Calculation of transformer tank losses

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Abstract: - This paper presents the application of two finite-element approaches to calculate losses in the tank of the transformer. The first one is related to a two-dimensional time harmonic finite-element model, while the second one is based on a three-dimensional finite-element technique. The equations, boundary conditions and excitations of models are explained with some detail in this work. 25MVA transformer was calculated.

Key-Words: Tank losses, eddy current losses, FEM, magnetic shielding.

1 Introduction

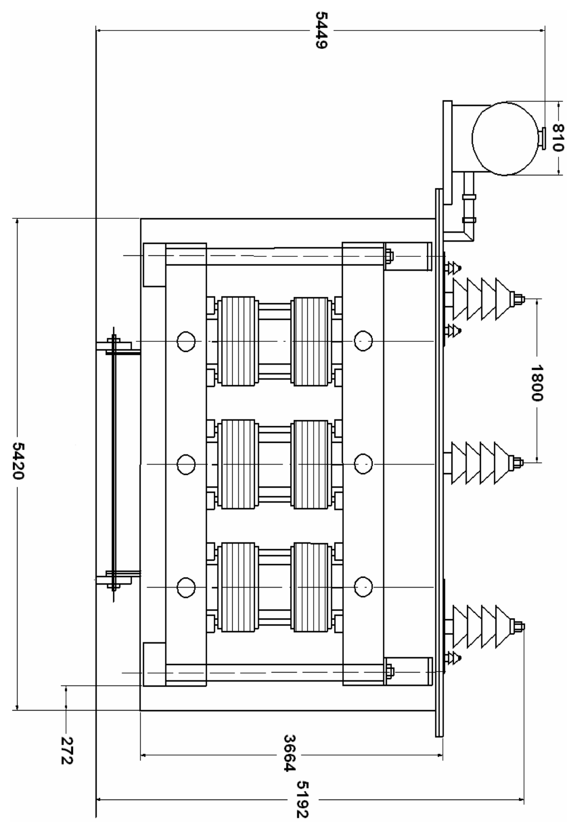
Tank and clamp losses are very difficult to calculate accurately [1]. The eddy current losses can be obtained from the finite element calculation, however the axisymetric geometry is somewhat simplistic if we really want to model a 3 phase transformer in a rectangular tank. Modern 3D finite element and boundary element methods are being developed to solve eddy current problems.

This paper shows the application of three-dimensional (3D) and two-dimensional (2D) finite element approaches to estimate stray losses on tank walls of distribution transformers. Details of the equations, excitations and boundary conditions that were used to solve the problem are given in the paper. The numerical approach taken in this work assumes that the stray magnetic field has linear behavior. The finite element approaches used in this work also assume that transformer currents are perfectly sinusoidal, thus the electromagnetic equations can be solved in the frequency domain. Parameters of the transformer are given in Table I.

TABLE I

Parameter	Value + Unit
Output	25 MVA
Voltage	110+(-) 2x8% /23 kV
Connection	Yd1

The experimental proof of calculation – short circuit test can be performed so that the power absorbed during the test consists of the I^2 R losses in the windings due to the presence of main current and eddy current in the copper and the stray losses in structural conducting parts.



Geometrical sizes shows Fig. 1.

2 2D electromagnetic equations

The magnetic vector potential can be described by [1] :

$$-\nabla^2 A_z + \mu\sigma \frac{\partial A_Z}{\partial t} = \mu J_Z \qquad (1)$$

where μ. is the permeability and s is the electric conductivity. A_Z is the axially directed magnetic vector potential and J_Z is the DC source current density within the conductors. It is important to note that this DC current density is the current distribution that would exist, if eddy currents were absent [3].
The governing equations for each case are as follows:

- Non conducting regions (such as air): These regions are governed by the Laplace equation:

$$-\nabla^2 A_Z = 0 \qquad (2)$$

- Stranded conductors (such as machine windings):

These regions are governed by the Poisson equation:

$$-\nabla^2 A_Z = \mu J_Z \qquad (3)$$

It is assumed that conductors have a very small diameter, so that eddy currents are negligible. The distribution of J_Z is known a priori.

