International Journal of Technical Innovation in Modern Engineering & Science (IJTIMES)
Impact Factor: 5.22 (SJIF-2017), e-ISSN: 2455-2585
Volume 5, Issue 08, August-2019

Thermal Analysis of Transformer Cooling System

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***Abstract*— In the power distribution sectors the power transformers are very important tool to altering the voltage along with current. As well as the power transformers are very high efficient electrical device (above 90% Oil Natural and Air Natural Transformers) because there is no rotating parts. But, the load on the transformer and atmosphere temperatures are dramatically increased in the hot weather conditions. The transformer working is plays a crucial role in efficient functioning of Security, hospitals, networking, banking and industrial sectors. The age of the transformer is based on insulating material life. The load on the transformer and atmosphere temperatures is important variables that are influencing on the life of insulating material that is used in the transformer.**

In this project, the enhanced natural cooling system designed by using CATIA 3D Modeling for Oil Natural and Air Natural (ONAN) Transformer to reducing the transformer hot spot temperature for increasing life of insulation. By this way, will get the increased transformer age and avoid the sudden failures

Keywords— Include at least 5 keywords or phrases

I. INTRODUCTION

. The transformer is an electrical static device; these are used to alter the voltage and current levels with constant power output. Generally, the transformers are high efficient (around 95% for ONAN) [3, 5]. The transformers are generally classified into two types. These are transformer with step-up and transformer with step down.

The age of the transformer purely depends on the load on the transformer and hot spot temperatures, because of the life of insulating material used in the transformer is affected [1, 2]. The insulating material is used transformer is obstruct the flow of electricity from on part to another part for avoiding the short circuit. In view mechanical arrangements, the transformers are having good life because there are no moving parts or rotating parts. The age of transformer is affected by temperature increase causing increasing load on the transformer or high atmosphere temperatures like summer sessions [1, 2, 3].

The transformers load in summer season is increased due to increasing the utilization. As well as the atmosphere temperature is also too high as compared with winter and rainy seasons. In this concern, many of the transformers will blow out in summer condition due to short circuit. This is occurs due to the increasing of transformer hot spot temperature, so than the insulating material used in the transformer, will burn due to the overheat [4]. To overcome this problem some external agencies like cooling fans are provided to cool down the transformer to avoid the failure of transformer. By this way, the transformer electrical efficiency will decreased due to power utilization from the input.

Based on the above literature, if the load on the transformer and atmosphere temperature will increase the transformer life is decreased. In this concern the need of enhanced transformer cooling system is required for OIL NATURAL AND AIR NATURAL transformer to dissipate the heat quickly and easily [7].

II. DESIGNING AND MODELING

2.0. Design of Transformer:

Designing of 500 kVA, 50 Hz, 6600/400 V, Oil Immersed and Natural Cooled Power Transformer.

2.1. Design Considerations:

1. Material of the lamination: 56 grade cold rolled oriented steel
2. Material of the tank: structural steel
3. Insulation material: pressboard (cellulose)

i. Total Heat Loss of Transformer:

Total Heat Loss of Transformer = Copper Losses+ Core Losses
= 3865 + 1460
= 5325 W.

2.2. Tank Dimensions

Height of the frame, H = 977.5 mm

Allowing 50 mm for base and 250 mm for oil.

Oil level = 977.5 + 50+ 250
= 1228 mm say 1300 mm

Allowing 300 mm further for leads and etc.

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Height of the tank, H_t = 1300 +300
= 1600mm

Allowing the 150 mm at each along the length.

Length of tank, L_t = 475 +418 + (2x150)
= 1193mm say 1200 mm

Allowing clearance 200 mm along with width for accommodate taps etc.

