

Effect of Foils on Electric Field Distribution of a 245kV Condenser Bushing

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Abstract— Bushing is an important component that is fitted to electrical equipment like switchgear and transformer etc. 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. In Indian scenario, it is observed that OIP bushing is used up to 765kV. 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 245 kV OIP bushing with varying number of foils and their thickness using finite element method. Simulation results shows that 12 foils, 2mm thickness each and 6mm 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.

INTRODUCTION

The transformers need terminal bushings for both primary and secondary windings. A bushing then provides the connection between the cable box and transformer winding. 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 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. MODELLING OF BUSHING

A. Dimensional details of 245 kV bushing

The bushing used in this study is a 245-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 3945mm
- ii) The diameter of the inner conductor is 24mm
- iii) The radial distance between the conductor and the porcelain is 175mm.

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



Fig.1. 245kV 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 245kV bushings model and meshed model developed according to CBIP for FEM analysis. The parameters assigned for the analysis are

- Input voltage = $(245 \cdot (1000/\sqrt{3}))$
- Relative permittivity of air =1
- Permittivity of conductor =100000
- Permittivity of foils =10000
- Relative permittivity of oil =2.2
- 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.

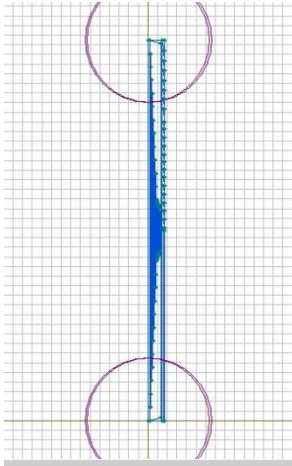


Fig.2. 14 foils OIP bushing model built in Quick field

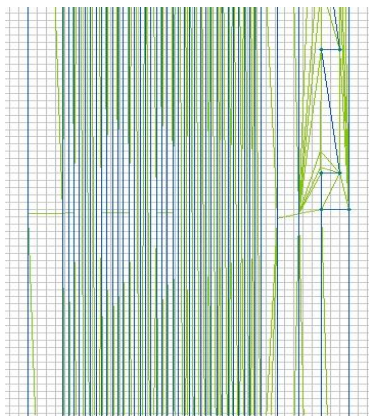


Fig. 3. Meshed model

III. ESTIMATION OF ELECTRIC FIELD

As mentioned earlier, the main objective of the paper is to obtain optimum electric field distribution inside a 245kV, 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 studied are listed below.

6 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 2mm thickness with 6mm thickness of OIP
- 9 foils of 4mm thickness with 4mm thickness of OIP
- 9 foils of 6mm thickness with 2mm thickness of OIP
- 9 foils of 4mm thickness with 2mm thickness of OIP

6 cases for 12 foils were performed:

- 12 foils of 2mm thickness with 2mm thickness of OIP
- 12 foils of 2mm thickness with 4mm thickness of OIP
- 12 foils of 2mm thickness with 6mm thickness of OIP
- 12 foils of 4mm thickness with 4mm thickness of OIP
- 12 foils of 6mm thickness with 2mm thickness of OIP
- 12 foils of 4mm thickness with 2mm thickness of OIP

3 cases for 14 foils were performed:

- 14 foils of 2mm thickness with 2mm thickness of OIP
- 14 foils of 2mm thickness with 4mm thickness of OIP
- 14 foils of 4mm thickness with 2mm thickness of OIP

All the above cases have been analyzed with the parameters mentioned in the section II. 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, 12 foils and 14 foils for all 15 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	9.062
2	9 foils 2mm foils and 4mm OIP	4.134
3	9 foils 2mm foils and 6mm OIP	2.848
4	9 foils 4mm foils and 2mm OIP	9.437
5	9 foils 4mm foils and 4mm OIP	4.559
6	9 foils 6mm foils and 2mm OIP	9.674
7	12 foils 2mm foils and 2mm OIP	7.120
8	12 foils 2mm foils and 4mm OIP	3.384
9	12 foils 2mm foils and 6mm OIP	2.088
10	12 foils 4mm foils and 2mm OIP	5.929
11	12 foils 4mm foils and 4mm OIP	3.443
12	12 foils 6mm foils and 2mm OIP	7.727
13	14 foils 2mm foils and 2mm OIP	6.261
14	14 foils 2mm foils and 4mm OIP	2.889
15	14 foils 4mm foils and 2mm OIP	6.696

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 6mm thickness.

