Material Optimization of 765kV Bushing using FEM

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***Abstract*— Transformer bushings are one of the important components in the construction of high voltage power transmission. The structure and materials used in electrical bushings play a vital role in the durability and lifespan of the bushing. Although the cost of transformer bushing is very minimal in the transmission system extensive damages are caused in case of failure. The main reason of failure in the insulation materials are caused due to moisture ingress and formation of voids, cavities. When the appropriate material is used along with an optimized structure, the electric field is distributed evenly which reduces the stress and increases the longevity of the bushing. In this paper, Finite Element Analysis(FEA) is used to calculate the electrical field distribution of 765kV transformer bushing by using different insulating materials such as Epoxy Resin, Porcelain, Oil Impregnated Paper, Resin Impregnated Paper and Polymer. Henceforth, by using the above insulating materials the total stress level of the bushings corresponding to the net electric field distribution is in turn calculated using ANSYS 13.0 Software. The results are compared and analysis is done for the different insulating materials. Based on the electric field distribution over bushing material, it is used to identify optimization of bushing design.**

Keywords*— Bushing, FEA, Insulating Material, Electric Field Distribution.

I. INTRODUCTION

Bushing is an insulating device used to protect an electrical conductor from another conducting barrier (Earthed) like the wall of a transformer. It must be constructed to bear extensive intensity of electric field. When the impact of electric field is more, a leakage path is developed inside the insulation. When the energy of the leakage path is more the insulation of the bushing is punctured which in turn causes burning and arching of the bushing. Around 25 % - 30% of transformer failures occur due to failure of bushing.[4] Especially in transformer bushing majority of failures are due to deterioration of the insulating material due to the moisture content and partial discharges. The bushing failure not only damages the transformer but also causes immense damage to the whole power transmission system.[9] The insulation is mostly damaged due to the formation of cavities which are created during the installation process.[5] The conductor inside the bushing is generally made with copper, aluminum etc. In the transformer bushing a fixing device is attached to keep the insulation of the bushing in place, since it is one of the highly stressed components of the transformer. There are two major types of bushing in practice: Porcelain bushings and Oil – filled condenser bushings, for small and large transformers respectively. Porcelain bushing consists of high grade porcelain cylinders and a series of skirts on the outside to increase the number of leakage paths formed. The condenser bushing consists of the conductor wound with alternating layers of paper and tin foil along with insulating oil. This structure is formed in order to give equal voltage drop between each condenser layer. Partial discharges are localized electrical discharges in the insulation formed due to voids or cavities in liquid, solid dielectrics. [11] The partial discharges can either be external or internal. The internal discharges usually occur in the edges of metallic surface while the external discharges occur in sharp edges or boundaries. [3]

II. FEA IN BUSHINGS

It is one of the extremely established and well developed techniques for solving complex problems using computerized solution. It is used in various fields of engineering; hydrodynamics heat conduction, geo-mechanics, biomedical applications, etc. FEA is a powerful and well organized tool to obtain the approximate solution of differential equations that describes various physical processes. [12]The FEA procedure is done in a highly sequential manner which stands to be successful. It consists of formulation of the problem in variation form, discretization [10] of the formulation using finite element thereby obtaining solution in the form of equation. These are the fundamental steps for any problem, which also includes use of digital equipments for further analysis of engineering problem. In FEA both static and dynamic analysis can be done. Initially the method was developed by Ritz for calculation of approximate solution in mechanics and solids. Later on the procedure had advanced a bit further by increasing the possibilities by introducing special linear functions for torsion problems. The main reason of the wide spreading of FEA is to utilize the computers for bulk volume of computation. [12]

FEA is compared with various numerical methods and transformation although it proves to be superior to other methods due to its approximate results. A finite element model is a design of an actual existing practical problem which includes a qualitative knowledge of understanding structural response of the physical values. It is mainly based on principles of mechanics and FEA procedure. The first step is to discretise the physical problem into a number of equal infinite parts. The shape, size, degrees of freedom, element type, meshing are to be chosen according to the origin and nature of the physical problem. The discretization process has many considerations like the number, size, type of elements, location of nodes, etc. Once the modeling is done the appropriate material properties and element types are assigned followed by meshing, boundary condition and post-processing of results. Various electric and magnetic analyses can be done in both static and dynamic forms. The location of the nodes plays a very vital role in the geometric, material properties and external conditions of the physical problem. The combination of number of elements depends on the type of analysis to be done and the nature of the problem. There are various types of meshing scheme like automatic free meshing, tri mesh, quad mesh etc. They usually depend on the arbitrary numbering scheme. There are a wide range of FEA packages in use like ANSYS, ADINA, LS-DYNA, COSMOS, etc. [12] Every FEA package consists of three parts pre-processing and manipulation of data, solution of FEA problem, post-processing of final results. The types of analysis that are generally going on are structural, thermal, fluid, mechanical, and electromagnetic. The application of the boundary condition depends on the atmospheric consideration where the problem is applied. The results can be viewed in many number of ways like color variations to graphical analysis.

