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PREDICTION OF STRAY LOSSES IN POWER TRANSFORMER

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Abstract *– Leakage flux and stray losses of three-phase power transformer are analyzed using 3D-FEM. The eddy current losses in the clamp plates and transformer tank are obtained by modeling them as skin depth independent shell element. The calculation is made under magnetodynamic steady state load condition treating the magnetic core magnetizing characteristic as non-linear. The results are obtained by varaying clamp plates and tank permeabilities. Influence of diferent transformer core material on the losses value is also investigated.*

1. Introduction

Calculation of the eddy current losses in the structural metal parts in power transformer has been made by different treatment of the thin conducting shell, e.g. transformer tank and clamp plates. The authors [1] treated this problem by surface impedance boundary condition (SIBC) based on scalar magnetic potential. The next possibility, which is shown in this paper is a skin depth independent shell element used to model thin conducting sheets in the finite element method context [2]. The 3-D finite element-based package [3] is used to determine the leakage magnetic flux and stray losses in the clamp plates and transformer tank. The eddy current losses calculation using shell element has been applied to a power transformer of 40 MVA. The transformer, clamp plates and tank walls data are given in [1]. The transformer FEM model is shown in Fig. 1.

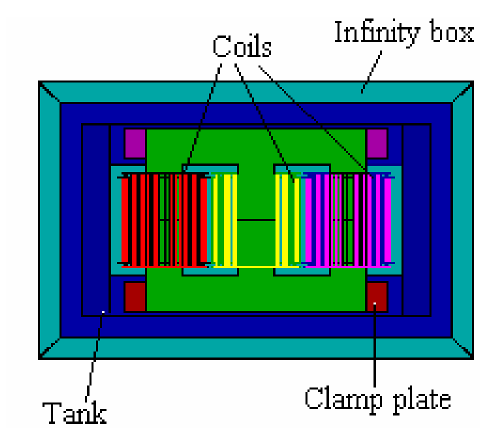


Fig 1 The transformer FEM model (symmetry plane).

2. Method of analysis

The electromagnetic field has been calculated using a magnetodynamic model. With the exception of the coils region, the sub-regions of the calculation domain are defined with total scalar potential formulation. Reduced potential is used to describe the coil regions. Calculation of the magnetic field from Biot-Savart's law allows for the exclusion of the coil from finite element mesh. The nonlinearity of the transformer core magnetizing characteristic is taken into account. The thin volume conductive region can be modeled by means of surface regions, for given frequency, permeability and conductivity of the material. The surface region of hyperbolic conductor type is chosen. The tangential component of magnetic field in a thin plate is described analytically by the following expression:

$$H_t(z) = \frac{1}{sh(ae)}\left[H_{1t} sh\left(\frac{ae}{2} + az\right) + H_{2t} sh\left(\frac{ae}{2} - az\right)\right], \tag{1}$$

while the volume current density variation has a tangential component only and is described by:

$$J(z) = \frac{a}{sh(ae)}\left[H_{1t} sh\left(\frac{ae}{2} + az\right) - H_{2t} sh\left(\frac{ae}{2} - az\right)\right], \tag{2}$$

where $a = (1 + j)/\delta$, H_{1t} and H_{2t} are the field values on both side of the plate and δ is the skin depth.

Eddy current losses per surface unit in the shell are:

$$P = \int_{-e/2}^{e/2} \frac{1}{2\sigma} |J(z)|^2 dz, \tag{3}$$

where σ is the conductivity of the material and z is direction normal to the surface.

The potential formulation used in the surface region is in total scalar. In this region the scalar potential is jumped, obtained by duplicating the nodes automatically at the beginning of the solving process.

The no load current creates a phase shift between ampere-turns phasors in high voltage and low voltage winding during transformer loading. The magnetizing component of no load current is taken into account. The ampere-turns balanced equation in phasor form is:

$$\bar{I}'_L (N_H + N_R) + \bar{I}_L N_L = -\bar{I}_\mu (N_H + N_R) \tag{4}$$

Right side of the equation (4) presents non-compensated ampere-turns due to magnetizing current $\bar{I}_\mu$. $\bar{I}'_L$ is the low voltage winding current expressed in the primary frame of reference. N_H, N_L and N_R are the number of turns of high voltage coil, low voltage coil and regulative coil, respectively.

