MODIFICATION OF THE DISTRIBUTION TRANSFORMER TO REDUCE THE POWER LOSSES +

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Abstract:

This study presents the modification for electromagnetic model of the three phase distribution transformer" D.T" 400 K_{VA} 11/.416KV,which have properties immersed oil and core type. It was fabricated at Ministry of industry in Baghdad/Iraq."ANSYS11 " was used to analyze this "D.T". The electromagnetic model analysis is used to explain the distribution of magnetic flux density and to calculate the losses of the transformer in case of no load which was $0.2K_W$ and the losses at load was (4.3KW) . The suggested model was compared with practical results which gave a good effect for model results. The modification of this work was done by changing the core material to amorphous steel "Am. St." from silicon steel "Si.St." .The no load losses is (0.08 KW) and the load losses is (4.01KW).

Key word: Distribution transformer, losses reduction, ANSYS package, amorphous steel materials, Finite Element Method.

تطوير محولة التوزيع للحد من خسائر القدرة

د.سحر راضي فرج

المستخلص :

هذه الدراسة قدمت تطوير نموذج كهرومغناطيسي لمحوله ثلاثية الاطوار بسعة (400 كيلو فولط امبير) و فولتية (0,416/11 كيلو فولط) مغمسه بالزيت ، نوع اللب والتي تم تصنيعها في وزارة الصناعه بغداد /العراق. "ANSYS11" استخدم لتحليل هذه المحولة للحصول على توزيع كثافة الفيض و ايجاد الخسائر الكهربائية.خسائر اللاحمل (0,82 كيلواط) وخسائر الحمل (4,3 كيلواط) .تمت مقارنة النتائج للنموذج المقترح مع النتائج العمليه و من خلالها تم التحقق من صحة النتائج المستحصلة. تم تطوير الموديل المقترح عن طريق تغير مادة القلب من السيلكون ستيل الى المادة العشوائية وكانت النتائج في حالة اللا حمل (0,08 كيلواط) و خسائر الحمل (4,01كيلواط).

Introduction:

The transformer has been essential component in the electronic circuits and electrical power which has no subrogate for it is main role. [1]

The "D.T" is a static machine which is used for transforming the power from one electric circuit to another one without change the frequency. Thus, there is no moving or rotating part

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in the transformer, so it's static devise. "D.T" operates on AC. supplied and works on a principle of the mutual induction.[2]

The losses in "D.T" account for almost one-third of the overall distribution and transmission loss. The efficiency for ideal modern transformer is an extreme of 97% which is perfectly satisfactory .However, up to 3% of overall electrical generated power is wasted in transformer losses. These ratio of losses are far from the negligible it , anything that can do reduce the losses have potential to deliver a huge saving and diminutive environmental effect .[3]

The "D.T" has a complex geometric in shape. Hence, the "finite element method" F.E.M. has been used in this paper to study the electromagnetic.

A "FEM" of electromagnetic, is the advance technique which is available as commercial software to designing and analyzing the electromechanical device as a reliable tool. In this study (ANSYS11) is used, this software is overall based on finite element algorithmic; to designing and analyzing the "D.T" which is required in this program.[4]

The losses in the transformer were studied by using "ANSYS package" by many researchers [5].

Amorphous core for distribution transformer reduce an impact on environment global. The transformer which use the amorphous core improve the electrical properties and reduce the energy cost and the emissions of CO_2 .[6]

Mathematic electromagnetic Model Of Distribution Transformer:

The flux "Ø" and the magnetizing current (I_m) are produced in the core of "D.T" at applied the alternating voltage through a primary windings . Around the core and the windings of the transformer the flux "Ø" is distributed uniformly. The flux generated as alternative shape, so , at a primary winding , "E.M.F" induced because of a changes at the flux, [7].

The "D.T" dimensions (core and coils) calculations by following equations:-

$$E_t = K\sqrt{Q} \qquad \dots (1)$$

Where K = 0.45- 0.5 [7]

$$Et = 4.444 f \varphi_{magnatic}$$

$$\text{And } Et = 4.444 f A_i B_{magnetic} \qquad \dots (2)$$

Therefore

$$A_i = Et/(4.444 f B_{magnetic}) \qquad \dots (3)$$

The dim.of core(*d*) :-

$$d = \sqrt{\frac{A_i}{Con.}} \quad (m) \qquad \dots (4)$$

Where Cons. =0.56 [7]

Voltage at low winding $V_{2\,pha.}$ Determined by :-

$$V_{2pha.} = \frac{V_2}{(3)^{1/2}} \quad (Volt) \qquad \dots (5)$$

Estimate the numbers of turns at the high(V_1) and low(V_2) voltage windings respectively:-

$N_1 = \frac{V_1}{E_t}$ (Turn) ...(6)

$N_2 = \frac{V_2}{E_t}$ (Turn) ....(7)

Therefore :-

$A_{wind.} = \frac{10^3 * Q}{3.333 \ A_i \ B_{magnetic} \ K}$ (m^2) ... (8)

$A_{wind.} = H_{wind.}(D - a)$

So:-

$H_{wind} \cdot /(D - a) = 2.5 \ to \ 4$ [2] ...(9)

Where:- $a = 0.85 * d$ (for two steep)[8] ... (10)

Width for core window ($W_{wind.}$):-

Diameter of windows (D).

