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TRANSFORMER LOSS CALCULATION AND L.V WINDING LOSS REDUCTION USING FINITE ELEMENT METHOD

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ABSTRACT:
Transformers are very important component of power system and their working efficiency directly influence the efficiency of the system. Hence it is always our concern to reduce losses of transformer and in turn improve efficiency of power system. Literature has presented various methods to calculate transformer losses, out of them Finite Element Method (FEM) is a modern technique which is emerging as an efficient tool. In this research work Finite Element technique is used using FEMM4.2 platform to calculate transformer losses. And then effect of variation in number of strands of winding conductors in transformer losses is analysed.

INTRODUCTION

As efficiency and security of power system has become an important concern, continuous research work is being done to reduce losses and improve efficiency of power system components. In power system whether it is distribution network or transmission network transformers always play an important role. Although efficiency of transformers is very high, research work is still carried out to reduce losses in the transformer and a unit with lower losses and better efficiency is always preferred. Performance of transformer is also affected by working conditions, power transformers are designed to have highest efficiency near full load capacity but distribution transformers are designed to have maximum efficiency near 70-75% of full capacity. Similarly, transformer working under overfluxing condition can also affect normal operation of transformers [15].

Different techniques are used to calculate losses in transformer. Roshen [1] used mathematical representation of hysteresis loop to determine core loss during arbitrary magnetising currents. But assumed that only eddy currents are dependent on system frequency and hysteresis losses are independent of system frequency and temperature. Haddon [2] used differential equations to represent important properties of hysteresis loop and also included frequency dependency of the losses. Drawbacks of these two methods are that they calculate only hysteresis losses and do not include temperature dependency. To include non-linear characteristics of losses R.Sevems [3] used Fourier Expansion of arbitrary magnetizing current waveform and also included flux density and frequency dependency. But this technique cannot be applied beyond limited frequency range. M.Albach et al. [4] proposed a technique of using a weighted time derivative of magnetic flux density to calculate core losses of transformer. Dolinar etc at. [5] Proposed a non-linear model for magnetic iron core and compared it with conventional model of saturated iron core. In their research work Gunter F. Mechler et al. [6] described an analytical solution to 2D finite difference method and included core magnetic material non-linearity and magnetic anisotropy to calculate all transformer core losses. J. C. Olivares et al. [7] suggested use of electromagnetic shielding to reduce stray losses in transformer for this purpose they carried out a comparative study by calculating losses with and without electromagnetic shielding.

A modern technique of transformer performance evaluation is Finite Element Method (FEM). It is a numerical technique and can be used as an important tool for problems related to electromagnetic and can work with system non-linearity's and complex boundary conditions and finding its use in the problems related to optimization, reliability enhancement, simulation of structural component etc. [10-12].

This paper presents 2D Finite Element Technique for calculation of transformer losses. 3D quasi-asymmetrical field equations are solved by converting them in 2D field equations. In this research work, transformer losses are calculated using Finite Element Method (FEM) in FEMM 4.2 software, which can solve a 3D structure in 2D work space. Then FEM results are compared with practical results to present efficacy of this technique. In the next step, numbers of strands of low voltage windings are increased keeping same overall cross- section area and its effect on losses reduction is analysed.

TRANSFORMER LOSSES

Transformer is a static device and due to absence of frictional losses efficiency of transformers is very high. But as transformers are very important component of power system and large numbers of units are being used in the system, these individual losses in each transformer units may result in great loss in overall efficiency of the system. Hence continuous research work is going on for transformer efficiency improvement.

Losses occurring in the transformer are core loss, copper losses and stray loss. Core loss consist eddy current and hysteresis loss which occur due to non-linear characteristics of magnetic core and varying magnetic flux density.

When a conducting material comes under the effect of time-changing magnetic field a voltage is induced around each closed path that encircles lines of magnetic flux, which causes flow of circulating currents, also called eddy currents, in the conductor and causes eddy current losses.

Hysteresis loss occurs due to the electrical energy which is required to align the molecule of magnetic material according to the direction of time varying magnetic flux. Copper losses, also called I^2R losses are load dependent losses and share a major portion of transformer losses. These losses occur due to the current flowing in transformer winding and produce resistive heating.

Stray losses are generally 10-40% of total losses. All the flux produced by primary does not link to secondary of transformer but some portion gets leaked and may linked to nearby conductive elements like tank, clamping structure etc. and cause heating. Sometime buzzing sound or vibrations are also experienced other than leakage flux losses eddy current losses in the winding are also the part of stray losses [8-9]. Eddy current losses in windings occur mainly because of two phenomenon; skin effect & proximity effect. In case of AC circuits whole wire is not used for the flow of current, instead it gets concentrated near the surface of the conductor. This depth, up to which current penetrates, known as skin depth, is given by

$$\delta = \sqrt{\left(\frac{2}{\omega\sigma\mu_0\mu_r}\right)}$$

Where, ω is frequency, σ is conductivity, μ_0, μ_r are permeability of air and relative permeability respectively.

Another phenomenon, Proximity effect takes place in a conductor due to the influence of alternating magnetic field of other conductors in the vicinity. When a conductor is in placed near to other current-carrying conductor and comes under its proximity, the current flowing in this conductor gets concentrated near one side of the conductor. This non-uniform distribution of current also causes reduction in effective area of conductor for the flow of AC currents. As a result, the effective winding AC resistance increases which results in increased losses.

