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MODELING AND ANALYSIS OF POWER TRANSFORMER USING FINITE ELEMENT METHOD

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ABSTRACT

The problem of evaluating the various performance characteristics of power transformer such as temperature distribution, flux distribution, and losses, is an age long issue in electrical engineering, and an attempt to manually or analytically evaluate them is very difficult and subject to errors. Hence the development and application of Finite Element Method to complex engineering analysis of this nature. This research presented enhanced finite element model application to Power Transformer. The method applied was modeling and simulation. The Finite Element Analysis of a 30/40MVA Power Transformer Model was created using ANSYS MAXWELL Analysis Software. The input, output voltage, and frequency of operation of the power transformer was defined and inputted into the design parameter section from where the phase current

Introduction:

Modeling of power transformers and their accurate simulation has been a challenging task for engineers worldwide. Power transformers are the most expensive element in energy transmission and distribution networks, it is very important to predict parameters such as electromagnetic forces, electromagnetic flux distribution, losses, and thermal distribution. In recent years, various powerful software programs have been developed to calculate transformer parameters, operating modes, and different types of losses. High accuracy designs can be made with FEA.

was computed. Other parameters of the Power Transformer were selected as appropriate in the design stage before the mesh generation was carried out by process of adaptive discretization. The Solution of the Model, covered Finite Element Force Calculation, Thermal Analysis, Short Circuit Analysis, and Insulation Analysis. In summary, the adaptive discretization result for winding loss was 98.4kW, and that of core was 19.62kW, produced a maximum flux density of 1.84T. For thermal model computation, the result showed 94.30℃ was the hot spot temperature on the winding while 75.84℃ on the core. The electrodynamics force distribution along the windings during the short circuit condition, translating to 1.25kN for low voltage radial force and 652.69kN high voltage axial force. The electrostatic field distribution between the high voltage and low voltage was 10.48kV/mm, while that exiting between core and low voltage was 3.74kV/mm. The performances of the designed models were compared with the performance of the transformer, which was determined analytically, and the performance of the transformer was also determined experimentally and the results were confirmed. When the results were compared, it was seen that the designed models gave more optimum results.

Keywords: Modeling, Analysis, Power Transformer, Finite Element Method, Design.

Losses occurring in different parts of the transformer can be easily calculated using finite element method (FEM).

The importance of transformers has been emphasized by Leela *et al.* (2020) in the power system domain and therefore suggested the use of FEM in power transformer design. This is because it is easy to analyze the Electromagnetic Field distribution and calculate the losses during design than when implemented in real-time. They went ahead to simulate a three-phase 11/0.4 kV power transformer using the Finite Element Method to demonstrate this idea. Only core loss was considered in this work while copper and flux distribution were not considered bringing a limitation to it.

Similarly, the efficiency of different protective and shunt applications is defined for the losses caused by leakage flux. In the design of the transformer, the electrical field distributions of the windings with the electric field model were analyzed and the levels of insulation of the system were obtained. Magnetic field model of the transformer core and winding design, the presence of equivalent parameters, and short circuit testing were be analyzed with the laplace forces coming to the windings. Studies have been conducted to reduce the eddy current loss significantly using FEM. Another new approach to reduce eddy losses was by using stranded iron in the structure of the core.

Simulation was done in the computer environment for the design of the proposed transformers. The FEM was used for studying both optimization and optimization efficiency. To obtain a more accurate result, the three dimensional magneto static solvent forms a finite element mesh by breaking the main problem into a number of sub problems. The quality and number of the network affects the accuracy of the finite element analysis. A combined electromechanical finite element method was used to calculate numerical values such as inductance, core and winding losses, and transient voltage current relations. It is possible to design a simple, rough estimate of the transformer characteristics using the method adapted to target performance. Estimated design parameters and details are made clear by using the designed method. This method was analytical and allows some parameter interval settings to be reported by evaluating the results of the study.

In this research, a model was developed for studying both the electromagnetic flux distribution and loss of transformer with thermal field analysis. Electromagnetic forces, electromagnetic flux, electric stresses, losses and thermal distributions of transformers were investigated. The numerical results were compared with the analytical results.

LITERATURE ON MODELING AND ANALYSIS OF POWER TRANSFORMER USING FINITE ELEMENT METHOD

The literature is quite replete with publications that span over 10 years. The relevant publications being reviewed are intended to provide the current state of art in the modeling and analysis of power transformer.

Orosz *et. al.,* (2020), proposed the optimal design of a power transformer by applying NSGA-II to minimize the total cost of ownership and calculating the optimal winding arrangement of the transformer using a geometric programming method. 2D FEA was included in the optimization process. They limited the work through the use of 2D and NSGA 11 while 3D and NSGA III could have been used.

Amir and Dan (2020) studies on the analysis and optimization of high-frequency planar transformers for full-bridge DC/DC converters used for power conversion in automotive applications. DC-DC converters used in automotive applications must be stable and reliable when used under extreme operating conditions, such as wide input/output voltage ranges and high temperatures. Improper transformer design can reduce inverter performance and cause thermal issues that may require additional design iterations. The best approach was to build a virtual prototype of the transformer. This goal is achieved using the finite element method (FEM). The analysis lies on medium transformer where they limited themselves to the use of 2D.

Vibhuti and Deepika (2020) chronicled the application of FEM solution to transformer parameter estimation from 2017 to 2019 revealing a total of 73 publications. These publications, spanned through high voltage and low voltage power transformers as well as three phase transformers. Parameters analyzed by various authors include Copper

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Loss, Eddy Current Loss, Stray Loss, and short circuit Loss. They do not consider the force and temperature rise which vital parameter in a transformer and makes it a limitation to their contribution.

Lingzh *et. al.,* (2019), proposed response surface methodology (RSM) to design electrostatic insulation structures, of power transformer ring to generate power transformer model using ANSYS Parametric Design Language (APDL) to realize automatic preprocessing of numerical calculations. To reduce the maximum electric field strength, the Taguchi method was used to select parameters that have a greater influence on the maximum electric field strength, which effectively simplifies the subsequent optimization process. Test points were configured through Central Composite Design (CCD) and response surface models were generated through mutual calls between MATLAB and ANSYS. Comparing the RSM and FEM results shows that the results obtained by both methods are consistent and the maximum field strength is significantly reduced. They limited the work through the use of RSM while other optimization techniques can serve.

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Nivashini *et. al.,* (2020) A three-phase power transformer with a rated voltage of 11/0.4 kV is designed keeping in mind specific parameters such as type of material used for the core, core stacking, frame size and type. Simulate the designed transformer model, including the type of winding (spiral, disk, cylinder, etc.), the material used for the winding, the number of turns of the primary and secondary windings, the resistance of the winding, and the operating frequency range. From ANSYS software. The results were compared to the actual transformer readings based on the nameplate, with only minor deviations. The work was limited on development of electromagnetics.

Tamás *et. al.*, (2020) proposed to determine the optimal conductor dimensions for transformer windings. Based on knowledge of the winding geometry and flux density, geometric programming-based methods are used to calculate the optimal winding arrangement and conductor geometry. Applying geometric programming ensures that an optimal solution exists and that the optimal solution found is a global optimum. This study showed that the optimal conductor size can be estimated so that the thermal characteristics of the transformer can be considered early in the design. The results of the objective function are consistent with those of established metaheuristic transformer optimization methods. They limited themselves on the use of Disk continuous winding.

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Yildrim, (2021) studies work on structural analysis of transformers was conducted in three dimensions using Maxwell's Ansys program. The goal was to reduce the number and cost of prototypes required by transformer designers and manufacturers. For this purpose, the value of the transformer designed based on the actual value of the transformer was very similar to the value of the actual transformer. The study demonstrates the accuracy and reliability of the methods used. The methods and analysis programs used provided results with sufficient accuracy to validate the designed model. They limited themselves on the development of electromagnetic model.

Hamid *et. al.,* (2021) presents a new method for diagnosing various types of winding-to-winding faults in a flapping pole synchronous generator using changes in flux linkage. The key feature of the proposed method was its ability to identify defective coils based on two types of winding defects. The air-gap flux coupling of the generator was measured via a search coil sensor installed beneath the stator wedge. The FEM-based theoretical approach confirms the feasibility of the work with experimental results derived from a 4-pole, 380 RPM, 1500 RPM, 50 Hz, 50 KVA, 3-phase salient pole synchronous generator. They limited the work through analysis with only frequency response analysis.