$W_{wind.} = D - a$ (m) ... (11)

Height for core window($H_{wind.}$):-

$H_{wind.} = {A_{wind.}}/{H_{wind.}}$ (m) ... (12)

To calculate the iron losses in D.T.(P_{iron}) :- [1]

$A_{yok.} = 1.151 * A_i$ (m^2) ... (13)

Where ($A_{yok.}$) cross-section area for the iron yoke & ($H_{yok.}$):High of yoke.

$H_{yok} = {A_{yok.}}/{a}$ (m) ...(14)

$H_{co.} = H_{wind.} + 2(H_{yok.})$ (m) ... (15)

($H_{co.}$):height of iron core limbs.

Iron core width(W):

$W = (2 * D) + d$ (m) ... (16)

The total iron losses:-

$P \ iorn_{Total} = (P_{yok.} + P_{limb.}) * 1.072$ (Watt) ...(17)

$P_{yok.}$: Iron loss of Yoke, $P_{limb.}$: iron loss of core limbs

While added seven percentage for the losses stray.

The total copper loss:-

$$P_{copp.Total} = (P_{copp.h.} + P_{copp.L.}) * 1.05 \quad \text{(Watt)} \qquad \dots (18)$$

$$P_{copp.h.} = 3 * I_h^{2*} R_h \quad \text{(Watt)} \quad , P_{copp.L.} = 3 * I_L^2 * R_L \quad \text{(Watt)} \qquad \dots (19)$$

Copper losses at high voltage winding ($Pcopper_{high}$), low voltage winding ($Pcooper_{Low}$:)

While, added five percentages for the losses of stray.

$$I_1 = Q * 10^3 / 3 * V_{high\ voltage} \quad \text{(Ampere)} \qquad \dots (20)$$

$$I_2 = Q * 10^3 / 3 * V_{Low\ voltage} \quad \text{(Ampere)} \qquad (21)$$

R_h: high voltage resistance.

R_L: low voltage resistance.

So the total losses in D.T. :-

$$P_{\text{Total at D.T.}} = P_{\text{copper losses total}} + P_{\text{iron losses total}} \quad \text{(Watt)} \qquad \dots (22)$$

The efficiency (η) at D.T. :-

$$\eta = \left(power\ out\ put / power\ out\ put + P_{total\ losses} \right) 100\% \qquad \dots (23)$$ and

$$\text{voltage regulation} = P_{\text{copper losses total}} / Q \qquad \dots (24)$$

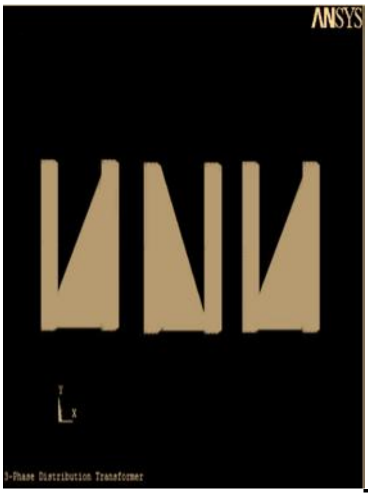
Model of three phase D.T. by using ANSYS programing :

The transformer dimension must be measured very accurate to build the model of it. The information of this study like the dimensions is taken from the company documents. The characteristics of "D.T." are:- 400KvA, 11/0.416 Kv, f=50Hz, 3-phase .This information which represent the key requirement to model the process for this transformer. The geometry of "D.T." which was studied in this research to characteristics the active parts like coil, core and the oil which was used for insulation and cooling, by using ANSYS Programing. Design Language (APDL) and Graphical User Interface (GUI) program. ANSYS package used to form the core model at the window as key points, these key points taken from the Ministry of industry in Baghdad/Iraq. The mesh designed by many various elements shapes.

