MODELING AND MODIFICATION FOR DISTRIBUTION TRANSFORMER (250 KVA, 11/0.416 KV) TO REDUCE THE TOTAL LOSSES

Assist. Prof. Ibtisam A. Hasan   **Dr. Sahar R. Fafraj**   **Eng. Azhar K. Azeez**
Electromechanical Eng. Dept.   **Electromechanical Eng. Dept.**   **Dept. Electromechanical Eng.**
University Of Technolog   **University Of Technology**   **University Of Technology**
Dr_ibtisam_ahmed@yahoo.com dr.sahar_alsakini@yahoo.com powerengineering79@yahoo.com

ABSTRACT:

This paper presents the electromagnetic model for the 3- phase distribution transformer 250 KVA 11/.416KV core type. This model based upon using "ANSYS PROGRAM" to obtain the flux density distribution and losses, in this work, it has been change core material from silicon steel (Si.St.) to amorphous steel (Am. St.). Where, the iron losses reduction with 90%. The result for computer program are compared with practical measurements.

Key word: **Distribution transformer, Flux density distribution, Transformer losses, amorphous steel, ANSYS.**

نمذجة وتطوير محولة توزيع (250 KVA, 11/0.416KV)

الخلاصه:

عرض البحث الحالي نمذجه كهرومغناطيسية لمحولة توزيع ثلاثية الأطوار 250KVA , 11/.416 فولت,50هيرتز مغطسة بالزيت من نوع اللب. نفذ الموديل المقترح بمساعدة التسهيلات التي يوفرها برنامج "ANSYS " للحصول على توزيع كثافة الفيض المغناطيسي وإيجاد الخسائر للمحولة. وقد تم تغيير مادة قلب المحولة من سيلكون ستيل إلى مادة الاستيل العشوائية حيث قلت الخسائر الحديديه بنسبة 90%.النتائج التي تم الحصول عليها من البرنامج قورنت مع النتائج العمليه المقاسه.

Nomenclature:

B_M:	Maximum magnetic flux density
E_1:	R.M.S value for Primary Electro motive force
E_2:	R.M.S value for Secondary Electro motive force
E_t:	Electro motive force per turn
e_1:	Electro motive force
e_{1m}:	Mean primary Electro motive force
f:	frequency
I_1:	Primary current
I_2:	Secondary current
N_1:	Primary turn number

N_2:   Secondary turn number
Pc_1:   Power losses of primary winding
$\emptyset$:   Magnetic flux
Pc_2:   Power losses of secondary winding
Pc_T: Total power losses of windings
$P_{i(sp.)}$ Specific power losses
Pi_T: Total power losses of core
P_T: Total power losses of transformer
R_1:   Primary winding resistance
R_2:   Secondary winding resistance
S: Transformer capacity
V_1:   Primary phase voltage
V_2:   Secondary phase voltage
We_l: Weight of leg
We_y: Weight of yoke
η: Efficiency

1. INTRODUCTION:

A transformer is a highly efficient static machine operating on the principle of mutual induction. In alternating current power circuit the transformer converts it's from one voltage level to another through inductively coupled conductors and is available in a variety of power ratings. Distribution transformer represents important part a power system. One of the major and important parameters dominant a distribution transformer's age is hot spot temperature. However, the heat dissipation is problem in distribution transformers. The losses in the distribution transformer convert to heat but by accumulated this heat without being dissipated the life of the transformer (**Haritha2011**). Because of this it must be reduce the losses in distribution transformer to increase the efficiency of it's and then the life of the distribution transformer become longest.

The distribution transformer is complicity so the finite element method has been used to study the electromagnetic; Finite element modeling (FEM) of electromagnetic fields, which is very advanced technique available as commercial software to provide a reliable tool for the design and performance prediction of electromechanical devices. In this work, the general-purpose finite element package "ANSYS15" is used.

ANSYS software is a powerful universal software based on the finite element algorithmic; the design and analysis the distribution transformer required its. The transformer is modelling before manufacturing and within the process of design (**Thamir et al 2014**).

(**Dorinel et al 2013**); study validate a designed three phase power transformer with modern software that use finite element method (ANSYS Maxwell 3D and ANSYS Mechanical). It found the magnitude of B field, the regions with problems and the value of the total core losses for the same transformer but at 3 types of voltages: 330 kV, 400 kV and 430 kV.

(**Diako et al**); used the finite element method to solve Maxwell and thermal (energy) equations to obtain the distribution temperature in the 3-phase (10 MVA, 63/20kV) transformer to find the flux density and hot spot temperature.

(**Kassim 2015**); they used the finite element method (ANSYS, APDL) to analyze the 3 phase distribution transformer wound type to find the magnetic flux density distribution and force.

(**Man 2012**); he used amorphous steel to reduce the losses for transformer. Where, it found the amourphous material reduced the iron loses by 90%.

(**Neha et al 2015**); they used new material to reduce the losses and improve the life time for transformer. Where, they found the amourphous material reduced the iron loses by 68% for 100 KVA.
(**Ravi et al 2013**); this paper covers design of transformer using a new technology superior magnetic material with thin sheets of lazer grade or amorphous core. This design of transformer was carried out to find the better quality core to reduce the losses and improve the efficiency.
(**Riath 2009**); presents an algorithm to design a complete three-phase distribution transformer. Where, this program gives several alternative designs for each required transformer and applied to standard distribution transformers used in the Iraqi power system.
(**Thamir et al 2014**); they used the finite element method (ANSYS, APDL) to analyze the 3 phase distribution transformer (250 KVA, 11/0.416 KV, core type) to find the magnetic flux density distribution.

