MODELLING AND ANALYZING ELECTROMAGNETIC SHORT CIRCUIT FORCES IN SINGLE AND DOUBLE HELICAL WINDINGS OF TRANSFORMER USING FINITE ELEMENT METHOD

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Abstract: Short circuit electromagnetic forces are considered as important factor from design point of view of transformer and should be taken care of while designing a transformer as it has very serious damaging effect to the transformer. Short circuit forces are more dominant in case of large power transformers. The work has been carried out on a power distribution transformer. The procedure for the analysis of power distribution transformer can be used to calculate the short circuit electromagnetic forces of large power transformer also. Therefore, a 630kVA, 11/.433kV power distribution transformer has been modelled for analysing the short circuit electromagnetic forces. Windings are modelled in twenty-three sections and short circuit force of each and every section of the winding is calculated using Finite Element Method of analysis. Electromagnetic forces are calculated for single helical and double helical windings of transformer.

Keywords: Finite Element Method, Transformer, Single Helical, Double Helical

I. INTRODUCTION

Power transformers are the most expensive and critical component of our power system. Its failure would be a costly event. Winding deformation is caused mainly due to short circuit events, other reasons may be ageing of insulation, and mechanical stresses developed due to transportation. Although, deformation may not result in immediate failure, however the dielectric strength of the winding is greatly reduced. And a further untoward short circuit faults may result in complete rupture of insulation which will result in complete damage of the winding. Finite Element Method Magnetics (FEMM) is a finite element package for solving 2D planar and axisymmetric problems of magnetostatics and electrostatics in low frequency magnetic and electrostatics. The current version of the program runs under Windows 2000, XP, Windows 7 and Windows 8. The program has also been tested running in Wine on Linux machines. Users commonly perform simulations with as many as a million elements, though simulations with tens of thousands of elements are typical. The program currently addresses linear/non-linear magnetostatics problems, linear/non-linear time harmonic magnetic problems, linear electrostatics problems, and steady state heat flow problems.

II. OBJECTIVE

Here in this work the user needs to constructa model of the part to be analysed in which the geometry is divided into a number of discrete subregions, or “elements,” connected at discrete points called “nodes.” Certain of these nodes will have fixed displacements, and others will have prescribed loads. These models can be extremely time consuming to prepare, and commercial codes vie with one another to have the most user-friendly graphical “pre-processor” to assist in this rather tedious chore. Some of these pre-processors can overlay a mesh on a pre-existing CAD file, so that finite element analysis can be done conveniently as part of the computerized drafting-and-design process. Once solved the system of equations, user can then compute the desired parameters and display the result in form of curves, plots, or color pictures, which are more meaningful and
interpretable. This final stage, often referred to as post-processing, can also be separated completely from the other steps.

III. METHODOLOGY
A typical work out of the method involves (1) dividing the domain of the problem into a collection of sub domains, with each sub domain represented by a set of element equations to the original problem, followed by (2) systematically recombining all sets of element equations into a global system of equations for the final calculation. The global system of equations has known solution techniques, and can be calculated from the initial values of the original problem to obtain a numerical answer.

IV. MODELING OF TRANSFORMER
For the analysis of short circuit forces of transformer, a model is being used. This model is three phases, three-legged power distribution transformer of 630 kVA. The procedure used in the analysis of this transformer can be used to calculate the short circuit forces in large power transformers. The low voltage winding of this transformer is employed with double helical type. The high voltage side of the transformer is connected in delta and low voltage is connected in star. The complete winding is divided into cells. Both the low voltage and high voltage winding is divided into twenty three cells. This division of cells help in analyzing the short circuit forces in each of the cell of the winding. Total number of turns in LV winding is twenty-three therefore cells of LV winding contains one turn each. In case of HV winding, each cell contains more than one number of turns. Figure-1 shows single helical winding and figure-2 double helical. Table-1 shows the specifications of 630 kVA, 11000/443 volts power distribution transformer.