Solution for Electromagnetic load:

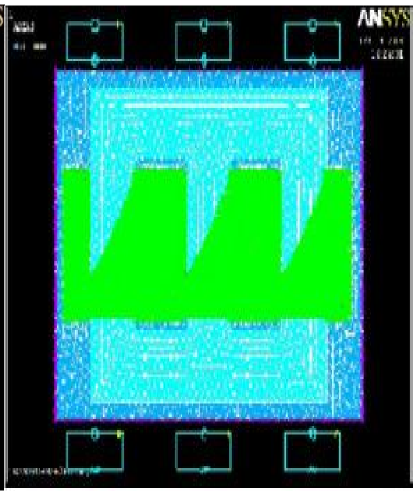
1. **Boundary condition with applying load:**

Each phase in transformer "primary and secondary" for the coils was coupled with degree of freedom. Fig (1) explain the coupled of nods with each other in Current Flow and electromagnetic force. These nods of the primary are coupled with each other in degree of freedom as show in fig (2). The voltage after that is excited directly with coil of primary for each phase, while the coil of the secondary was coupled to the outer load circuit. Fig (3) shows the applied of flux as a boundary condition for the core.



Fig(1) secondary coil coupled node

Fig(2) primary coil coupled node



Fig(3) apply load and boundary conditions.

2. The solution steps:

Electromagnetic model analysis must be specified clearly by "ANSYS package ". The types of analysis are static, transient and harmonic.[11] In this paper the harmonic analysis was used. The finite element analysis formulation was used in this model were based on "Maxwell's equations". Numerical solution was used for calculation by model of finite element. Unknown quantities are used to find the solutions which represent the degree of the freedom.

An analysis is carried out to solve the electromagnetic field and to calculate the distribution magnetic flux and the losses for solving the model, two methods are used. The first method: no-load to check the design correct or incorrect. The second method: with load, it was applied at a secondary winding. See fig. (4),(5)

