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Analysis of Electric Field in 72.5kV condenser bushing using FEM based software

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ABSTRACT

Transformers are important components in electrical power system and also represent very huge investments. The effects of failures in power systems namely faults, outages lead to loss of revenue and have serious effects on operational performance. Transformer failure analysis shows that about 10% of the transformer failures are caused due to damages in the bushings and this percentage is even more for large rating.Condenser types have a central conductor wrapped with alternate layers of paper insulation and aluminium foils filled with insulating oil. Each aluminum foil/conductive layer acts as a condenser and voltage equalizer. The condenser model is designed in UNIGRAPHICS, and the potential and field distributionare analyzed using FEM based software ANSYS MAXWELL. The filed analysis of the model also carried out for different cases like by equalizing the dielectric thickness between the foils, by increasing the foil length and by increasing the foil numbers.

KEYWORDS: 72.5kV condenser bushing, Aluminum foils, Oil impregnated paper insulation, FEM, ANSYS MAXWELL

1. INTRODUCTION:

The power transformer plays significant role in power network and has huge investment. The consequence of failure of bushings caused due to moisture ingress, puncture, flashover, and insulation degradation are the main reason for transformer failure. This causes loss of economy and increases cost of repair in modern power network. In modern days, power transformer requires oil-paper insulation type of condenser bushings for high voltage rating from 52kV and above [1].

OIP bushing of condenser-type are most in service and about 80% of power transformers in the world are depends on condenser bushing operation. Reasons behind the failure of power transformers is 20%-35% of faults by bushings [2]. The preponderance of bushing failures is from moisture ingress, puncture and electric flashover. Hence dimension of insulation material and dielectric permittivity values are essential for field distribution analysis of bushing to enhance the power system reliability. The radial stress and intensity of field have more impact on insulation failure and higher field distribution that develops the leakage path along insulation which in-turn causes puncture of bushings that leads to huge impairment of whole power system [5]. The axial stress and effect of vertical field distribution are the main reasons for the electrical flashover.

In this work, electric field distribution has been carried out on condenser bushing by FEM using ANSYS Maxwell software. For 72.5kv condenser bushing design purpose ABB company GOB type bushing data [7] is used and modeled in UNIGRAPHICS software. ANSYS Maxwell software which is work on FEM is used for the analysis for better accuracy. The proposed work discusses the distribution of electric field and potential of OIP condenser type bushing.

2. MODEL SIMULATION OF OIP CONDENSER TYPE BUSHING

72.5kV OIP bushing of condenser-type is modelled on voltage rating according to IEC 60137 standard and 3D model is modelled in the UNIGRAPHICS software according to GOB type technical guide. It is imported and converted to 2D proposed model, designing of condenser bushing and analysis is carried out to determine the potential and field distribution. In 2D model the 16 layers of conductive foils designed with 0.025mm thickness and 17 OIP layers are designed with 1.1mm and 1.2 mm thickness alternative to the conductive foils.

Further the different cases are made they are, case (1) condenser bushing OIP layer thickness is increased. And in case (2) condenser aluminum foils length is increased in case (3) condenser aluminum foils number is increased to observe

the radial and surface axial field distribution. The analysis is done using electrostatic field solver to analyses the static field distribution around and in the condenser bushing by using the ANSYS Maxwell software. OIP condenser bushing is shown in fig.1.