Width of the tank, W_t = 418 + 200
= 618 mm say 650 mm

The below figure -6 produced from the above obtained tank dimensions

2.3. Transformer Models:

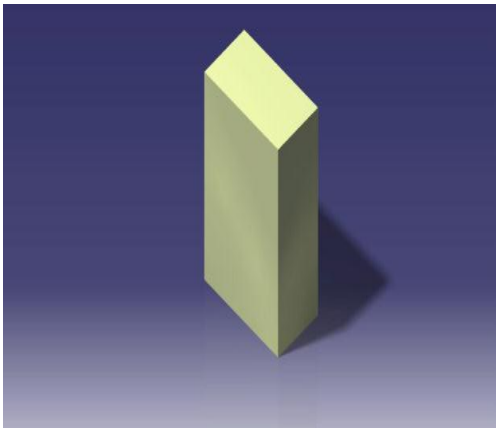

Fig-17. Plane Transformer Model

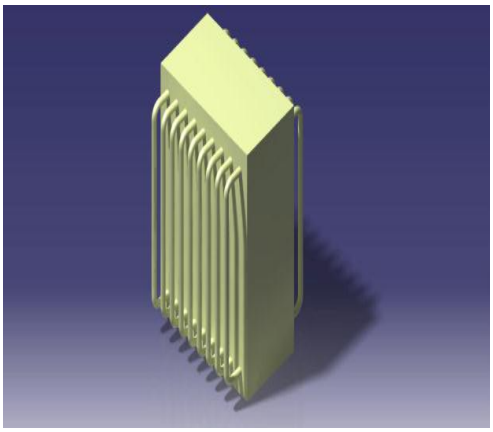

Fig-18. Transformer with Tubes Model

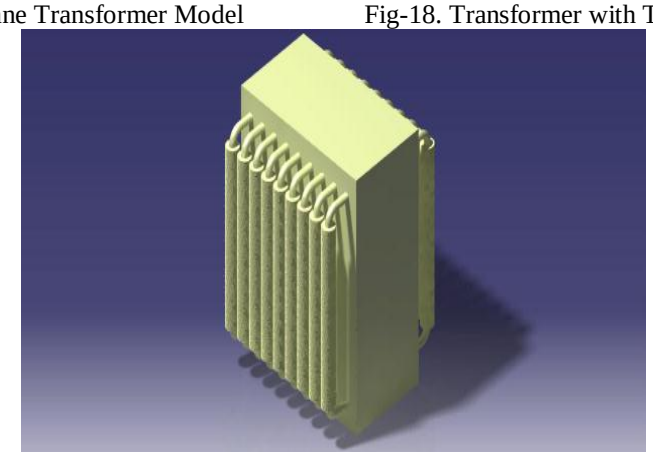

Fig-19. Transformer with Finned Tubes Model

III. MATHEMATICAL CALCULATION

3.1. Mathematical Analysis Based on Heat Transfer for Ambient Temperature 45 ^{O}C.

A. Solution for Transformer model-1

Q = $h A_s (T_w - T_a)$ ----------(1)

Life of insulation = $72000 X e^{(-0.09X Tw)}$ ----------(2)

Q = Heat to be transfer as per transformer design = 5325 Watts

h = Convective heat transfer coefficient
= 5 W/M^2 ^{o}C

T_w = Wall Temperature (^{o}C) = ?

T_a = Ambient Temperature (^{o}C) = 45 ^{o}C

Surface area A_s = 2 (L+W) X H
= 2(1.2+0.65) X 1.6
= 5.92 M^2

Substituting the values of Q, h, A_s and T_a in equation (1), we get T_w

5325 = 5X5.92 X (T_w – 45)

$$T_w = \frac{5325}{5 X 5.92} + 45$$

T_w = 224.9 ^{o}C

Substituting the wall temperature T_w in equation -2, we get

Life of Insulation In Years = **72000 X e $^{(-0.09X\ Tw)}$**
= 0.000116635 Years
= 0.001399626 Months
= 1.007730609 Hours

B. Solution for Transformer model-2

Q = h A_s (T_w-T_a) ----------(1)
Life of insulation = 72000 X e $^{(-0.09X\ Tw)}$ ----------(2)

Q = Heat to be transfer as per transformer design = 5325 Watts
h = Convective heat transfer coefficient
= 5 W/M^2 ^{o}C
T_w = Wall Temperature (^{o}C) = ?
T_a = Ambient Temperature (^{o}C) = 45 ^{o}C

