Theoretical Temperature Distribution Investigation in Electrical Transformer by Using Nano-Technology

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ABSTRACT:

A proposed thermal model is examined for a distribution transformer. A 2d simulation by a transient analysis in light of the Finite Element Method (FEM) was done to obtain the temperature distribution in the three phase transformer (250 KVA 11/.416 KV core type, mineral oil) using "ANSYS PROGRAM". Meanwhile, the effects of type of oil on HOST are investigated using the proposed model. To test the effect of nanoparticles on heat transfer process, the insulation oil was changed with Nano fluid; it has been used two types of Nano particles (CuO and Al_2O_3) with 0.5% as a volume concentration, where the maximum temperature reduced about (5%). The core material also has been changed from silicon steel to amorphous steel and caused a reduction in maximum temperature about (9.9%) in HV winding and change the interior angles from 90^o to 135^o, where the temperature distribution transformer is improved. The present model successfully accomplished for expecting the temperature distribution at any locations in the transformer when compared with practical measurement.

Keyword: proposed thermal model, Nano fluid, distribution transformer.

Nomenclature

A: Latin Symbols

Symbol	Meaning	Unit
	Cross section area	m^2
	Surface area	m^2
	Inner diameter of winding	m
b	outer diameter of winding	m
	Specific heat	J/kg. K
g	Gravity	N/m^2
	Film coefficient	$W/K.m^2$
	Mean film coefficient	$W/K.m^2$
	Thermal conductivity	W/K.m
	Thermal conductivity of oil	W/K.m
	Characteristic length	m
	Nusselt number	none
	Nusselt number for base	none

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	Nusselt number for lid	none
	Mean Nusselt number	none
	Nusselt number for vertical side	none
	Power losses of primary winding	Watt
	Power losses of secondary winding	Watt
	Total power losses of core	Watt
q	Heat flux	W/m^2
$\dot{q}$	Heat generated in core	W/m^3
$\dot{q}$	Heat generated in low voltage winding	W/m^3
$\dot{q}$	Heat generated in high voltage winding	W/m^3
$\dot{q}$	Heat generation	W/m^3
	Rayleigh number based heat flux	none
	temperature	K
	Bulk temperature	K
	Surface temperature	K
	Ambient temperature	K
	Volume of core	m^3
	Volume of low voltage winding	m^3
	Volume of high voltage winding	m^3

B: Greek Symbol

Symbol	Meaning	Unit	Symbol	Description	Symbol	Description
	density	kg/m^3	**B**	bulk	**L.V.**	Low voltage
	Characteristic length	m	**b**	Base	**m**	mean
	Thermal expansion coefficient	$1/^oC$	**H.V.**	High voltage	**s**	surface
	dynamic viscosity	kg/m.sec	**hf**	Heat flux	**V**	vertical

D: Abbreviations

Symbol	Description
APDL	ANSYS Programming Design Language
HST	*Hot spot temperature*
ONAN	*Oil natural air natural*

INTRODUCTION:

A distribution transformer is a very efficient static power transformer machine and a main part in power transmission grids. Through the conversion process for the electricity power in a transformer, many types of losses are arising. These losses usually take place at active parts (windings and core) of the transformer and then converted into heat. This heat spread throughout the transformer and then to the air by means of its insulation material such as minerals oil. But accumulation for this heat without efficient dissipation will cause deterioration in the transformer insulation paper and damage in their windings [1]. So, the temperature rise must be limited through safety rang, in order to increase the operational life of the distribution transformer.

Earlier researchers have been studied the causes of heat generation in the many transformers types. They proposed a various theoretical models to predict the profile of temperature distribution and to determine the location of maximum temperature, in order to be as a design tool for a specific transformer. Some of them are; Jamal A. Ramadhan Dofan used the theory of heat transfer by apply (lumped capacitance method) [2]. I. Amoiralis et al. investigated several benefactress designs for cooling system of transformer (oil natural air natural type) [3], Hjalmars, studied an investigation methods to improve the thermal design of windings to reduce the temperature of hot spot without increasing the mean temperatures of windings. Two methods were used in this study to investigate the continuous and discrete parameters that effect on the flow of oil through the transformer [4], and other researchers focused on the existing facilities in numerical methods to simulate the actual transformer operation by assist of some commercial software packages, like ANSYS.

The distribution transformer have complex geometric shape therefor finite element method is an efficient way to predict thermal manner for the transformer. ANSYS software is powerful universal software based on the finite element algorithmic, and providing the ability for analyzing the performance of each component alone and evaluating the overall performance of the transformer. So, the modeling for the transformer will be easy and lowering the manufacturing cost within the process of design [5]. Constantin et al. , used method of finite element to analyze magnetic and thermal fields of three-phase power transformer. ANSYS (3D Maxwell and mechanical) used to analyze transformer [6].

At primary stage of the designing programs for the transformer components, it is necessary to investigate temperature distribution inside it in a hypothetical operation, to avoid temperature rise over design border, which might seriously damage or get low performance for this important and expensive equipment of power distribution [7].

So, thermal models to foresee this essential data before the real operations must be prepared In the scope of this study; temperature distribution in the transformer "***- ٢٥0 KVA 11/.416 KV core type***" which was manufactured by Electrical Industries Company in AL WAZYRIA had been modeled in two dimensions by a transient analysis with using Finite Elements package "ANSYS11, APDL and GUI" as a reliable tool for the design and analyzing performance. The model can be used for obtaining the temperature distribution in the transformer and the effects of oil type are investigated using the model.

Thermal Model:

Thermal model for the transformer has been based on tracking the generated heat at active parts of the transformer, and when transferred and exchanged; in the core and winding materials, therefore between the core and winding surfaces with the surrounding oil, to be dissipated through the tank walls to ambient.