Fig. (6) Explains the block diagram of "MATHLAB" solution

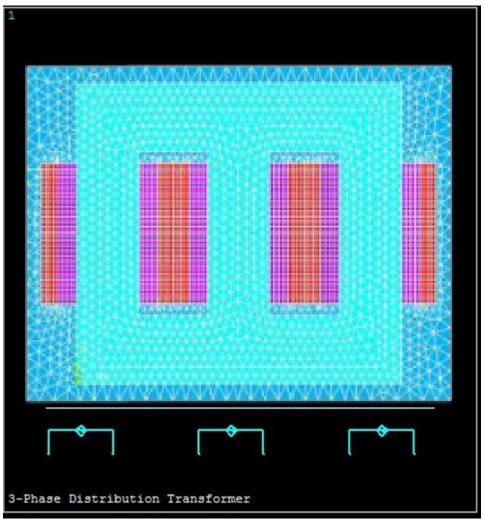


Figure (4) Distribution transformer at no-load

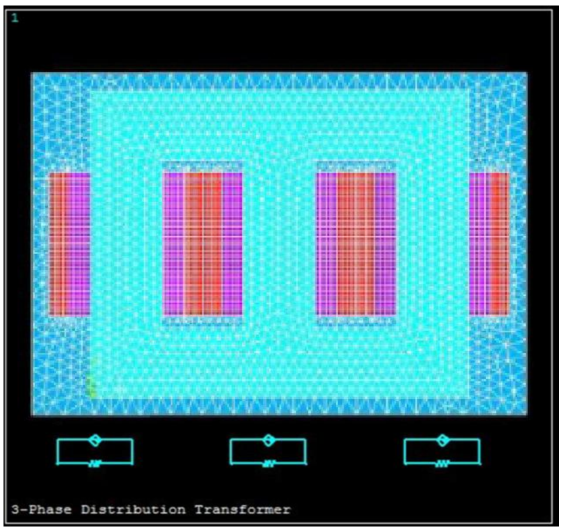


Figure (5) distribution transformer with external load

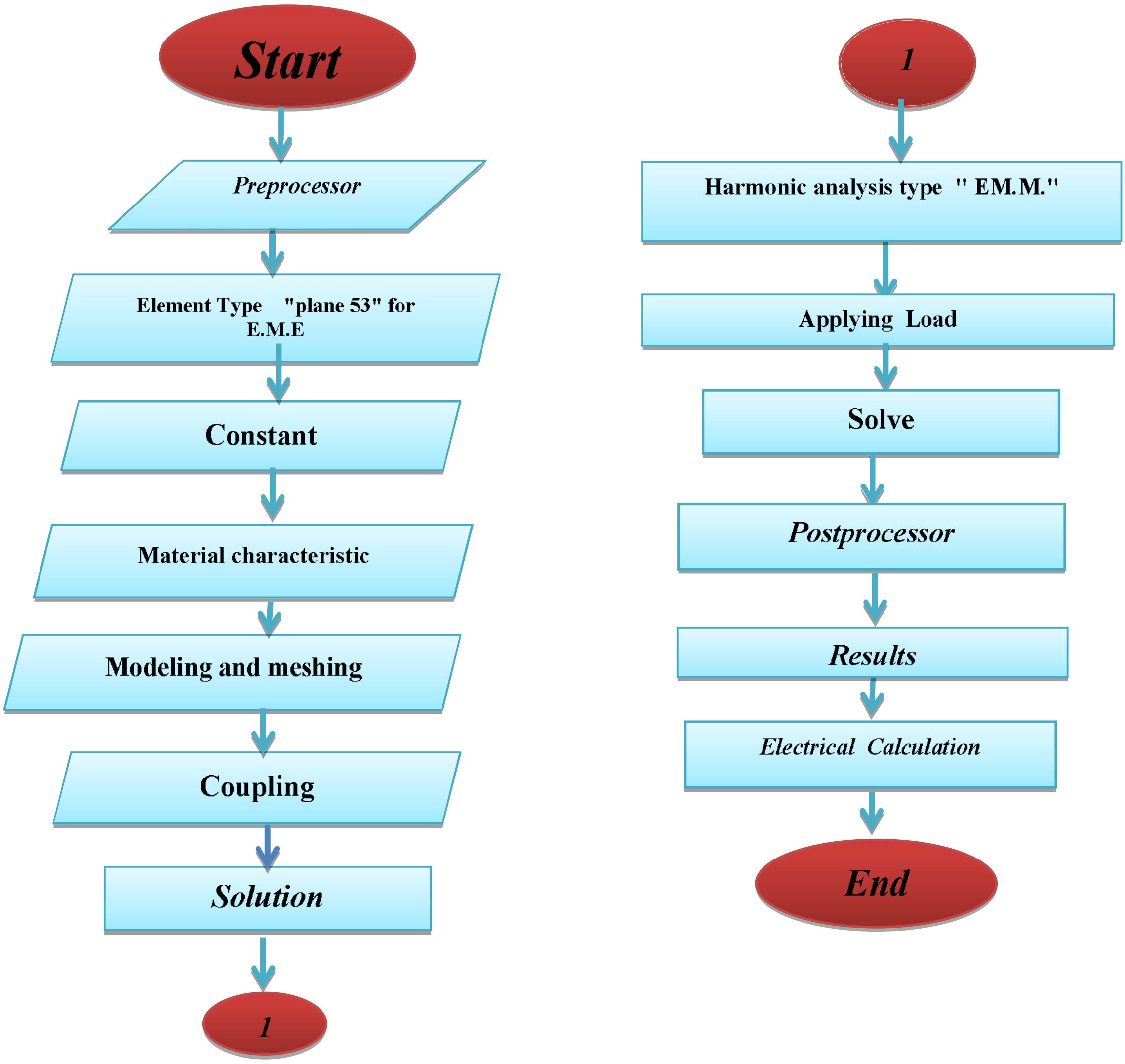


Fig. (6) Block Diagram of "ANSYS Package"

The Result and Discussion:

To calculate the losses and to show the performance of "D.T." , "ANSSYS program" was used .
Following the figures and the results of this work which were for traditional core and amorphous core. The behavior of electrical design is discussed as below:

- Figs. (7) & (8) are explain the distribution of magnetic flux lines at no load for traditional core and amorphous core .
- Figs. (9) & (10) are explain the distribution of magnetic flux lines at load for traditional core and amorphous core.

These figures show that the lines of flux at figs(7,8,9 & 10) are same when operates at no-load and load.

- The plot for traditional core of transformer at fig. (11) and the nodal plot for amorphous core of transformer at fig.(12). In overall, the flux in the amorphous core transformer was less than at the traditional core transformer due to the fullness of flux density at a traditional core more than an amorphous core.

- Figs. (13) & (14) are explain the D.T. vector plot for two cases: traditional and amorphous. The flux in the traditional core more than in the amorphous core due to the fullness flux density for the traditional core more than the amorphous core.
- Figs. (15) & (16) are explaining the magnetic flux density at primary winding coil and secondary winding coil. Fig (15)&(16) explain , the flux at "Y-axis" which was gradually decreased towards the center point of height of coil. However X-axis the flux increasing linearly toward the coil of low voltage. So we can say the distribution of the flux directly proportional with the current flow and the numbers of the turns.
- Figs. (17) & (18) are explaining the leakage of the flux direction. A current flows at high voltage windings in obverse direction to the low voltage windings. So, the high voltage windings flux has obverse direction with low voltage windings. The flows of current obverse directions with high and low voltage windings. Inside the primary and secondary windings. At phase (b), found the max. value for the flux density due to the angel of this phase(b) which was zero degree at real component. While the flux density at imaginary component has the min. value. Table (1) shows the total losses results.

