

# Electric Field Distribution of 800kV OIP Transformer Bushing

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**Abstract**—Electrical bushings are the fundamental components of high voltage power transformers and their reliability is crucial for their successful operation. The majority of power transformer high voltage bushings today are of the condenser oil impregnated paper (OIP). High voltage insulated bushings are required to bring out the electrical energy through earthed barrier. This paper deals with improving the electric field distribution inside 800 kV OIP condenser bushing by varying number of foils and their thickness using finite element method. Simulation results show that 18 foils of 4mm thickness each and 6mm gap between the foils is optimum for better distribution of the field.

**Index Terms**—*Electrical field intensity, finite element method, high voltage bushing, oil impregnated paper.*

## I. INTRODUCTION

Electrical bushings are elementary component of high voltage power transformers; their reliability is crucial for the successful operation of the transformers. The porcelain bushing in transformers of low voltage range consists of four dielectrics namely Bakelite tube/ PVC/ paper tape, transformer oil, porcelain and air [1]. These materials must have high dielectric and mechanical strength. Bushings mechanically support external conductors and provide insulation from earth as the conductors are fed into the transformer tank [2]. The bushing represents a small fraction of the power transformer cost but their failure is often catastrophic.

The study of electric field distribution in and around HV bushings is of great significance for improving reliability of HV transformers. The distribution of electric field is mainly governed by the bushing geometry, permittivity, volume, resistivity of the insulating materials and the surface resistivity due to surface contamination. Control of voltage distribution and electric field intensity in the metal flange section is a concern which needs to be resolved.

Capacitance graded bushings are usually made of paper insulation. The metallic foils are placed between the paper insulation at calculated radial distances. The potential is equally distributed because the capacitance between is equally distributed. In this

paper, transformer employs Oil Impregnated Paper (OIP) as the main insulation. The advantage of OIP over others is that it is relatively cheap, its dielectric and thermal performance is satisfactory [3]. The paper is vacuumed, dried and soaked in a tank of pure impregnated oil. During the process of drying of insulating paper, several parameters are carefully controlled as dried paper contains between 0.2 % and 0.3 % moisture [4]. The number of foils and location is chosen such that the dielectric stress is within the dielectric breakdown of insulation.

The important stresses are electrical, thermal and their combination [5]. Electric field distribution of an insulator is a function of the geometry, material and also the external contamination severity and distribution [6]. The reliability of power transformer is critical for the safety operation as it depends not only on the core, but on the inner insulation [7]. It is recorded that more than 15% of transformer failures are due to failure of bushings [8]. Field analysis of a transformer is essential from design considerations. With insulation around the current carrying conductor, it is subjected to electrostatic stress which is high at the center and reduces at the periphery. This can cause the failure of insulation.

In transformer insulation ageing is a complex and irreversible phenomena. Stresses are due to operation (normal to extreme), ambient conditions and contamination contribute to the deterioration of the insulation chain. Therefore insulation is a layer of one or more dielectrics between plates. One plate is at a high potential and the other at a lower or ground potential [9].

In recent days the computer software preferred for design analysis are commercially available and these software's reduce the mathematical drudgery [10]. The OIP condenser design is the most common in service and it accounts for 80% of the world's operational bushings [11].

To the best of author's knowledge, minimal work is dealt with the electric stress within the bushing and field distribution along the oil reservoir side of bushing. The present work concentrates on minimizing the effect of electric stress and voltage distribution along the oil reservoir side of bushing to enhance the performance of the bushing. The main challenge is to decide the number of foils of proper thickness and

thickness of OIP to be used in order to achieve the uniform field distribution.

## II. MODELING OF BUSHING

### A. Dimensional details of 800 kV bushing

The dimensions details of 800kV bushing are taken according to Central Board of Irrigation and Power [12].

- i) The total length of the bushing is 9655 mm
- ii) The diameter of the inner conductor is 30 mm
- iii) The radial distance between the conductor and the porcelain is 350 mm.

Aluminum foil is used in-between paper layer in order to make the electric field uniform.