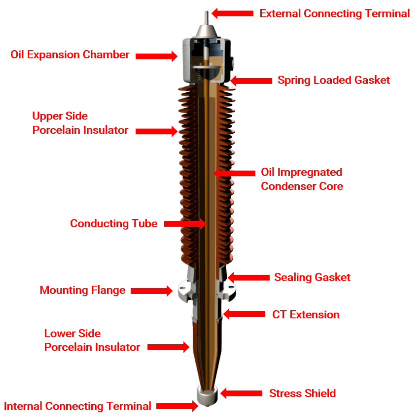


Fig.1: OIP condenser type bushing

3. SOLUTION USING FINITE ELEMENT METHOD

ANSYS is a simulation software which solves using finite element method. It solves electromagnetic low-frequency scenarios for both 2D and 3D models. ANSYS uses four Maxwell's equations .

$$\nabla \times H = J + \frac{\partial D}{\partial t} \qquad (1)$$

$$\nabla \times E = -\frac{\partial B}{\partial t} (2)$$

$$\nabla \cdot D = \rho (3)$$

$$\nabla . B = 0 (4)$$

E- electric field intensity, V/m

H- magnetic field intensity, AT/m

D- electric displacement,

ρ- charge density, C/m^2

B- magnetic flux density, T

J- conduction current density, A/m^2

ANSYS Maxwell is a simulation software which is uses finite element method to solve the electric and magnetic problems It solves using finite element method by using following steps:

1. Model geometry is built or imported.
2. Model is assigned by materials with respective electric properties.
3. Model is assigned with mesh operation for all region.
4. Model is assigned with boundary and excitation condition.
5. Respective Solver is used for field simulation.

The 3D model from UNIGRAPHICS is imported to ANSYS Maxwell. Then 3D model is converted to 2D by Maxwell 2D converter. For conversion from 3D to 2D the YZ section plane is chosen and 2D geometry mode is about Z-axis. Then after 2D conversion the axial-symmetry part of bushing is taken for the analysis.

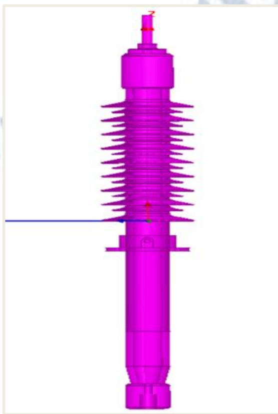


Fig.2: 3-Dimensional model of 72.5kV condenser bushing

The filling of material for each part is done with specification of material. The parameter of relative dielectric permittivity and volume resistivity to the model is given in the table.1.

Table1: Parameters assign to the model

Materials	*Relative permittivity(ε_r)*	*Volume resistivity (Ωm)*
Air	1	7.6×10^{15}
Aluminium	1	2.4×10^{15}
Aluminium foil	10000	10^{14}
Copper conductor	1	1×10^{15}
Mineral oil	2.4	1.72×10^{-8}
Porcelain	6	2.82×10^{-8}
OIP(kraft paper)	4	2.82×10^{-8}

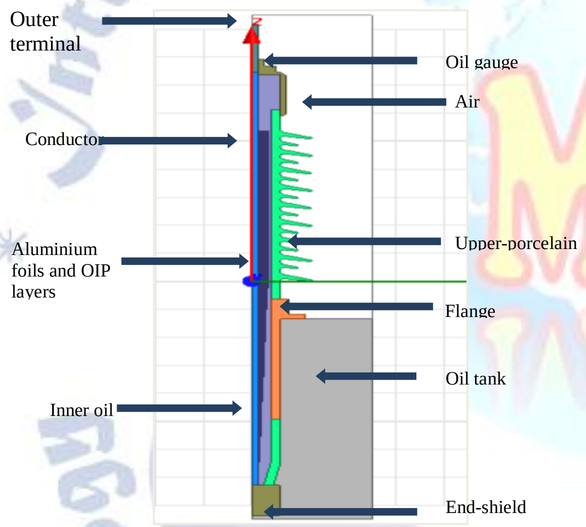


Fig 3:2-Daxi-symmetricalproposed model of 72.5kV condenser bushingcondenser bushing

The electro-static solver is used to analyze the static electric distribution in and around the condenser bushing. The excitation conditions are employed with the voltage parameter to the 72.5kv rating bushing copper conductor is 72.5kV according to IEC standard. The ground potential of 0V is applied on mounting flange and uttermost foil layer.