Heat generated in an operating transformer is due to the electrical and magnetic losses arising in the main parts of the transformer (windings and core).

Finite element method have been suggested to estimate the amount of an electromagnetic losses, which be used as heat sources in thermal analysis. Heat follows a several modes to despite to the surrounding as a result of temperature difference.

These modes and their boundaries with required variables are summarized as follow:

1- Conduction mode for Heat transfer process occurs when heat generated inside the core and windings, then heat was extended to the outer surface boundaries and between them. *Fourier's law governs* conduction heat transfer mode, which expressed as:

$$q = k \nabla T \qquad (W/m^2) \qquad \ldots(1)$$

∇T is the rate of temperature change across a distance in the flow direction of heat ($^0C/m$), and k the thermal conductivity for core and windings materials

So the required properties at this boundary are the thermal conductivity (k) for core and windings materials, which must be determined.

2- Heat has been transferred from the external surfaces of the core and windings to the insulation oil by convection mode. And then, heat is transfer to the surrounding air through the outer surface of tank in a like manner or by convection. *Newton's law of cooling governs* convection heat transfer mode, which expressed as:

$q = h A_s (Ts - T\infty)$ (W) … (2)

Heat transfer coefficient (h) is not having specific value or it is not a property, but its value depend on the convective domain characteristics (geometries, cooling fluids properties, degree of the surface inclination, etc.) at every location of heat transfer process occurs via convection mode. So, appropriate formula must be selected to utilize for getting correct value. So, following formulas are selected to use;

For laminar flow along vertical surfaces inside the transformer (core and coil), the Nusselt number equation is used as below [8]:

… (3)

The Rayleigh number based on the constant heat flux is formulated as following:

… (4)

Where δ is:

… (5)

While, The Nusselt number equation for the upper surfaces (used for laminar and turbulent) is:

… (6)

And for the lower surfaces (used for laminar and turbulent) is:

… (7)

The mean film coefficient for each case is:

… (8)

The domain of the convection, in the outer surfaces of the tank is classified into three sections (the lid, the base and the vertical fin).

For the lid (the top cover of the tank) of the transformer tank, The Nusselt number equation is shown as follow [9]:

… (9)

And for the Base of transformer tank [9]:

… (3-70)

While, for the Vertical fin [4]:

$.22(0.6108 Ra_L^{0.2364})$ … (10)

3- Heat transfer by radiation take place too between the surface of operating parts (core and windings) and the internal tank surfaces and from the outer tank surfaces to the immediate surroundings of transformer, which arises due to temperature difference between them. Thermal radiation can be ignored and not affect the accuracy of results. Because the transformer components made from materials have relatively low emissivity, and this reduce the quantum of thermal radiation [10].

The following assumptions has been taken into account for the present theoretical analysis of model

i. 1- The transformer can be treated as a geometric structure which is constructed from a parallel plane. Therefore, the problem is decreased from a three-dimensional (3D) to other case have only a plane (a two-dimensional (2-D)) simulation, with an acceptable accuracy when used finite elements technique [11].

ii. 2- All external surfaces including the base of the tank have exchanged heat with ambient, because this kind of transformer used in overhead Iraq national network.

iii. The average measured values for the peak ambient temperature during the transformer operating condition are considered.

iv. Thermal properties of the transformer component solid materials are assumed to be constant with temperature variables, but for insulation oil properties variations are considered which is significantly affected with temperature rise.

v. Inside the core and windings, the heat has been generated and distributed uniformly at each unit volume and unit time.

4- The losses in the dielectric papers are ignored, because it is insignificant when compared with the copper and iron losses [10].

The transition analysis option is chosen to simulate the transformer running to give a real simulation for this process from initial condition until steady state condition

The two-dimensional equation related with transient heat conduction mode can be formulated as given in [12]:

$$-\left(kA-\right) \quad -\left(kA-\right) \quad \dot{q} \qquad - \qquad \ldots(11)$$

The heat generated ($\dot{q}$) for each unit volume and time within any point (x, y) inside the core material may be calculated from:

May be calculated from:

$$\dot{q} \qquad \text{———} \qquad \ldots(12)$$

Likewise, for coils $\dot{q}$ may be calculated as follow:

$$\dot{q} \qquad \text{——} \qquad \ldots(13)$$

$$\dot{q} \qquad \text{——} \qquad \ldots(14)$$

An energy balance at the specified surface is applied for obtaining the required mathematical formula as [12]:

$$- \qquad - \qquad) + \left(\rho V c -\right) \qquad \ldots(15)$$

T_B is the neighboring bulk temperature and h is the film coefficient in ($W/m^2 \cdot C$) which could be defined by Nusselt number correlations as [12]:

$$- \qquad \ldots(16)$$

To determine temperatures distribution at the whole transformer locations, convective heat transfer coefficients must be determined at each location in the surface with their conditions, so several film coefficient value are needed, which are given in obvious explanation previously . It should be noted that, in this model only free convection is considered.

Relation between Oil Properties and Temperature:

When heat is generated in transformer, the oil temperature increased. Thus, the oil properties will change such as density, thermal conductivity, viscosity and specific heat. The influence temperature on oil properties are shown in the following equations [13]:

$Cp=807.163+3.58\ T_{oil}$ … (17)

$\rho=1098.72-0.712\ T_{oil}$ … (18)

$k=0.1509-7.101*10-5\ T_{oil}$ … (19)

$\mu=0.08467-4*10-4\ T_{oil}+5*10-7\ T_{oil}$ … (20)

Physical Properties of the Working Fluid:

The thermal properties of the working fluids are changed due to the influence of. The Nano properties depend on concentration of nanoparticles and fluid temperature.
The Nano fluid volume concentration is defined as [14]:

$$\frac{\quad}{\quad} \qquad \dots (30)$$

The viscosity is calculated by [14]

$$\dots (31)$$

The thermal conductivity of Nano fluid mixture is derived by Maxwell for spherical particles [14]:

$$\left(\frac{\;p \quad f \quad 2(k_f \quad p)\phi}{k_f-(k_f-k_p)\phi}\right)k \qquad \dots (32)$$

The Nano fluid density for all volume concentration is [15]

$$\dots (33)$$

The specific heat of Nano fluid is calculated from this equation for all volume concentration [14]:

$$)(c_p) \quad \phi(c_p) \qquad \dots (34)$$

Preparations for testing the model:

Building transformer:

In order to exam the proposed methodology, the details of a transformer configuration must be determined. A transformer of a 250 KVA 11/.416 KV (ONAN),three phase distribution core type "stacked core" in a typical two step rectangular core, which was manufactured Electrical Industries Company / AL WAZERYA was considered.