Surface Area A_s

= **(2 (L+W) X H) + (No of Tubes X ∏ X D_1 X H $_{tube}$) – (2X NO of Tubes X(∏/4) X D_1^2)**
= (2(1.2+0.65) X 1.6) +(18+ ∏ X 0.05 X 1.5)- (2X 18 X(∏/4) X 0.05^2)
= 5.92+ 4.24-0.07
= 10.08 M^2

Substituting the values of Q, h, A_s and T_a in equation (1), we get T_w

5325 = 5 X 10.08 X (T_w – 45)
T_w = $\frac{5325}{5X10.08} + 45$
T_w = 150.6548 ^{o}C

Substituting the wall temperature T_w in equation -2, we get

Life of insulation in years = 72000 X e $^{(-0.09X\ Tw)}$
= 0.093060341 Years
= 1.116724086 Months
= 804.0413421 Hours.

C. Solution for Transformer model-3

Q = h A_s (T_w-T_a) ----------(1)
Life of insulation = 72000 X e $^{(-0.09X\ Tw)}$ ----------(2)

Q = Heat to be transfer as per transformer design = 5325 Watts
h = Convective heat transfer coefficient
= 5 W/M^2 ^{o}C
T_w = Wall Temperature (^{o}C) = ?
T_a = Ambient Temperature (^{o}C) = 45 ^{o}C
R_1 = 0.025 m
R_2 = 0.05 m
t = 0.003 m

As per the above fin effectiveness table

R_{2c} = R_2 + (t/2)
= 0.05+ (0.003/2)
= 0.0515 m
L_c = L+ (t/2)
= 0.025+ (0.003/2)
= 0.0265 m
A_p = L_c X T
= 0.0265X0.003
= 7.95X10 $^{-5}$
$L_c^{3/2}\sqrt{\frac{h}{K\,Ap}}$ = $0.0265^{3/2}\sqrt{\frac{5}{60.5X7.95X10^{-5}}}$
= 0.139
$\frac{R_{2C}}{R_1}$ = $\frac{0.0515}{0.025}$
= 2.06
η = 0.96 (From the above chart)

Surface Area A_s

= **A_{tank} +(No of Tubes X ((No of Fins/tube X A_{fins})+ $A_{tubeucf}$))- (2X NO of Tubes X(∏/4) X D_1^2)**
A_{tank} = **2 (L+W) X H,**
= 2(1.2+0.65)X 1.6
= 5.92 M^2

$A_{tubeucf}$ = $\prod$ **X** D_1 **X** $H_{tubeucf}$
= $\prod$ X 0.05X 1.158
= 0.18189

A_{fin} = **2** $\prod$**(** R_{2c}^2 **-** R_1^2**) X no of fins**
= 2 $\prod$($0.0515^2 - 0.025^2$) X 114
= 1.4520

Surface area A_s = 5.92+(18x(1.4520+0.18189))-0.07
= 35.26 M^2

Substituting the values of Q, h, A_s and T_a in equation (1), we get T_w

5325 = 0.96 X 5 X 35.26 X (T_w – 45)

$T_w = \frac{5325}{5 X 35.26} + 45$

T_w = 76.46 ^oC

Substituting the wall temperature T_w in equation (2), we get

Life of insulation in years = **72000 X e** $^{(-0.09X\ Tw)}$
= 73.9 years
= 886.8 month
= 638537.5446 hours.

3.2. Mathematical Calculations Based on Transformer Cooling System Design.

3.2.1. Formula

The transformer tank walls dissipate the heat by both convection and radiation. As per the experimental investigation that the walls of transformer tank dissipate the heat with combined heat transfer coefficient 12.5 $W/M^2\ ^oC$.