Proposed Model of 72.5kV condenser bushing

The 72.5kV bushing of condenser type in 2D is modelledwith 16 layers of aluminium foil and 17 layers of OIP. In this proposed model, the 15 aluminium foils thickness is of 0.025mm and foils length is referred from [5]. The last layer of foil the thickness is 0.13mm.Then material is assigned with analysis setup. The excitation is employed with voltage of 72.5kV to the bushing copper conductor. The ground potential of 0V is applied on mounting flange and uttermost foil layer of this 72.5kV bushing. And this proposed model is simulated for the estimation of potential and field distribution in the bushing.

CASE(1) Modification case of OIP thickness

The modification of OIP thickness for proposed model dimensions of bushing is done by changing the thickness of each OIP layers by 1.4mm. Then, the model is simulated to analyze the field distribution.

CASE(2) Modification case of layers of aluminium foils length

The modification of layers of aluminium foils for proposed model dimensions of bushing is done by increasing the length of each foil by 25mm. Then, the model is simulated to analyze the field distribution.

CASE(3)Modification case of layers number of aluminium foils

The modification of layers number of aluminium foils for proposed model dimensions of bushing is done by adding extra two layers of length 515mm and 470mm of each foil by 0.025mm thickness [5]. Then, the model is simulated to analyze field distribution.

4. RESULTS AND COMPARISON

After, simulating above proposed model of 72.5kV using 2d electrostatic solver to analyze the static field in the bushing by ANSYS MAXWELL following results are obtained for voltage and field distribution in three vicinities.

The condenser bushing model design is done as stated in the GOB type. The proposed model is sectionalized into three areas for appropriate analysis. The region sections vicinities 1, 2, and 3 as shown in figure 4.

Sections of region consists of vicinity-1 consist mainly of air region, large and small sheds of upper porcelain which is spot of air region. Then plots are taken axial length through the external surface of upper porcelain. The polyline is drawn along the external surface for graph plotting purpose.

Vicinity-2 is considered with aluminium foils and OIP layers surrounded by mineral oil. Then plots are taken from the path of central copper conductor through the layers of foils and OIP layers. The polyline is drawn across the length of layers to plot graphs on that path.

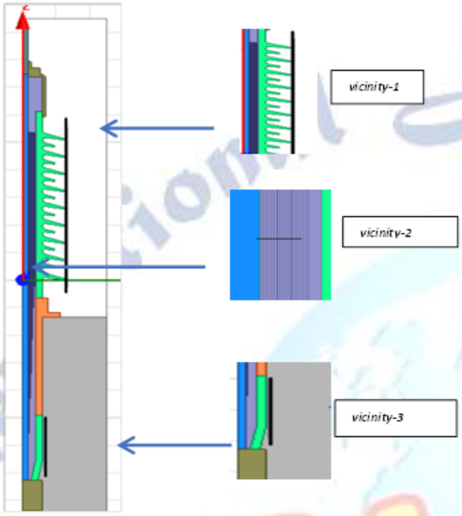
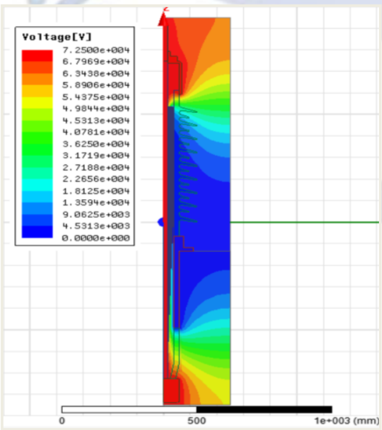


Fig.4: 72.5kV condenser bushing with different-vicinities

Vicinity-3 consists of lower porcelain part which is dipped in the oil present in the transformer tank. Then plots are taken through axial length to analyze the potential and field of the vicinity-3. The polyline is drawn along the lower porcelain part to plot graphs.

