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Flux Simulation on 100kVA Three-Phase Transformer Core

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Abstract – *This paper describes the flux distribution on 100kVA 3phase distribution transformer assembled with 60°-45° T-joint and mitred lap corner joint with stagger yoke and limb. The core material that used is 3% Silicon Iron Cold Rolled Grain Oriented (CRGO) material. The flux distributions have been simulated using 2 (two) Dimensions Finite Element Method (2DFEM) based on a vector potential formulation. In order to find the loss of magnetization of transformer core lamination used the hysteresis curve of core material. The result of this simulation was 1.78 T flux density maximum at the centre limb of transformer core, hence produced the losses of 2.54 W/kg.*

***Keywords**: Finite Element, Hysteresis, Flux Distribution, Core Loss.*

I. Introduction

The electrical transformer was invented by an American electrical engineer, William Stanley, in 1885 and was used in the first ac lighting installation at Great Barrington, Massachusetts. The first transformer was used to step up the power from 500 to 3000 V and transmitted for a distance of 1219 m (4000 ft). At the receiving end the voltage was stepped down to 500 V to street power and office lighting. By comparison, present transformers are designed to transmit hundreds of megawatts of power at voltages of 700 kV and beyond for distances of several hundred miles. [1]

Loss evaluation has become important because of high energy cost. Therefore, it is necessary to know in detail the behaviours of flux in transformer in order to develop cores with higher efficiency. [2, 3]

The efficient operation of power transformer cores depends to a large extent on the design of the joints between their limbs and yokes. In the three-phase, three limb core the most complex joints are the T-joints at the intersection the centre limb and yokes.[4]

The objective of this investigation is to find the flux distribution and the losses that occur on the transformer core assembled with 60°-45° T-joint built from 3%SiFe Cold Rolled Grain Oriented (CRGO) material using 2DFEM.

The quantitative analysis of localized flux and loss distributions has become easier through the remarkable progress of numerical field calculations such as the finite element method. The numerical simulation is more effective and economical than experimental method. Moreover, useful suggestions for improving transformer can be obtained from the calculated flux distribution and loss. [5]

II. Methodology

Methodology that is used to complete this investigation had been divided into three major tasks:

1) Drawing transformer core assemble with 60°-45° T-Joint
2) Simulation of the transformer core drawing
3) Loss calculation for the transformer core material

Drawing the transformer core configuration is the first step before doing the simulation. In this simulation, this drawing had been done using Quickfield v5.2 software. QuickField is an interactive environment for electromagnetic, thermal and stress analysis. In QuickField, it works with several types of documents: problems, geometry models, material libraries and others. QuickField can perform linear and nonlinear magnetostatic analysis for 2D and asymmetric models. The program is based on a vector potential formulation.[6]

Dimension of the 100kVA transformer core model are as figure 1. The configuration of T-Joint is drawing in Figure 2. To identify the material, B-H curve reading need to be tuck at the data column for each of the limb. The values for material can be obtained from the B-H curve. The data should be tucking as indicated in figure 3.

B-H curve data can obtain from the technical details of the 3%SiFe Cold Roll Grain Oriented (CRGO) material with thickness of 0.30mm. Each of the limb and yokes block label need to be entering with the data such as coercive force of magnet, field source and others.

Directions of the coercive force of magnet are set to be 90˚ for the right and left limb and the centre limb will be set to -90˚. This will make sure flux from left and right limb will flow through the centre limb. Meanwhile for the

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upper yoke and lower yoke the direction were set to zero degree for both upper and lower yokes. [4]

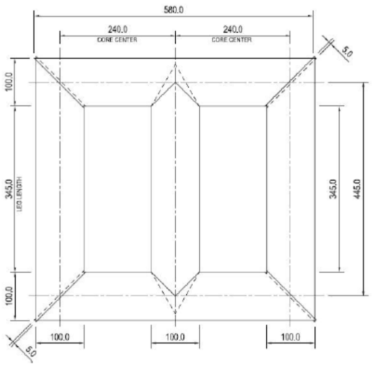

Fig. 1. Dimension (mm) of 100kVA transformer core model

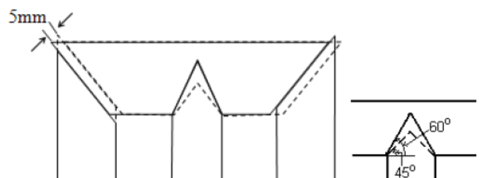

Fig. 2. Transformer core type with the mix 60°-45° T-joint

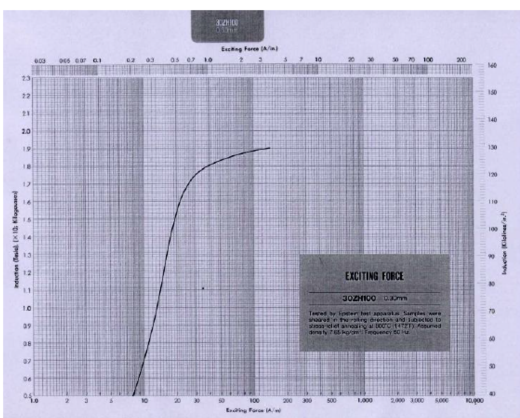

Fig. 3. B-H curve data material data sheet.