3. Results

The calculation of the losses in the clamp plates and transformer tank is made for the following cases:

a) clamp plates permeability is varied while tank permeability is fixed at μ_r =500.

b) both clamp plates and tank permeability are simultaneously varied in the range from μ_r =100 to μ_r =1000.

c) tank permeability is varied while clamp plates permeability is fixed at μ_r =500.

d) magnetic core material is varied.

The leakage magnetic field in the transformer symmetry plane in the winding area and components of the leakage magnetic field on the upper clamp plate surface are showed in Fig.2 and Fig.3 respectively.

Fig.4 shows the tank losses values as a function of the permeability, for both, constant and variable clamp plate's permeability. Fig.5 shows the total clamp plates losses values as a function of the permeability, for both, constant and variable tank permeability.

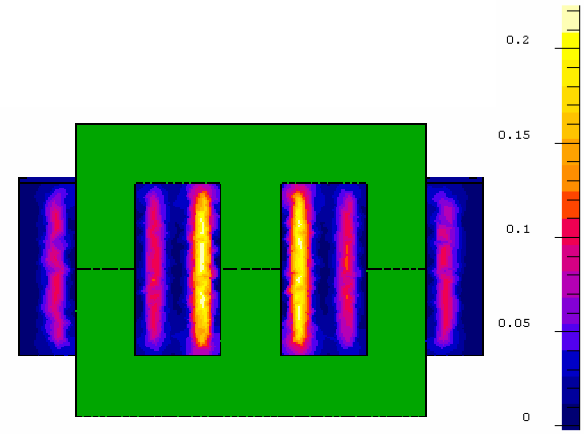
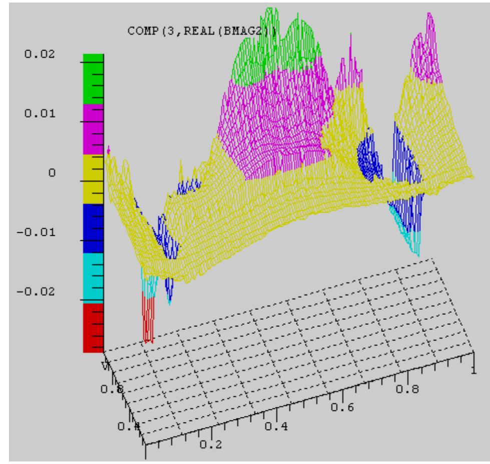
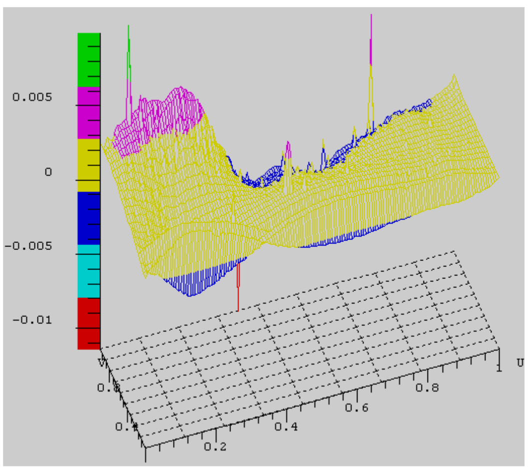


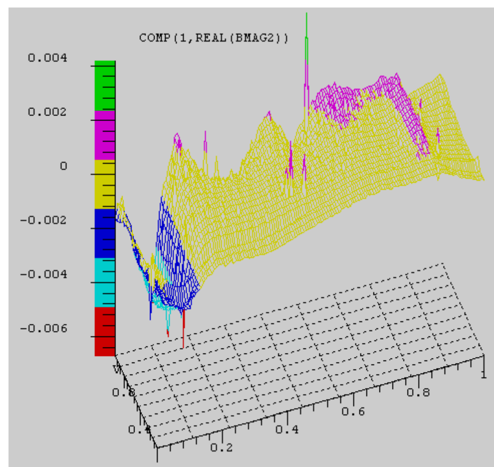
Fig. 2 Distribution of magnetic induction (leakage field) at instant ωt=0°, (T), on the symmetry plain.