Proposed model of 72.5kV condenser bushing

In this work, by applying 72.5kV voltage to the condenser bushing the static potential and field distribution of bushing is analyzed. The potential and the field distribution is shown in fig.5 after the simulation.



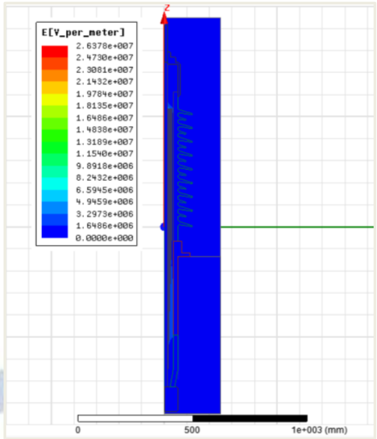
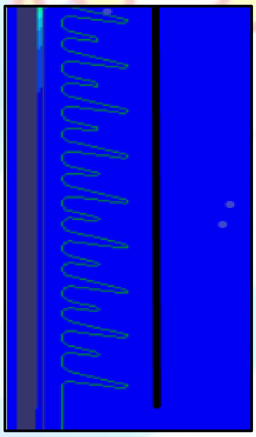


Fig.5: Potential and field distribution in proposed model of condenser bushing

The field distribution is uniformly distributed due to the presence of aluminium foils and OIP layers. And field is higher at the OIP layers and as we move towards the porcelain body and air it decreases. Because the dielectric value of permittivity is different for OIP layers, porcelain and air. The maximum electric field is 2.6378 × 10^7V/m in proposed model of condenser bushing.



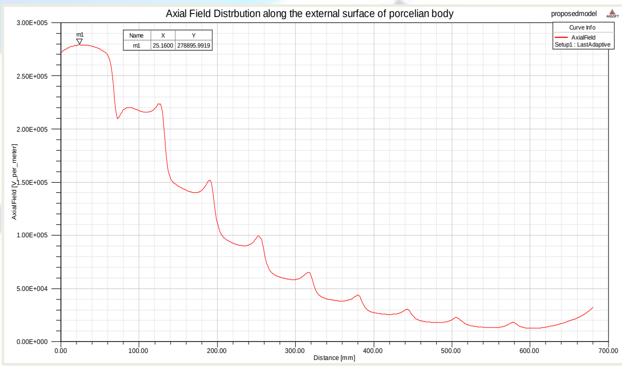


Fig.6: Field distribution of proposed model along the surface and its plot in vicinity-1

As the vicinity-1 is the external surface of 700mm polyline is drawn that is the part of porcelain in air region the field distribution is maximum at the first shed as moving towards the field decreases at the last shed of the porcelain bushing. The maximum field is at 25mm distance from the upper porcelain the value is 2.7889× 10^5 V/m.

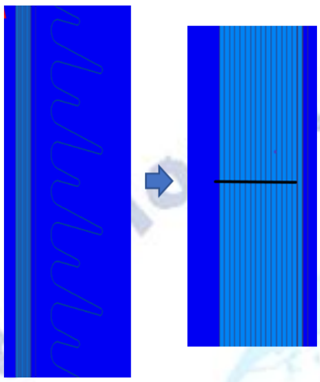


Fig.7: Radial field distribution in proposed model of condenser bushing across the

The field distribution across the aluminium foils and OIP layers from the copper conductor is shown in fig.7. The foils of 0.025mm thickness are arranged in alternative with the OIP kraft paper. This presence of aluminium/conductive foils make the uniform distribution in field across the radial length of vicinity-2. The plot across the layers as shown by polyline in fig.8. The plot appears in the stack like structure with zero value in 0.025mm gap at each stack because it covers the area of aluminium foil.