To build this solid model by using **F.E.M**, it is need to measure the dimensions of this transformer accurately. These dimensions of transformer were taken from the design documents from the manufacturing company. 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. All these steps are formed by codes which were written in APDL in ANSYS.

For mesh design, the element type and material properties must be define. PLANE 53 as element type has been used for core, coils and insulation. The materials thermal properties are determined for the main component (core, windings and insulation oil) of the transformer, these properties are determined from the manufacturer company team.

Then, the next step is to designed mesh for the transformer body. In this work, it has been use the mapped mesh for the coils and free mesh for the core and insulation because the coils is regular area but core and insulation is irregular area. The designed mesh was built by 22434 various elements shapes (squares, triangles, etc.) and 42494 nodes for creating these elements. Figure (1) shows the final designing forms of the geometry shape and their mesh

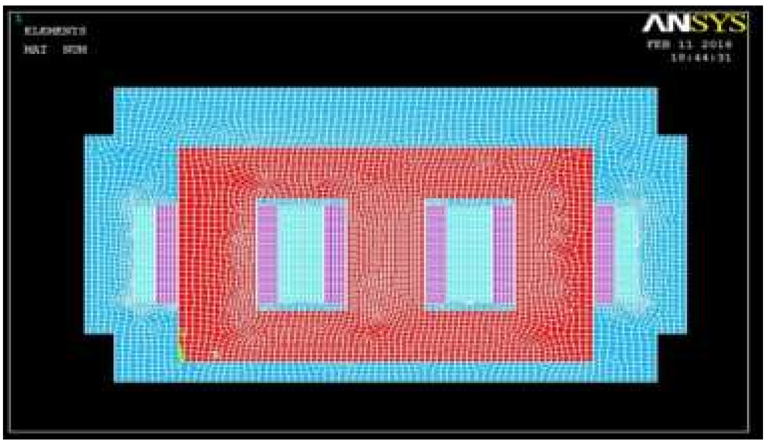


Figure (1): the designed forms for the geometric shape and mesh.

The final step of simulation procedure, the thermal load at various zones in the transformer must be applied. It has been apply heat generation for the core and each coil (H.V. and L.V. windings). The quantum of generated heat has been determined when analyzed the electromagnetic field. And then, the convection condition on line for the core, coils and fins are applied. See figure (2).

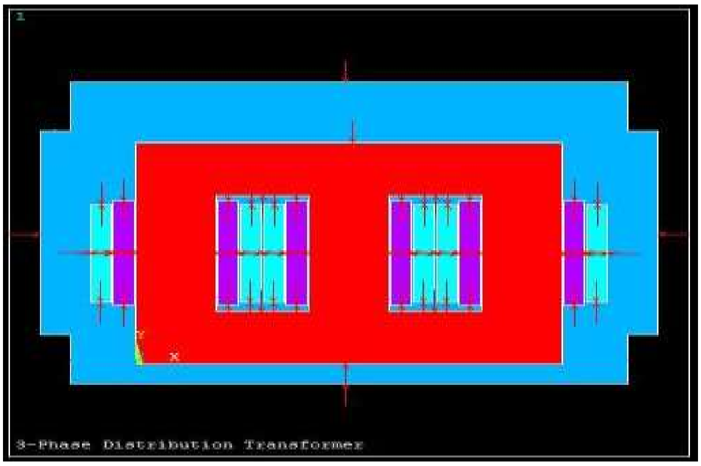


Figure (2): Applying load in the transformer parts.

Result and discussion:

Transformer oil properties have been calculated with nanoparticles using semi empirical formula (mentioned above in the theoretical model). The Nano fluid have higher heat transfer for this reason, it is used in cooling system [16].

Figure (3, a) shows, the density of oil before and after additives is decreased with temperature.

Figure (3, b) shows, the thermal conductivity of oil before and after additives is reduced with increase temperature and figure (3, c) shows the specific heat of oil before and after additives decreased with increasing in temperature.

To validate the models results, it was applied on the transformer -400 KVA 11/.416KV core types -ONAN-cooled unit, which is also manufactured in ALWAZEREYA Company. Their experimental results, which have been obtained from the heat run test, are compared with the models results, and give reasonable discrepancies (about 1.2%) for predicted maximum temperature.

The results will be explained for the proposed thermal model specified for 3 phase distribution transformer (250 KVA, 11/.416V, core type, and oil immersed).

Figure (4) shows the temperature distribution in transformer. As it is observed from this figure, the highest temperatures occurred in the center of the H.V. and L.V. windings, and they have **87^{o}C** and **92^{o}C** respectively as shown in figures (5, a, b) , as a results of their relatively large losses (about 80% from the total) which it will be converted to heat in them. While, the maximum temperature in the core (about **84.5^{o}C**) at the middle leg of core, see Fig (5, c). The core losses are less than in windings, approximate15% from all losses in transformer and having relatively large surface area.

