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Electric Field Analysis of High Voltage Condenser Bushing

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***Abstract*—Porcelain bushings are universally employed for power transformers. However, non-condenser bushings are unsuitable for high voltage applications owing to their extreme non-linearity in potential and electric field distribution. High voltage insulated bushings are required to bring out the electrical energy through earthed barrier. Synthetic resin bonded paper condenser bushing (SRBP) and oil impregnated paper (OIP) bushing are commonly used bushings. These bushings have series of dielectric layers with conducting aluminum foils in between each layer to improve the distribution of electric field. The present paper discusses analysis of electric field distribution in a 145 kV OIP bushing with varying number of foils and their thickness using finite element method. Simulation results show that 9 foils, 4mm thickness each and 2mm gap between the foils is optimum for better distribution of the field. The paper also discusses the experimental verification of the field estimated through the simulation.**

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

I. INTRODUCTION

High HV bushings are an integral part of electrical Equipment for carrying one or more high-voltage conductors through a grounded barrier such as transformers, reactors etc. which carry current at high potential through a grounded barrier, e.g. a transformer tank or a wall. Therefore, bushings must be designed to handle electrical, mechanical, thermal and environmental stresses. High voltage bushing can be divided into three categories; porcelain bushing, composite bushing, condenser bushing [1]. Condenser bushing is the one which has metallic conducting layers arranged within the insulating material for the purpose of controlling the distribution of the electric field of bushing, both axially and radially by capacitance grading. 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. The paper is vacuumed, dried and soaked in a tank of pure impregnated oil. During the process of drying of insulating paper, several parameters, the temperature, pressure and the duration, are carefully controlled. The dried paper contains between 0.2 % and 0.3 % moisture. The selection of number of foils and location is chosen such that the dielectric stress is within the dielectric breakdown of insulation. If OIP bushings are carefully

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processed, then there will be no gas cavities in the bushings. Bushings have evolved with power transformers. Condenser bushings are one of the key components in power transformers. Although their price is negligible compared to the total price of the transformer their quality has an important effect on performance and reliability of the transformer. The insulation is always subjected to stresses of different types at the same point in time. Among the various stresses, more important is the electrical stress. In high voltage condenser bushing, the intensity of voltage and electric field is very high [2]. The reliability of power transformer is critical for the safety operation of power system, which depends not only on the core, but the inner insulation [3]. It is recorded that more than 15% of transformer failures are due to failure of bushings. The main reason for bushing failure is the insulation failure within it. Field analysis of a transformer is essential from design considerations [4]. With insulation around the current carrying conductor, it is always subjected to electrostatic stress. This stress is high near the center and reduces towards the periphery. This uneven electrostatic stress can cause the failure of insulation. The radial electric field strength can cause breakdown in insulating material and axial field strength can cause surface discharge along the boundary. The tool used for analysis is Finite Element Method [5].
To the best of author's knowledge, no or less work deals with the electric stress within the bushing. The present work concentrates on minimizing the effect of electric stress 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 145 kV bushing

The bushing used in this study is a 145-kV OIP condenser bushing. The dimensions are taken according to Central Board of Irrigation and Power [6].
i) The total length of the bushing is 2405mm
ii) The diameter of the inner conductor is 19mm
iii) The radial distance between the conductor and the porcelain is 145mm.
Aluminum foil is used in-between paper layer in order to make the electric field uniform.

Fig 1: 145kV 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 145kV bushings model and meshed model developed according to CBIP for FEM analysis. The parameters assigned for the analysis are
i) Input voltage = (145*(1000/√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.

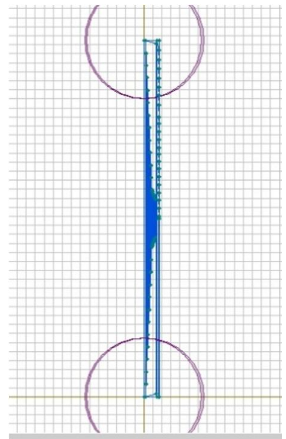

Fig 2: 12 foils OIP bushing model built in Quick field

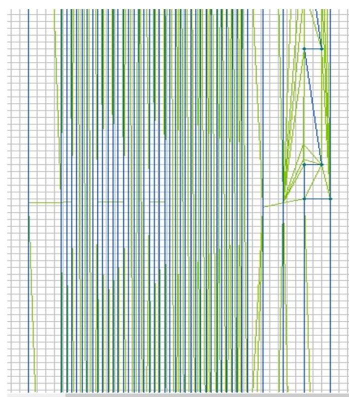

Fig 3: Meshed model

III. Estimation of Electric Field

As mentioned earlier, the main objective of the paper is to obtain optimum electric field distribution inside a 145kV, 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 and 12 foils. The different combinations studied are listed below.