2. MATHEMETICAL MODEL OF DISTRIBUTION TRANSFORMER:

For initiating the design of the magnetic circuit (main dimensions of core)
When applied the alternating voltage across the primary windings in transformer, flux ($\emptyset$) and magnetizing current (I_m) is produced in the core. The flux is distributed uniformly over the core of transformer section and all primary and secondary turns of windings. The generated main flux is in alternative form, hence in the primary turns of windings, the electro motive force (e.m.f) induced due to the main flux changes as a follow (**Mittle 2009**),

$$e_1 = -N_1 \frac{d\emptyset}{dt} \tag{1}$$

Assuming sinusoidal time variation of the flux, let $\emptyset = \emptyset_m \cos wt$, where is $\emptyset_m$ the time-maximum value of the mutual flux in Weber, w=2πf, and f is the frequency of flux pulsation. Then

$$e_1 = -N_1 \left(\frac{d}{dt}\right)(\emptyset_m \cos wt) = T_1 \, w \, \emptyset_m \sin wt \tag{2}$$

The instantaneous value, the maximum is e_{1m} $\emptyset = T_1 w \emptyset_m$ and the R.M.S. value:

$$E_1 = \frac{1}{\sqrt{2}} w \, N_1 \emptyset_m = (\sqrt{2}) \, \pi f \, N_1 \emptyset_m = 4.44 f \, N_1 \emptyset_m \tag{3}$$

In each turn, the e.m.f. is:

$$E_t = 4.44 \, f \emptyset_m \tag{4}$$

Whether the turn is part of the primary, secondary, or other winding, provided only that it links the flux Φ_m (**Ravi et al 2013**).
Similarly, induced e.m.f. in secondary winding,

$$E_2 = 4.44 \, f \, N_2 \emptyset_m \tag{5}$$

Obviously the primary and secondary e.m.f. the same ratio

$$\frac{E_1}{N_1} = \frac{E_2}{N_2} \tag{6}$$

The iron losses produced from the eddy current and the hysteresis losses.it is can be calculated by weight of core

$$P\,i_T = p_{(sp)} * (We_{legs} + We_{yokes}) \tag{7}$$

Where, $p_{(sp)}$, is a specific iron loss for the core W/Kg taken from the curve of specific iron losses versus flux density.

The copper losses produced from the load can be calculated by:

$$P\,c_T = 3*(I_1^2 * R_1) + 3*(I_2^2 * R_2) \tag{8}$$

$$P_T = P\,i_T + P\,c_T \tag{9}$$

The efficiency of transformer is:

$$\eta = \frac{s}{s+P_T} \tag{10}$$

3. TRANSFORMER MODEL USING FINITE ELEMENT METHOD:

The details of building FEM of the distribution transformer under study are presented to analyze of the distribution magnetic flux in the transformer. It has been used ANSYS Package Version 11 to model the distribution transformer. **Table (1)** shows the data of distribution transformer.

3.1 Transformer Geometry (Building and meshing):

The transformer study is 250 kVA, three phase distribution core type "stacked core" transformer. To build this solid model, it has been measured the dimensions of this transformer accurately. These dimensions of transformer were taken from the design documents from the manufacturing company (AlWAZIRIYA Company of Electrical Industries). Building of this solid model started by the key points, following step connect these key points by lines, and then create areas from these lines. ANSYS package includes several elements that can be used to model electromagnetic phenomena. In this work for low frequency electromagnetic analysis, 2-D Solid Element PLANE53 for iron core, coils and oil. The objective in building a solid model is to mesh that model with nodes and elements. Where, it must be specify the size and type of mesh before generating the mesh. It has been found (45560) nodes and (23634) elements as the best formatted mesh.

3.2 Applying Loads and Solution:

The coils of each phase (primary and secondary) is coupled degree of freedom, all nodes of secondary is coupled together in **CURR** and **EMF** but the nodes of primary is coupled together in **CURR** degree of freedom. Then the voltage is excited directly to primary coil for each phase, but the secondary coil is coupled with external load circuit. Flux parallel is applied as boundary condition to the outer line of core. The analysis of the electromagnetic model by **ANSYS** package must be specified. The analysis types of solution are static, harmonic and transient. In this work, harmonic analysis is used (**ANSYS. 15 theory guid, 2015).** The formulations of finite element analyzing for this model are based on

Maxwell's equations (magnetic vector potential formulations). This solution requires sub-step calculation which is used for the numerical solution in finite element model. The solution gives the unknown quantities which are represented as a degree of freedom.

3.2.1 Harmonic Analysis:

Two conditions are used for solving the model. The first condition at no-load to check if the model is true or not. Second condition at load, the model is resolved by applying a load on the secondary windings as explained below.

a- No-Load Condition:

In this condition, the secondary winding is opened and applied voltage by direct excitation on the primary coils. The objective of this condition is to obtain the magnetizing current and to be sure the model is ready to the analysis. **See figure (1)**

b- Full Load Condition:

In this case, the resistance is connected to the secondary coils. Where the load circuit is build and adjusted the load resistance to reach the primary coils rated current. Then, it has been calculate the losses and compared with practical measurement. **See figure (2). Figure (3)** shows the block chart for ANSYS steps**.**