Air type and steel type need to be set for the edge label property. In the edge properties, for every edge of the steel need to be assign to tangential field and for the air edge, it need to be assign to magnetic potential

Before any simulation took place, the drawing should be check either mesh can produce all over the drawing or not as indicated in figure 4. Simulation only can be executed after mesh had been built off. To execute the simulation, there is executing button on the toolbar icon. If the simulation success without having any error on the drawing a result with flux line flow through the core will come out. Value of flux density can be obtained from the field picture by right clicking on the result drawing. To check the local value, click on local value button and just pointing mouse at any space of the simulation result to get the result value.

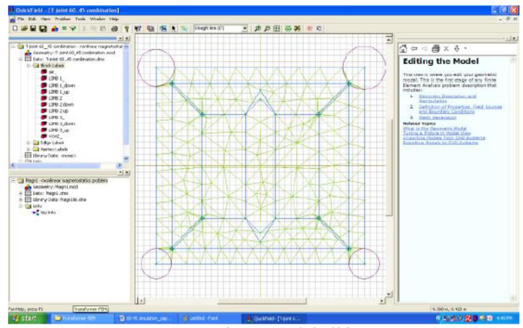

Fig. 4. Mesh build

III. Analysis

To simulate the flux density so will use equation such as:

$$B = \mu H \tag{1}$$

$$\mu = \mu_0 \mu_r \tag{2}$$

where μ = material permeability

H = material intensity from figure 3

The flux density is assumed to lie in the plane of model (xy or zr), while the vector of electric current density $\boldsymbol{j}$ and the vector potential $\boldsymbol{A}$ are orthogonal to it. Only j_z and A_z in planar or j_θ and A_θ in axisymmetric case are not equal to zero. We will denote them simply j and A. Finally, the equation for planar case is

$$\frac{\partial}{\partial_y}\left(\frac{1}{\mu_y}\frac{\partial A}{\partial y}\right)+\frac{\partial}{\partial y}\left(\frac{1}{\mu_x}\frac{\partial A}{\partial y}\right)=-j+\left(\frac{\partial H_{cy}}{\partial x}-\frac{\partial H_{cx}}{\partial y}\right) \tag{3}$$

and for axisymmetric case is

$$\frac{\partial}{\partial_r}\left(\frac{1}{r\mu_z}\frac{\partial (rA)}{\partial y}\right)+\frac{\partial}{\partial z}\left(\frac{1}{\mu_y}\frac{\partial A}{\partial z}\right)=-j+\left(\frac{\partial H_{cy}}{\partial z}-\frac{\partial H_{cz}}{\partial r}\right) \tag{4}$$

where components of magnetic permeability tensor μ_x and μ_y (μ_z and μ_r), components of coercive force vector H_{cx} and H_{cy} (H_{cz} and H_{cr}), and current density j are constants within each block of the model.

In order to find the loss of energy per cycle or magnetization of transformer core lamination as follow;[7]

Let l = mean of iron bar

A = its area of cross section

N = No of turns of wire of the solenoid.

with relate the B-H curve of core material shown in figure 5.

If B is the flux density at any instant, then $\Phi = BA$ when current through solenoid changes, then flux also changes and so produces and induced e.m.f whose value is

$$e = N\frac{d\Phi}{dt} \tag{5}$$

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$$e = N\frac{d(BA)}{dt} = NA\frac{dB}{dt} \qquad (6)$$

Now, $H = NI/l$ or $I = Hl/N$ (7)

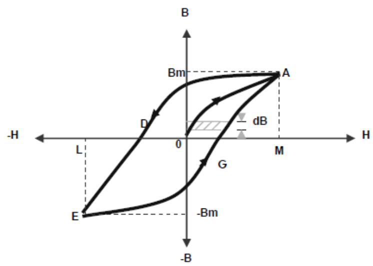

Fig. 5. Hysteresis curve

The power of rate of expenditure of energy is maintaining the current 'I' against induced e.m.f 'e' is

$$= eI = \frac{H.l}{N} \times N.A\frac{dB}{dt} = A.l.H\frac{dB}{dt} \text{ Watt} \qquad (8)$$

Energy spent in time 'dt'

$$A.l.H\frac{dB}{dt} \times dt = A.l.H.dB \quad \text{Joule}$$

Total network done for one cycle of magnetization is

$$W = A.l.\oint H.dB \text{ Joule} \qquad (9)$$

Where

$\oint H.dB =$ area of the loop, i.e the area between B-H curve and the B-axis.

work done, cycle = $A.l. \times$ (area of the loop) Joule

$A.l = volume\ of\ material$

net work done/cycle/m^3 = (loop area) Joule

W = (area of B-H loop) joule/m^3/cycle

IV. Results and Discussions

As an overview flux will flow through the core limb in various patterns. From figure 6 it shows that flux flow through centre limb from each left and right limb. Simulation using Quickfield software showing the flux lines flow through the limb and yoke of transformer core.