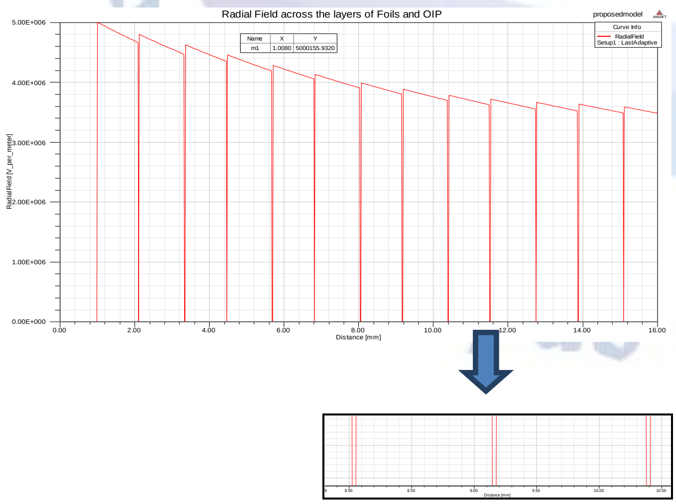


Fig.8: Radial field distribution in proposed model of condenser bushing across the vicinity-2

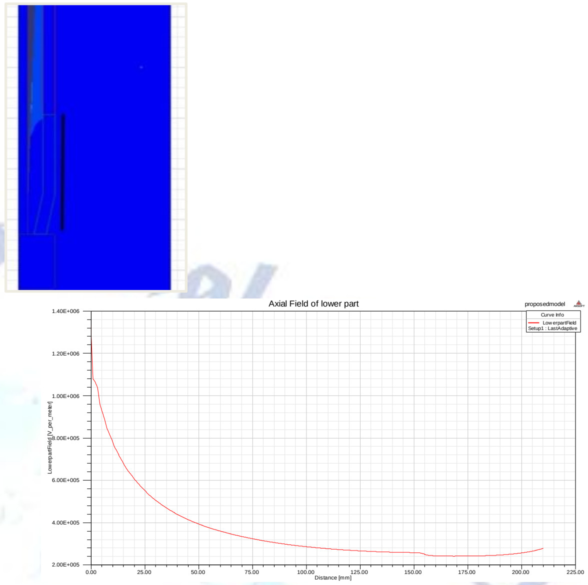


Fig.9: Potential and field distribution along the vicinity-3 and its plot

Fig.9 shows the axial field distribution along the lower porcelain part and its plot. The porcelian lower part provides the supporting structure to entire condenser bushing body. As the lower porcelain is under attachment with the aluminium mounting flange the potential distribution occurs along the lower porcelain part including end shield. Maximum field concentrated at the contact of flange and the lower porcelian part.

CASE(1) Modification with OIP thickness

As the dimension from [5] for foils is maintained the same with changing the thickness of OIP layer from 1.1 – 1.2mm to 1.4mm is made in this case. As oil impregnated kraft paper having the dielectric constant value 4 having the best dielectric strength which helps to decrease the field distribution. The modified case of condenser bushing is simulated for same parametric conditions of proposed model. The simulated modified model gives the lesser field distribution than the proposed model. Maximum field distribution is 1.8000×10^7 V/m. Fig.10 shows the potential distribution of the OIP thickness modified model of 72.5kV condenser bushing.