Kamran *et, al*. (2022) evaluate the accuracy of different models for calculating leakage reactance. Additionally, analytical formulas and a complete method to calculate the leakage reactance of a zigzag transformer are provided. The scattering reactance was calculated using experimental tests, numerical techniques and analytical methods. The leakage reactance of various finite element models, namely three-phase 3D, one-phase 3D, three-phase 2D, and one-phase 2D, was examined and these models were compared with experimental tests and analysis methods. Among the analysis techniques, the Rogowski method was used to evaluate scattering reactance. Meanwhile, a prototype experiment was conducted to find an accurate solution. It is limited on the use of Rogowski method which cannot be the best solution.

Hernandez *et, al.* (2023) presented an optimal design for determining the core geometry and high-and low-voltage windings of a power transformer. The multi-target electromagnetic design minimizes transformer power losses as well as copper and core weight through equal constraints on the transformer apparent output power and leakage reactance. This problem is solved using the NSGA-III multi objective optimization algorithm, analytical transducer model, response surface methodology (RSM) polynomial model, and 3D FEA. Analysis of optimal solutions achieved using NSGA-II and NSGA-III optimizers, convergence performance using execution metrics, computation time, and accuracy are reported. Harmonics analysis was not considered upon which brought out a limitation on this work.

Daniel *et, al.* (2023) performance of high-frequency transformers composed of different types of core materials was studied. This involved rapidly analyzing the performance of newly produced core materials compared to known core material types to quickly identify improved core material designs. This empirical approach can analyze the key material efficiency of high-frequency transformers using a standard half-bridge inverter topology. Real voltage and current measurements were used to determine output power efficiency and performance for a specified constant current load range at various switching frequencies. First, commercially available polycrystalline or ferrite-E core materials were used to verify the curve trends measured by characterization. The usability of the mold was then demonstrated through comparative analysis and subsequent validation of the expected performance differences between polycrystalline and Nano crystalline toroidal core materials. Voltage regulation which happens to be a performance index was not considered in this research and thereby leads it as a limitation.

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Behnam, *et. al.* (2024) Modeled 1MVA and 1.MVA power transformer using FEM to ascertain their no-load losses. They further carried out a tripartite comparison of the result with theoretically calculated values and that of experimental result. Their conclusion is that the percentage error for the result obtained using FEM and experimental result were less than 1%, far better than the result obtained using theoretical approach which ranged from 5–10% difference. They limitation their research on electromagnetic model and did not considered the development of other models.

Anionovo *et. al.,* (2024) present enhanced finite element model application to Power Transformer loss computation. The method applied is modeling and simulation. The Finite Element Analysis of a 1.25MVA Power Transformer Model was created using the TrafoSolve unit of the Simcenter MAGNET Multi-physics Analysis Software. During the research, it was noted that reasonable number of research data are available in this domain, though most of them are based on adaptive FEM and standard coarse mesh FEM. In this research the application of adaptive finite element analysis method, which is a Multiphysics scenario was examined. And double discretization algorithm or model developed in this research was applied to simulate the winding and the coil loss of the same transformer, finer mesh was obtained and hence better results. This validates the double discretization algorithm developed in this research. They limited themselves only on electromagnetic model development.

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METHODOLOGICAL DIRECTION

In the program, the boundary conditions of the transformer model, geometric dimensions, and properties of all materials used are defined on the model. The electrical information used in the analysis of the transformer is presented in Table 1.

Table 1: Name plate rating of the proposed transformer

Quantity	Value
Power	30MVA
Primary Voltage	132kV
Secondary Voltage	33kV

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Quantity	Value
Circumscribing circle diameter (d)	701.23mm
Frequency	50Hz
Height of window (H_w)	2125.7mm
Width of window (W_w)	1062.8mm
Area of window (A_w)	$2.2592 \times 10^6 mm^2$
Distance between adjacent limbs (D)	1764.1mm
Height of the frame (H_f)	3357.6mm
Width of the frame (W_f)	4124.2mm
Depth of the frame (D_y)	596.05mm
Connection Type	Ynd11
Connection	Star/Delta
Dimension of bare conductor	$6.5mm \times 4.5mm/7.5mm \times 4.5mm$
Insulation	$7mm \times 5mm/8mm \times 5mm$
Number of parallel conductor	2/4
Current density	$2.3A/mm^2$
Turns per phase	862/317
Conductor per turns per disc	2/4
Turns per disc	20/12
Number of discs in HV/LV	64/64
Height of winding per discs	14mm/32mm
Width of the winding	50mm/15mm
Distance between discs	20mm
Pressboard	5mm
Primary cross sectional area (A_p)	57.05mm^2
Secondary cross sectional area (A_s)	131.75mm^2
Coil diameter inside	795.23mm/721.23mm
Coil diameter outside	895.23mm/751.23
Mean diameter turn winding	845.23mm/736.23mm
Length of mean turn winding	2656.4mm/2313.9mm
Window clearance	324.83mm/370.83mm
Level of maximum turn	1476mm/1384mm
Primary Resistance (r_p)	8.4299Ω
Secondary Resistance (r_s)	1.1703Ω
PU Resistance	0.0294
PU Reactance (%)	5.62
PU Impedance	0.0634
Core loss	$19.63kW$
Short Circuit loss	$149kW$

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The properties of the materials used to perform design and thermal analysis in ANSYS@Maxwell environment are given in Table 2.

Table 2 Properties of the materials used

	Density(kg/m³)	Conductivity(W/m²°C)	
Core	7650	5	
Winding	8933	400	
Insulation material		4.5	

Stages of creating an Electromagnetic model of transformer

The transformer models examined in this study were adapted using ANSYS MAXWELL software based on the finite element method. With this program, analyzes were carried out to estimate the core losses, stray losses, DC losses, and winding eddy current losses of transformers. A large number of meshes were used in FEM analysis of 2D and 3D models to examine the losses in detail. In the main menu of the program, the winding, core, terminals, and tank of the transformer were created by following the path given in the figures below in the draw section. The templates used in the program are the templates available in the relevant library. The geometrical and electrical values of the winding or core used in the design of the transformer can be adjusted on the interface. The step by step method for achieving the development of electromagnetics model is given in the flow diagram in Figure 5.

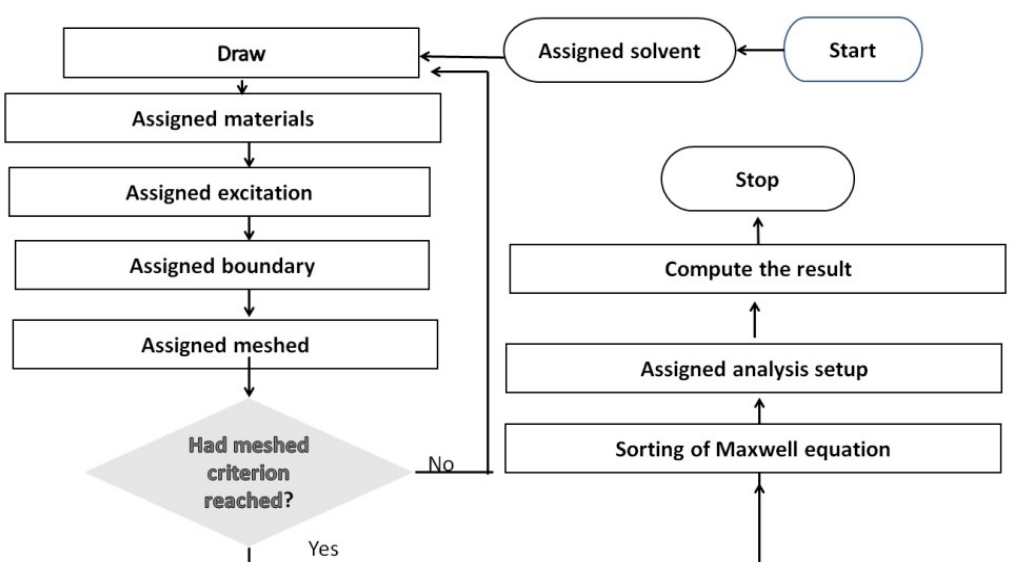

Figure 5: Flow chart of the FEA

Design of core

The design of the core is done in the order given below. First, the core to be used is selected, and then the geometric properties of the core are determined in the window that opens. **Draw> User Define Primitive> RmExpert> Transcore** were selected respectively. Modeling Stages and created model were given in Figure 6.