MODELLING and SIMULATION

Modelling:

For analysis purpose a 630KVA, 11000/433KV, 1062/23 turn ratio, delta/star connected distribution transformer is considered. LV winding is helical type with litz wire consisting 6 numbers of strands with 3W×2D placement and HV winding is of cross-over type. Core material of transformer is C.R.G.O grade M4 with maximum flux density of 1.68T, transformer windings are made of copper. 2D model of the above mentioned transformer in FEMM 4.2 is as shown in fig.[1]

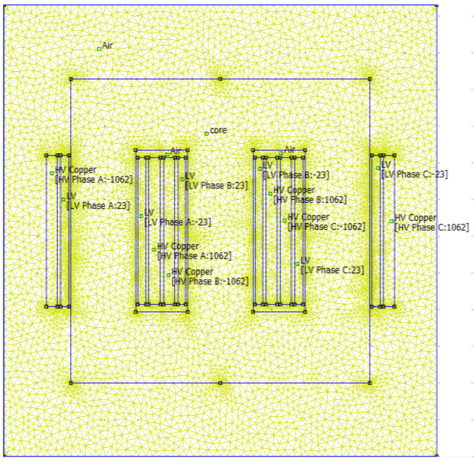

Fig 1: 2D representation of 3 phase transformer

Simulation:
For solving electromagnetic field related problems FEM applies Maxwell equations in a region of finite area (mesh) under specified boundary conditions. In order to solve algebraic equations 2D model of transformer is first discredited into small triangles. The entire 2D model is meshed by mesh operation and appropriate properties of material parameters, boundary conditions, circuit parameters are applied.
After modelling of transformer and applying parameters program is run and then results are calculated. Fig.[2] shows flux density distribution for the transformer at a particular time instant.

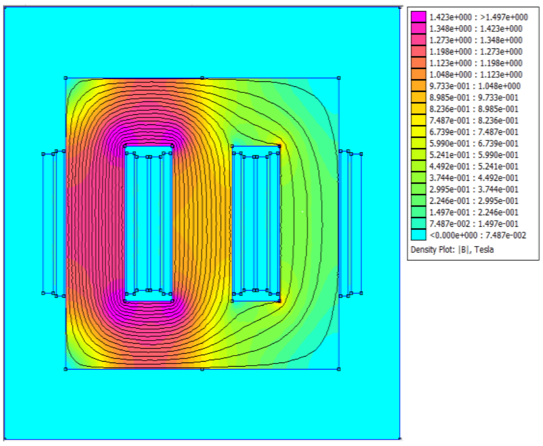

Figure 2: flux density distribution at particular time instant

RESULTS
FEMM4.2 provides steady state analysis of the problem and analysis done by this are for per unit depth. Hence results are multiplied with proper depths. For core loss calculation, losses calculated by FEMM4.2 are multiplied by breadth of transformer in z direction and winding losses are calculated by multiplying FEMM4.2 calculated losses by Π×mean diameter of respective winding.
Losses per mm depth of FEMM are given in table.1:

Table.1: Calculation of transformer losses:

	Losses per mm depth	**Total losses**
Core losses	4.9333	4.9333×195= 962W
LV winding losses	4.0548	4.0548×Π×230.75=2938W
HV winding losses	3.19406	3.19406×Π×306.5=3074W

Now these losses are compared with practical results and percentage error is calculated in table.2:

Table.2 Comparison of transformer losses

Losses	FEM Result	Test Result	% Absolute Error
Core losses	962W	985 W	-2.3%%
LV winding losses	2938 W	2880 W	2.01%
HV winding losses	3074 W	3100W	-0.84%

Above mentioned table shows that finite element method (FEM) is an efficient tool for the calculation of transformer losses and can generate results almost nearer to the practical results and it can calculate losses in different parts of transformer separately. Winding losses in the above mentioned values include I^2R losses and eddy current losses in the windings.
Now, instead of using 6 strands of 3W×2D in LV, winding conductor is replaced by conductor with 10 number of strands with 2W×5D placement and equal cross-section area, again losses are calculated with new conductor wire and results are analysed. Results show that for LV winding with more number of strands i.e. 10 strands LV winding losses is reduced and these losses are given in table. 3

Table.3 2W×5D Helical LV winding losses

Losses	2W×5D helical LV winding losses
Core losses	961W
LV winding losses	2853W
HV winding losses	3074W

Table.4 shows, increasing number of strands in LV winding, winding losses are reduced. When numbers of strands are increased keeping same overall cross-sectional area the effect of skin effect is reduced hence more effective area is available for current flow which can be seen as reduction in overall resistance.

Table.4 Comparison of double layer & single layer losses

Losses	3W×2D helical LV winding	2W×5D helical LV winding
LV winding	2938 W	2853 W

CONCLUSION and FUTURE SCOPE

Finite element technique can be used to calculate losses with good accuracy in each part of the transformer simply by 2D modelling of the transformer. Capability of FEM to work in 2D work space makes modelling of transformer easier and faster for designer and still gives good results. Also, by judicious selection of number of strands of conductor wire losses of the transformer can be reduced.
This analysis can be extended to include losses due to leakage of flux to other conducting parts of transformer such as support structure, clamping structure etc and further to thermal analysis of transformer.

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