III. MATHEMATICAL FORMULATION

Electric field distribution is calculated using the following relation:

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

From Maxwell's Equation

$$\nabla E = \frac{\rho}{\varepsilon} \qquad (2)$$

Where ρ is resistivity ohm/ m,

ε Is material dielectric constant.

Poisson Equation is,

$$\varepsilon\nabla(\nabla V) = -\rho \quad (3)$$

Without space charge $\rho = 0$, Poisson's equation becomes Laplace Equation [1]

$$\nabla\varepsilon(\nabla V) = 0 \qquad (4)$$

If the domain under consideration does not have any surface charges and space, the 2D functional F(u) in the Cartesian system can be formed as follows:

$$F(u) = \frac{1}{2}\left[\int_D \varepsilon_x\left(\frac{du}{dx}\right)^2 + \varepsilon_y\left(\frac{du}{dy}\right)^2\right]dxdy \qquad (5)$$

Where,

ε_x And ε_y are x- and y- components of dielectric constant in the Cartesian system and u are the electric potential.

$$F(u) = \frac{1}{2}\left[\int_D \omega\varepsilon_0(\varepsilon - j\varepsilon tg\delta)\left(\frac{du}{dx}\right)^2 + \left(\frac{du}{dy}\right)^2\right]dxdy \qquad (6)$$

Where,

ω Is angular frequency, tgδ is tangent of the dielectric loss angle, and u is the complex potential. Inside each sub domain D_e a linear variation of the electric potential is assumed.

$$u_e(x,y) = \alpha_{e1} + \alpha_{e2}x + \alpha_{e3}y; (e = 1,2,..ne) \quad (7)$$

Where, $u_e(x,y)$ is the electric potential of any arbitrary point inside each sub-domain $D_e, \alpha_{e1}, \alpha_{e2}$ and α_{e3} represent the computational co efficient for a triangle element e, n_e is the total number of triangle elements. The calculation of the electric potential at every knot in the total network composed of many triangle elements was carried out by minimizing the functional F(u), that is,

$$\frac{\partial F(u_i)}{\partial u_i} = 0; i = 1,2, \dots np \qquad (8)$$

Where,

np stands for the total number of knots in the network then a compact matrix expression

$$\lfloor S_{ji}\rfloor\{u_i\} = \{T_j\} \quad \text{i,j} = 1,2,\dots\text{np} \qquad (9)$$

Where,

$\lfloor S_{ji}\rfloor$ Matrix of coefficients is, $\{u_i\}$ is the vector of unknown potentials at the knots and $\{T_j\}$ is the vector of free terms. After (9) is successfully formed, the unknown potentials can be solved accordingly [12].

IV. MATERIAL OPTIMIZATION IN BUSHINGS

In early days porcelain bushings were used in both indoor and outdoor application, Due to its low cost, flexibility and easy to manufacture. It is resistant to moisture to some extent when it is thoroughly glazed ceiled. Although the major drawback using porcelain is that flexible steel and metal fittings should be used to cope up with the expansion process due to heat. It is generally filled with oil to give a better insulation. It is generally made with wet process fired porcelain with a semi-conducting glaze to enhance the electrical potential via the bushing length. In order to reduce the partial discharges from the bushing resin and paper insulating conductors are used along with porcelain to improve the fiber strength. [15]

The use of paper also has a set of disadvantages like the nature of paper being hygroscopic and linear inflexibility design. [3]The use of cast bonded resin and epoxy has dominated the insulation industry over the period of time, Due to its extremely high dielectric strength and flexibility. In general paper, resin or epoxy is impregnated with oil to enhance the insulation properties and increase the durability and value of the chemical bonds that are involved. These impregnated bushings are used in very high voltage bushings due to its promising and high reliability features. The transformer oil is used for impregnation [8] of the above materials due to its strong dielectric strength and impervious nature to high voltages. It prevents any form of leakage and the oil acts as excellent bonding material. It also enhances control due to oil expansion with respect to temperature which gives an additional insulation. [3]Resin and epoxy proves to be one of the best insulation materials due to its high dielectric strength and light weight, strong chemical bonds, withstanding capacity from partial discharges and voids. [15][6]