- Massive conductors: Equation (1) holds for this kind of regions. However, additional constrains may be required depending on the type of problem. For problems where the total current of the conductor is known, but its distribution is unknown, it is necessary to include the following constraint:

$$\int_S \sigma\left(E_a - \frac{\partial A_Z}{\partial t}\right) dS = I_{tot} \qquad (4)$$

and J_Z in equation (1) is given by:

$$J_Z = \sigma E_a \qquad (5)$$

where E_a is the voltage gradient applied to the massive conductor. Here, E_a is unknown whereas I_{tot} is known. This is the 2D formulation used for the massive conductors analyzed in this work.
The transformer walls are modeled by assuming that eddy currents can return at infinity. The total eddy current I_{eddy} is simply calculated as

$$-\int_S \sigma \frac{\partial A_Z}{\partial t} dS = I_{eddy} \qquad (6)$$

It is important to emphasize that for sinusoidal steady-state conditions the problem can be easily formulated by substituting j for partial derivation and treating each electromagnetic variable in the previous equations as a phasor.

2.1 2D finite element simulations

For calculation was used program FEMM [5].
The cross-section of the transformer (Figure 2.) is divided into several parts [2]:
Oil- the subdomain with μ_r =1.
Sheets - nonlinear B-H charakteristik, 2 MS/m, fig. 9.
Cu Primar - 56.2 MS/m
Cu Sekundar - 56.2 MS/m
Tank - the iron, thickness 30mm, nonlinear BH charakteristik, 5 MS/m
Air - μ_R =1.

TABLE II
Currents of windings

Primary winding, current [A]	**Secondary winding, current [A]**
A 887,5 + j.0	A -185,6 + j.0
B -443,7 – j 768,6	B 92,82 + j. 160,8
C -443,7 + j 768,6	C 92,8 – j. 160,8