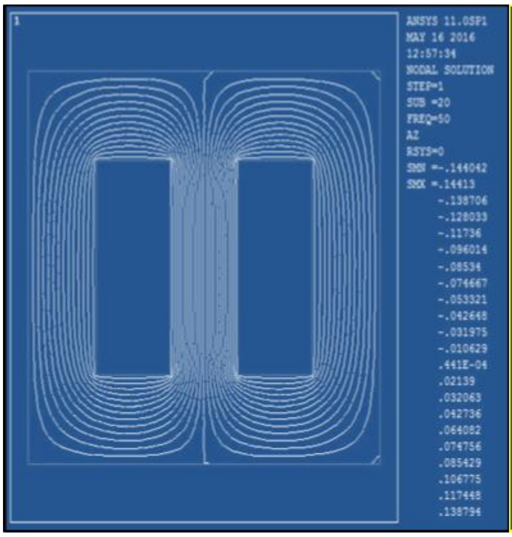


Fig. (7) 2D distribution line flux at no- load for traditional **core**

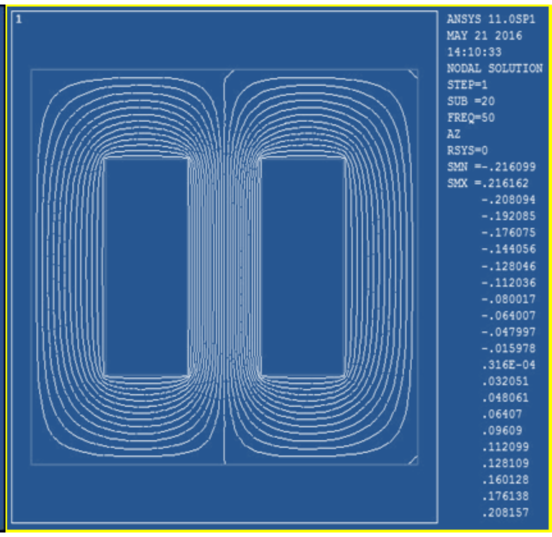
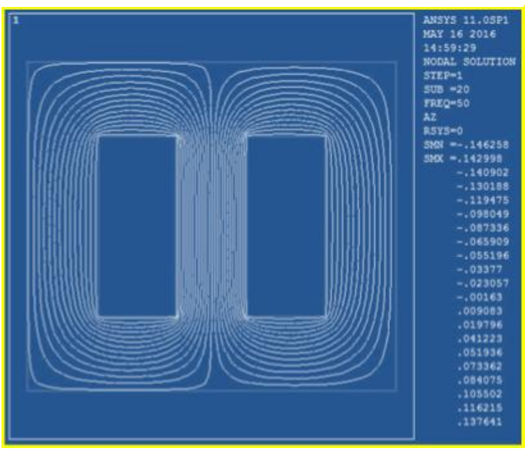


Fig. (8) 2D distribution line flux at no- load for Amorphous core



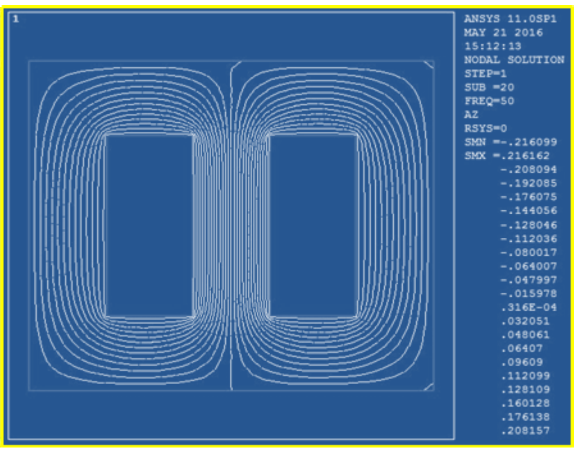
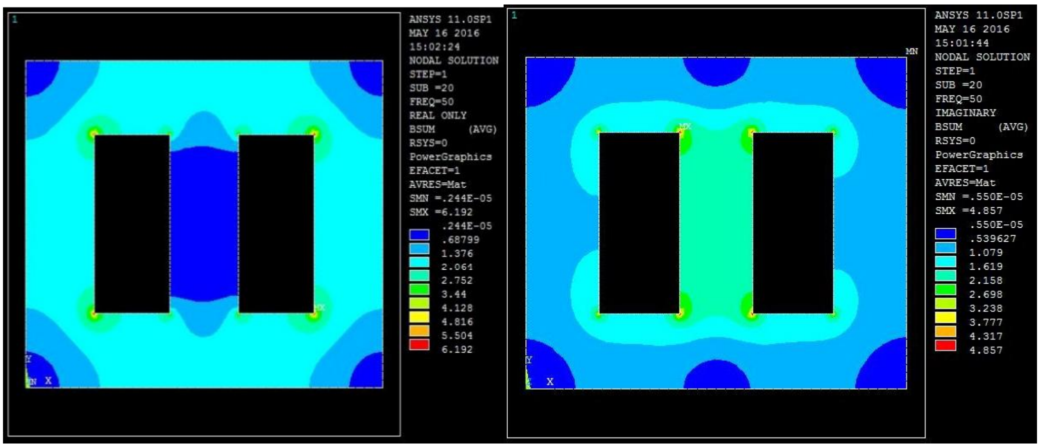