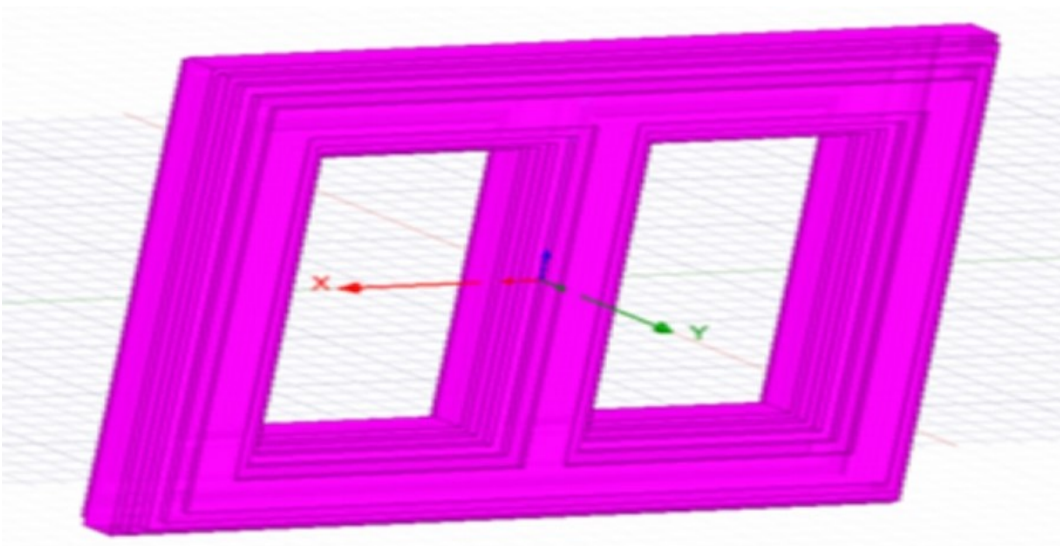

Figure 6: Core model

Table 3 Window geometric features of the core

Name in Ansys	Value	Description
Dialeg	596.05mm	Net core diameter
Distleg	1062.8mm	Limb Pitch
DistYoke	2721.75mm	Limb height plus core diameter (Yoke centre-to-centre distance)
Stages	18	Total number of pockets
ThickCore	10.8mm	Packet thickness for stages=1
WidthYoke	0mm	Yoke width, =0 for same section as leg's
InfoCore	0	Generate whole core (1:legs only, 2:yokes only

Design of windings

Transformers use concentrated winding type and hence the winding factor is $k_W = 0.07$. It is known that each limb of the core will need to carry three coils and thus three terminals. This is why the coils and terminals are designed for three legs respectively. Similar to the core, the windings are designed in the order given below. First, the windings are selected from the menu and then the geometric properties of the windings are determined in the window that opens. **Draw> User Define Primitive> RmExpert> Transcoils** is selected respectively. The screen where winding properties are defined is given in Tables 4 and 5. The windings model is given in Figure 7.

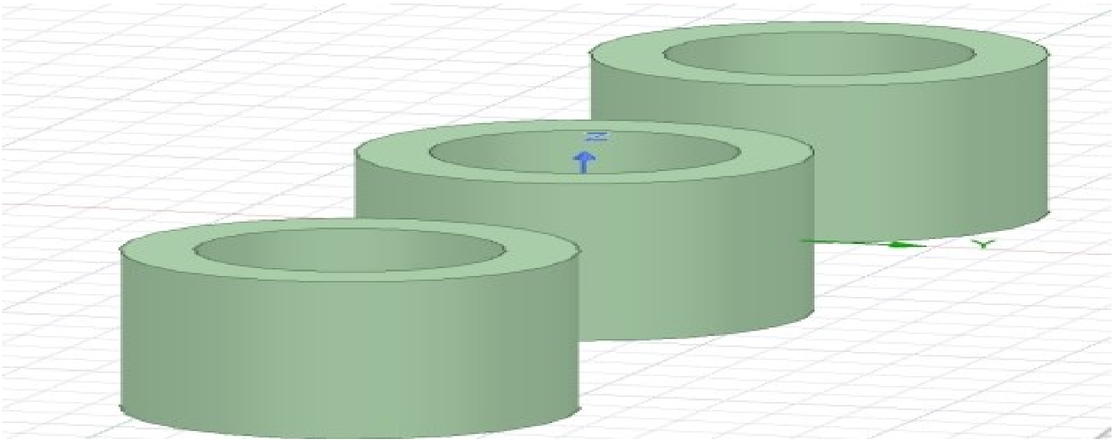

Figure 7: 3D model of designed windings

Table 4 The window with the geometric features of the low voltage windings

Name in ANSYS	Value/Type	Description
DistLeg	1062.8	Limb pitch or centre-to-centre distance
CoilType	1	1: Solenoid coil, 2: Pancake coil
WidthIn	701.23	Coil width between two inner sides
DepthIn	701.23	Coil depth between two inner sides
RadiusIn	350.62	Coil inner fillet radius
ThickCoil	50	Coil thickness of one side
HeightCoil	1476	Coil height
Layers	1	Type of winding is helical (5 layers)
GapLayer	0	Gap between two layers
InfoCore	0	0: all coils, 1: one coil only

Table 5 The window with the geometric features of the high voltage windings

Name in ANSYS	Value/Type	Description
DistLeg	1062.8	Limb pitch or centre-to-centre distance
CoilType	1	1: Solenoid coil, 2: Pancake coil
WidthIn	891.23	Coil width between two inner sides
DepthIn	891.23	Coil depth between two inner sides
RadiusIn	445.62	Coil inner fillet radius
ThickCoil	50	Coil thickness of one side
HeightCoil	1476	Coil height
Layers	1	Type of winding is helical (5 layers)
GapLayer	0	Gap between two layers
InfoCore	0	0: all coils, 1: one coil only

The tables 4 and 5 shows the optimal design parametization of the proposed transformer windings with centre to centre distance, coil height and coil thickness. The winding model is obtained through the use of dimensions of table 4 and 4.

Determination of transformer terminals

After the windings are designed, low voltage (LV_A, LV_B, and LV_C) or high voltage (HV_A, HV_B, and HV_C) objects are selected by holding up and down the Ctrl key to form the coil terminals of a three phase (for example A, B, C) transformer. After selecting the windings, the terminals of the windings are created with the option **Modeler> Surface >Section** in the main menu. The process flow is like this**; Modeler> Boolen> Separate Bodies.**

Determining material for cores and coils

It is necessary to define the type of vacuum zone and the materials that make up the cores and windings of the designed model. "Assign Material" is used to assign the materials used in the design. Material assignment for windings or core can be made to **"View / Edit Material" or "Add Material"** options from the library of the program. In this work, copper was chosen as the winding material. **M125-027S** laminated steel is used as the core material of transformers. Similarly, B-H and B-P curves of the material used are given in Figures 8 and 9.