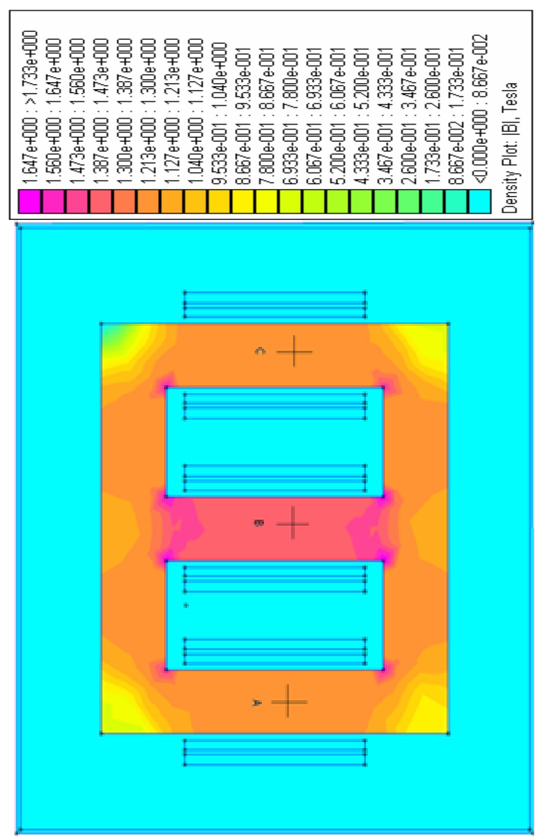


Fig. 2. Map of the magnetic field

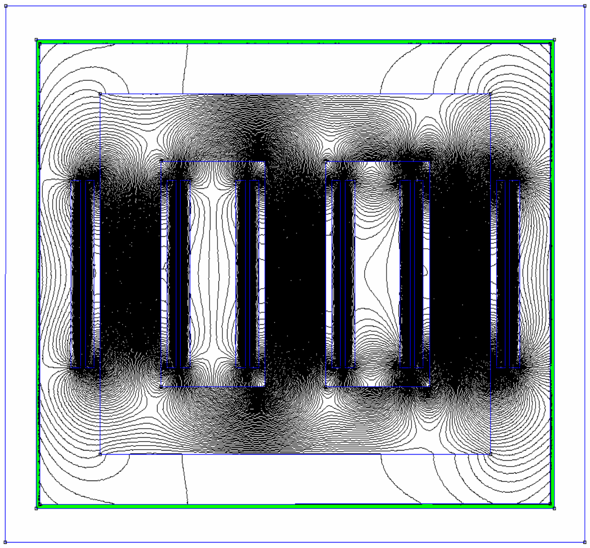


Fig. 3. Map of the magnetic field

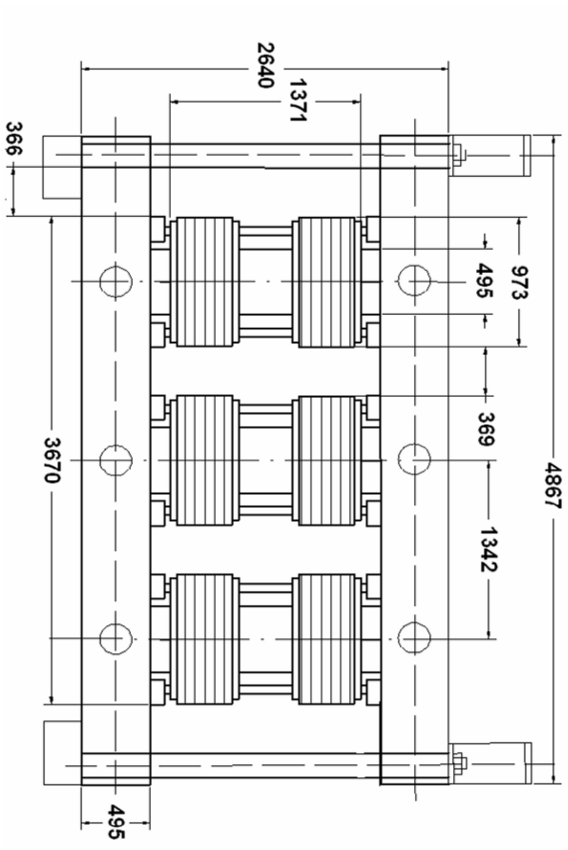


Fig. 4. Geometrical sizes

Total losses in the tank of the transformer are 3,8 kW.

Fig. 2.,3 shows the map of the magnetic field for no-load state of the transformer.

2.2 3D finite element simulation

For calculation was used program OPERA 3D [6].