Figure (5, d) shows temperature distribution in oil. Where, the highest temperature is located in the surrounding region for primary and secondary coils and then it was decreased gradually. The coldest point located at the outer edges of tank and its fins.

Thermal Performance Enhancement in Transformer are restricted by using two kinds of Nano fluids by adding (**CuO** and **Al_2O_3** Nanoparticles) to the mineral oil, used amorphous steel material for core, and then the interior corner of core modified to be **135°** instead of **90°**. These parameters are studied separately. To improve the thermal properties of transformer, **CuO** Nano particle was added to the oil of the transformer to be **0.5%** volume concentration of **CuO** Nano fluid because the cooling system in this type of transformer is natural therefore, if increase the volume concentration, the Nano particles is accumulate. These particles caused an increasing in the surface area for heat transfer and then helped to reduce temperatures in transformer because the thermal conductivity of them by reduced the Nano particle size and then the surface area is increased [17].

Figure (6) shows the temperature distribution for the transformer with **CuO** Nano fluid as insulation oil. The maximum temperature is reduced by **4.5°c** which is located in the primary winding, see Figures (7).

The thermal analysis has been applied for the distribution transformer with **Al_2O_3**Nanofluid (**0.5%** volume concentration) as insulation oil. Figure (8) shows the temperature distribution in transformer with Al_2O_3 Nano fluid. It shows that, the maximum temperature is reduced about **5.5°c,** which placed in H.V. winding see Figures (9).

The enhancement in maximum temperature values, for using two types of Nano fluids, is coming closer together when used as insulation oil.

When the interior corners core of modified to be **135°** instead of **90°,** the temperature distribution is improved although the maximum temperature in core is remain same value before change these coroners but, the distribution is better. Figure (10) shows the temperature distribution in the distribution transformer. As shown in this figure, this angle give slightly improved in the distribution of temperature in the inner corner of core when compared with right angle for these corner, see Figure (11).

The core material has been changed from silicon steel to amorphous steel. This case is analyzed thermally by calculate heat generation according the previously equations and then apply this value as a load and found the temperature distribution in transformer.

Figure (12) shows the temperature distribution in transformer with amorphous core. It has been noticed that the maximum temperature is reduced approximately **10°c**. This result represents good improvement for obtaining relatively low maximum temperature and then protecting the insulation papers from deteriorating. Figure (13) shows the temperature distribution in H.V. winding.

In this case, it is used **CuO** Nano fluid with the amorphous core to show the rate of reduction.

Figure (14) shows the temperature distribution in transformer with amorphous core with **CuO** Nano fluid. The maximum temperature reduced by **13°c**. Figures (15) shows the temperature distribution in H.V winding.

Finally, it is used **Al_2O_3** Nano fluid with the amorphous core to show the rate of reduction.

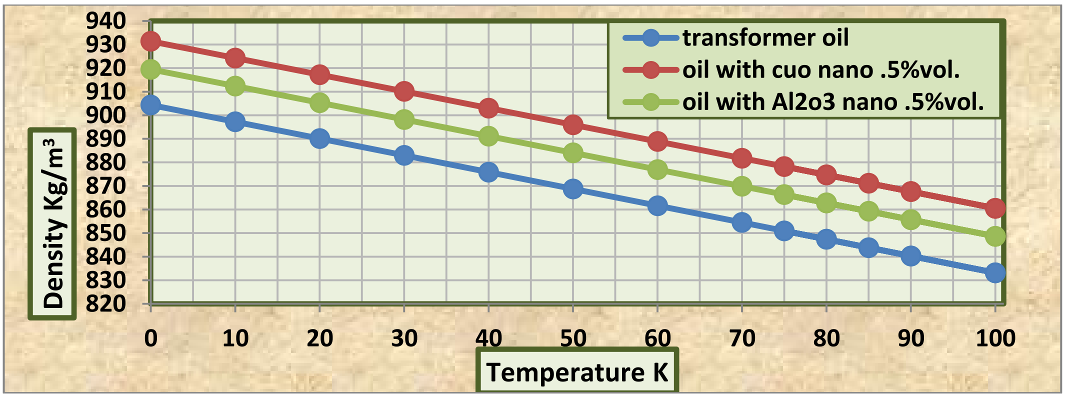
Figure (16) shows the temperature distribution in transformer with amorphous core with **Al_2O_3** Nano fluid. The maximum temperature reduced by **14°c**. Figures (17) shows the temperature distribution in H.V winding.

All these results summarized in the table (1) to show the percentage enhancement.

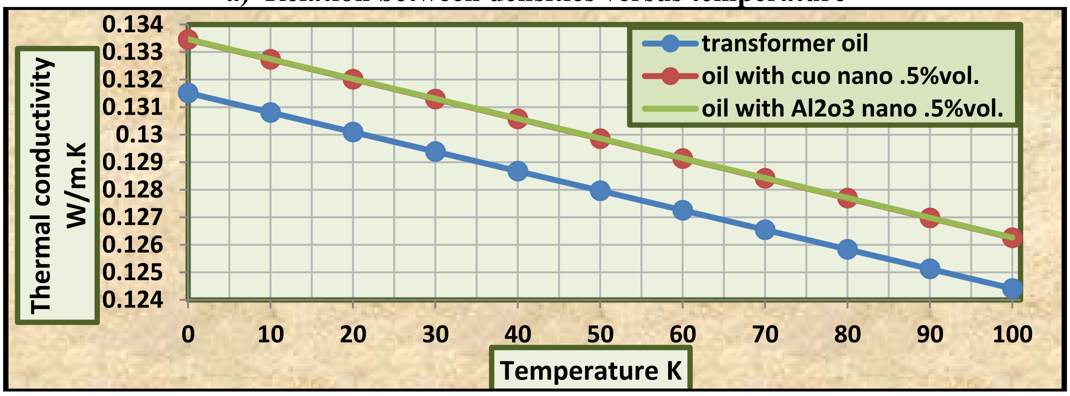
Table (1): The Temperatures and Percentage of Reduction at Each Transformer's Part