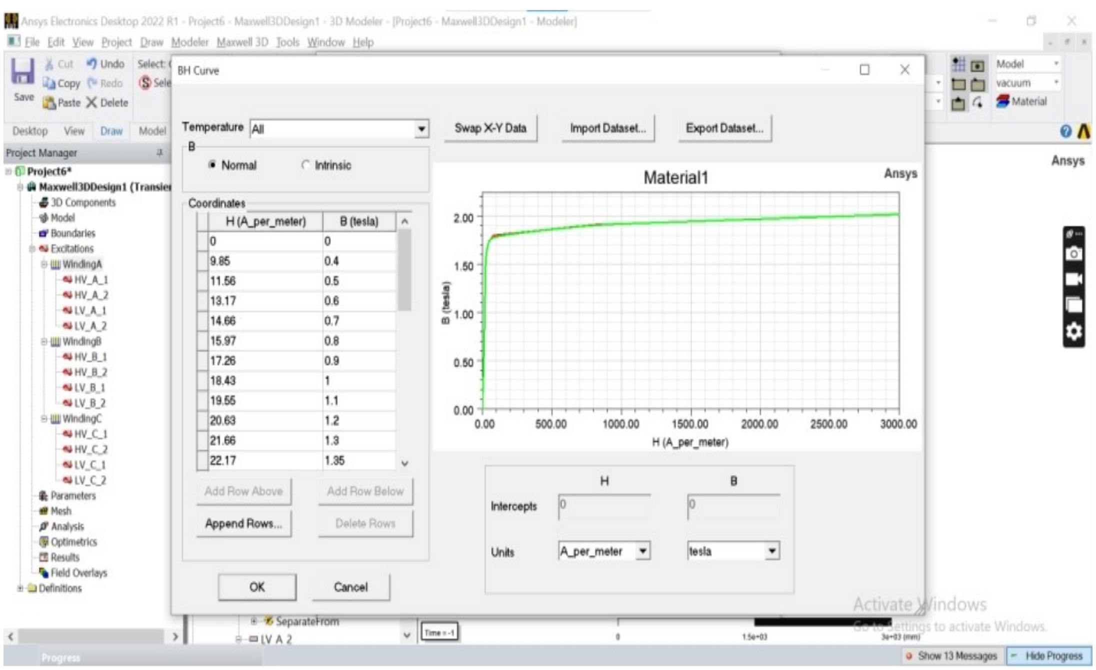

Figure 8 B-H curves of the core material

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In designs made with ANSYS MAXWELL program, the core loss coefficients K_h, K_c, and K_e values of the material used as core material vary depending on the frequency and thickness of the lamination. Specific core losses of materials used for 50 Hz frequency are presented in Figure 8 and 9.

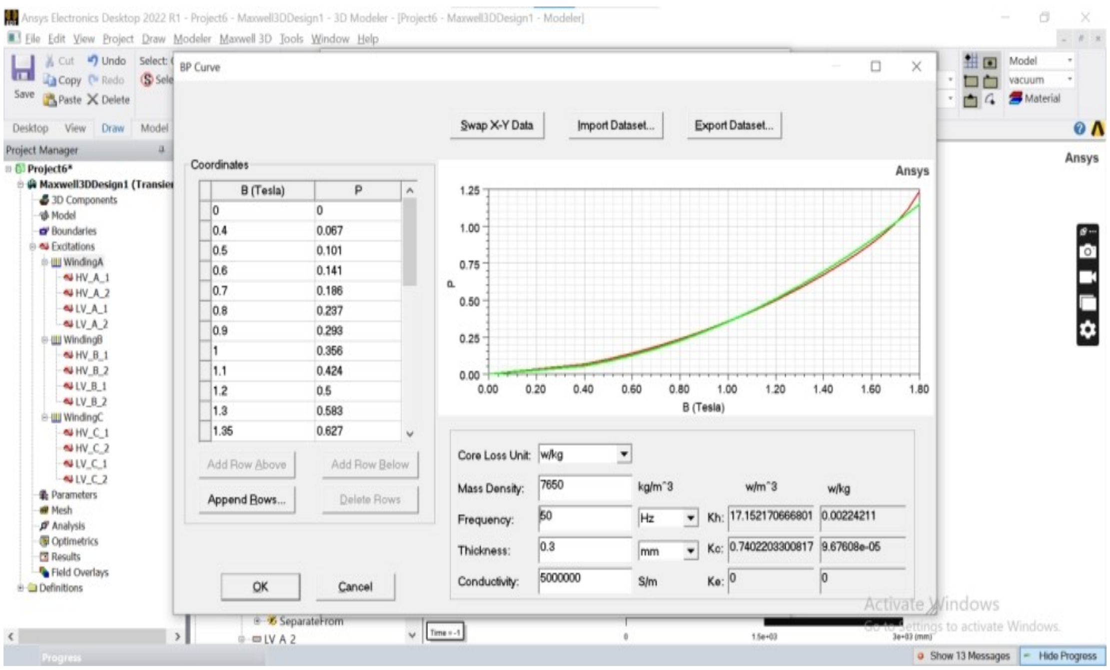


Figure 9 B-P curves of the core material

Mesh settings of the model

According to the model designed in ANSYS MAXWELL program, a network is automatically generated by the program. After the network is created, a field solution is calculated for each model. The network created automatically for the designed model is generally not sufficient for a realistic analysis result. For a closer analysis of real values, each element is divided into a small region, and the correct solution is approached by increasing the mesh number. As the mesh number of the model increases, the results of the simulation obtained from the analysis become very realistic. The disadvantage of increasing the number of networks is that it increases the analysis time.

Stages of creating an electrodynamics force (winding) model of transformer

Following standard procedures, the effect of applying an external short circuit were represented by an injection of 2,783.52A at the HV and 11,134.04A at the LV windings. The step by step method for achieving the development of electrodynamics force model is given in the flow chart in figure 10.

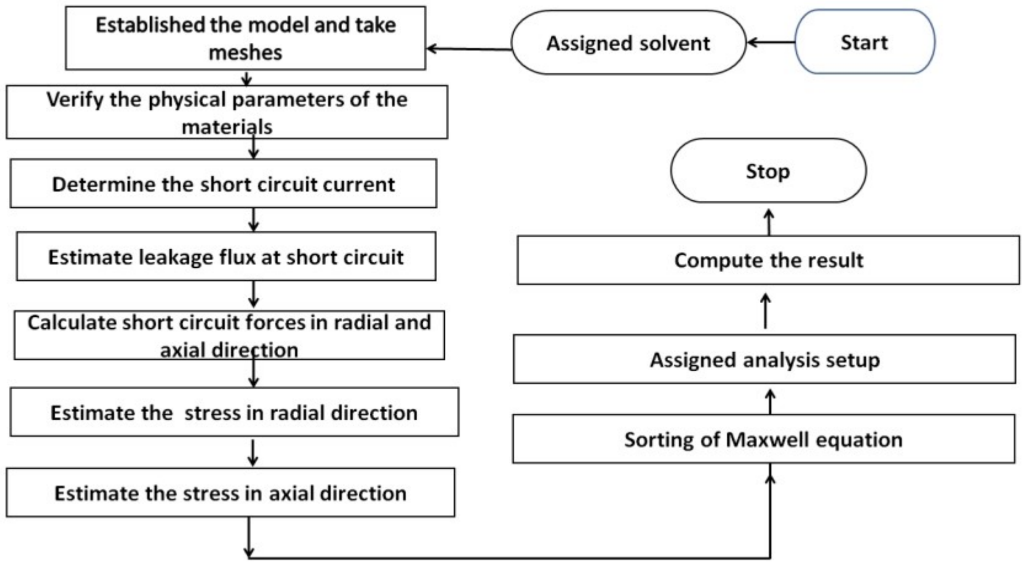


Figure 10 Flow chart of electrodynamic analysis

Stages of creating thermal model of transformer

In Figure 5 above, the model of transformer designed in ANSYS@Maxwell3D environment was presented. This model was analyzed in a Maxwell 3D environment and then transferred to ANSYS@Mechanical for thermal analysis. The radiation mode of heat transfer takes place between the transformer components and the medium as a result of the temperature difference. However, the transformer components are produced from materials with low emissions and are ignored because the radiation effect is minimal. This has little effect on the accuracy of the results. To improve the thermal field simulation and the development of the thermal field simulation, several assumptions were taken into account.

1. Depending on the symmetry, the transformer can be considered as a structure in a parallel plane. Therefore, when solved using the FEM, it can be simulated in two dimensions (in one plane) with the accepted accuracy.
2. The average daily average value of the ambient temperature is taken into account.
3. The thermal properties of the transformer materials are considered to be constant.
4. The heat generated in the active materials is uniformly distributed.
5. The losses of dielectric isolation are neglected because these losses are very low compared to the losses caused by copper and iron.
6. The heat transfer rate with convection mode is accepted as natural convection.
7. The flowchart of 3D coupled thermal analysis is shown in figure 11.