Therefore,

Temperature rise $= \frac{Total\ loss}{combined\ heat\ transfer\ coefficent\ X\ surface\ area}$ **……(1)**

$= \frac{Total\ loss}{12.5\ X\ A_s}$

Where

A_s = surface area

Life of insulation = 72000 X e $^{(-0.09\ X\ Tw)}$ **…….…… (2)**

Where

T_w = wall temperature

3.2.2. Dimensions:

As per transformer design, we obtain the transformer geometrical details are given below

A. FOR TRANSFORMER MODEL-1

Height of the transformer	=	1.6 M
Length of the transformer	=	1.2m
Width of the transformer	=	0.65 m
Surface area	=	5.92

B. FOR TRANSFORMER MODEL-2

Height of the transformer	=	1.6 M
Length of the transformer	=	1.2m
Width of the transformer	=	0.65 m
Length of the tube	=	1.5 m
Outer diameter of the tube	=	0.05m
No of tubes	=	18 tubes (consideration)
Surface area	=	10.08

C. FOR TRANSFORMER MODEL-3

Height of the transformer	=	1.6 M
Length of the transformer	=	1.2m
Width of the transformer	=	0.65 m
Length of the tube	=	1.5 m
Outer diameter of the tube	=	0.05m
No of tubes	=	18 tubes (consideration)
Circular Fin outer diameter	=	0.1 m
Circular Fin inner diameter	=	0.05 m
Fin thickness	=	0.003 m
No of fins per tube	=	114

Space between two fins = 0.007 m
Surface area = 35.26

3.2.3. Boundary Conditions:

Combined heat transfer coefficient = 12.5W/M^2 ^{o}C
Heat to be transfer as per transformer design = 5325 Watts
T_w = Wall Temperature (^{o}C) = ?
T_a = Ambient Temperature (^{o}C) = 45 & 35 ^{o}C

3.2.4. Mathematical Analysis Based on Transformer Cooling System Design for Ambient Temperature 45 ^{O}C.

A. SOLUTION FOR TRANSFORMER MODEL-1

Temperature rise = $\frac{Total\ loss}{combined\ heat\ transfer\ coefficent\ X\ surface\ area}$

= $\frac{Total\ loss}{12.5\ X\ A_s}$

Total loss = 5325 watts
Surface area A_s = 5.92
Temperature rise (T_w-T_a) = $\frac{5325}{12.5X5.92}$
= (T_w -45)
= 72
T_w = 72+45
= 117 ^{o}C

Life of insulation in years = **72000 X e $^{(-0.09X\ Tw)}$**
= 1.924 years
= 23.08 month
= 16623.61 hours.

B. SOLUTION FOR TRANSFORMER MODEL-2

Temperature rise = $\frac{Total\ loss}{combined\ heat\ transfer\ coefficent\ X\ surface\ area}$

= $\frac{Total\ loss}{12.5\ X\ A_s}$

Total loss = 5325 watts
Surface area A_s = 10.08
Temperature rise (T_w-T_a) = $\frac{5325}{12.5X5.92}$
= (T_w -45)
= 42.26
T_w = 42.26+45
= 87.26 ^{o}C

Life of insulation in years = **72000 X e $^{(-0.09X\ Tw)}$**
= 27.96 years
= 335.6 month
= 241633.95 hours.

C. SOLUTION FOR TRANSFORMER MODEL-3

Temperature rise = $\frac{Total\ loss}{combined\ heat\ transfer\ coefficent\ X\ surface\ area}$

= $\frac{Total\ loss}{12.5\ X\ A_s}$

Total loss = 5325 watts
Surface area A_s = 35.26
Temperature rise (T_w-T_a) = $\frac{5325}{12.5X5.92}$
= (T_w -45) = 12
T_w = 12+45 = 57 ^{o}C

Life of insulation in years = **72000 X e $^{(-0.09X\ Tw)}$**
= 425.99 years
= 5111.9 month