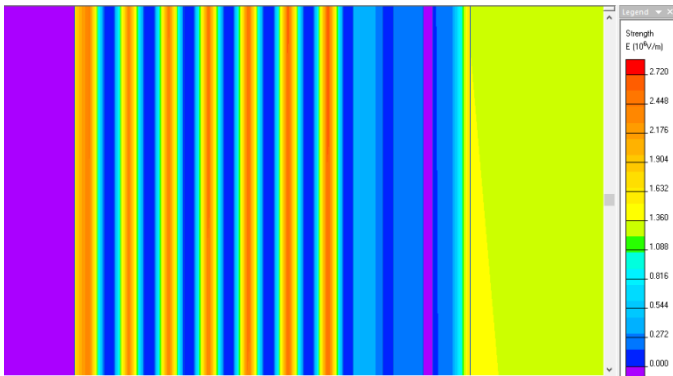


Fig.5. Electric field distribution for 9 foils with 2mm thickness and OIP with 6mm thickness.

To verify the distribution of the field, electric field has been plotted as function of radial distance inside the bushing for 9, 12 and 14 foils and shown in the figures 6, 7 and 8 respectively.

The figure 6 shows field distribution of 9 foils

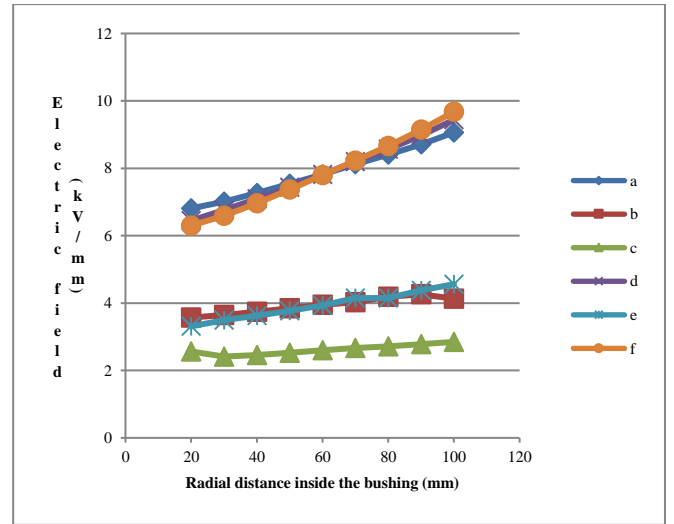


Fig.6. Electric field distribution inside 9 foils results.

Where,

- a = 2mm foils and 2mm OIP (Graded)
- b = 2mm foils and 4mm OIP (Graded)
- c = 2mm foils and 6mm OIP (Graded)
- d = 4mm foils and 2mm OIP (Graded)
- e = 4mm foils and 4mm OIP (Graded)
- f = 6mm foils and 2mm OIP (Graded)

From fig 6, it is observed that the maximum electric field strength 2.848 kV/mm is obtained from 9 foils which are graded with 2mm thickness and 6mm thickness of OIP.