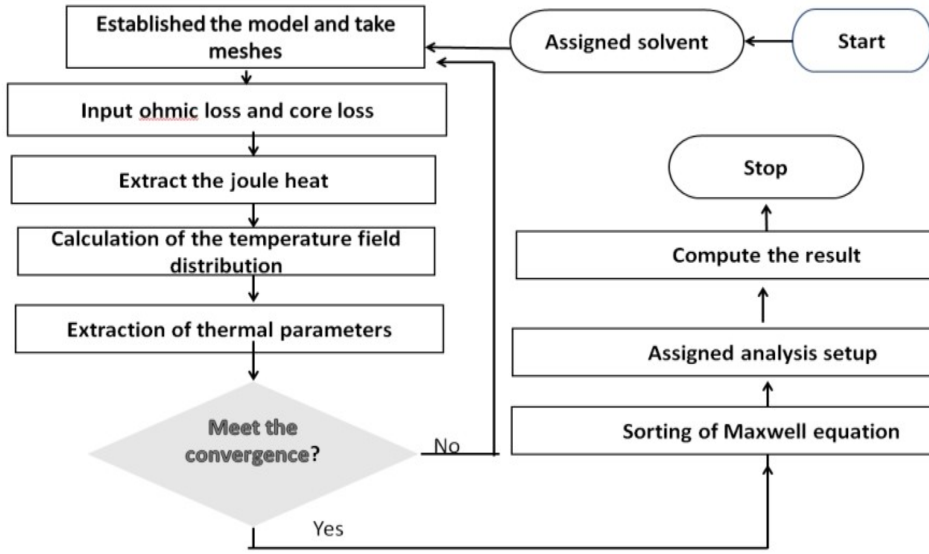


Figure 11 Flowchart of coupled thermal field analysis

Stages of creating an Electrostatic analysis of insulation model

Following standard procedures, the effect of applying an input voltage were represented by putting a voltage of 1500V at the HV and 384V at the LV windings. The step by step method for achieving the development of electrodynamics force model is given in the flow chart in figure 12.

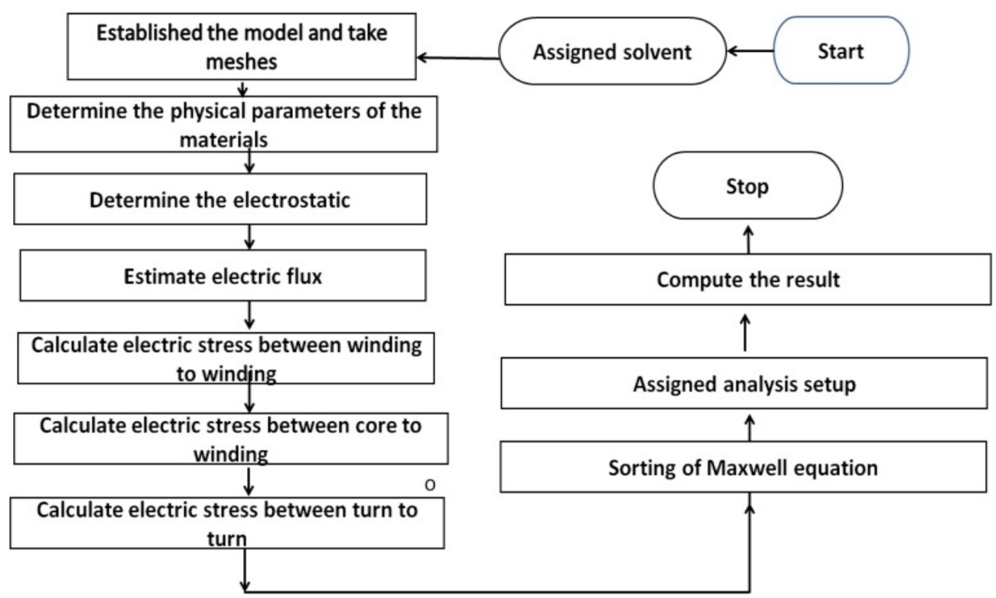


Figure 12 Flowchart of electrostatic analysis

RESULTS

The aim of this project is modeling and analysis of a power transformer having a rating of 30/40MVA, 132/33kV, three phase, 50 Hz, Star/Delta, connection, ONAN/OFAN core type, oil immersed power transformer so as to have low cost and maximum operating efficiency. In the following subsections, development of electromagnetic, thermal, winding and insulation model were carried out in ANSYS MAXWELL based on the name plate rating where magnetic flux density distribution, magnetic losses, thermal distribution, electrodynamics force distribution and electrical stress were determined (Abdulkadir, *et.al.,* 2021).

In Figure 13, 14 and 15 shows the designed model and mesh of the proposed transformer model.