= 3680573.939 hours

IV. SIMULATION ANALYSIS

4.1. Ansys Steady State Thermal Analysis on Transformer model-1

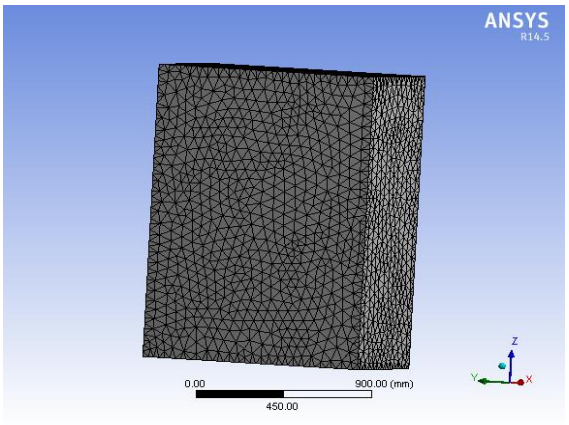

Figure-27. Meshing

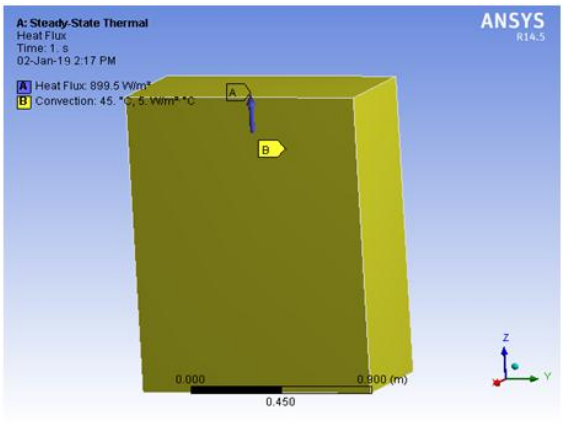

Figure-28. Boundary Conditions

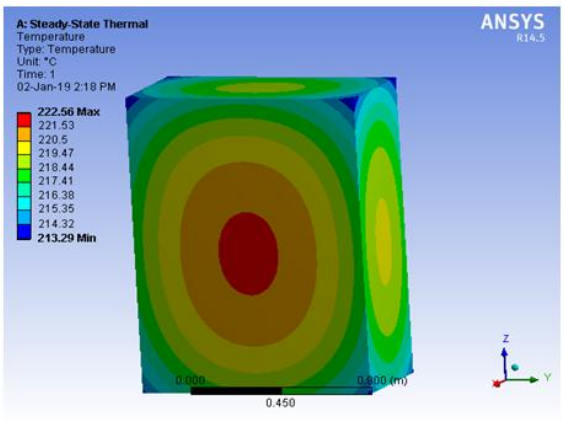

Figure-29 Temperature result

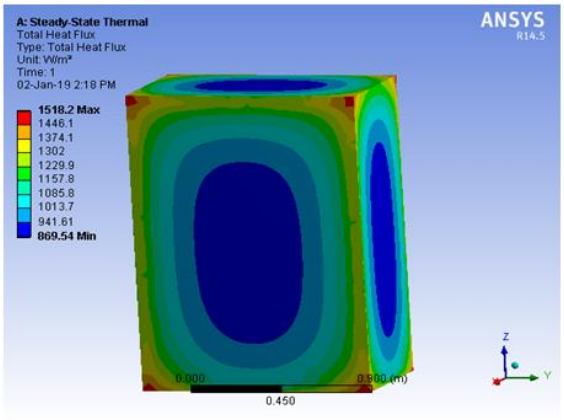

Figure-30. Total Heat Flux Result

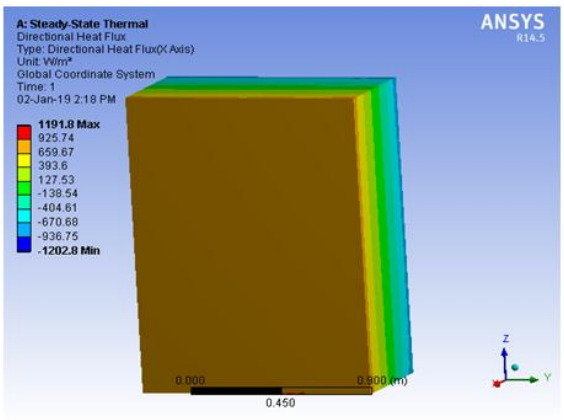

Figure-31. Directional Heat Flux Result

4.2. Ansys Steady State Thermal Analysis on Transformer model-2

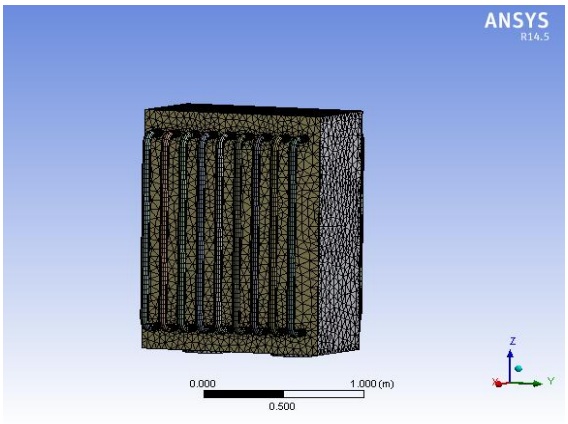