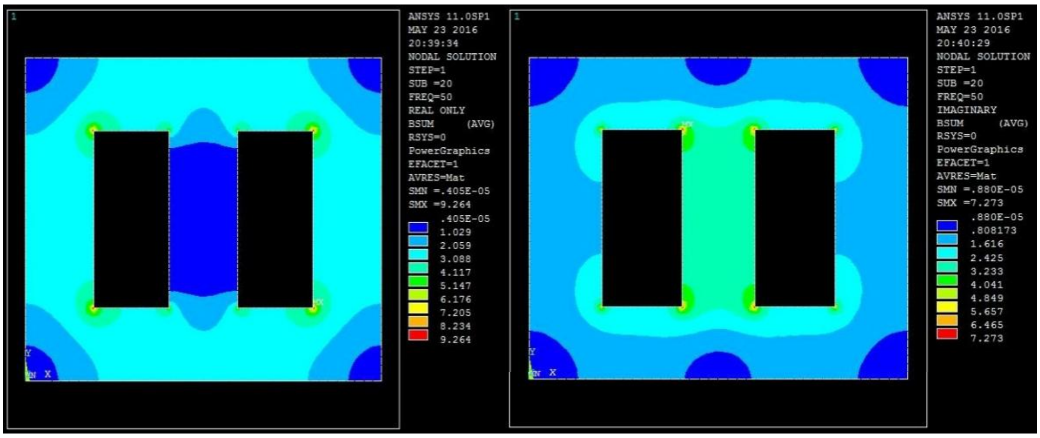
Fig. (9) 2D distribution line flux at load for traditional **core**

Fig. (10) 2D distribution line flux at load at Amorphaus core



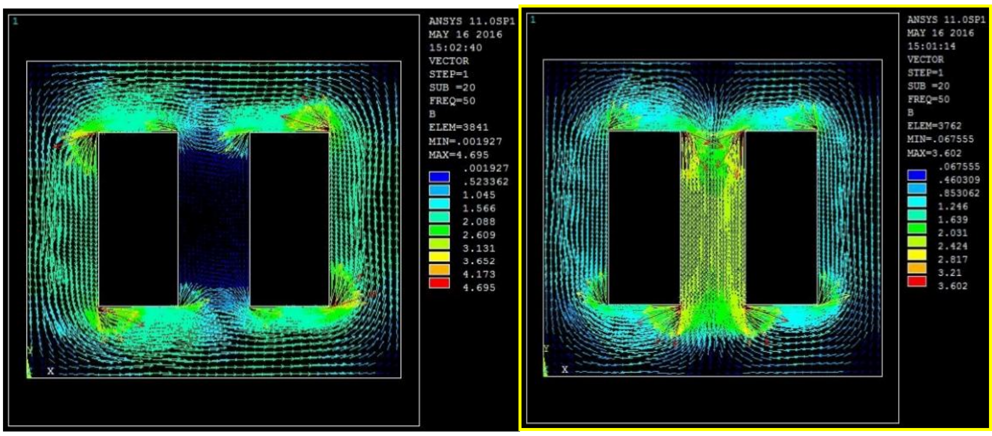
a) real components **b) imaginary components**

Fig. (11) magnetic flux density for traditional core



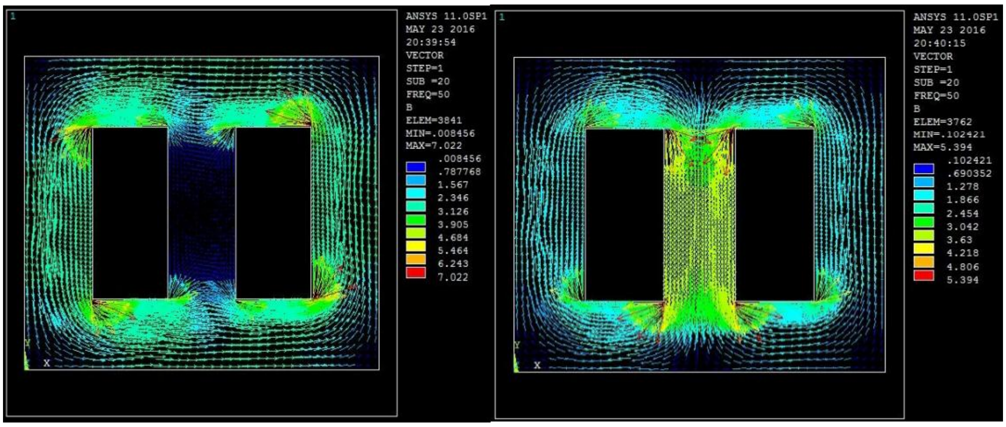
a) real components **b) imaginary components**