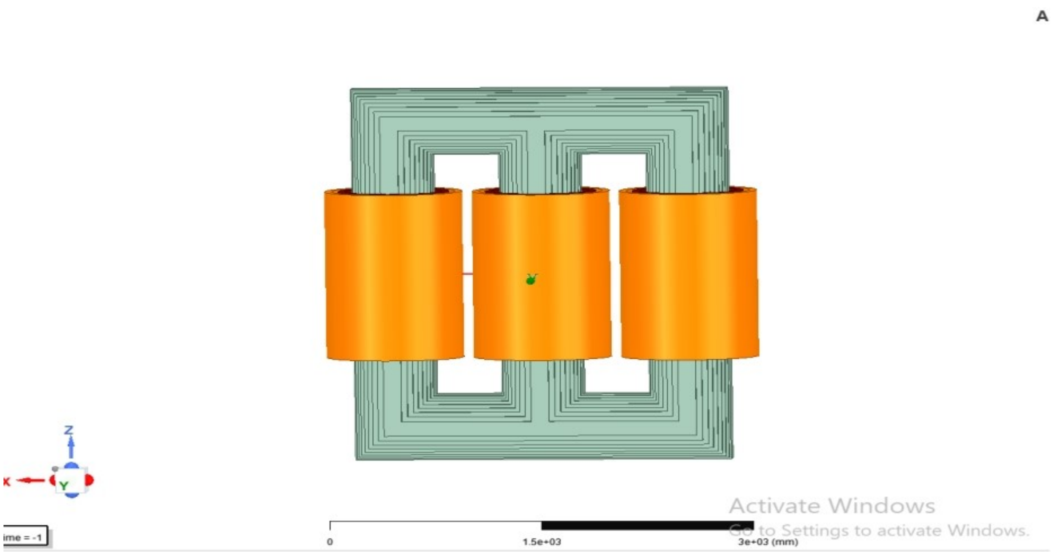


Figure 13 Transformer model

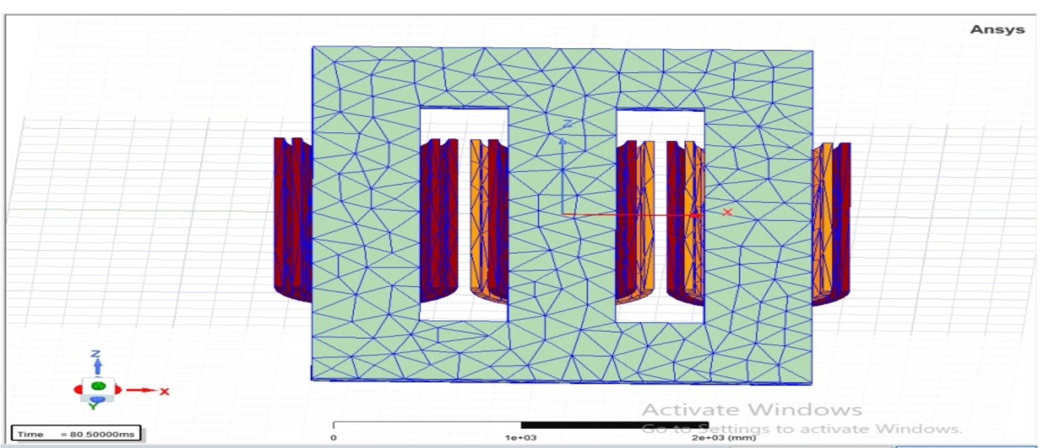


Figure 14 Front view

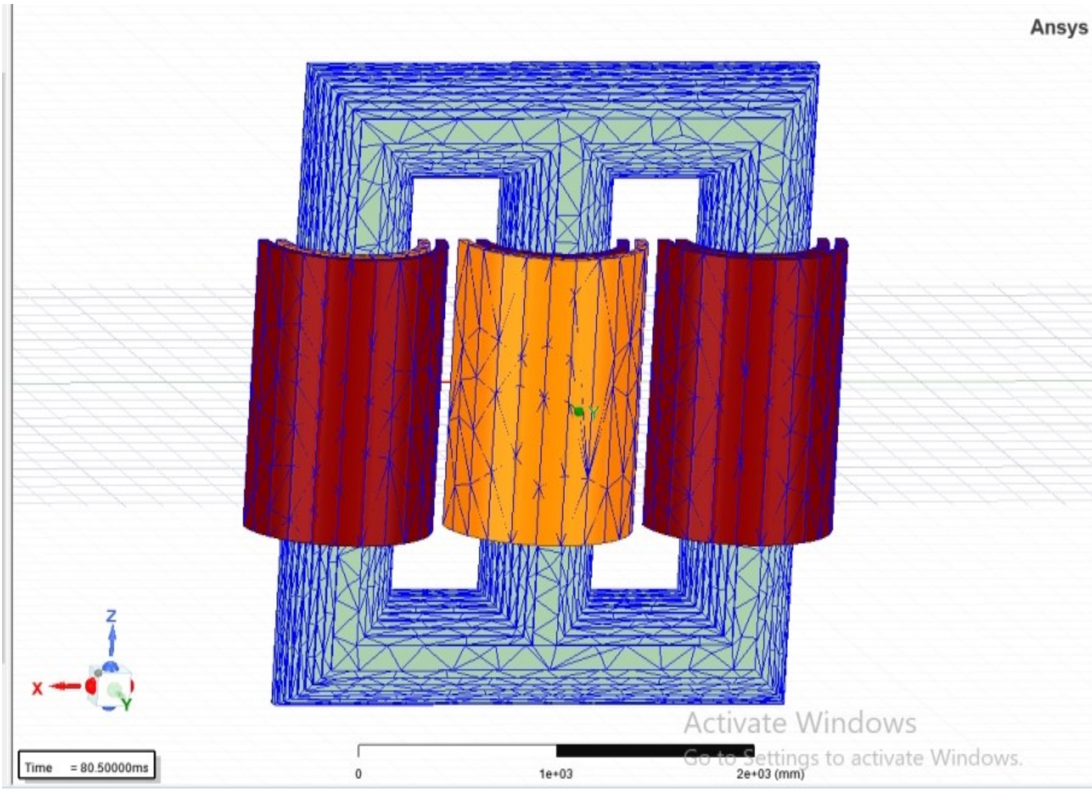
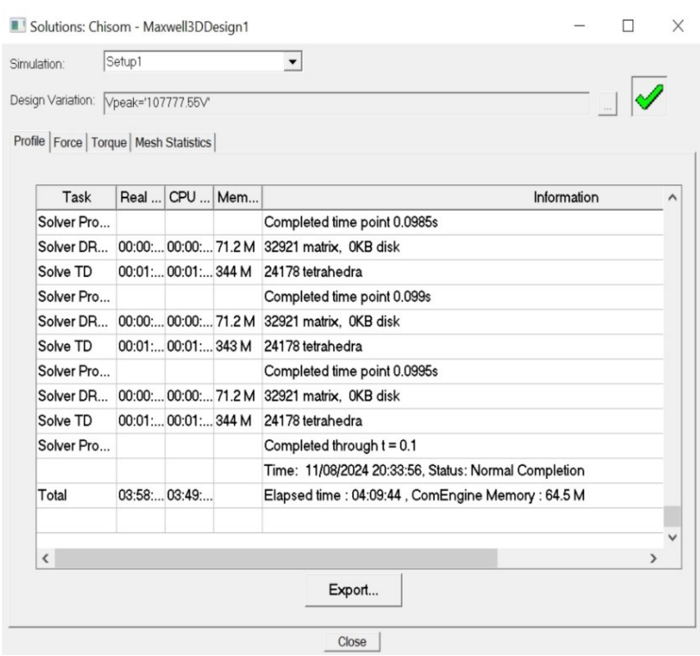


Figure 15 Back view

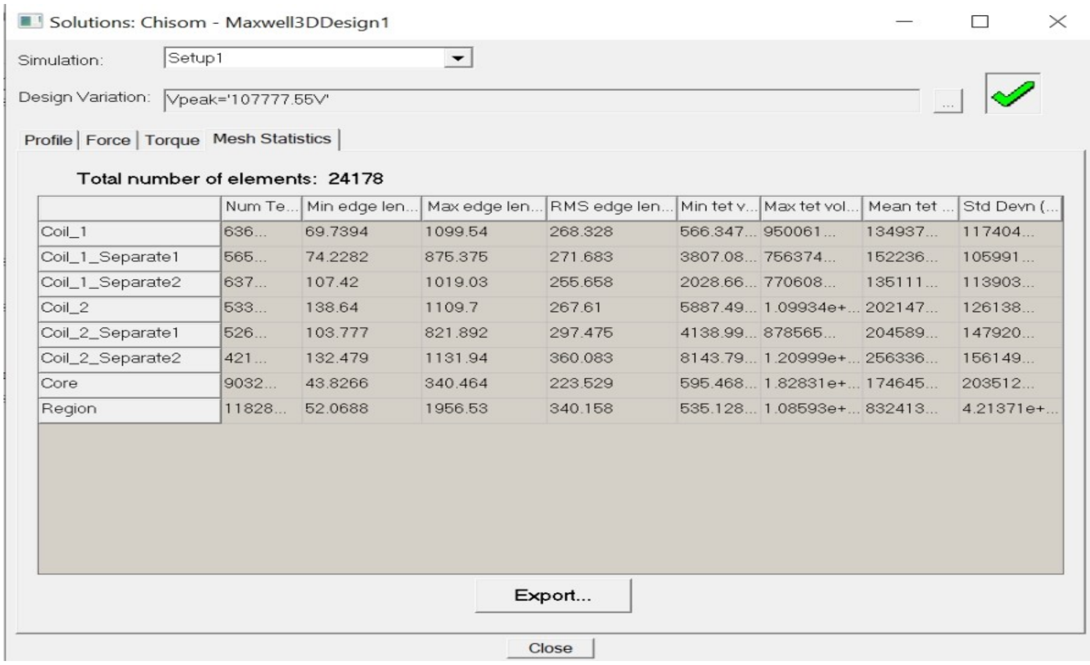


Task	Real ...	CPU ...	Mem...	Information
Solver Pro...				Completed time point 0.0985s
Solver DR...	00:00:...	00:00:...	71.2 M	32921 matrix, 0KB disk
Solve TD	00:01:...	00:01:...	344 M	24178 tetrahedra
Solver Pro...				Completed time point 0.099s
Solver DR...	00:00:...	00:00:...	71.2 M	32921 matrix, 0KB disk
Solve TD	00:01:...	00:01:...	343 M	24178 tetrahedra
Solver Pro...				Completed time point 0.0995s
Solver DR...	00:00:...	00:00:...	71.2 M	32921 matrix, 0KB disk
Solve TD	00:01:...	00:01:...	344 M	24178 tetrahedra
Solver Pro...				Completed through t = 0.1
				Time: 11/08/2024 20:33:56, Status: Normal Completion
Total	03:58:...	03:49:...		Elapsed time : 04:09:44 , ComEngine Memory : 64.5 M

Figure 16 Memory statistic

Through mesh statistic, one will be able to have an idea of the time taken to complete the mesh, memory size occupied by the mesh as in Figure 16 and the number of mesh element in the core, low voltage, high voltage winding and the region occupied by them, their mean length, area and volume of each mesh element would be known which was shown in Table 7.