3 cases for 9 foils were performed:

9 foils of 2mm thickness with 2mm thickness of OIP

9 foils of 2mm thickness with 4mm thickness of OIP

9 foils of 4mm thickness with 2mm thickness of OIP

1 case for 12 foils is performed:

12 foils of 2mm thickness with 2mm thickness of OIP

All the above cases have been analyzed with the parameters mentioned in the section 2. The results obtained are discussed in the next section.

IV. Results and Discussions

A. Estimated Electric Field

The FEM simulation has been carried out for 9 foils and 12 foils for all 4 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	9 foils 2mm foils and 2mm OIP	8.295
2	9 foils 2mm foils and 4mm OIP	6.001
3	9 foils 4mm foils and 2mm OIP	6.000
4	12 foils 2mm foils and 2mm OIP	9.810

Figure 4 and 5 shows respectively the complete model and zoomed out sketch of electric field strength distribution inside the OIP bushing with 9 foils of 2mm thickness and OIP thickness of 6mm.

Fig 4: Electric field distribution of 9 foils with 2mm thickness and OIP 2mm thickness

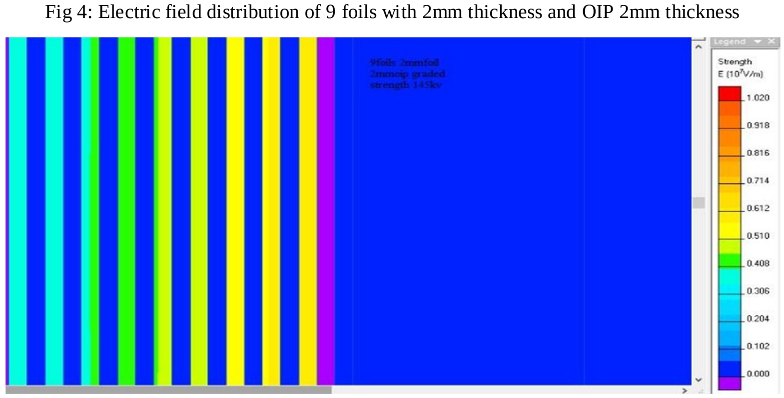

Fig 5: Electric field distribution for 9foils with 2mm thickness and OIP with 2mm thickness

To verify the distribution of the field, electric field has been plotted as function of radial distance inside the bushing for 9 and 12 foils and shown in the figures 6 and 7 respectively.
The figure 6 shows field distribution of 9 foils

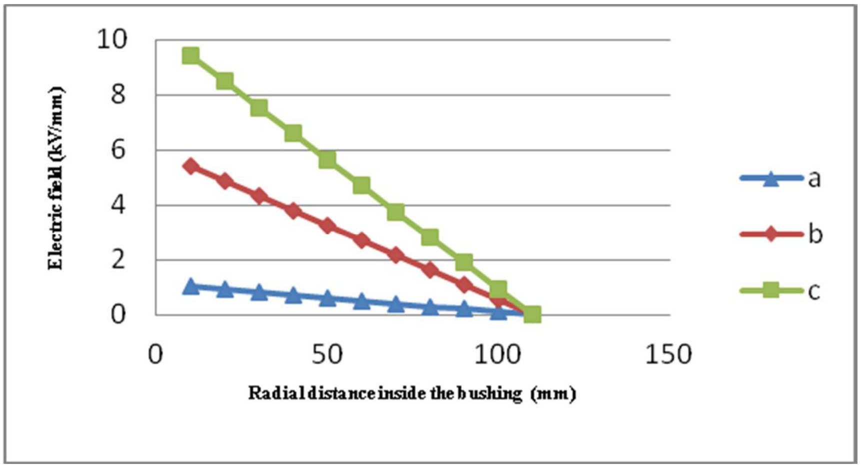

Fig 6: Electric field distribution inside 9 foils results

Where,
a = 2mm foils and 2mm OIP (Graded)
b = 2mm foils and 4mm OIP (Graded)
c = 4mm foils and 2mm OIP (Graded)
From fig 6, it is observed that the maximum electric field strength 6.000kV/mm is obtained from 9 foils which are graded with 4mm thickness and 2mm thickness of OIP.
The figure 7 shows field distribution of 12 foils