4. RESULT AND DISCUSSION:

ANSYS program was used to show the performance and to calculate the losses for the transformer. In the following results and figures for two cases (conventional and amorphous core) the electrical behavior are discussed:
Please note that the belonging arrangement of the figures is for conventional core and amorphous core respectively
- **Figures (4) and (5)** show the flux line distribution of magnetic density of the model at no load condition for two cases.
- **Figures (6) and (7)** show the flux line distribution of magnetic density of the model at full load condition.
These figures show that the flux line distributions are same when the transformer operates at two conditions (no-load and full load). This result was confirmed that the model gets good result.
- **Figures (8) and (9)** show the nodal plot of the flux density distribution for transformer. In general, the flux in the amorphous core less than in the conventional core because the saturation flux density for the amorphous less than the conventional core.
- **Figures (10) and (11)** show the vector plot for flux density distribution for transformer.
- **Figures (12) and (13)** show the nodal plot of magnetic flux density in High and low voltage coils. These figures show, the flux in Y-direction (height of coil) decreased gradually from the middle point of the coil height toward its endings. But, in X-direction the flux linearly increasing from outer side to inner side of low voltage coil and decreased linearly from inner side to outer side of high voltage coil. The reason of this distribution is that the flux increase with current and number of turns. The maximum value for flux density in real component was noticed in the phase (b) because the phase angle of it (0^0) but it has minimum value in the imaginary component.
- **Figures (14) and (15)** show the direction of leakage flux by vector plot. The flux in the primary winding has opposite direction of the secondary winding, because the current was flowing in the opposite directions inside the primary and secondary windings. The maximum value of flux density is at the phase (b) for real

component because the phase (b) has an angle equal to (0^0). And the imaginary component has the minimum value.

- **Figures (16) and (17)** show the heat joule in primary and secondary windings. In FEM heat joule value has been obtained by integrated the values of losses at all nodes, which forming each part of the transformer and then converted to heat. The amorphous core has lower heat joule than for the conventional core.

5. THE LOSSES RESULT:

The no load and load (iron and copper) losses have been calculated, using the ANSYS and MATLAB packages and then compared with experimental results to determine error percentage. Therefore, the efficient performance of the proposed model is checked. The type of core material plays a fundamental role in determining the amount of the losses generated. The core material has been replaced with amorphous; this caused to reduce the core losses about 90% from the losses for conventional core this percentage is match with ref. **(Man 2016)**. The initial cost of the conventional core is approximate 200000 but the amorphous core is 230000 **(Ravi et al 2013)**. This reduction depends on the amount of flux density saturation. In this material (amorphous), the saturation flux density is less than conventional core (silicon steel). Therefore, the specified core losses are reduced and subsequently the amount of heat generation, and caused decreasing the temperature rise inside the transformer and then enhance the efficiency of transformer. **Table (2)** shows the transformer losses.

6. CONCLUSION:

The distribution transformer **(250 KVA, 11/.416V, core type, oil immersed)**, the results indicated that total losses for no load and load conditions be **0.59** and **2.99 Kw** respectively by ANSYS but the when change the core material to Am.St. (Amorphous steel) the no load and load losses reduced by 90% and 5% respectively.

REFERENCES:

(Dorinel C., Petre-Marian N. and Cristiana-Maria N. 2013), "3D Finite Element Analysis of a Three Phase Power Transformer", EuroCon., Zagreb, Croatia, pp. 1548-1552.

(Diaco Azizi, Ahmad, Gholami, Diar Azizi), "Hot Spot Temperature Analysis in 3 Phase Transformers Using FEM Method", International Journal of Modern Engineering Research, Vol. 1.

 (Kassim R. H. 2015) , " ZIG-ZAG GROUNDING TRANSFORMER MODELING FOR ZERO-SEQUNCE IMPEDANCE CALCULATION USING FINITE ELEMENT METHOD ˝ , Diyala Journal of Engineering Sciences, Vol. 08, No. 06, pp. 36-87.

(Man M. 2016) , ""Distribution Transformer with Multi-Stepped Amorphous-Core"," Journal of Emerging Trends in Engineering and Applied Sciences , Pp 265-269.

(Mittle D. 2009), "Design of electrical machine", published by Standard Publishers Distributors, Delhi.

(Neha S. and Sameena E. M.,2015) ""Evaluation of Energy Efficient Core Material of Distribution Transformer"," International Journal of Electrical and Electronics Research, vol.3, no. 1, pp. 113-117.

(Ravi K. V., Shalini V. and S.K. Bajpai 2013) "Efficiency Improvements in Transformers by Adoption of New Magnetic Material", International Journal of Emerging Technology and Advanced Engineering, Pp 794-797, Volume 3, Issue 3, March 2013.

(Riath t. t. 2009) , "An algorithm for optimum design of three phase core type distribution transformer"," University of Babylon Journal, Vol.17, pp. 291-307.

(Thamir A. and Methaaq T. J. 2014), "Design and Simulation of 11/0.4 kV Distribution Transformer Using ANSYS"," Eng. & Tech. Journal , Iraq, Vol.32,Part (A), No.2.

ANSYS. 15 theory guid, 2015.