![Figure-1 Single helical winding](image1)

![Figure-2 Double helical winding](image2)

**TABLE-1: SPECIFICATIONS OF 630 kVA THREE PHASE POWER DISTRIBUTION TRANSFORMER**

| Parameters                  | HV winding  | LV winding  |
|-----------------------------|-------------|-------------|
| Type of coil                | Cross over  | Two Helical |
| No. of coils per phase      | 2           | 1           |
| No. of turns per phase      | 1062        | 23          |
| Conductor size(bare)        | Diameter:2.850mm | 10.02 X 4.70 X 6 |
| Conductor size covered      | 3.150 mm    | 10.42 X 5.10 |
| Conductor placement         | -           | 3W X 2D     |
| Inner diameter of coil(mm)  | 275.5       | 207         |
| Axial length of coil(mm)    | 398         | 398         |
| No. of turns per coil       | 531         | 23          |
| Parameters                        | Specifications |
|----------------------------------|----------------|
| Core material                    | M4             |
| Maximum flux density(T)          | 1.68           |
| Stacking factor                  | 0.97           |
| Window height(mm)                | 440            |
| Leg centre(mm)                   | 350            |
| Core diameter(mm)                | 200            |
| Yoke height(mm)                  | 195            |

**TABLE-2: DESIGN PARAMETERS& DIMENSIONS OF CORE FOR 630kVA, 3-PHASE POWER DISTRIBUTION TRANSFORMER**

V. **SIMULATION OF TRANSFORMER MODEL**

The transformer is modeled in 2-dimensional plane with per unit depth in millimeter. The software used for simulation is Finite Element Method Magnetics 4.2(FEMM). Dirichlet boundary condition is used for solving problems. The windings present on the central limb is usually subjected to higher amount of force so analysis is done on the central limb of the transformer. To fill the research the gaps, magnetic density plots are obtained. Magnetic density plots are obtained for (i) ideal condition of single helical winding (ii) double helical winding. The density plots are shown in figure-4 and figure-5 respectively. To validate the result obtained from simulation, radial forces are calculated analytically and the result is almost same, slight difference is there because the windings are assumed to be rectangular blocks in simulation. The simulation result and the result obtained analytically are nearly close to each other and are shown in table-3.
**Figure-3 Methodology for simulation**

**TABLE-3: SIMULATION AND ANALYTICAL RESULT**

| Classification of winding          | Analytical result(KN) | Simulation result(Kn) |
|-----------------------------------|-----------------------|-----------------------|
| Inner winding (LV), single helical| 815.58                | 773.84                |
| Inner winding (LV), double helical| 506.87                | 439.65                |
| Outer winding (HV), single helical| 1137.93               | 1020.95               |
| Outer winding (HV), double helical| 779.54                | 706.65                |
VI. RESULT AND ANALYSIS

To understand the short circuit magnetic forces, radial force, axial force and radial compressive force are calculated under two conditions (i) short circuit force for single helical winding (ii) short circuit force for double helical winding.
SHORT CIRCUIT FORCE FOR SINGLE HELICAL WINDING

Radial force
Radial force is calculated for both the LV and HV windings and it is found that radial force have less magnitude at the end of the turns in the winding as compared to the magnitude at the centre of the winding for both single helical and double helical winding. In case of single helical winding, the radial force for LV winding is 773.844Kn and in case of double helical it is 439Kn. For HV winding, this force is 1020.959kn in case of single helical, and in case of double helical it is 739kn. The radial force is bursting in nature which pushes the winding away from core. The computed values for both the single and double helical winding is shown in figure 6 and 7 respectively.

Axial force
The axial force at the turns which are at the centre of the winding is very in magnitude as compared to the axial force at the centre of the winding. Short circuit force at each cell of the winding for both LV and HV in case of single and double helical is shown in figure 8 and 9 respectively.

Axial Compressive force
To find the axial compressive force, axial force on the first cell of the winding is added with the next cell of the winding and so on. Figure 10 and 11 shows the axial compressive force on single and double helical windings. The maximum value of axial force is at the centre of the winding.
In this study, a two-dimensional study is done to find out electromagnetic forces with the help of finite element method. Comparison of forces on single helical and double helical winding is done, it is found out that forces on double helical windings are less than forces acting on single helical winding. The research analysis suggest that the transformers should be designed by keeping in mind the short circuit forces acting on them during short circuit situation. The technique used and result obtained from research may help in the design of transformer. Further work can also be extended to double helical windings with tapings.

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