Part of transformer	Core		H.V		L.V		Oil	
Temperature (°c)	Max	Min	Max	Min	Max	Min	Max	Min
Transformer 250	84.5	83.5	92	91.4	87	86.6	92.2	44
With CuO Nano (0.5%vol)	82.5	81.3	87.6	87	83	82.7	87.6	43.8
Reduction %	2.4	2.7	4.84	4.74	4.57	4.53	5	0.46

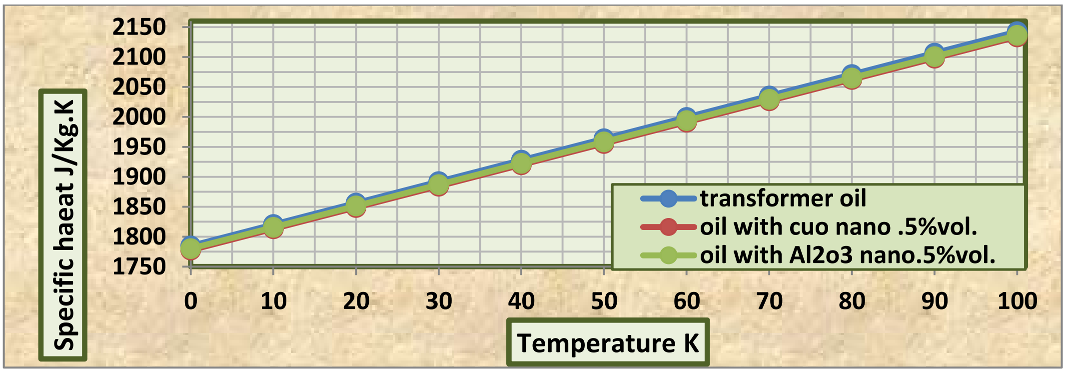
Oil with Al_2O_3 Nano (0.5 % vol.)	82.5	81.2	86.6	86.2	82.7	82.3	86.6	43.8
Reduction %	2.46	2.76	5.8	5.7	4.97	4.97	6	0.46
Conventional core 135° with traditional oil	84	83	92	91.3	86.4	86	91.9	43.5
Reduction %	0.68	0.61	0.02	0.08	1.1	0.61	0.23	1.1
Transformer with amorphous core	66.6	65.5	81.9	81.4	78.2	77.9	81.9	43.3
Reduction %	21.2	21.5	10.9	10.9	10.1	10	11	1.59
amorphous core Oil with CuO Nano (0.5%vol.)	56.1	54.6	78.8	78.3	73.2	72.9	78.7	43.9
Reduction %	33.6	34.6	14.3	14.3	15.8	15.7	14.5	0.15
Amorphous core Oil with Al_2O_3 Nano (0.5%vol.)	55.5	54.2	77.9	77.3	69.2	68.9	77.8	43.8
reduction%	34.2	35	15.3	15.3	20.5	20.4	15.5	0.39



a) Relation between densities versus temperature



b) Relation between thermal conductivity versus tempera



c) Relation between specific heat versus temperature

Figure (3): Relation between the properties and temperature

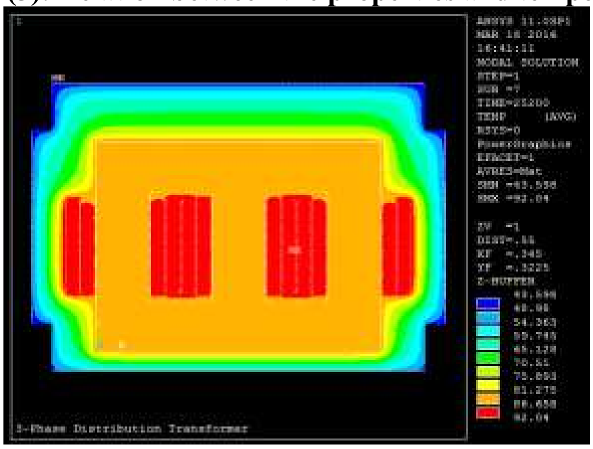
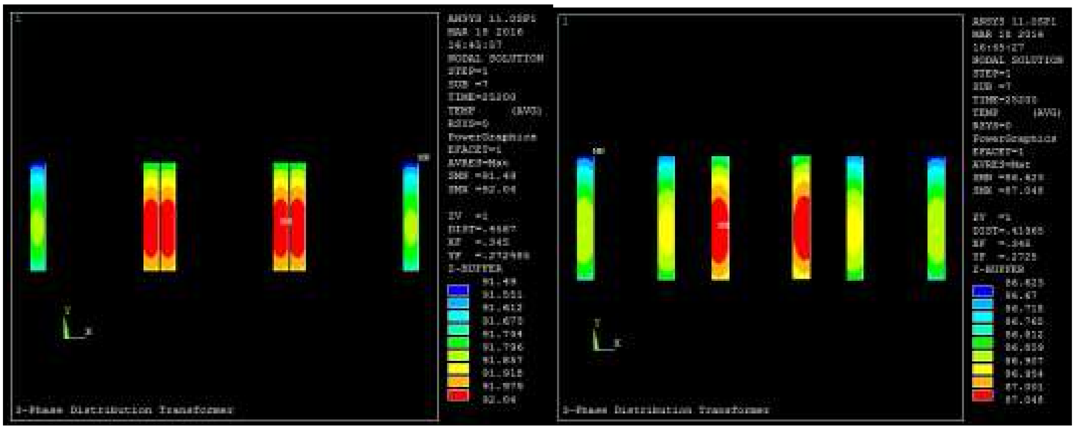
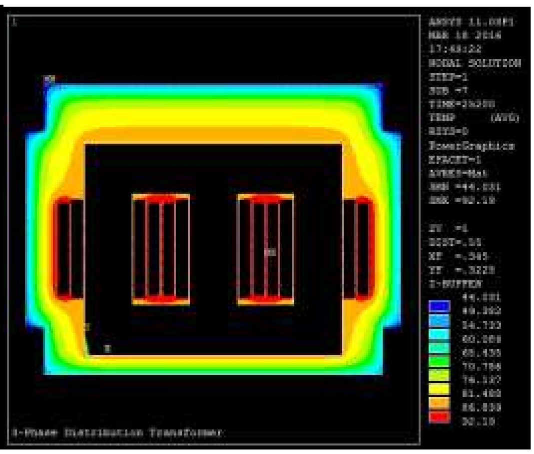