Table (1) data of 250 KVA, Distribution Transformer, and Oil immersed

Transformer Data	Symbol	Value	Unit
Transformer rated power	S	250	KVA
Frequency	f	50	Hz
Primary winding voltage HV	V_1	11000	volts
Secondary winding voltage LV	V_2	416	volts
Number of phases		3, (delta/star)	

Table (2): Transformer losses

		No Load Losses (KW)	Load Losses (KW)
Conventional core	**Theoretical**	**0.53**	**2.7**
	ANSYS	**0.59**	**2.99**
	Experimental	**0.577**	**2.88**
Amorphous core	**Theoretical**	**0.05**	**2.6**
	ANSYS	**.07**	**2.8**
Conventional core with 135°	**Theoretical**	**.528**	**2.7**
	ANSYS	**.588**	**2.99**
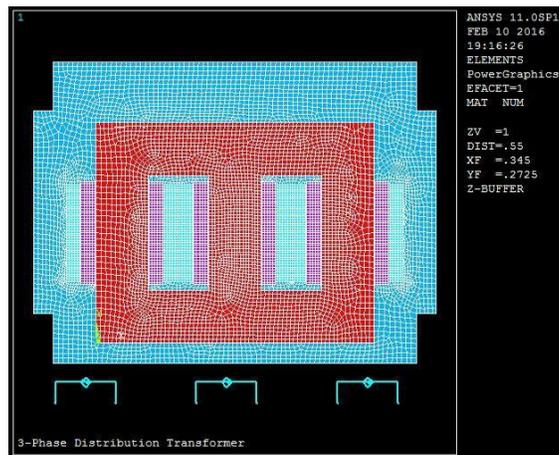
Figure (1): Distribution transformer with open circuit (no-load)
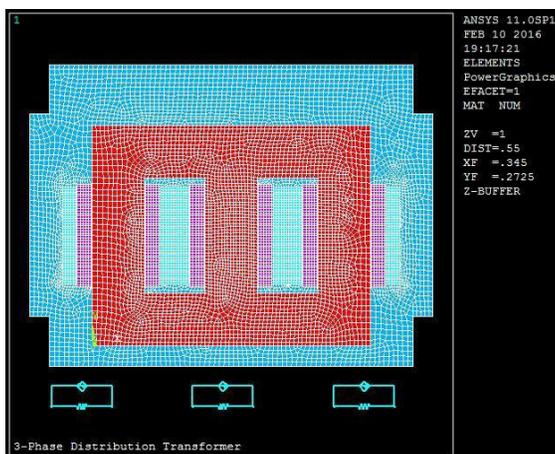
Figure (2): distribution transformer with external circuit load