The figure 7 shows field distribution of 12 foils

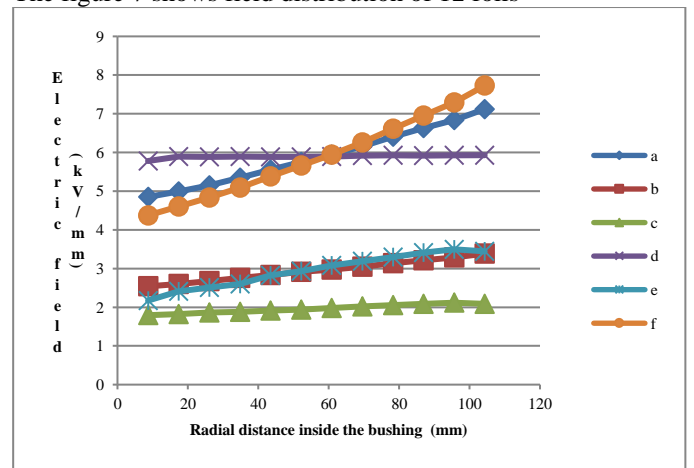


Fig.7. Electric field distribution inside 12 foils results.

Where,

- a = 2mm foils and 2mm OIP (Graded)
- b = 2mm foils and 4mm OIP (Graded)
- c = 2mm foils and 6mm OIP (Graded)
- d = 4mm foils and 2mm OIP (Graded)
- e = 4mm foils and 4mm OIP (Graded)
- f = 6mm foils and 2mm OIP (Graded)

From fig 7, it is observed that the maximum electric field strength 2.088 kV/mm is obtained from 12 foils which are graded with 2mm thickness and 6mm thickness of OIP.

The figure 8 shows field distribution of 14 foils

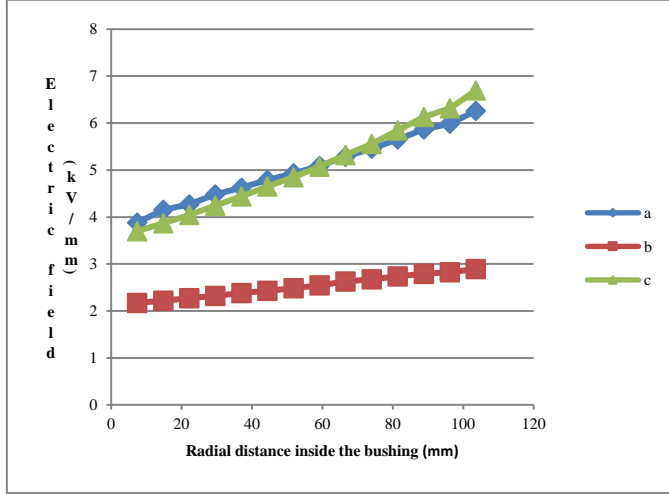


Fig.8. Electric field distribution inside 14 foils results.

Where,

- a = 2mm foils and 2mm OIP (Graded)
- b = 2mm foils and 4mm OIP (Graded)
- c = 4mm foils and 2mm OIP (Graded)

From fig 8, it is observed that the maximum electric field strength 2.889 kV/mm is obtained from 14 foils which are with 2mm thickness and 4mm thickness of OIP.

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

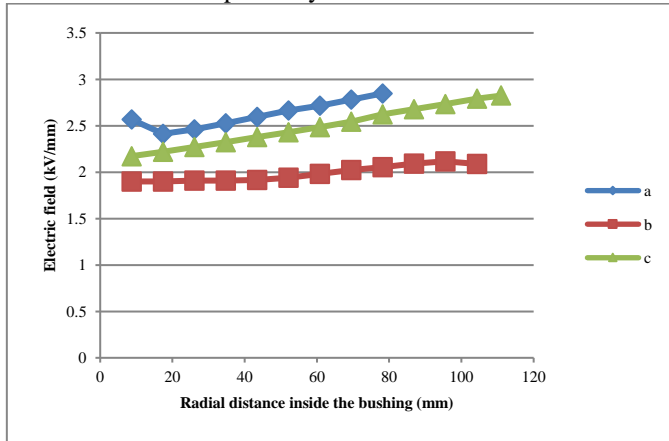


Fig.9. Uniform and Least Electric field in 9 foils, 12 foils and 18 foils respectively.