Figure (4): Temperature distribution for transformer (250KVA) with traditional oil



a)Temperature distribution in H.V winding **b) Temperature distribution in L.V winding**

c) Temperature distribution in conventional core



d) Temperature distribution insulation (traditional oil)

Figure (5): Temperature distribution in each part of transformer (250 KVA)with traditional oil

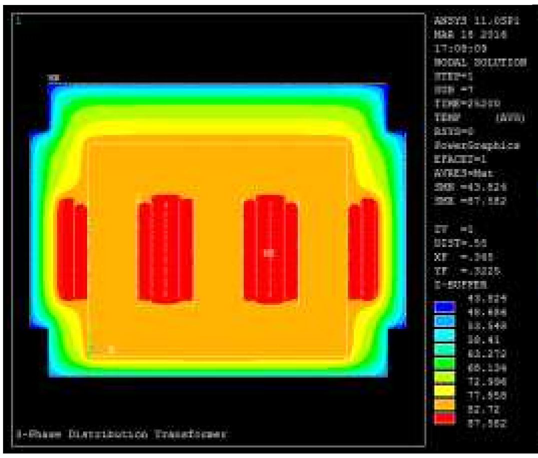


Figure (6): Temperature distribution in the transformer (250KVA) with CuO Nano fluid

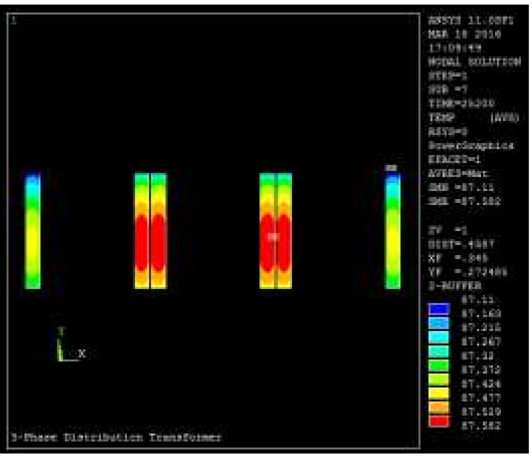


Figure (7): Temperature distribution in H.V. the transformer (250KVA) with CuONano fluid

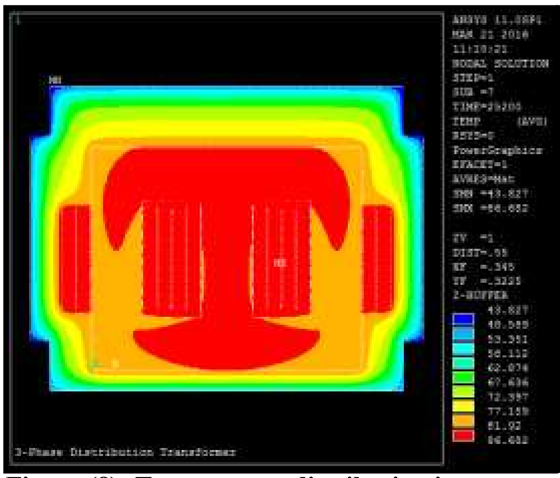


Figure (8): Temperature distribution in transformer (250KVA) with Al_2O_3 with Al_2O_3 Nano fluid

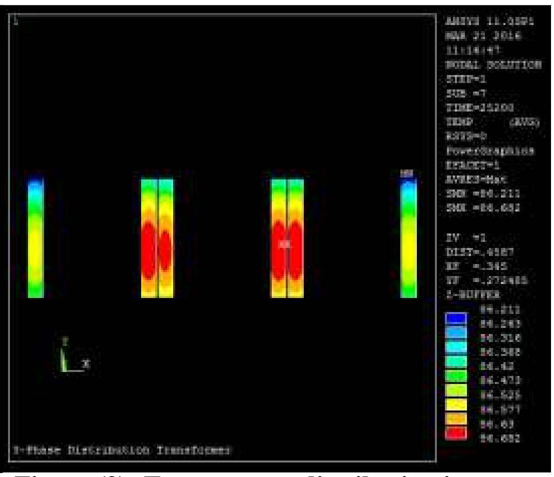


Figure (9): Temperature distribution in H.V. winding in transformer (250KVA) Nano fluid

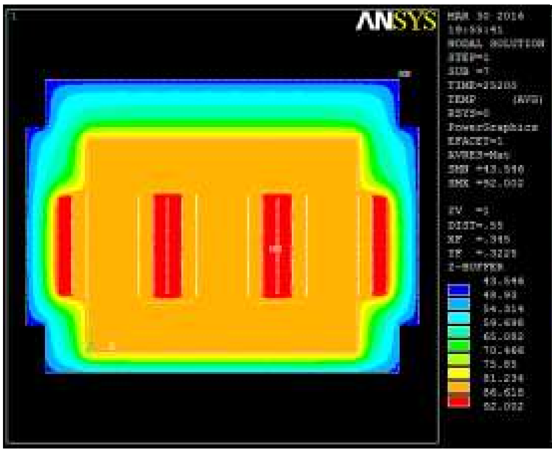


Figure (10): Temperature distribution in transformer (250KVA) conventional angle 135^{o} with traditional oil