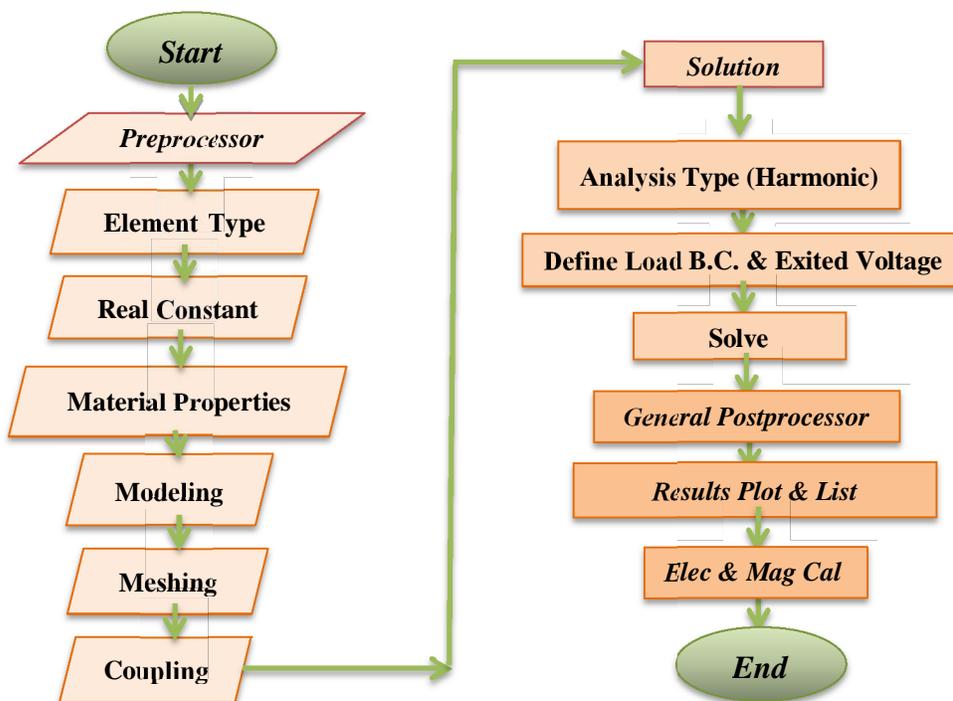
Figure (3): Block Diagram for ANSYS
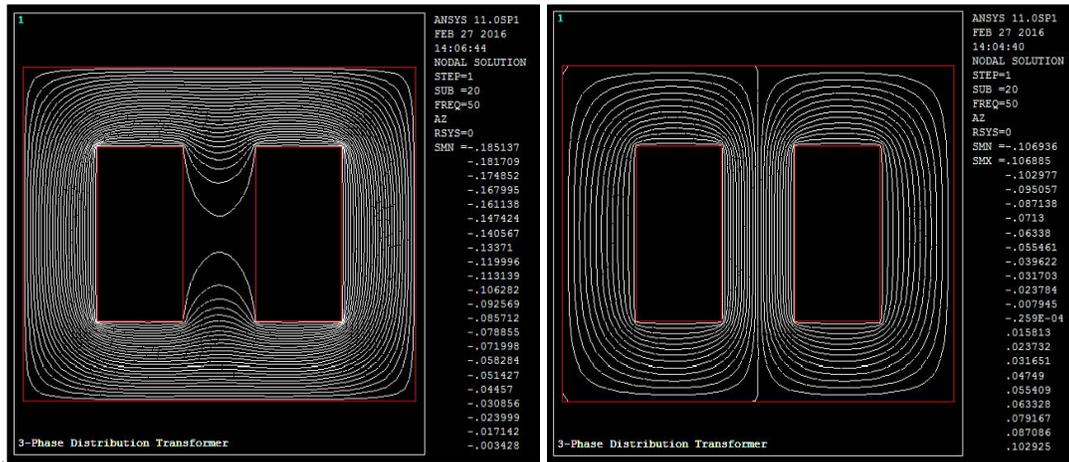
(a) Flux line distribution real component   (b) Flux line distribution imaginary component
Figure (4): 2D flux line distribution at no load of conventional core
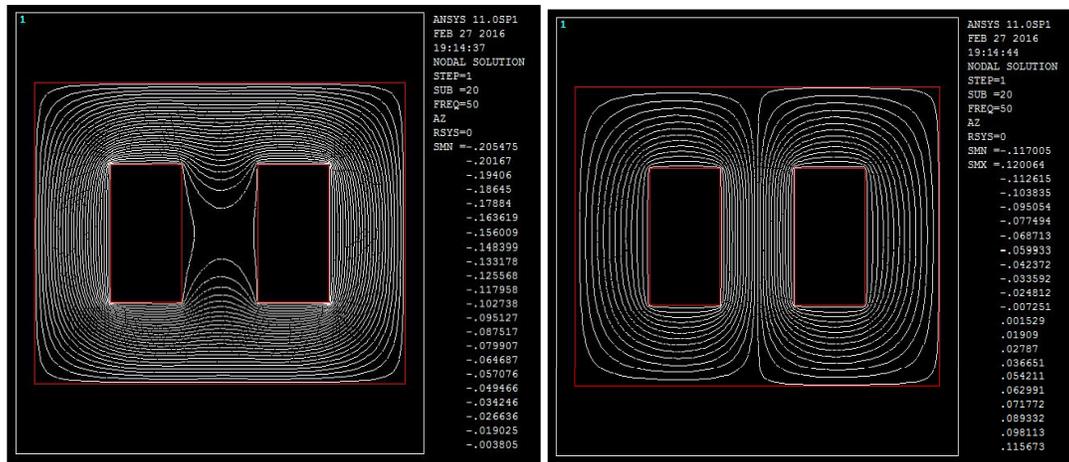
(a) Flux line distribution real component   (b) Flux line distribution imaginary component
Figure (5): 2D flux line distribution at no load of amorphous core
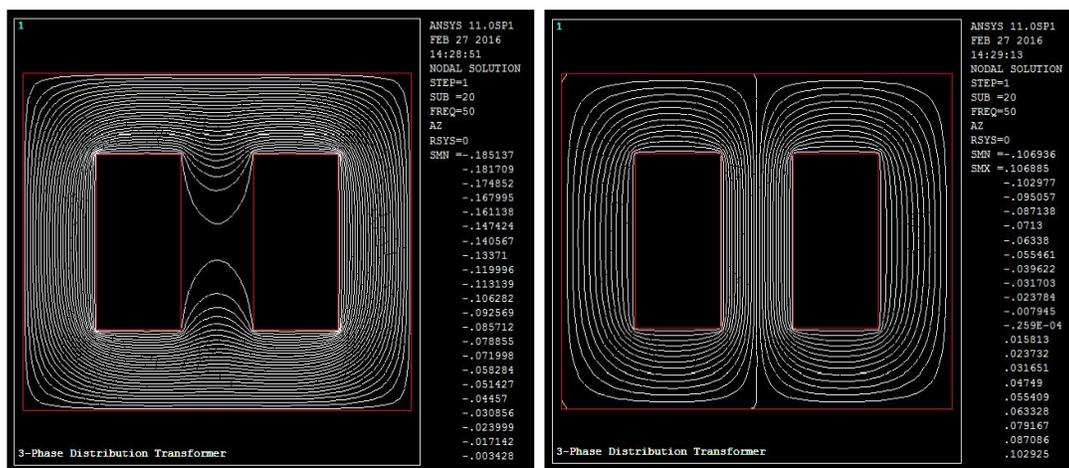
(a) Flux line distribution real component   (b) Flux line distribution imaginary component
Figure (6): 2D flux line distribution at full load of conventional core
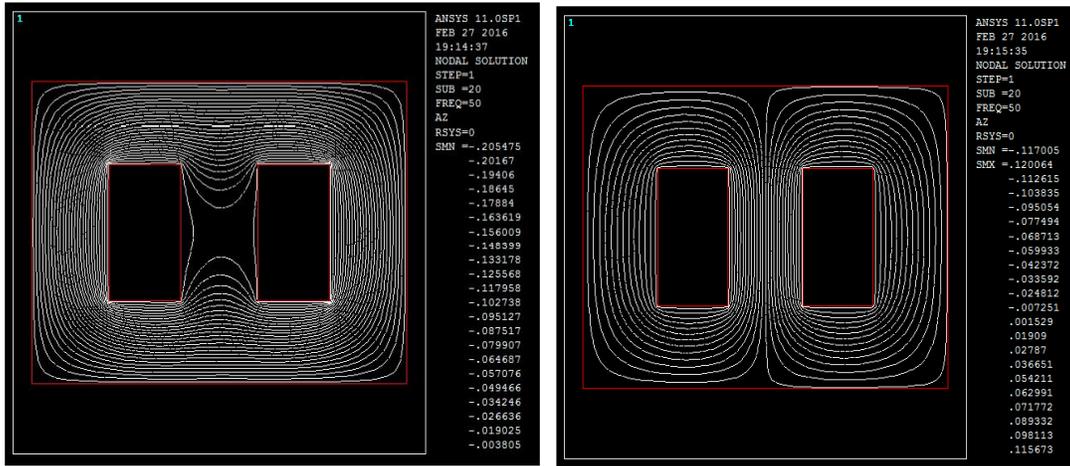
(a) Flux line distribution real component   (b) Flux line distribution imaginary component