Fig.1.General model of 800 kV OIP Bushing

### B. FEM model developed for OIP bushings.

The model is built for different number of aluminium foils within it for different thickness of OIP and different thickness of foils as discussed in section III. Figure 2 and 3 shows the 800 kV bushings model and meshed model developed according to CBIP for FEM analysis.

The parameters assigned for the analysis are

- i) Input voltage =  $(800 \times (1000) / \sqrt{3})$
- ii) Relative permittivity of air = 1
- iii) Permittivity of conductor = 100000
- iv) Permittivity of foils = 10000
- v) Relative permittivity of oil = 2.2
- vi) Relative permittivity of OIP = 4

Electric field analysis for different foils and thicknesses have been carried out and details of which are discussed in next section.

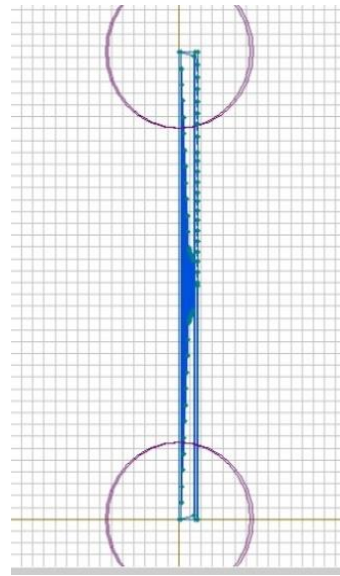


Fig.2. 12 foils OIP bushing model built in Quick field

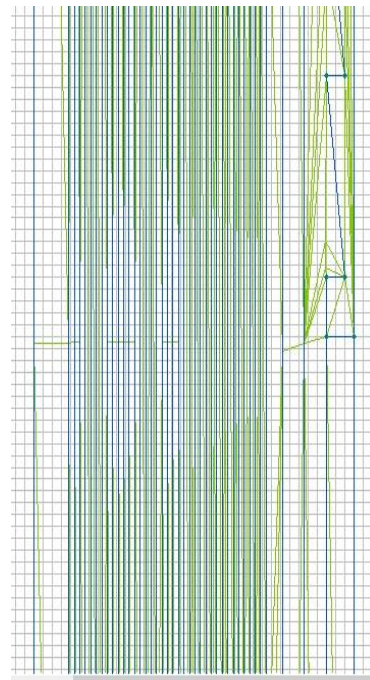


Fig.3. Meshed model of 800kV

## III. ESTIMATION OF ELECTRIC FIELD

As mentioned earlier, the main objective of the paper is to obtain optimum electric field distribution inside and voltage distribution along the oil reservoir side of bushing 800kV, OIP bushing. The estimation of electric field has been carried out with different number of foils and thicknesses without changing the dimensions of the bushings. The study has been made with 9 foils, 12 foils and 14 foils. The different combinations are studied.

The FEM simulation has been carried out for 12 foils 15 foils and 18 foils for all 12 cases mentioned above. Table 1 gives the maximum electric field estimated in each of the cases.

Table 1. Maximum electric field estimated

Case	Description	Maximum electric field kV/mm
1	12 foils 4mm foils and 4mm OIP	1.176
2	12 foils 4mm foils and 6mm OIP	7.896
3	12 foils 6mm foils and 4mm OIP	12.236
4	12 foils 6mm foils and 6mm OIP	7.758
5	15 foils 4mm foils and 4mmOIP	9.848
6	15 foils 4mm foils and 6mm OIP	6.473
7	15 foils 6mm foils and 4mm OIP	10.390
8	15 foils 6mm foils and 6mm OIP	6.796
9	18 foils 4mm foils and 4mmOIP	9.010
10	18 foils 4mm foils and 6mm OIP	5.666
11	18 foils 6mm foils and 4mm OIP	9.403
12	18 foils 6mm foils and 6mm OIP	5.969

IV. RESULTS AND DISCUSSIONS

Figure 4(a) and 4(b) shows respectively the complete model and zoomed out sketch of electric field strength distribution inside the OIP bushing with 12 foils of 4mm thickness and OIP thickness of 4mm.



