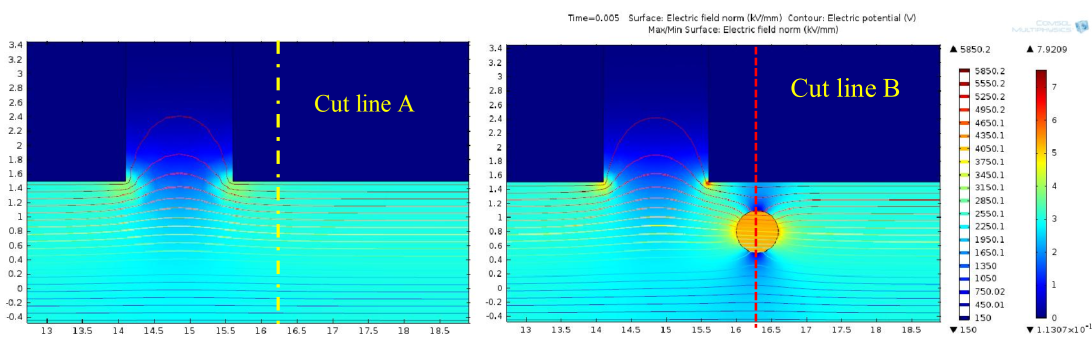


Figure 5. The electric field distribution in the stator bar at θ = 90° (peak value).



(a) (b)

Figure 6. (a) The potential and electric field distribution in the stator bar insulation around the cavity area for the cases of (a) without the cavity present, (b) with a cavity present. The values are for θ=90° or 0.005 s instant.

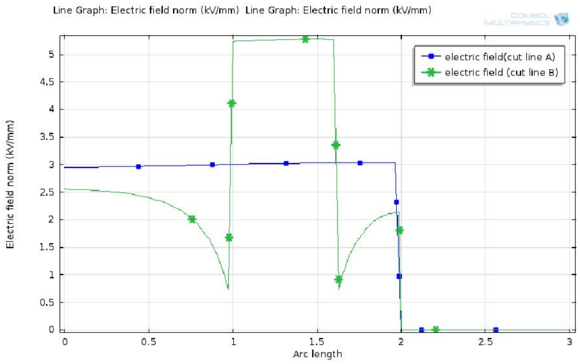


Figure7. The electric field in the stator bar insulation

From the theoretical and from the result of simulation the electric field is strong inside the void compare to the main part of insulator due to the lower permittivity of air filled cavity. Based on these figures, it is clear that epoxy insulator around cavity in horizontal axis (axial) and vertical axis (axial) of electrical field tension will increase and decrease respectively. This change in electrical field stress is because of electric potential around the cavity and also lower permittivity of the cavity and its spherical shape.

Figure 8shows the effect of void location on the electric field through the stator bar insulation at the time 0.005 second while the applied AC voltage on conductor is maximum. As it can be seen, location of the void is one of the important factors that have effect on the strength of the electric field inside the void.

Base on the result From the Figure 6, the electric field stress inside the void is 5.54kV/mm while the void is located near the ground boundary. Also it is 5.74kV/mm when it is inserted near the conductor.

Another important factor that is interesting for studying the effect of cavity on electric field and potential distribution is the size of the cavity inside the insulator. Figure 9 shows the result of simulation about this phenomenon. For investigating the behavior of holes in different size in insulator, the diameter of hole increase from 40 um to 350 um.

Figure 10 shows the uniformity of the electric field within various size of the cavity. It is clear that the increasing in void size will decrease the tension of electrical field. Three point of the cavity is measured for showing the uniformity of electric field inside the cavity. The blue curve shows the electric field at the top point of the cavity. Furthermore; the red curve shows electric field at the bottom of the cavity. The electric field at the center of the cavity is shown in green curve.

The electric field is non-uniform when the size of the cavity is larger than 150um. It is due to electric potential dispersion around the cavity. As it is mentioned before PDs are small electrical discharges that occur in high value of electrical field. Therefore existence of cavity in insulator is one of the most reasons that why partial discharge is happens in insulation. Internal discharges also happen in insulation due to the high stress of electrical field with help of voids, breaks or blobs. Therefore Simulation the behavior of electric field stress in the cavity can help the researcher to investigate about partial discharge.

5. Conclusion

Electrical filed modeling and electrical potential distribution are performed by FEM method for simple stator insulator. Air filled void in insulator will increase electrical filed stress inside the insulator due to lower permittivity. The simulation is done in studying the effect of size and location of void in insulator. The result from the previous work that was done on 11kV XLPE cable is shown the electric field is 4.38kV/mm while the applied voltage is 16kV that it is because of the thickness of the XLPE insulation and geometry of cable.