Figure-37. Meshing

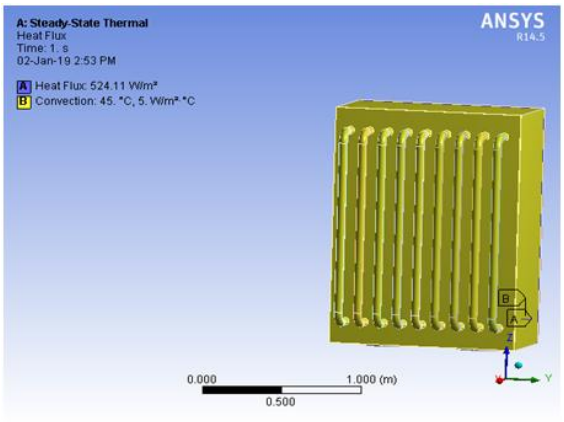

Figure-38. Boundary Conditions

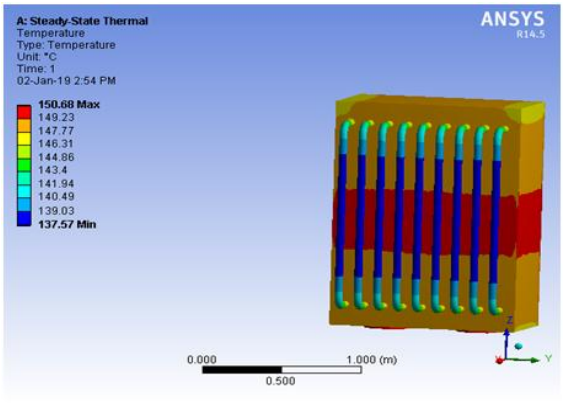

Figure-39. Temperature result

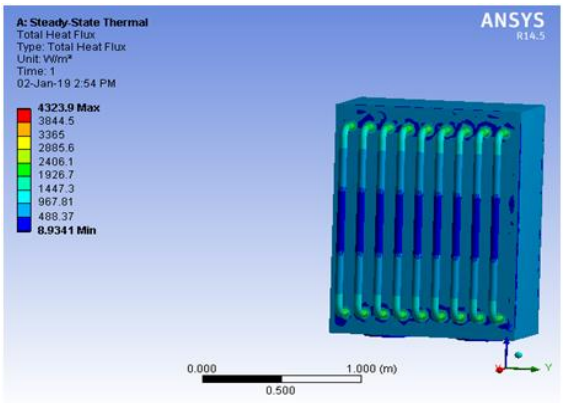

Figure-40. Total Heat Flux Result

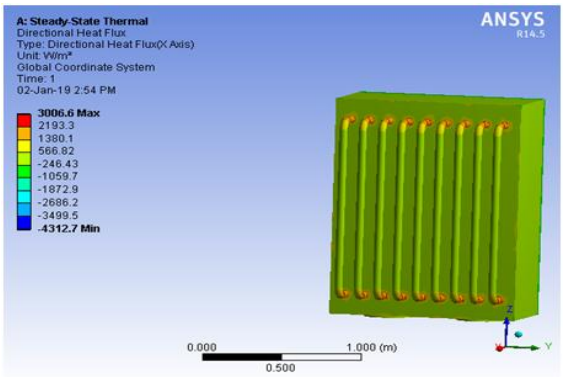

Figure-41. Directional Heat Flux Result

4.3. Ansys Steady State Thermal Analysis on Transformer model-3

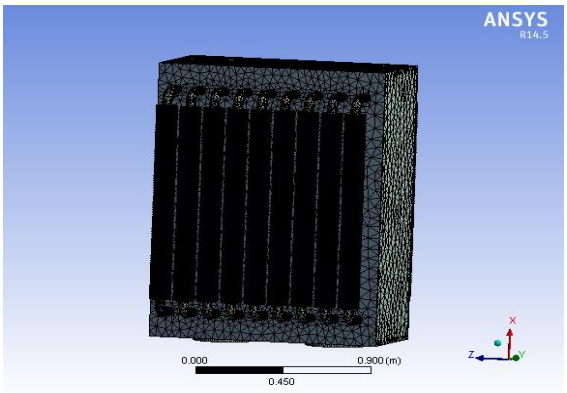

Figure-47. Meshing

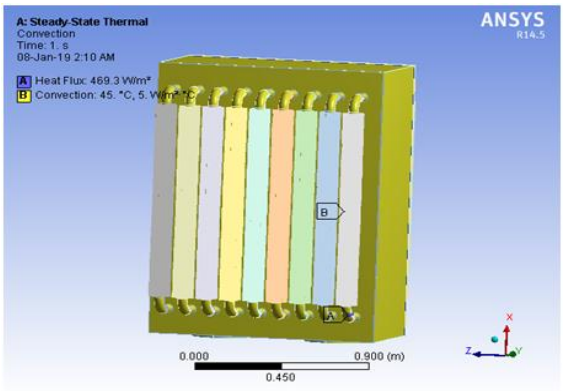

Figure-48. Boundary Conditions

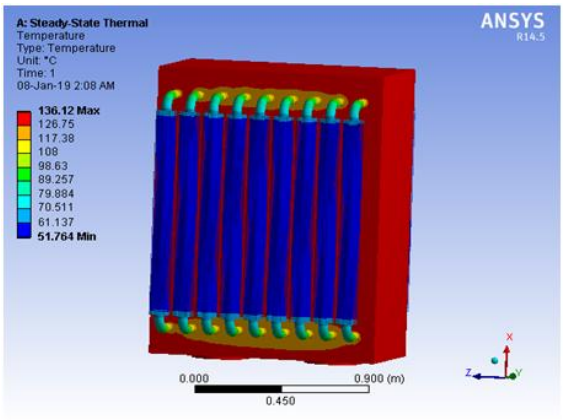