(a)



(b)



(c)

Fig. 3 Distribution of the magnetic induction on the clamp plate surface (T): (a) z -direction, normal to the surface, (b) y- direction and (c) x- direction.

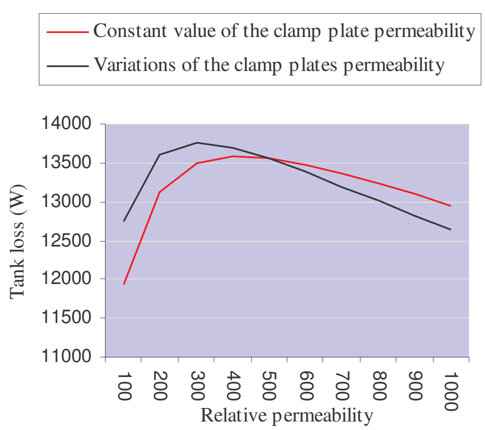


Fig. 4 Tank losses as a function of the permeability.

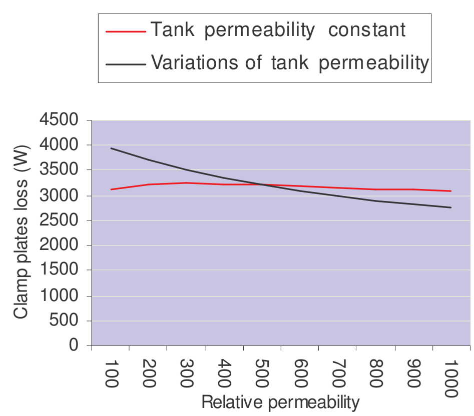


Fig. 5 Clamp plates losses as a function of the permeability.

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The calculated losses obtained for two cases with different transformer core material applied, are given in table I. It is shown that for the same distribution of the magnetic induction inside the core, magnetizing currents are different. In the present cases, both the tank and plates relative permeabilities are fixed at 500. The phase shift of 45° is chosen between magnetizing current and low voltage winding current.

For the cases of prescribed equal ampere-turns in the HV coil and LV coil, the obtained losses values are equal even the magnetic core materials are chosen different. A distribution of power loss on the clamp plate surface is shown in the Fig. 6. The average losses value is 522 W/m^2 on the plate surface.

Table I

Core material	Core induction (T)	Magnetizing current (%)	Power losses (W)	
			Tank	Clamp plates
M4	1.5	0.062	13558	3208
M800	1.5	2.6	17060	3676

Fig.7 shows eddy currents distribution on the clamp plate surface. The average value of the surface current density is 1333 A/m.

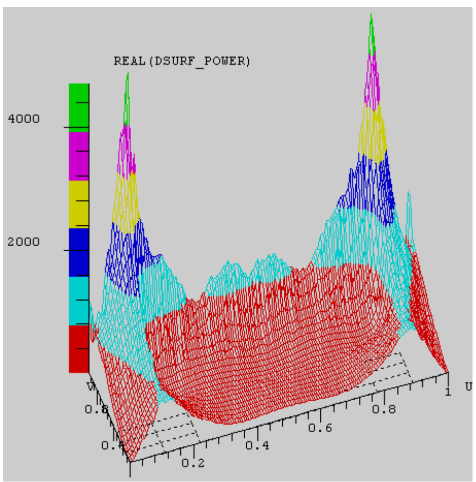

Fig. 6 Power losses distribution in the clamp (W/ m^2), spatial diagram.

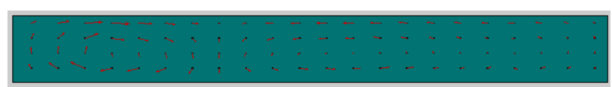

Fig. 7 Eddy current density distribution (A/m) plate on the clamp plate surface.

4. Conclusion

The losses effect of induced eddy current in the transformer clamp plates and unshielded tank walls have been computed. The obtained results simultaneously depend on both the plates and the tank permeability. The load character or phase shift between magnetizing current and secondary current has influence on the losses value. The influence depends on transformer core magnetizing characteristics.

References

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