Figure (7): Flux line distribution for amorphous core
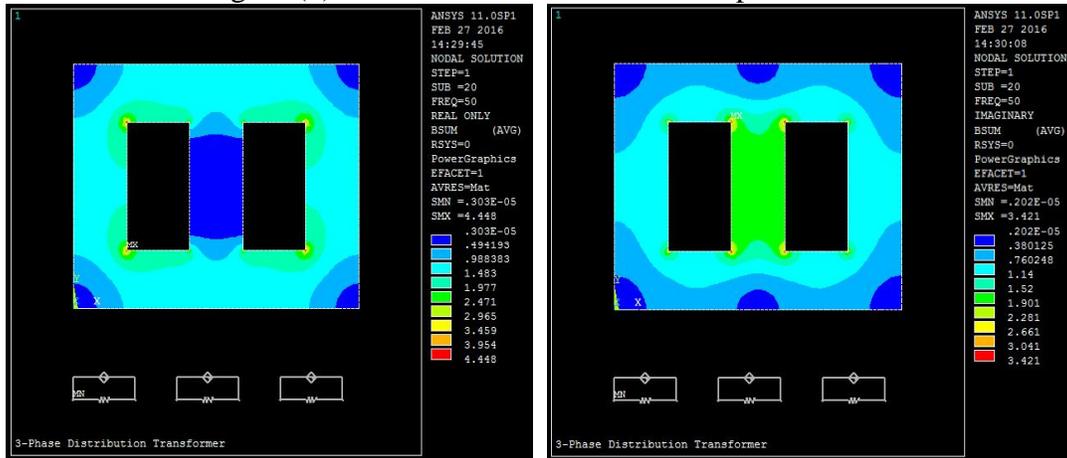
(a) Magnetic flux density real component   (b) Magnetic flux density imaginary component

Figure (8): Nodal plot of magnetic flux density of conventional core
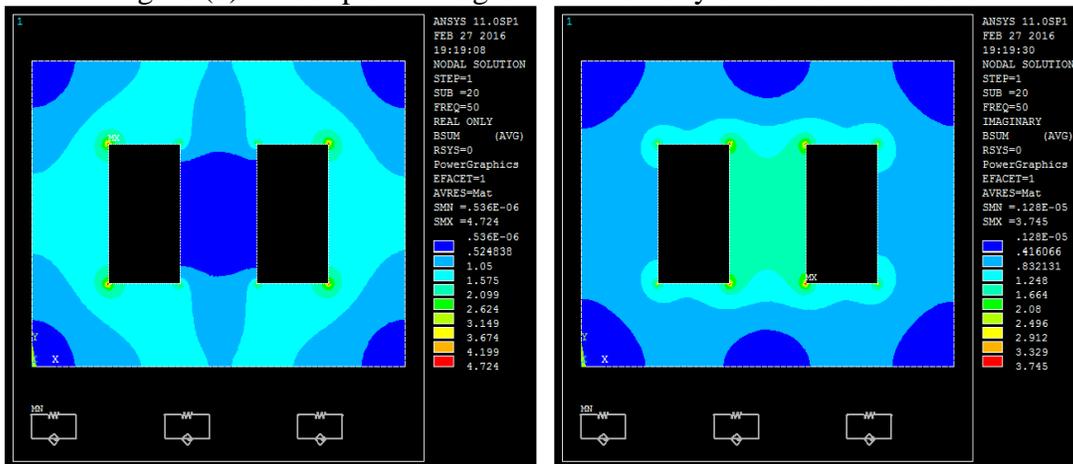
(a) Magnetic flux density real component   (b) Magnetic flux density imaginary component