Figure-49. Temperature result

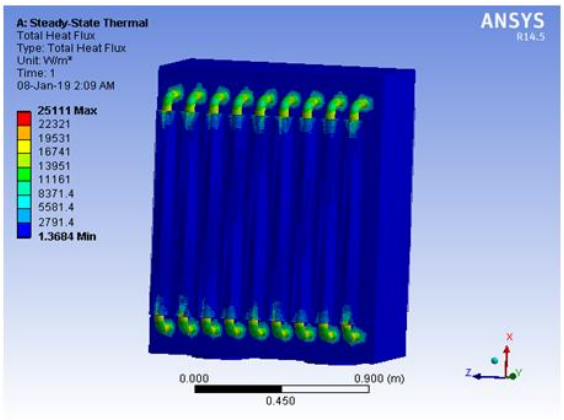

Figure-50. Total Heat Flux Result

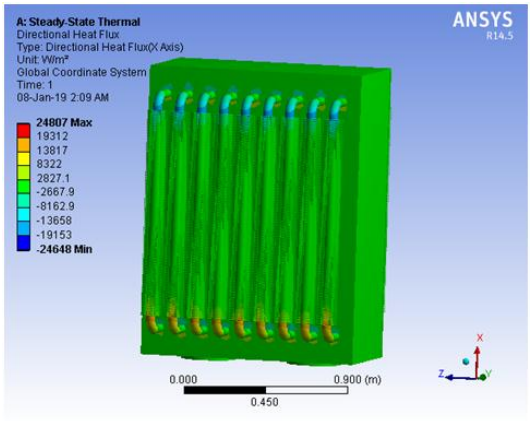

Figure-51. Directional Heat Flux Result

6. RESULT AND DISCUSSION

6.1. Mathematical Results Based on Heat Transfer Analysis:

	Total Heat	Convective Coefficient	Surface Area	Temperature Rise	
				T_w	T_a
	WATTS	$W/M^{2O}C$	M^2	^oC	^oC
Model-1	5325	5	5.92	**224.89**	45
Model-2	5325	5	10.08	**150.65**	45
Model-3	5325	5	35.26	**76.46**	45

Table-3 Comparison of temperature results for all three Transformer models Based on heat transfer analysis.