Table 7: Mesh statistics


Solutions: Chisom - Maxwell3DDesign1

Simulation: Setup1

Design Variation: Vpeak='107777.55V'

Profile | Force | Torque | Mesh Statistics

Total number of elements: 24178

	Num Te...	Min edge len...	Max edge len...	RMS edge len...	Min tet v...	Max tet vol...	Mean tet ...	Std Devn (...
Coil_1	636...	69.7394	1099.54	268.328	566.347...	950061...	134937...	117404...
Coil_1_Separate1	565...	74.2282	875.375	271.683	3807.08...	756374...	152236...	105991...
Coil_1_Separate2	637...	107.42	1019.03	255.658	2028.66...	770608...	135111...	113903...
Coil_2	533...	138.64	1109.7	267.61	5887.49...	1.09934e+...	202147...	126138...
Coil_2_Separate1	526...	103.777	821.892	297.475	4138.99...	878565...	204589...	147920...
Coil_2_Separate2	421...	132.479	1131.94	360.083	8143.79...	1.20999e+...	256336...	156149...
Core	9032...	43.8266	340.464	223.529	595.468...	1.82831e+...	174645...	203512...
Region	11828...	52.0688	1956.53	340.158	535.128...	1.08593e+...	832413...	4.21371e+...

Export...

Close

Electromagnetic analysis results

Figure 17 and Figure 18 represent the results input and output voltage waveforms from FEM. It is clearly seen that the output is a balanced three phase supply from a three phase input. Individual output phases are shown along with their respective input voltages. A slow rise start up exponential function was used in other to remove the inrush.

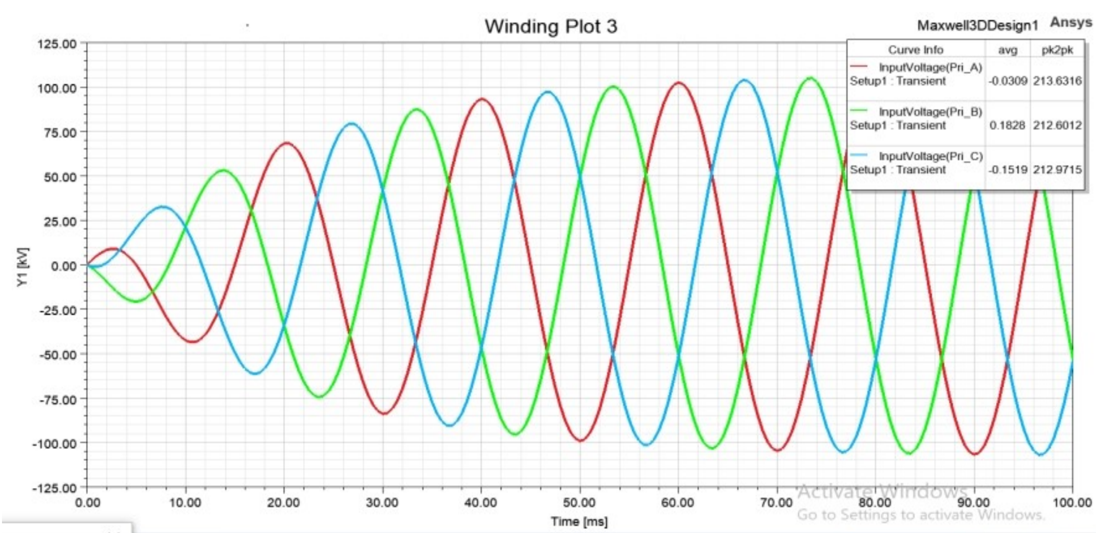


Figure 17 Input Primary Voltage of the transformer.

Since the output is open circuited there would be no value as indicated in figure 18.

Figure 18 Secondary Voltage of the transformer.

The result of figure 19 is the magnetizing current of the primary winding from the ANSYS MAXWELL simulation with some spikes due magnetization in the steel core materials. The average value obtains by it along the third limbs is 8.26A.

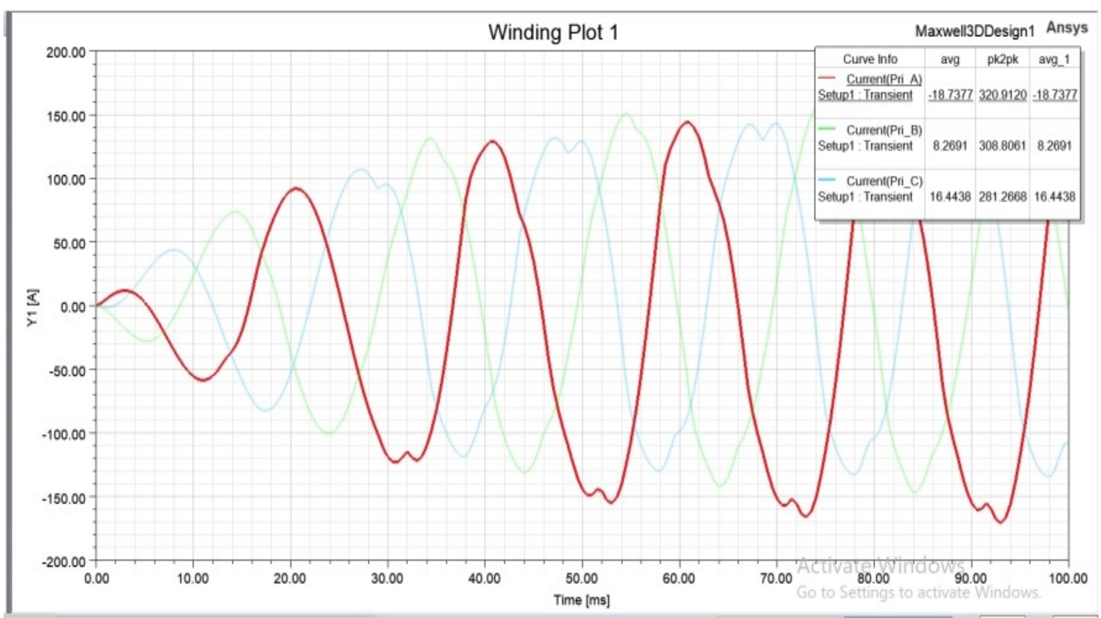


Figure 19 Magnetizing current of the transformer.

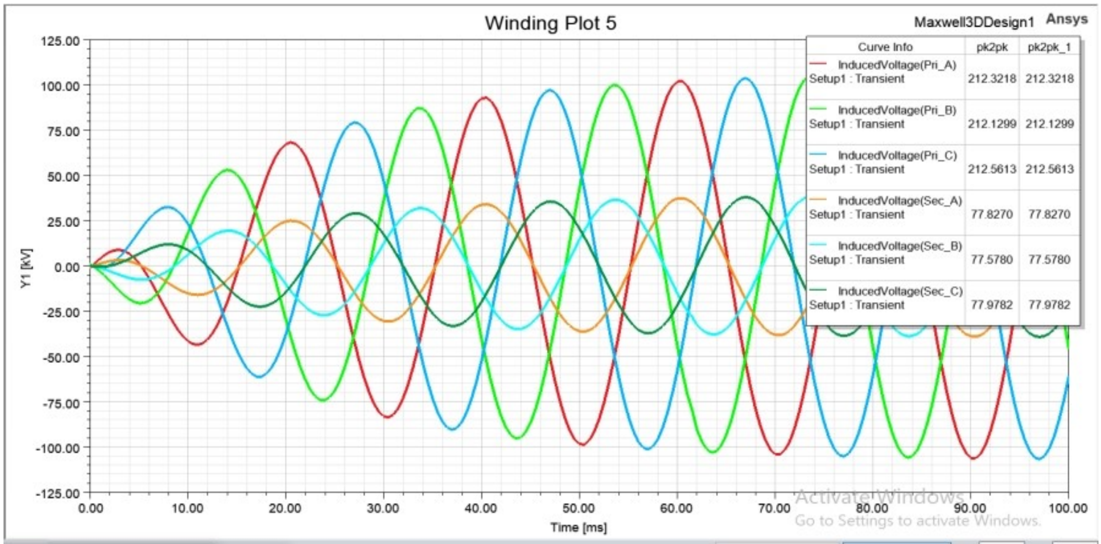


Figure 20 Superimposed Induced Primary and Secondary voltage of the transformer

There is perfect transformation of voltages at the core of the transformer, due to the number of turns at the primary and secondary side, and the differences of voltage values are as a result if the length of distances between the limbs. It has proven to us the input voltage is approximately equal to the induced voltage of the simulation.