V. SIMULATION AND RESULTS

The results of the 765Kv transformer bushing are analyzed by modeling the bushing in ANSYS software and by using a wide range of insulating materials like Epoxy, Porcelain, Polymer, Oil-Resin impregnated paper. The analysis is done in 2D using element Plane-230.The concept is based on Finite Element Analysis. A triangular mesh is used for finer and accurate results.

A. Epoxy

The electric field distribution of epoxy is very minimal compared to the other insulating materials used in transformer bushings because of its good tensile strength in cured form, good compressive strength, The electric field distribution of the bushing model using epoxy is shown, which is designed in ANSYS SOFTWARE. And the graphical representation along the centre of the bushing is also shown. Since Epoxy has good insulating properties the intensity of the damage would be very minimal.

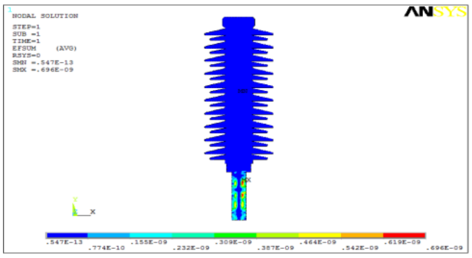

Fig. 1. Electric Field Distribution in 765Kv transformer bushing using Epoxy as insulating material.

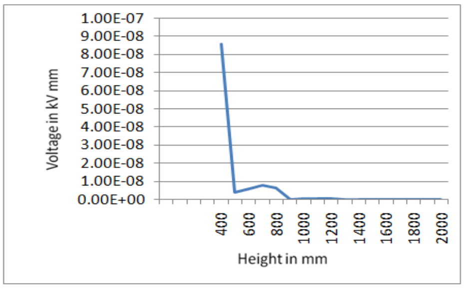

Fig. 2. Central view of Electric Field Distribution in 765Kv transformer bushing using Epoxy as insulating material.

B. Polymer

The electric field distribution of the bushing model using Polymer is shown, which is designed in ANSYS SOFTWARE. [13] And the graphical representation along the centre and radial of the bushing is also shown. The use of polymer is usually in low voltage bushings due to its very moderate mechanical properties. The withstanding capability is comparatively low.

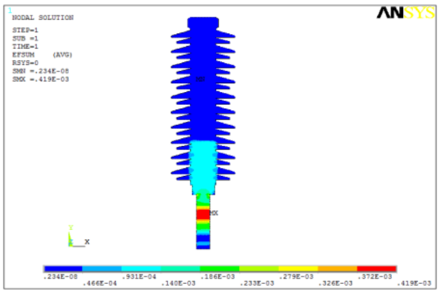

Fig. 3. Electric Field Distribution in 765Kv transformer bushing using Polymer as insulating material.

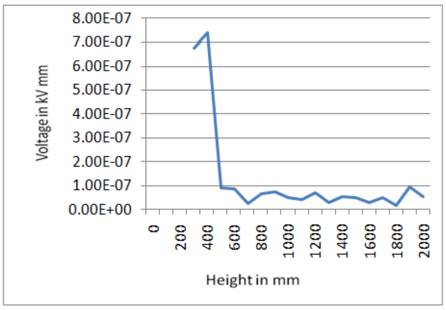

Fig. 4. Central view of Electric Field Distribution in 765Kv transformer bushing using Polymer as insulating material.

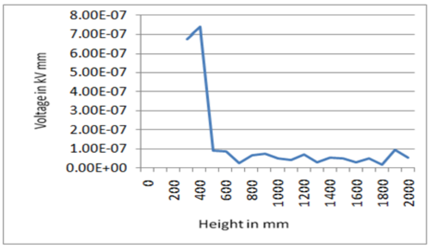

Fig. 5. Radial view of Electric Field Distribution in 765Kv transformer bushing using Polymer as insulating material.

C. Porcelain

The electric field distribution of the bushing model using Porcelain is shown, which is designed in ANSYS SOFTWARE.[13] And the graphical representation along the centre and radial of the bushing is shown. This is one of the widely used insulating materials due to its very low cost and availability and hence used prevailingly in low power bushing applications.