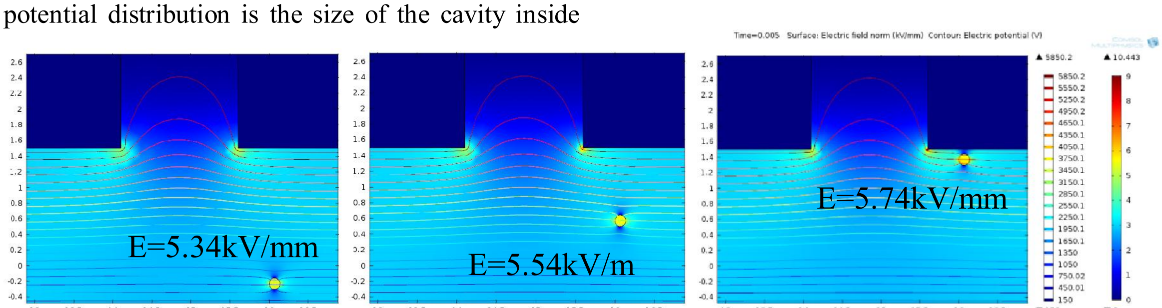


Figure 8. (a) The electric field and potential distribution through the stator bar insulation at the time 0.005 second when the void is near ground boundary 5.54kV/mm, (b) when the void is in the middle of insulator 5.34kV/mm, (c) when the void is near the conductor 5.74kV/mm

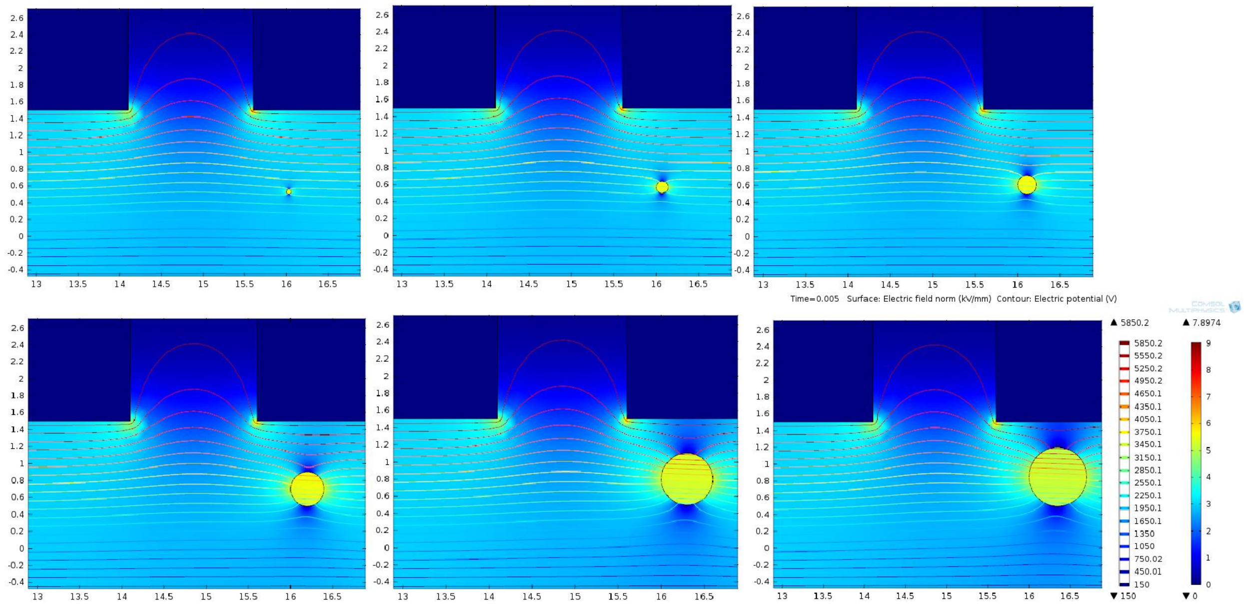


Figure 9. The electric field and potential distribution through the stator bar insulation at the time 0.005 second various sized cavities 40um,50um, 70um, 200um, 250um,300um,350um.

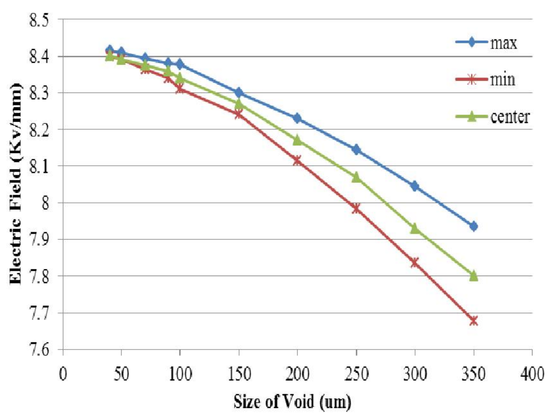


Figure 10. Electric field in a cavity for various sized cavities.a:40um, b:50um, c:70um, d:200um, e:250um,f:300um, g:350um

In addition other work that was done with another software for simulation and different geometry and material on Oil Impregnated Paper and oil barrier insulation also show the effect of cavity, air filled or oil filled, on the insulation[7- 10]. In this simulation the COMSOL is used for analyze the effect of void in the stator bar epoxy mica insulator. From the results, the electric field is higher when the void is located near the high voltage electrode.

The electric field is 5.74kV/mm when the void is located near the conductor and it is 5.34kV/mm when it is close to ground boundary. In addition electric field stress is decreased when the size of the void is increasing. On the other hand the electric field is more non-uniform within the bigger size of void. It is changed from 5.57kV/mm to 4.94kV/mm while the size of void inside the insulator is changed from 0.03mm to 0.35mm.

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