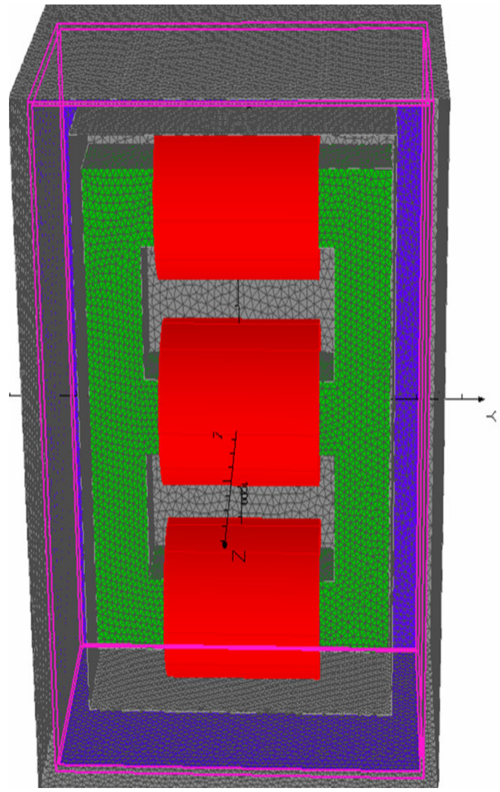


Fig. 5. Example of mesh

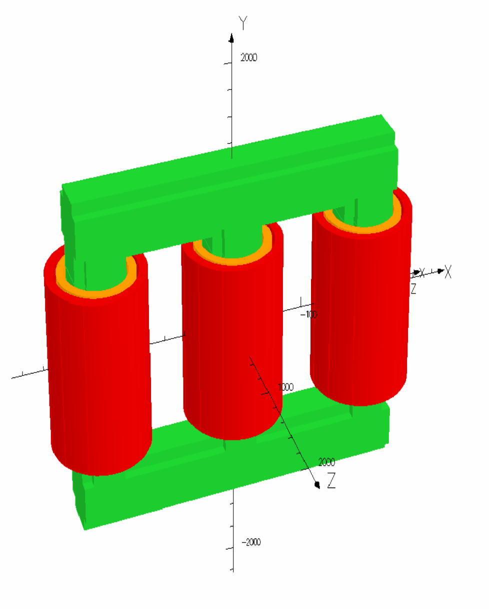


Fig. 6. Model of transformer

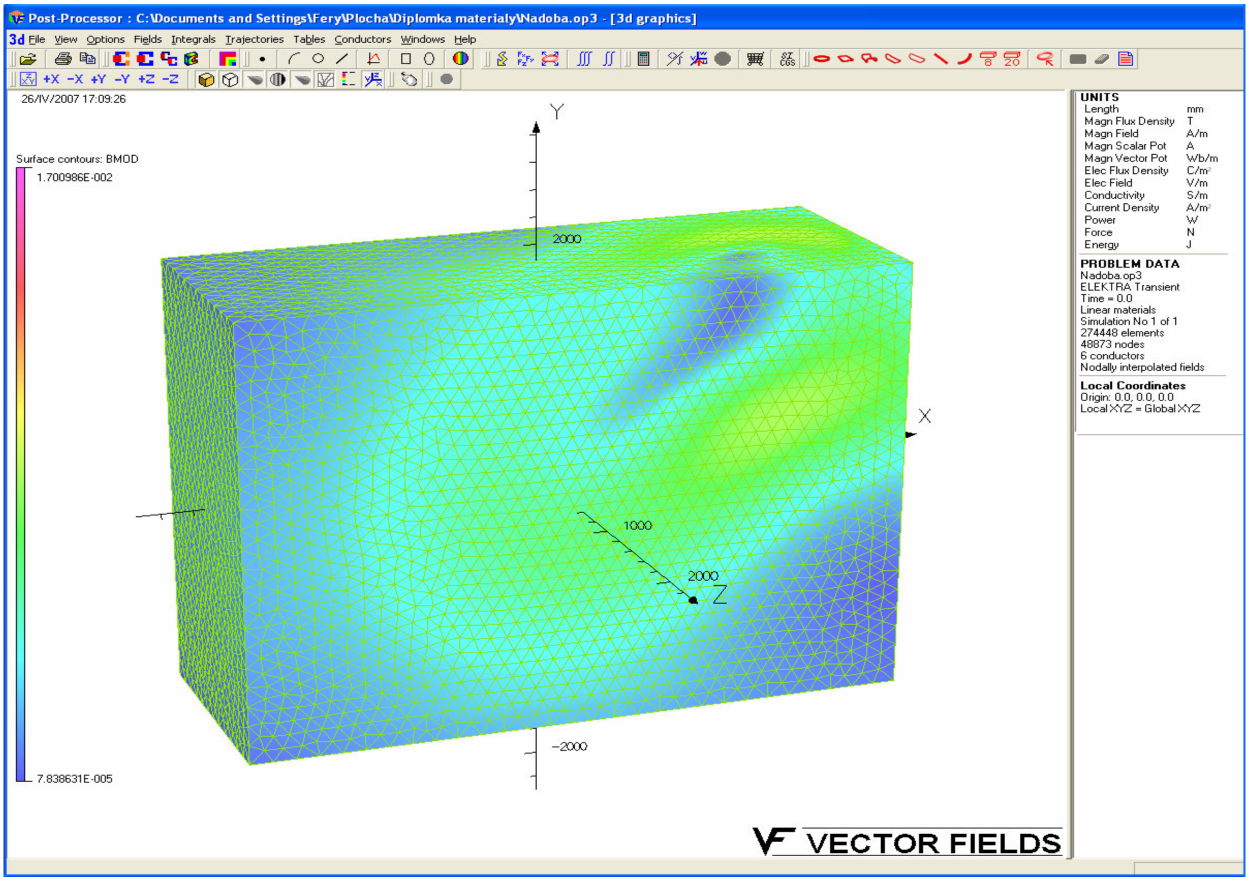


Fig.7. Map of the magnetic field

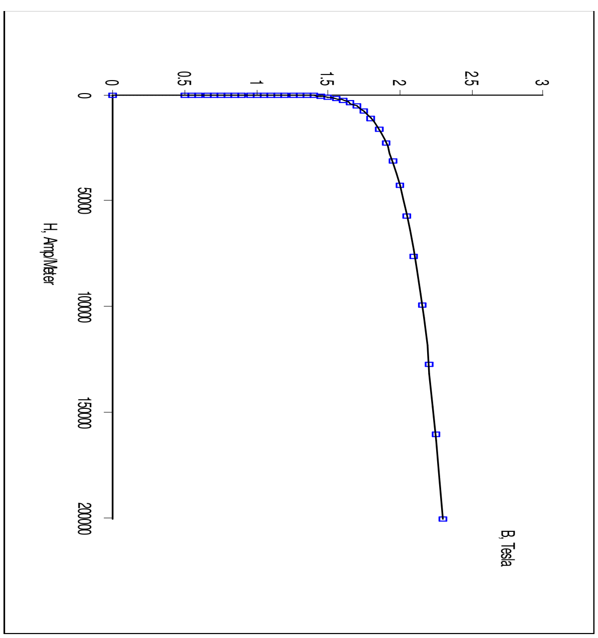


Fig. 8. Nonlinear B-H characteristic

3 Conclusion

The losses effects of induced eddy current in the transformer tank have been computed. 2D model is relatively simple but inaccurate. Losses in the tank of the transformer - 3D model - were evaluated nearly zero Watts. The main problem is low density of mesh. Next problems are generated with incommensurated between electromagnetics and tank parts. The experimental proof of calculation is difficult to realize. The comparison with calculation may come from industrial experiences. Usually value of losses in the tank transformer 25MVA is about 4kW [2].

ACKNOWLEDGEMENT

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[5] manual FEMM 4.0

[6] manual OPERA 9.0