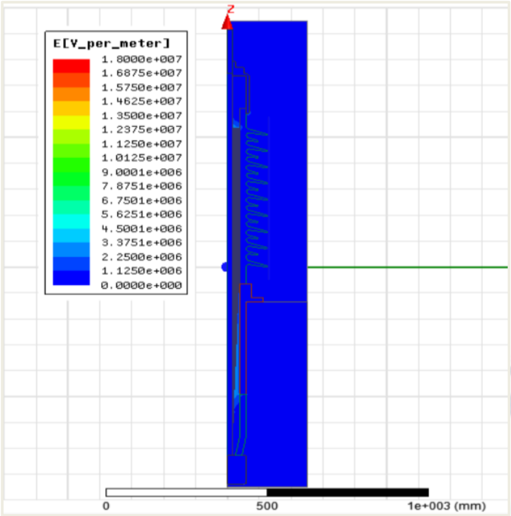
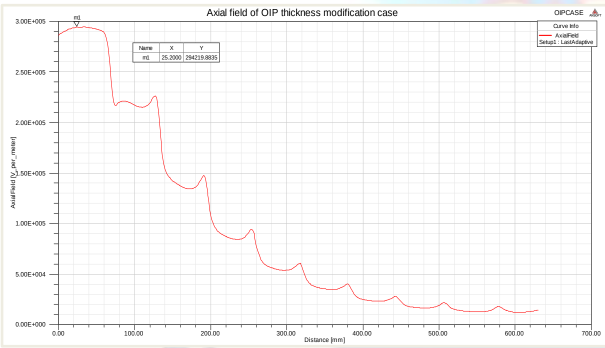
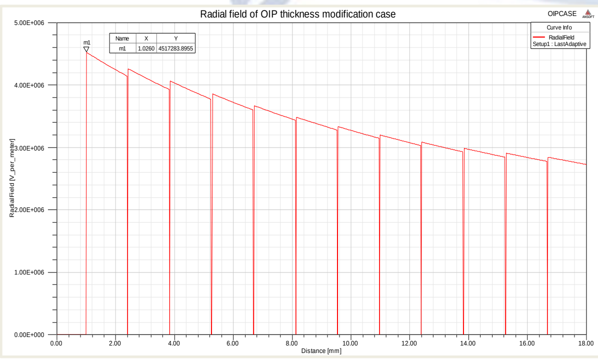


Fig.10:Field distribution of the OIP thickness modified model of condenser bushing.

Fig.11 (e) and (f) shows the plot of field distribution along the axial surface of the upper porcelain and across the radial path of the layers arranged next to the copper conductor respectively. The maximum field distribution point along the surface is 2.9422×10^5 V/m and across the radial path is 4.5173×10^7 V/m. Due to modification of OIP thickness to 1.4mm the field along the surface is increased compared to proposed model but the radial field distribution is decreased. Hence OIP thickness decreases the radial stress of the bushing.



(e)



(f)

Fig.11: Field distribution along the surface of upper porcelian and across the layers of foil and OIP

CASE(2) Modification with layers of aluminium foils length

As the dimension from [1] for foils are increased by 25mm with the thickness of OIP layer from 1.1 – 1.2mm to 1.4mm is the modified case. The dielectric constant of foils is 10000 which provide the uniform distribution in OIP layers with decreased field distribution. The modified case of condenser bushing is simulated for same parametric conditions of proposed model. The simulated modified model gives the lesser field distribution than the proposed model. Maximum field distribution is 2.4875 × 10^7 V/m. Fig.12 shows the potential distribution of the OIP thickness modified model of 72.5kV condenser bushing.