The flux density value from simulation is 1.78 T as indicated in figure 7. Flux density that is flow through the transformer core is not uniform. The maximum flux density is found in the centre limb of transformer core. Because the flux density that is flow from the left and right limb of the transformer core is enter toward the centre limb of transformer core.

An energy density value is recorded in unit J/m³. For 3% SiFe material of the transformer core has the value of energy density is 384 J/m³. Energy density obtained from the simulation result is shown in figure 8. In this figure shows the energy density occurs at the left and right limb of transformer core.

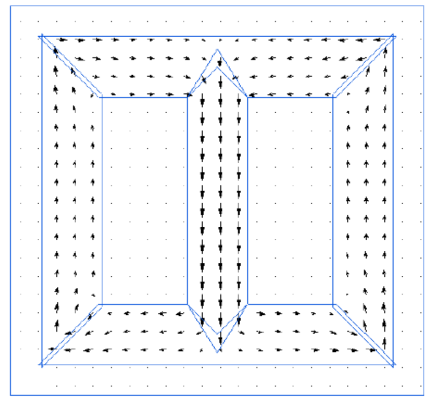

Fig. 6. Flux lines flow through transformer core

From the simulation result, some data can be obtained such as;

Energy Density, ωH = 384 J/m^3

Density = 7.65kg/dm^3 (from the B-H curve)

In order to find frequency, the equation that used is;

$f = \frac{1}{t} = \frac{1}{t\sec} = 50Hz$; $t = \frac{1}{50} = 0.02\sec$

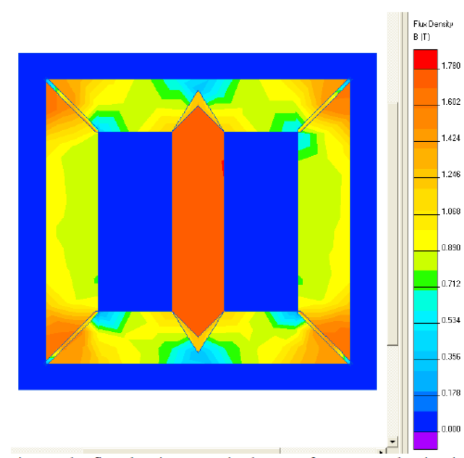

Fig. 7. The flux density occur in the transformer core lamination

From simulation result data, power loss per kg can be obtained using eq. (9) that is;

$$\frac{384J/m^3}{7.65kg/dm} = 2.54Watt/kg$$

Hence will obtained the losses of transformer core is 2.54 Watt/kg at flux density of 1.78T.

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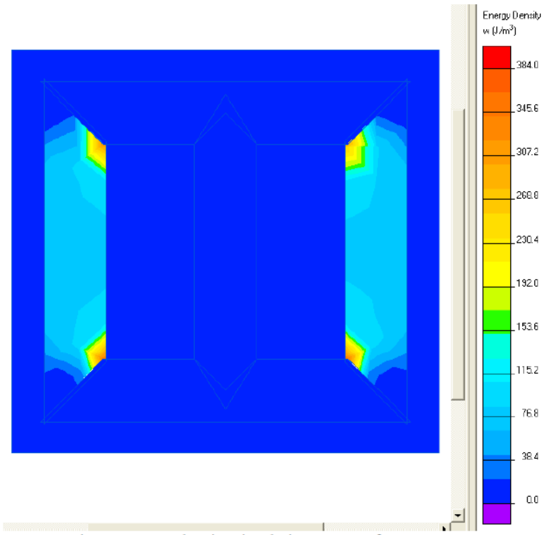

Fig. 8. Energy density simulation on transformer core

V. Conclusion

Loss calculation has become important because of high energy cost. Therefore, it is necessary to know in detail the behaviours of flux in transformer in order to develop cores with higher efficiency.The values for material can be obtained from the B-H curve material data sheet.

From the result of simulation found the flux density is 1.78 T and the loss calculation is 2.54 W/kg. Flux density that is flow through the transformer core is not uniform. The maximum flux density is found in the centre limb of the transformer core.

Acknowledgements

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