Model No	Temperature	Life of Insulation (In Years)
Mode-1	224.89	0.000116635
Mode-2	150.65	0.093060341
Mode-3	**76.46**	**73.90480843**

Table-4 Comparison of Insulation life results for all three Transformer models Based on heat transfer analysis.

6.2. Mathematical Results Based on Transformer Design Analysis:

	Total Loss	Combined Heat Transfer Coefficient	Surface Area	Temperature Rise	
				T_w	T_a
	WATTS	$W/M^{2O}C$	M^2	^oC	^oC
Model-1	5325	12.5	5.92	**116.96**	45
Model-2	5325	12.5	10.08	**87.26**	45
Model-3	5325	12.5	35.26	**57.08**	45

Table-7 Comparison of temperature results for all three Transformer models Based on transformer design.

Model No	Temperature	Life of Insulation (In Years)
Mode-1	116.96	1.931061876
Mode-2	87.26	27.96209853
Mode-3	**57.08**	**422.872321**

Table-8 Comparison of Insulation life results for all three Transformer models Based on transformer design.

6.3. Simulation Results:

Model No	Temperature		Total Heat Flux		Directional Heat Flux	
	Max	Min	Max	Min	Max	Min
Mode-1	**222.56**	**213.29**	1818.2	869.54	1191.8	-1202.8
Mode-2	**150.68**	**137.57**	4323.9	8.9341	3006.6	-4312.7
Mode-3	**136.12**	**51.764**	25111	1.3684	24807	-24648

Table-11 Comparison of Result for all three Transformer models.

Model No	Temperature		Life of Insulation	
	Max	Min	Max	Min
Mode-1	222.56	213.29	0.000143959	0.000331568
Mode-2	150.68	137.57	0.0928492	0.302135828
Mode-3	**136.12**	**51.764**	**0.34425294**	**682.4309829**

Table-12 Comparison of Insulation Life Results for All Three Transformer models

V. CONCLUSIONS

In this paper, three transformer different models are designed by catia 3d modeling software for 50 MVA, 6600/400 V Oil Natural Air Natural cooling transformers at constant load. In the above three transformer 3d models first two transformer models (i.e. model-1 and model-2) are existing transformer cooling systems and last one (i.e. model-3) is newly modeled transformer model. The above three transformer 3d models are drafted by CATIA 3d modeling and which are evaluated by mathematically (heat transfer, transformer design analysis) and simulated by (ANSYS study state thermal analysis)

Method of Analysis		Mathematical Analysis		Simulation Analysis	
		Heat Transfer Analysis	Transformer Design Analysis	Maximum	Minimum
Model-1	Temperature	214.89	106.96	212.56	203.29
Model-2		140.65	77.26	140.68	127.57
Model-3		**66.46**	**47.08**	**126.12**	**41.764**
Model-1	Life of Insulating Material	0.0002869	4.74964	0.00035408	0.000815525
Model-2		0.2288915	68.77566	0.22837218	0.743134222
Model-3		**181.7765**	**1040.09807**	**0.8467256**	**1678.50937**

VI. Table-13 conclusion in all aspects

By observing the results obtained from mathematically and the simulation analysis, the model-3 transformer gives the best outcomes over the model-1&2 transformers with same load.

I concluded that based on above tabulated results the transformer model-3 i.e. Finned Tube Transformer's cooling system having the low hot spot temperature and large in insulating material life compared with the first two models. It is indicated that, if you provide the fins on the transformer tubes the heat dissipation is increased and life the insulating materials increased. Hence, we will get the enhanced age of transformer and avoid the sudden failures in hot weathers.

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