Figure (9): Nodal plot of magnetic flux density of amorphous core
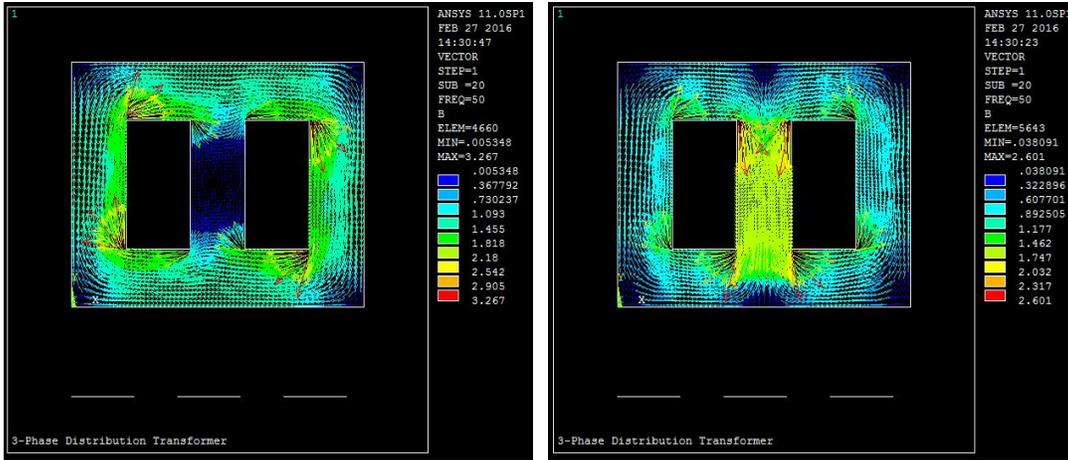
(a) Magnetic flux density real component   (b) Magnetic flux density imaginary component
Figure (10): Vector plot of magnetic flux density of conventional core
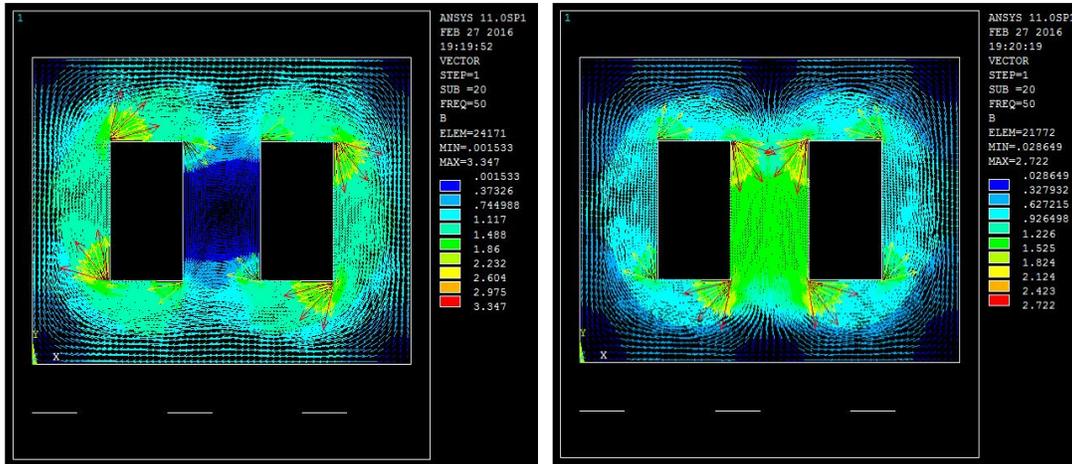
(a) Magnetic flux density real component   (b) Magnetic flux density imaginary component
Figure (11): Vector plot of magnetic flux density of amorphous core
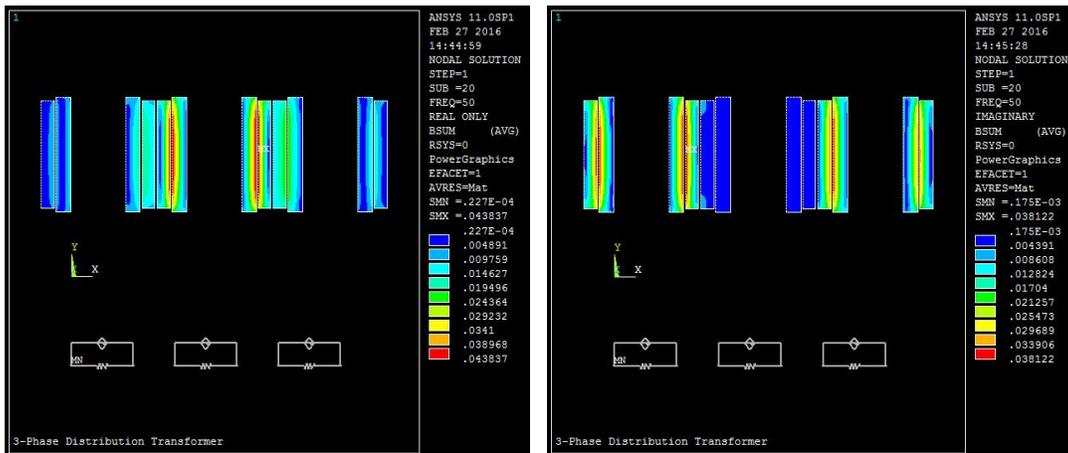
(a) Magnetic flux density real component   (b) Magnetic flux density imaginary component
Figure (12): Nodal plot of magnetic flux distribution of conventional core
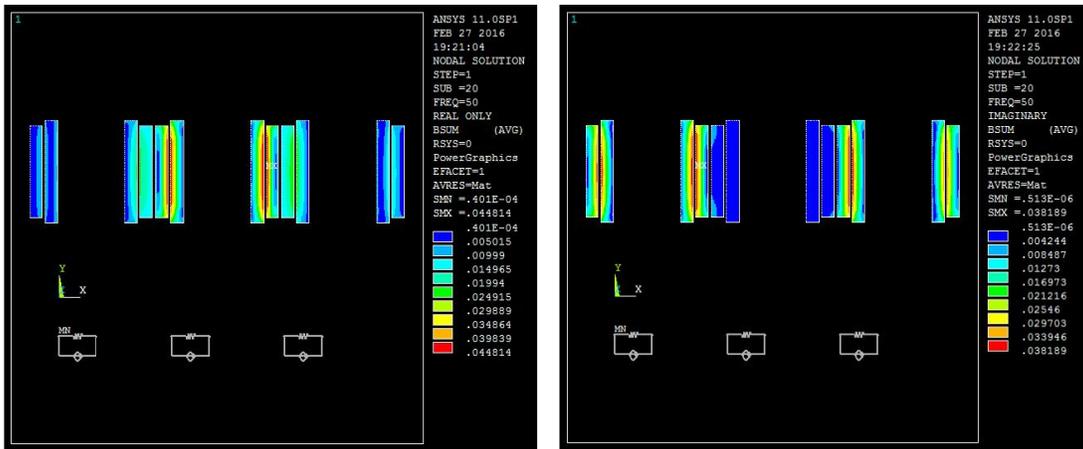
(a) Magnetic flux density real component   (b) Magnetic flux density imaginary component