Fig.4(a). Electric field distribution of 12 foils with 4mm thickness and OIP 4mm thickness.

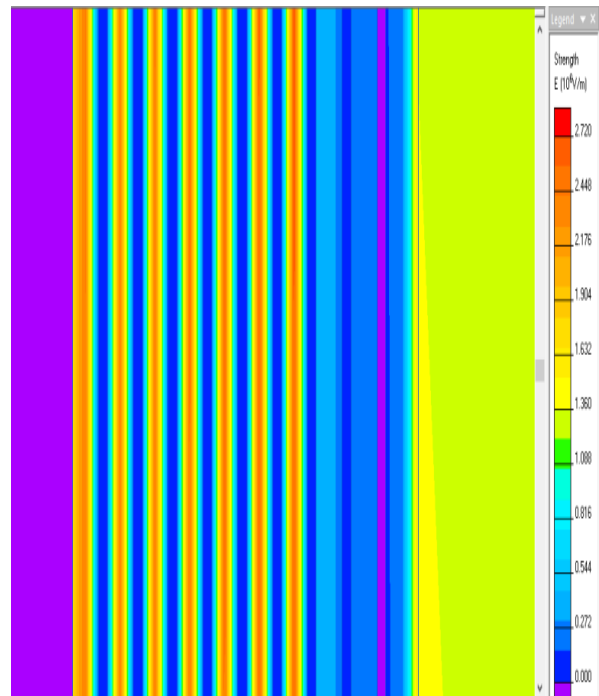


Fig.4(b). Electric field distribution for 12foils with 4mm thickness and OIP with 4mm thickness.

To verify the distribution of the field, electric field has been plotted as function of radial distance inside the bushing for 12, 15 and 18 foils and shown in the figures 5, 6 and 7 respectively.

The figure 5 shows field distribution of 12 foils

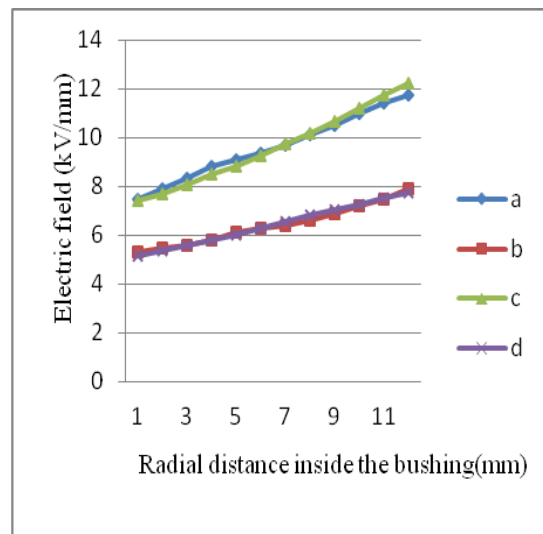


Fig.5. Electric field distribution inside 12 foils results.

Where

- a = 4mm foils and 4mm OIP (Graded)
- b = 4mm foils and 6mm OIP (Graded)
- c = 6mm foils and 4mm OIP (Graded)
- d = 6mm foils and 6mm OIP (Graded)

From figure 5, it is observed that the least electric field strength 7.758kV/mm is obtained from 12 foils which are graded with 6mm thickness and 6mm thickness of OIP.

The figure shows the representation of 15 foils results

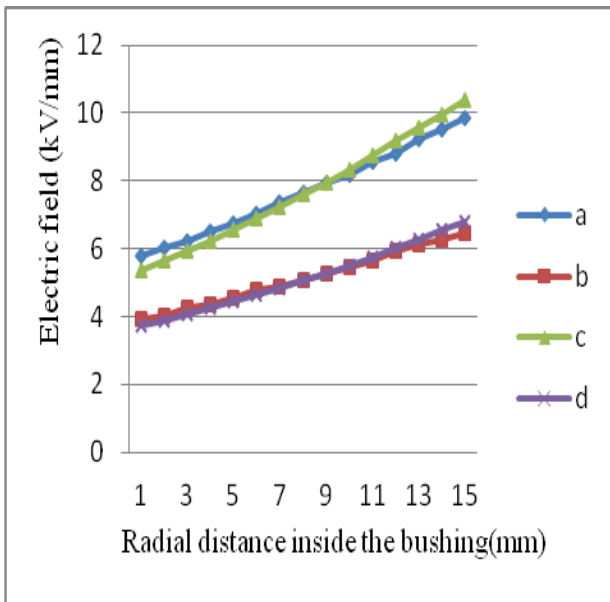


Fig.6. Electric field distribution inside 15 foils results

Where,

i = 4mm foils and 4mm OIP (Graded)