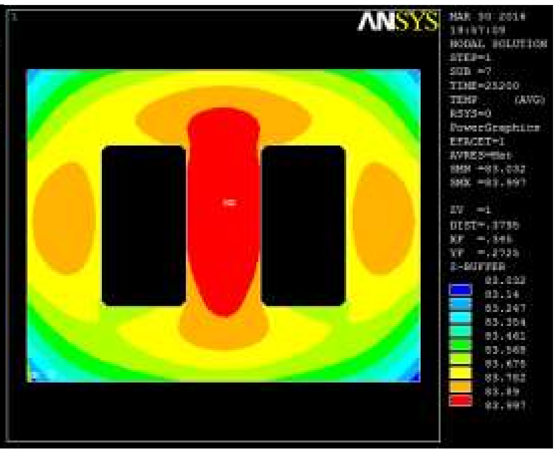


Figure (11): Temperature distribution in conventional core with angle 135^{o} with and traditional oil

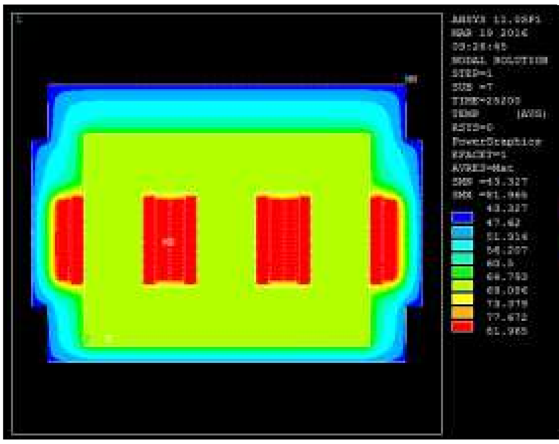


Figure (12): Temperature distribution in (250KVA) with amorphous core traditional oil

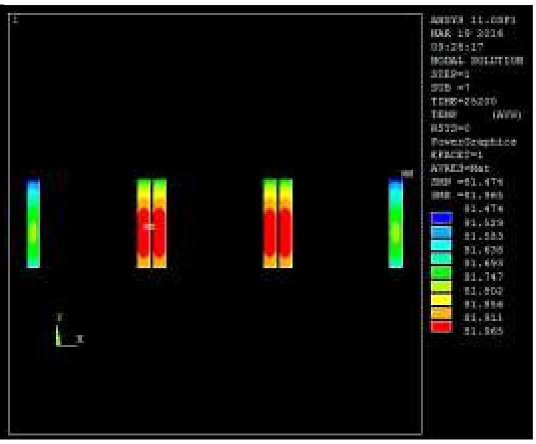


Figure (13): Temperature distribution transformer in H.V. winding with amorphous core and and traditional oil

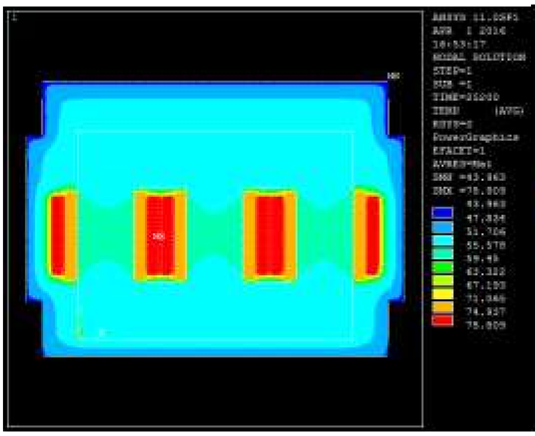


Figure (14): Temperature distribution in (250KVA) with amorphous core and CuO Nano fluid

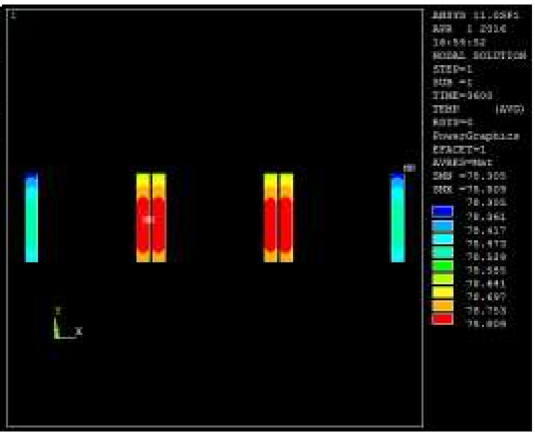


Figure (15): Temperature distribution transformer H.V. winding of transformer with CuO Nano fluid

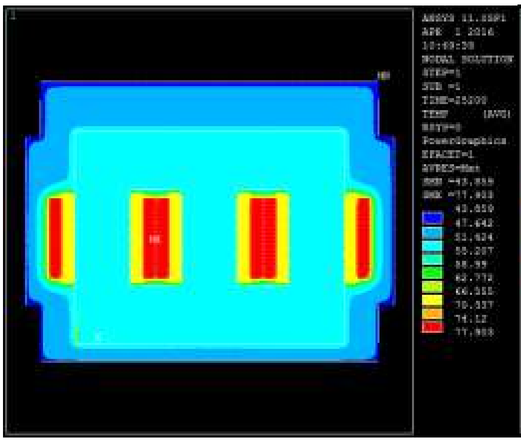


Figure (16): Temperature distribution in transformer (250KVA) with amorphous core and Al_2O_3 Nano fluid