Fig. (12) magnetic flux density for amorphaus core



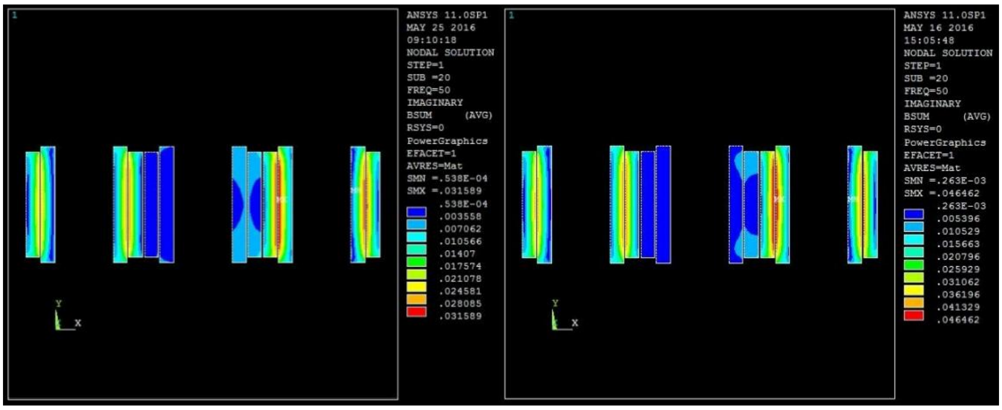
a) real components **b) imaginary components**

Fig. (13) magnetic flux density for traditional **core**



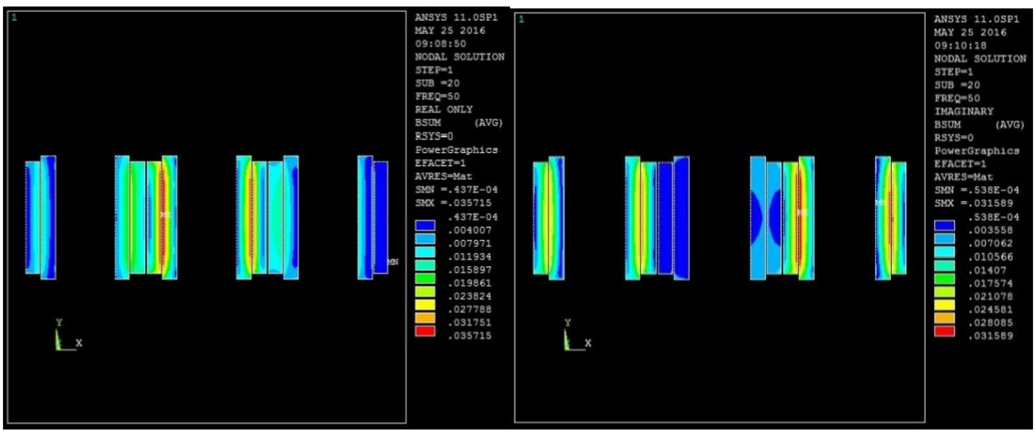
a) real components **b) imaginary components**

Fig. (14) Magnetic flux density for amorphaus core



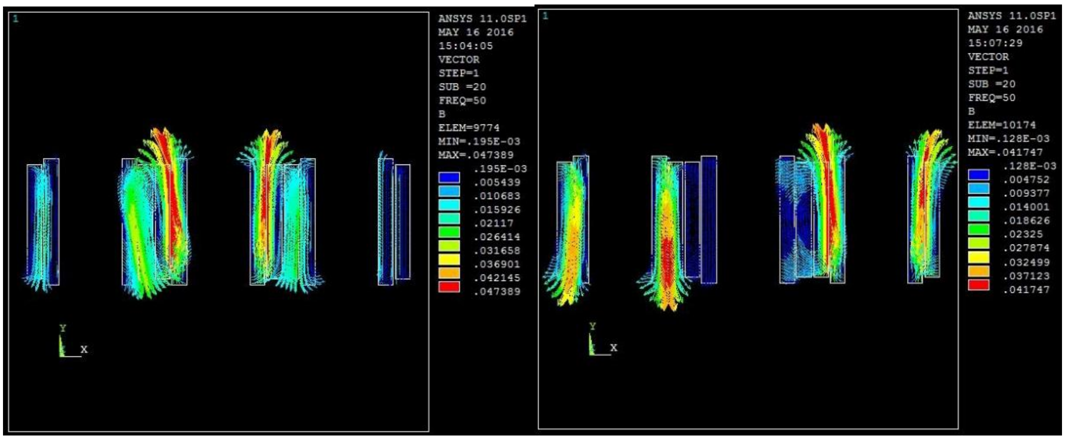
a) real components **b) imaginary components**