Figure (13): Nodal plot of magnetic flux distribution of amorphous core
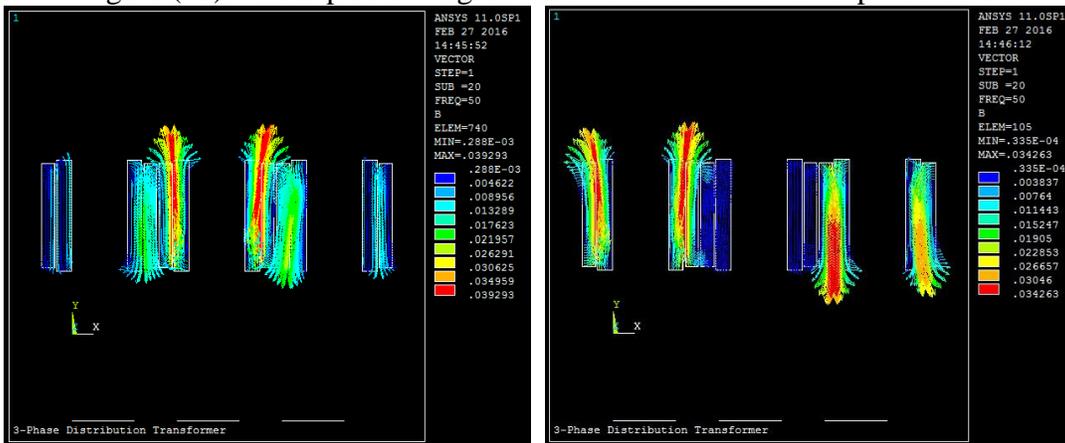
(a) Magnetic flux density real component   (b) Magnetic flux density imaginary component

Figure (14): Vector plot of magnetic flux density of conventional core
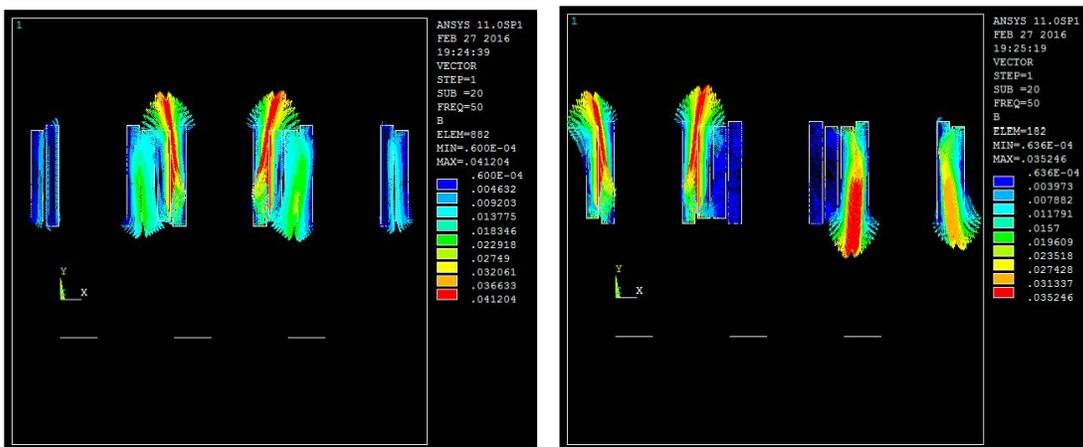
(a) Magnetic flux density real component   (b) Magnetic flux density imaginary components

Figure (15): Vector plot of magnetic flux density of amorphous core
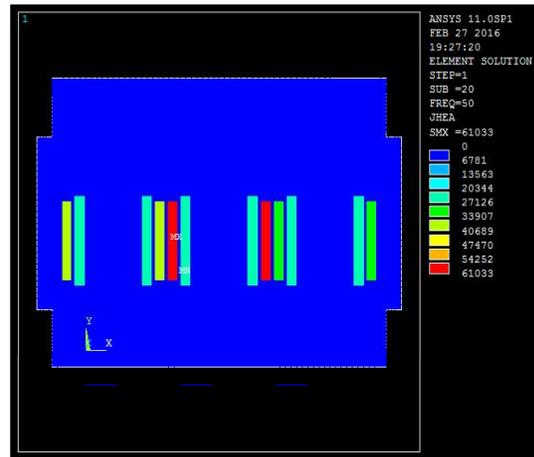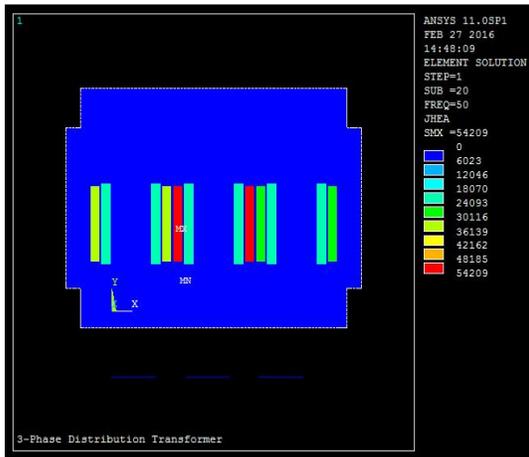
Figure (16): Heat generation of conventional core   Figure: (17): Heat generation of amorphous core