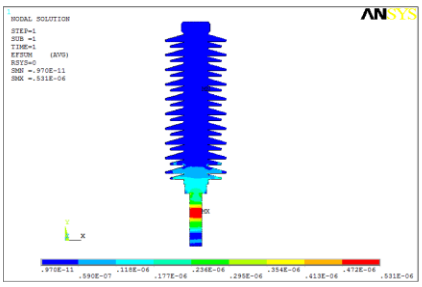

Fig. 6. Electric Field Distribution in 765Kv transformer bushing using Porcelain as insulating material.

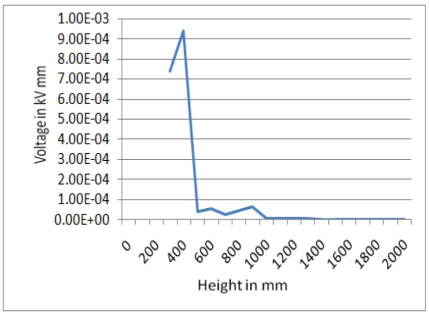

Fig. 7. Central view of Electric Field Distribution in 765Kv transformer bushing using Porcelain as insulating material.

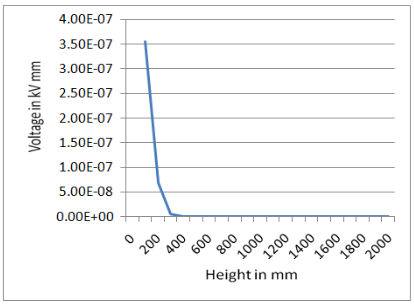

Fig. 8. Radial view of Electric Field Distribution in 765Kv transformer bushing using Porcelain as insulating material.

D. Oil -Resin Impregnated Paper

The electric field distribution of the bushing model using Oil-Resin Impregnated Paper is shown, which is designed in ANSYS SOFTWARE.[13] And the graphical representation along the centre and radial of the bushing is shown. It is one of the key insulating materials in high voltage bushings due to its strong mechanical properties and promising and reliable insulation capabilities.

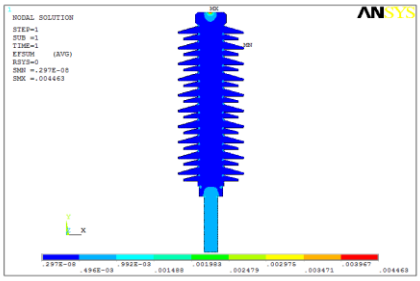

Fig. 9. Electric Field Distribution in 765Kv transformer bushing using Oil-Resin impregnated paper as insulating material.

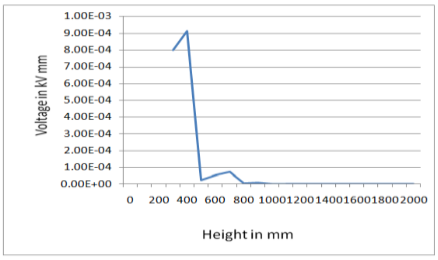

Fig. 10. Central view of Electric Field Distribution in 765Kv transformer bushing using Oil-Resin impregnated paper as insulating material.

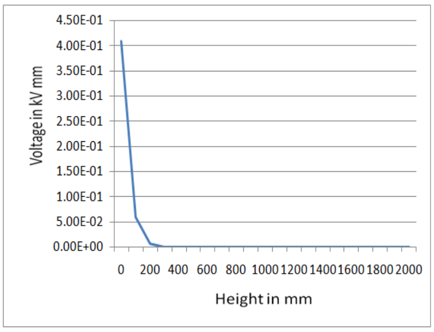

Fig. 11. Radial view of Electric Field Distribution in 765Kv transformer bushing using Oil-Resin impregnated paper as insulating material.

CONCLUSION

Thus, In this paper the material optimization of 765kV transformer bushing is done and the results are analyzed for four materials like Epoxy, Porcelain, Polymer and Oil- Resin impregnated paper respectively .Hence, based on the above obtained results Epoxy proves to be the best insulating material for transformer bushing in case of high power rated ones .However Porcelain is currently used for low rated bushings due to its cheap price, availability and easy installation. Although epoxy is comparatively of the higher end price and harder installation process, it proves to be far more efficient than the other insulators that are used in bushings. Furthermore optimization can be done by modifying the structural properties of the bushing like its Hood Depth and its Cree page distance. Also the thermal properties like Temperature [2] can also be analyzed in transformer bushings.

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