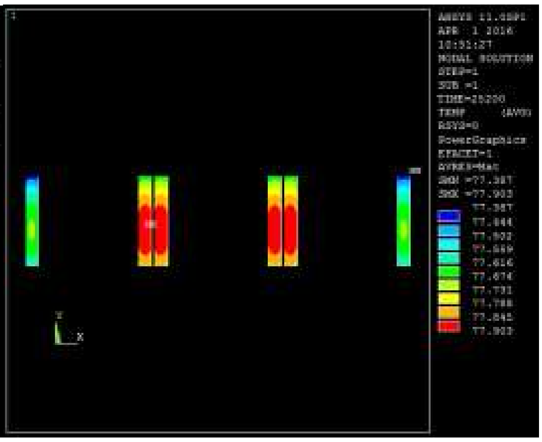


Figure (17): Temperature distribution in H.V. winding of transformer with Al2O_3 Nano fluid

CONCLUSIONS

For present work, it is concluded the following points:

A- At detecting the effect of using the conventional core, **(CuO)** Nano fluid and **(Al_2O_3)** Nanofluids) separately), it is deduced the following:

1- For the transformer with **CuO** Nano fluid gave a reduction in the maximum temperature about **4.5^{o}c (4.9%)**.

2- But the transformer with **Al_2O_3** Nano fluid gave a reduction in the maximum temperature about **5.5^{o}c (5.9).**

3- Using the amorphous core, the maximum temperature was reduced approximately **10 ^{o}c** (**10.8%)** and total losses decreased **90%** at no load case and about **5%** for load conditions.

B- At studying the effect of using one type of Nano fluid and amorphous core together, it's **found the following**:

1- The transformer with **Cuo** Nano fluid as an insulation and amorphous core gave a reduction in the maximum temperature about **13^{o}c (14%)**.

2- But the transformer with **Al_2O_3** Nano fluid as insulation and amorphous core gave a reduction in the maximum temperature about **14^{o}c (15%)**.

C- Finally it can be said, the proposed model was succeeded in simulating the distribution transformer, and it could be adopted as a tool design with assist of **ANSYS** Package.

REFERENCES:

[1] Haritha V., "Thermal Modeling Of Electrical Utility Transformers", International Institute of Information Technology, M.Sc. Thesis, November, 2011.

[2] J. Dofan, "Study On Thermal Model For Calculating Transformer Hot Spot Temperature ", Faculty Of Electrical & Electronic Engineering, Ms.C. Thesis, May, 2011.

[3] E. Amoiralis, M. Tsili and G. Kladas, ""Distribution Transformer Cooling System Improvement By Innovative Tank Panel Geometries"," *IEEE Transactions On Dielectrics And Electrical Insulation Vol. 19, No. 3; June 2012.*

[4] M. Hjalmars, "Optmiization Study on Oil Flow and Temperature Distribution in Power Transformer Windings", M.Sc. Thesis, Stockholm, Sweden, 2012.

[5] Methaaq T. Jabbar, "Electromagnetic Modeling And Design Of 11\0.4 Kv Distribution Transformer", Electrical Power Engineering Department, Univercity Of Technology, Iraq, M.Sc. Thesis, January, 2013.

[6] D. Constantin, P.Marian and C.Nitu, ""3d Finite Element Analysis of A Three Phase Power Transformer"," *Eurocon.,Zgreb, Croatia.* Pp. 1548-1552, July, 2013.
[7] C. S. Wei, "Modifications in Transformer Design to Reduce Temperature Rise", M.Sc. Thesis, 2008. University Malaysia Sarawak.
[8] L. Nasrat, M. Abdelwahab and G. Ismail , ""Improvement Of Used Transformer Oils With Activated Bentonite"," *Engineering, June, 2011,Pp 588-593.*
[9] J. Gastelurrutia, J. Ramos, G. Larraona, A. Rivas and J. Izagirre, "Numerical Modelling Of Natural Convection Of Oil Inside Distribution Transformers", *Applied Thermal Engineering 31 (2011) pag.493-505.*
[10] Rukiye Kardag, "Temperature Distribution In Power Transformers", M.Sc. Thesis, September, 2012, Electrical And Electronics Engineering Department. The Graduate School of Natural and Applied Science Middle East Technical University.
[11] J. Shazly and A. Adly , ""Extensions To The Finite Element Technique For The Magneto-Thermal Analysis Of Aged Oil Cooled-Insulated Power Transformers"," Journal of Electromagnetic Analysis And Applications, 2012, 4, 167-176, March,2012.
[12] T. Bergman, A. Lavine, F. Incropera and D. Dewitt, "Fundamental Of Heat Transfer and Mass", puplished by,John Welly and Sons.
[13] F. Torriano, M.Chaaban and P.Picher, ""Numerical Study Of Parameters Affecting The Temperature Distribution In A Disc-Type Transformer Winding"," *Applied Thermal Engineering ,* Pp. 2034-2044, 2010.
[14] A. R. Abdulmunem, "Experimental Investigation and theoretical modeling for improving the solar collector performance by using tracking system" M.Sc. Thesis, 2015 University of Technology.
[15] A. H. Dhiaa, M. I. Abdulwahab and S. M. Thahab, "Study the Convection Heat Transfer of TiO_2/ Water Nano Fluid in Heat Exchanger System", Eng. Tech. Journal, Vol.33, Part (E), No.7,Pp. 1319-1329, 2015.
[16] J. M. Ali, B. A. Abid and K. M. Essa, "Pooling Boiling Heat Transfer Using Nano Fluid", Eng. Tech. Journal, Vol.33, Part (A), No.2, Pp 512-525, 2015.
[17] Mutuki and W. Nduku "ANALYSIS OF HYDROMAGNETIC BOUNDARY LAYER FLOW AND HEAT TRANSFER OF NANOFLUIDS", M.Sc. Thesis, January,2014, Cape Cape Peninsula University of Technology, South Africa.