Where,

- a = 2mm foils and 6mm OIP in 9 foils (Graded)
- b = 2mm foils and 6mm OIP in 12 foils (Graded)
- c = 2mm foils and 6mm OIP in 14 foils (Graded)

The above figure summaries comprehensively the three best possible cases in each of the cases of permutation with 9 foils, 12 foils and 14 foils. It is observed that in the case of 12 foils the maximum electric field recorded is

2.088kV/mm. This is specifically for foils of 2mm with OIP of 6mm.

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 245kV OIP bushing.

From figures 6, 7 and 8, it can be observed that, case (9) in 12 foils is optimum for better distribution of Electric Field in 245kV OIP bushing. Further, to verify the breakdown strength of OIP insulation, experiment has been conducted.

V. EXPERIMENTAL RESULTS

Experiment has been conducted as per IS2584 [7] to find the breakdown strength of insulation OIP and the setup is as shown in fig 10. The impregnated insulating material of thickness 0.20 mm has been placed in between the test electrodes, ensuring the proper grounding and autotransformer position. Voltage is gradually applied across the electrodes until the insulation breakdown.

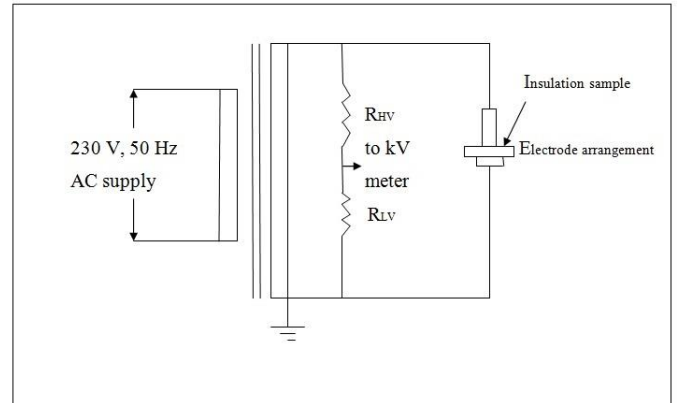


Fig.10. Experimental setup for finding the breakdown strength of OIP.

A solid insulating (unimpregnated pressboard) material was cut into small samples of 8cm on each side. The thickness of samples was found using screw gauge. These samples were then immersed in oil and dried. Henceforth, these oil impregnated paper insulation samples has been placed between the test electrodes ensuring the proper grounding. Gradually, the voltage has been applied across the electrodes until the insulation breaks down. The corresponding voltage at which the insulating material breaks down has been noted and autotransformer was brought back to initial position. This has repeated for 3 insulating samples to verify the consistency.

Specifications of equipment being 230V AC as the input, 5kV AC as the output and with 0.5 kVA rating.
Thickness of unimpregnated paper = 0.13 mm
Mean thickness of Impregnated paper = 0.20 mm

Table 2: Experimental results of breakdown voltage (kV)

Trial	Impregnated paper insulation		Unimpregnated paper insulation	
	Breakdown Voltage (kV)	Average Breakdown Voltage (kV)	Breakdown Voltage (kV)	Average Breakdown Voltage (kV)
1	1	1.113	0.52	0.5166
2	1.14		0.53	
3	1.2		0.5	

The breakdown strength of OIP is observed to be 5.566 kV/mm, whereas, the breakdown strength of unimpregnated paper is 3.9743 kV / mm.

In the case (8), the electric field varies from 2.54 kV / mm to 3.38 kV / mm and in the case (9), the electric field varies from 1.795 kV / mm to 2.088 kV / mm and in the case (10), the electric field varies from 5.78 kV / mm to 5.929 kV / mm. Hence, the configuration of 12 foils of 2mm with OIP of 6mm gives least field with uniform distribution and it is found to be lesser than that of breakdown strength of OIP. Therefore, case (9) is found to be optimum for 245kV.

VI. 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 245kV, 2.088 kV/mm is obtained from 12 foils which are with 2mm thickness and 6mm 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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