ii = 4mm foils and 6mm OIP (Graded)

iii = 6mm foils and 4mm OIP (Graded)

iv = 6mm foils and 6mm OIP (Graded)

From the figure 6, it is observed that the least electric field strength 6.473kV/mm is obtained from 15 foils which are graded with 4mm thickness and 6mm thickness of OIP.

The figure shows the representation of 18 foils results.

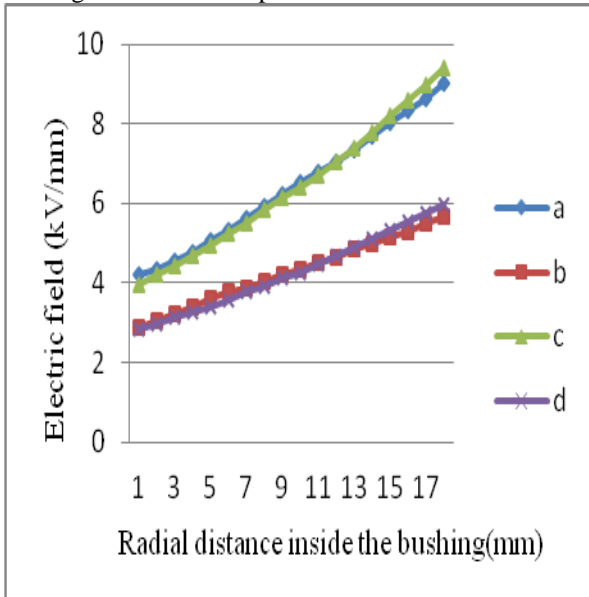


Fig.7. Electric field distribution inside 18 foils results

Where,

i = 4mm foils and 4mm OIP (Graded)

ii = 4mm foils and 6mm OIP (Graded)

iii = 6mm foils and 4mm OIP (Graded)

iv = 6mm foils and 6mm OIP (Graded)

From the figure 7, it is observed that the maximum electric field strength 5.666 kV/mm is obtained from 18 foils which are with 4mm thickness and 6mm thickness of OIP.

The figure 8 shows uniform field distribution in 9 foils, 12 foils and 18 foils respectively.

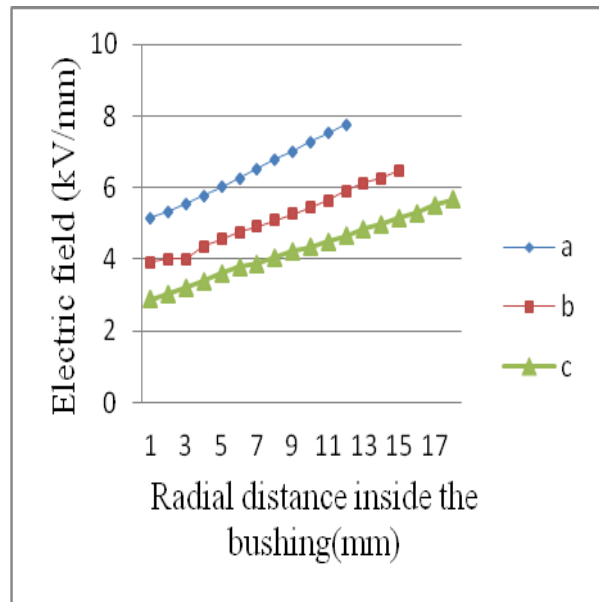


Fig.8. Uniform and least Electric field in 9 foils, 12 foils and 18 foils respectively.