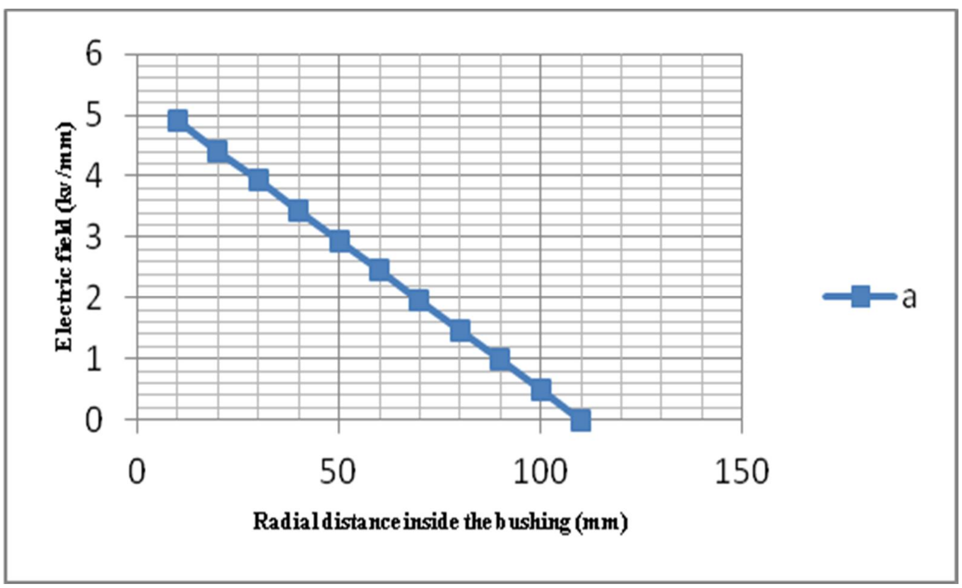

Fig 7: Electric field distribution inside 12 foils results

Where,
a = 2mm foils and 2mm OIP (Graded)
From fig 7, it is observed that the maximum electric field strength 9.810kV/mm is obtained from 12 foils which are graded with 2mm thickness and 2mm thickness of OIP.
The figure 8 shows uniform field distribution in 9 foils and 12 foils respectively.

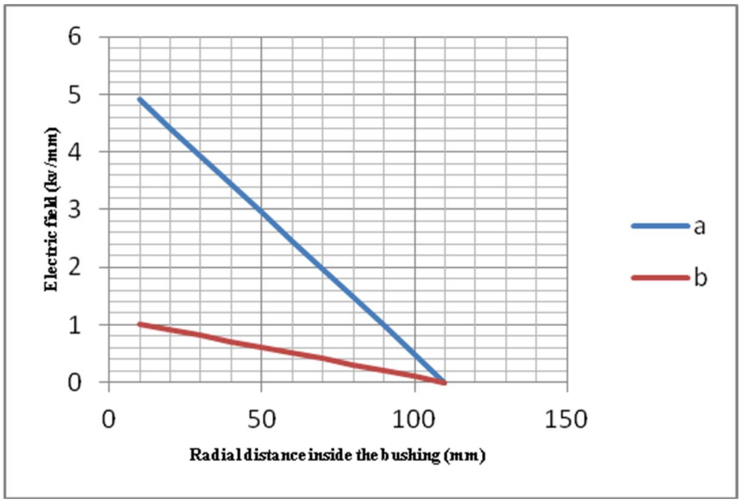

Fig 8: Uniform and Least Electric field in 9 foils and 12 foils respectively

Where,
a = 2mm foils and 2mm OIP in 9 foils (Graded)
b = 2mm foils and 2mm OIP in 12 foils (Graded)
The above figure summaries comprehensively the two best possible cases in each of the cases of permutation with 9 foils and 12 foils. It is observed that in the case of 9 foils the maximum electric field recorded is 6.000kV/mm. This is specifically for foils of 4mm with OIP of 2mm.

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 145kV OIP bushing.

From figures 6 and 7 it can be observed that, case (1) in 9 foils is optimum for better distribution of Electric Field in 145kV OIP bushing.

IV. Conclusion

The present paper deals with the estimation of the field strength using FEM for different number of foils and thickness and also different thickness of insulation paper (OIP). In 145kV, 6.00kV/mm is obtained from 9 foils which are with 4mm thickness and 2mm OIP is found to be well suited for optimum distribution of electric field inside the bushing. Further, the experimental breakdown strength is considerably higher than the maximum electric field estimated with the case mentioned above resulting in no partial arcs or breakdown of insulation.

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