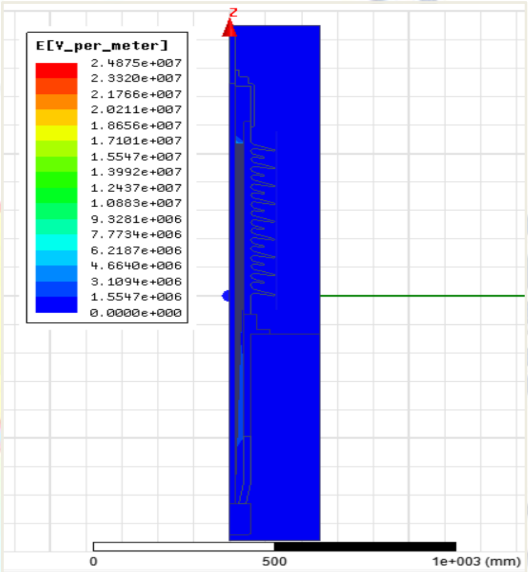
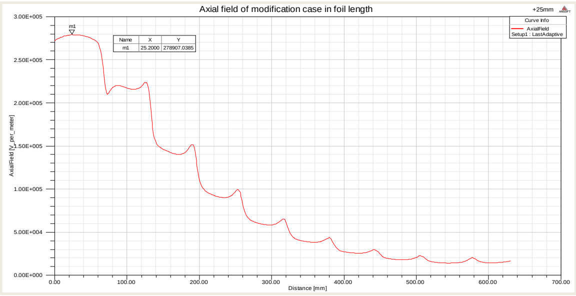
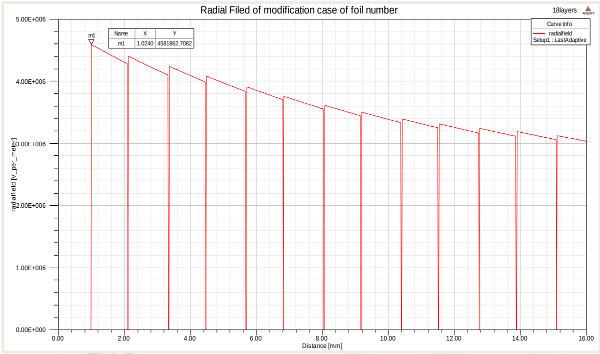


Fig.12:Field distribution of the OIP thickness modified model of 72.5kV condenser bushing.

Fig.12: (g) and (h) shows the plot of field distribution along the axial surface of the upper porcelain and across the radial path of the layers arranged next to the copper conductor respectively. The maximum field distribution point along the surface is 2.7891×10^5 V/m and across the radial path is 4.9674×10^6 V/m. Due to modification in the aluminium foil length the field along the surface and also the radial field distribution across the layers were decreased. Hence increase in the length of foil decreases both axial and the radial stress of the bushing.



(g)



(h)

Fig.13 (g) and (h) Plot of field distribution along the axial surface of the upper porcelain and across the radial path of layers

CASE(3) Modification with layers number of aluminium foils

From the dimension of proposed model of bushing 16 layers of aluminiumfoils and 17 layers of OIP with the thickness of OIP layer from 1.1 – 1.2mm. As aluminium foils are used for regular custom field distribution in OIP layers. By increment in number of foils the decreased field distribution can be reached out. As 16 layers presence in proposed model the extra two layers of foils wrapped on OIP layers of length of 515mm and 470mm respectively [5]. The modified case of condenser bushing is simulated for same parametric conditions of proposed model.

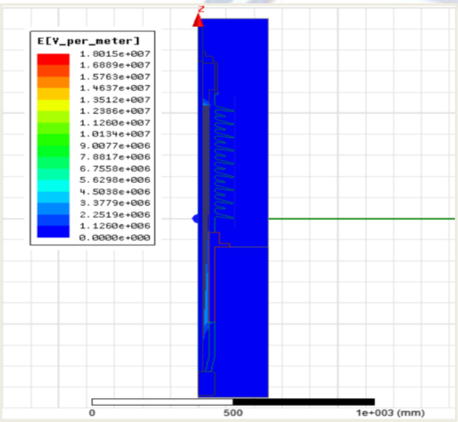
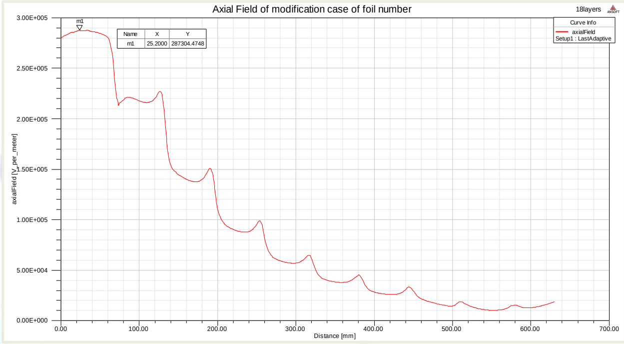
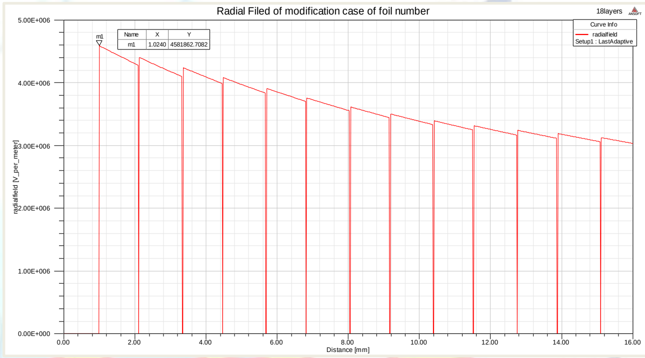