Where,

a = 6mm foils and 6mm OIP in 9 foils (Graded)

b = 4mm foils and 6mm OIP in 12 foils (Graded)

c = 4mm foils and 6mm OIP in 14 foils (Graded)

From figures 5, 6 and 7, it could be observed that, case (10) of 4mm thickness with OIP of 6mm 18 foils the least electric field recorded is 5.666kV/mm and it is optimum for better distribution of Electric Field in 800kV OIP bushing. It is perhaps the least value to be found in comparison for all other readings taken in all other cases. This apparently suggests that the field is largely uniform in the above case. Consequently, the electric stress is relatively less and the possibility of insulation failure would be least, and hence it is optimum for 800 kV OIP bushing.

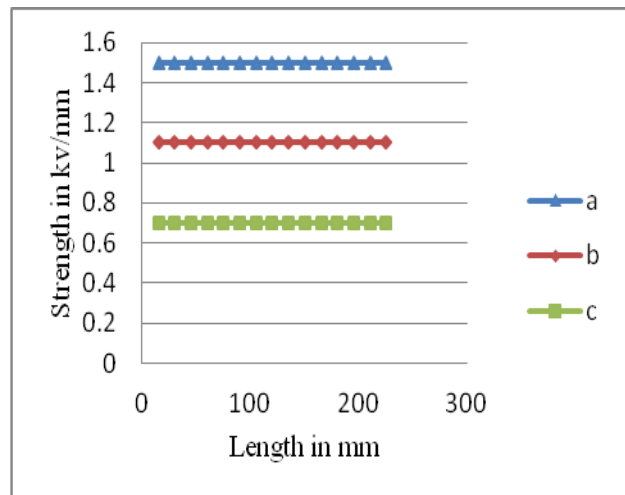


Fig.9. Field distribution along the oil reservoir (upper) side of bushing for 12, 15 and 18 foils

Where,

a = 6mm foils and 4mm OIP in 12 foils (Graded)

b = 6mm foils and 4mm OIP in 15 foils (Graded)

c = 4mm foils and 6mm OIP in 18 foils (Graded)

From figure 9 it is observed that 4mm foils and 6mm OIP in 18 foils, the electric field strength is recorded close to the conductor 0.786 kV/mm which is optimum

for better distribution along the oil reservoir top of the foils in 800 kV OIP bushing.

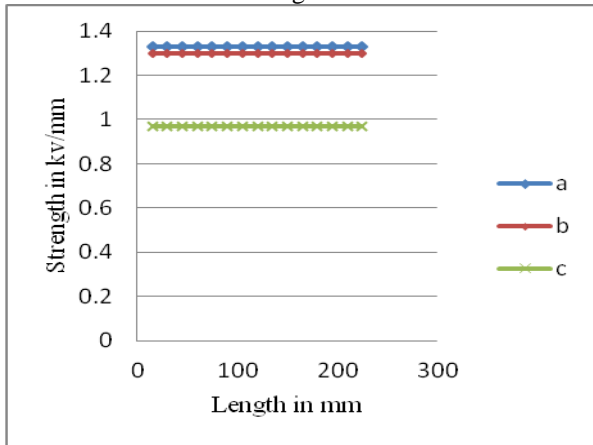


Fig.10.Field distribution along the oil reservoir (down) side of bushing for 12, 15 and 18 foils

Where,

a = 6mm foils and 4mm OIP in 12 foils (Graded)

b = 6mm foils and 4mm OIP in 15 foils (Graded)

c = 4mm foils and 6mm OIP in 18 foils (Graded)

From figure 10 it is observed that 4mm foils and 6mm OIP in 18 foils, the electric field strength is recorded close to the conductor 0.974 kV/mm which is optimum for better distribution along the oil reservoir bottom of foils in 800 kV OIP bushing.

## V. CONCLUSIONS

The present paper deals with the estimation of electric field inside the 800kV OIP bushing using FEM. The study involves with different number of foils and thickness of OIP. The study shows that 18 foils which are with 4mm thickness and 6mm OIP is found to be well suited for optimum distribution of electric field inside the bushing.

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