Fig. (15) magnetic flux distribution for traditional **core**



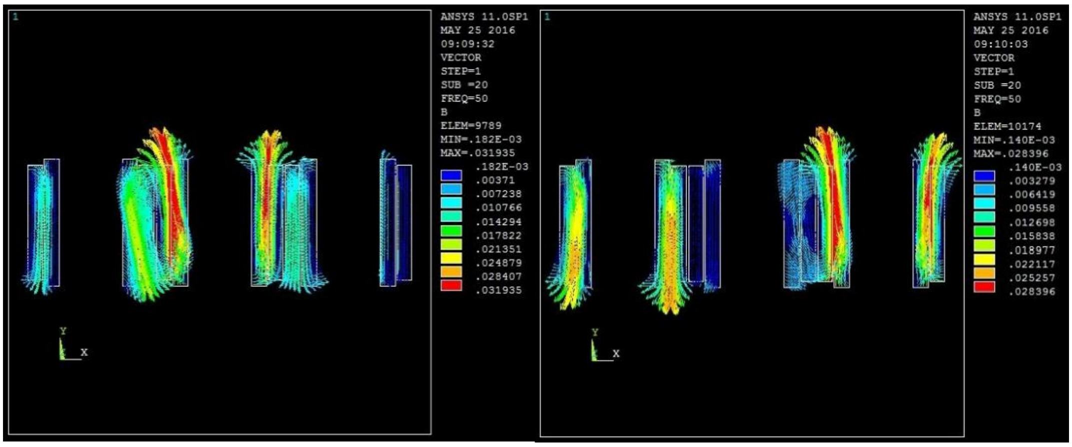
a) real components **b) imaginary components**

Fig. (16) magnetic flux distribution for amorphaus core



a) real components **b)imaginary component**

Fig. (17) magnetic flux density for traditional core



a) real components **b) imaginary components**

Fig. (18): magnetic flux density for amorphaus core

The magnitudes and locations for losses in D.T.:

At the "D.T" the electromagnetic magnitudes and locations for losses must be calculated. A main source of the losses in the transformers is the cores and the coils. In this study the total losses was calculated by classified the losses into two types: i) no-load losses ii) load losses.
The "ANSYS package" and "MATLAB package" were used to calculate the cupper and the iron (no-load and load) losses, and then this losses results were compared with the experimental results which were done it with the worker at Ministry of industry .Hence, the efficiency (η) of the suggestion model was checked. A material of core play a base role for the calculated losses generated. A material core has been changed to amorphous, that change reduced the core losses from (0.82KW) to (0.08KW) {92.24%} at no-load and from (4.3KW) to (4.01KW){ 7.23%} at load , from the losses at traditional core .
The fullness flux density of the amorphous is less than the silicon steel material (traditional), so the core losses were reduced and that enhanced the efficiency (η) of the transformer. Shows the table (1)

Table (1): transformer losses and efficiency

Types of D.T. core		No Load Losses (KW)	η% at 0.8P.F. lag.	Load Losses (KW)	η% at 0.8P.F. lag
traditional core	Theoretical	0.798	99.751	3.9	98.795
	ANSYS	0.82	99.744	4.3	98.674
	Experimental	0.83	99.741	4.2	98.704
Amorphous core	Theoretical	0.0625	99.980	3.9	98.795
	ANSYS	0.08	99.975	4.01	98.834

Conclusion:

From the present study, the following can be concluding:-

- At the electrical measurements, at no-load and at load losses at traditional core where (0.82KW), (4.3KW) respectively, but when changed the material core to amorphous the no-load and load losses are (0.08KW) , (4.01KW)respectively by using "ANSYS package ".
- The analyzing of D.T results gave a suitable difference at a practical work which was gave a confidence and reliability to this study.
- D.T. losses reduction gave a good opportunity to improve the efficiency.
- This study summarizes our particular approach to reduce the loss in D.T

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Symbol	Description	Unit
A	cross section area	m^2
$B_{magnetic}$	Magnetic flux density	*Tesla*
D	Diameter of winding.	*m*
D	Diameter of cross section area of core	*m*
F	Frequency	*Hz*
H	Height of core	*m*
N	Turns number	*Turn*
P_{Losses}	Power losses	*Watt*
R	Winding resistance	*Ohm*
Q	Rating power	*KVA*
V	Line voltage	*Volt*
W	Width of core	*m*
I	*Current*	*Ampere*

List of symbol