Fig.14:Field distribution of the modified model by increment in number of foils in condenser bushing.

The simulated modified model gives the lesser field distribution than the proposed model. Maximum field distribution is 1.8015 × 10^7 V/m. Fig.14 shows the potential distribution of the modified model by increment in number of foils of condenser bushing.



(i)



(j)

Fig.15 (i) and (j) Plot of field distribution along the axial surface of the upper porcelain and across the radial path of layers in increased number of foils modified case

Fig.15(i) and (j) shows the plot of field distribution along the axial surface of the upper porcelain and across the radial path of layers in increased foils number modified case. As the increment in the layers of aluminium foil the maximum field distribution is immensely reduced. The field distribution along the surface of upper porcelain part is 2.8730×10^5 V/m and radial field distribution is 4.5819×10^6 V/m. This alteration of increased number of foils affects mainly on overall maximum distribution in bushing.Table 3.1 shows the field distribution at particular points.

Proposed model and modification cases	Field distribution in (V/m)		
	Point of maximum distribution (10^7 V/m)	Maximum point at vicinity 2 (10^7 V/m)	Maximum point at vicinity-2 (10^6 V/m
Proposed model	2.6378	2.7889	5.0002

Modification with OIP thickness	1.8	2.9422	4.5173
Modification with increase in Aluminium foil length	2.4875	2.7891	4.9674
Modification with increase in number of foils	1.8015	2.8731	4.5819

4. CONCLUSION

The paper discussed the potential and field distribution on 72.5kV condenser bushing analysis using simulation in ANSYS Maxwell software and investigating the impact of the change in OIP thickness, foil length and increment in the foils number by analyzing the field distribution. The conclusion of this work is as follows.

- For proposed model of condenser bushing the field distribution is minimal and consistent because of the existence of conductive layers in the midst of OIP layers. The axial field distribution along the external part of upper porcelain is decreases as move downwards to the flange. The field distribution in radial cross section is evaluated across the layers from the point of central conductor and towards the layers, it is observed that decrease in field distribution.
- For same dimension of proposed model case the OIP thickness is changed. It is observed that the overall maximum field distribution in bushing is decreased compared to proposed model, axial and radial field are reducing as moving away from start point. It is observed that the maximum field distribution is reduced radially across the cross section of layers compared to proposed model of bushing.
- For the same dimension of proposed case the foil layers length is changed, it is observed that the overall maximum field distribution is decreased, then the value of 39 field distribution is reduces radially across the cross section of layers compared to proposed model.
- From proposed model the optimization is done by increasing foils number by two that is two extra foils are utilized. Then the simulation yields the results, due to a greater number of foils in bushings reduces the overall maximum distribution in the bushing. Regularity in field spreading is observed with decrease in field across the layers radially.

  The analysis for proposed model is done to evaluate the potential and field distribution in three vicinities of the model. As optimization in the dimensions of OIP and foil layers by modification instances is done in many ways such that change in thickness and increment in length, number of foils respectively. The increase in OIP thickness and increase in foils number have a prodigious impact on the field distribution is documented in this work.

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Conflict of interest statement

Authors declare that they do not have any conflict of interest.

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