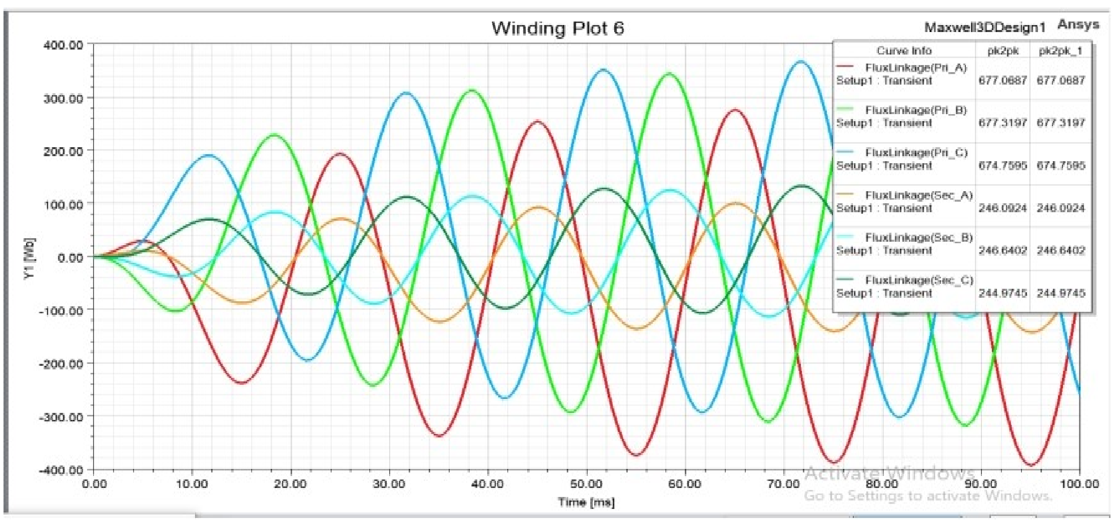


Figure 21 Superimposed Primary and Secondary flux linkage of the transformer

For perfect transformation the input current in the primary and secondary must be equal or approximately equal to the flux linking the primary and secondary in the simulation, as from the result it has satisfy that principle.

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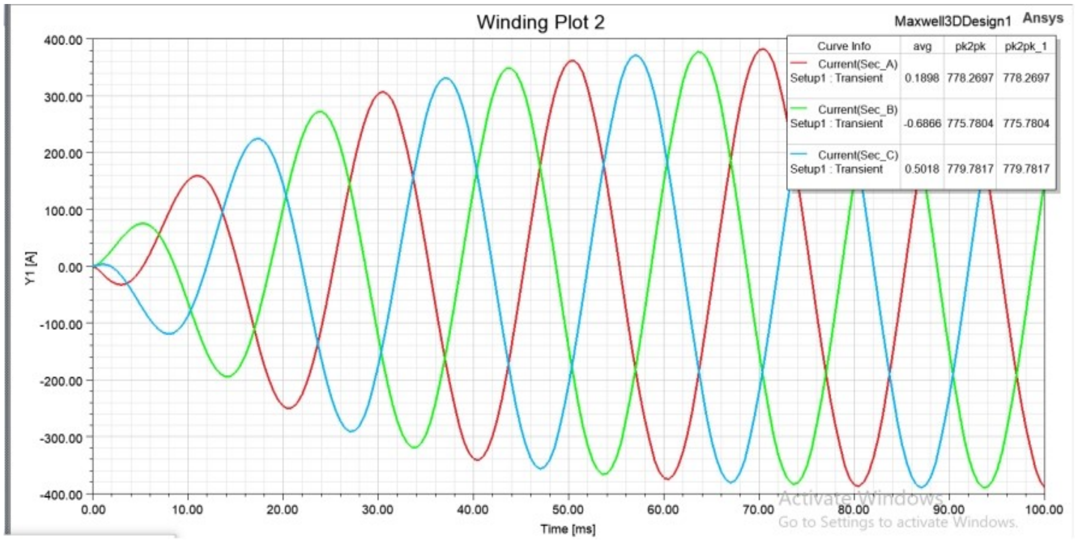

Figure 22 Induced Secondary current of the transformer

The secondary current value of the proposed transformer is in closed agreement with analytical values due the design agreement.

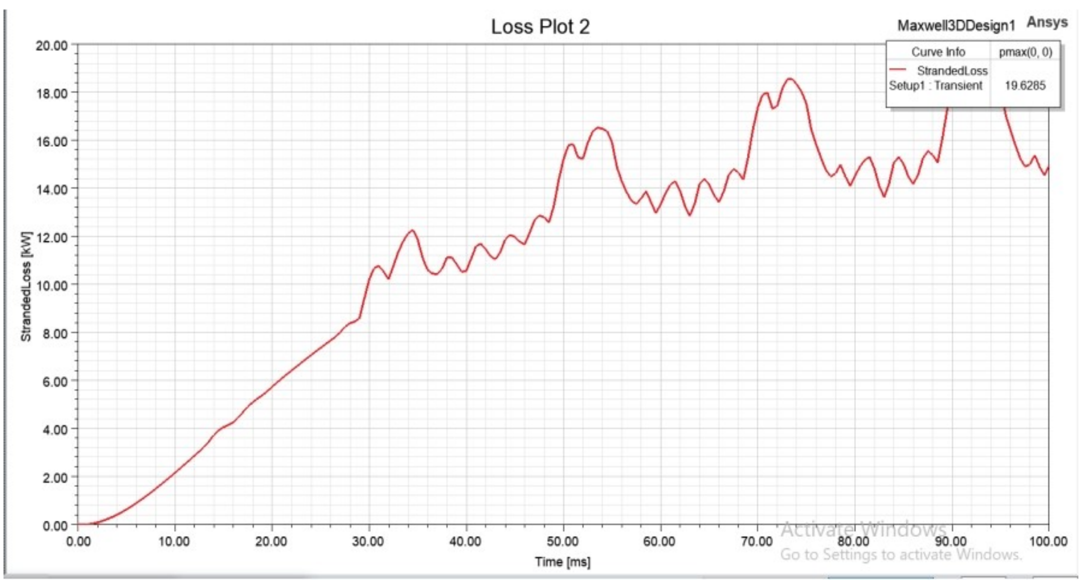

Figure 23 Core loss of the transformer

Figure 23 shows the plot of core loss v/s time. Core loss is the no load loss it does not changes with the load. So the core loss can be computed by simulating the LV windings only. It can be seen that the core loss becomes stable within five cycles (as transient analysis is performed). The obtained value of core loss is 19.63kW.

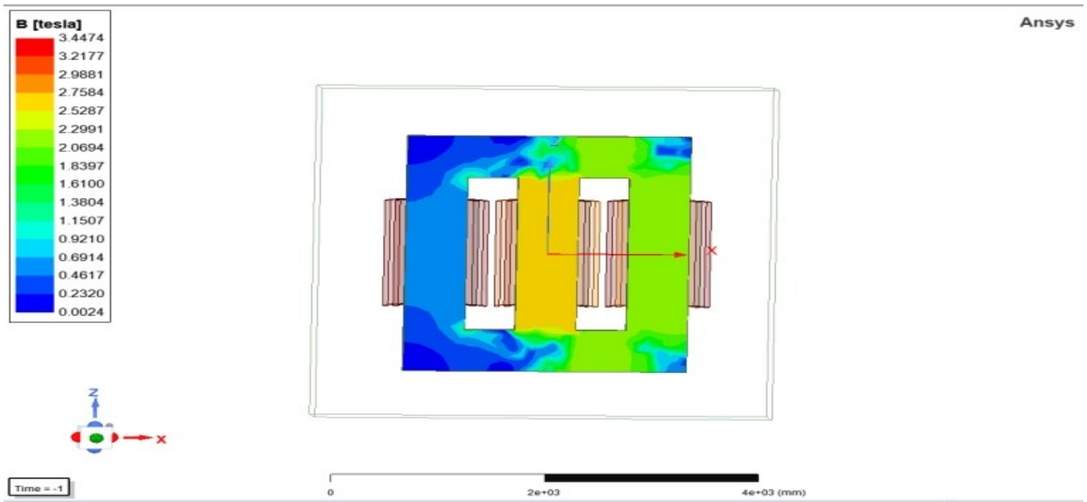

Figure 24 Magnetic flux distributions

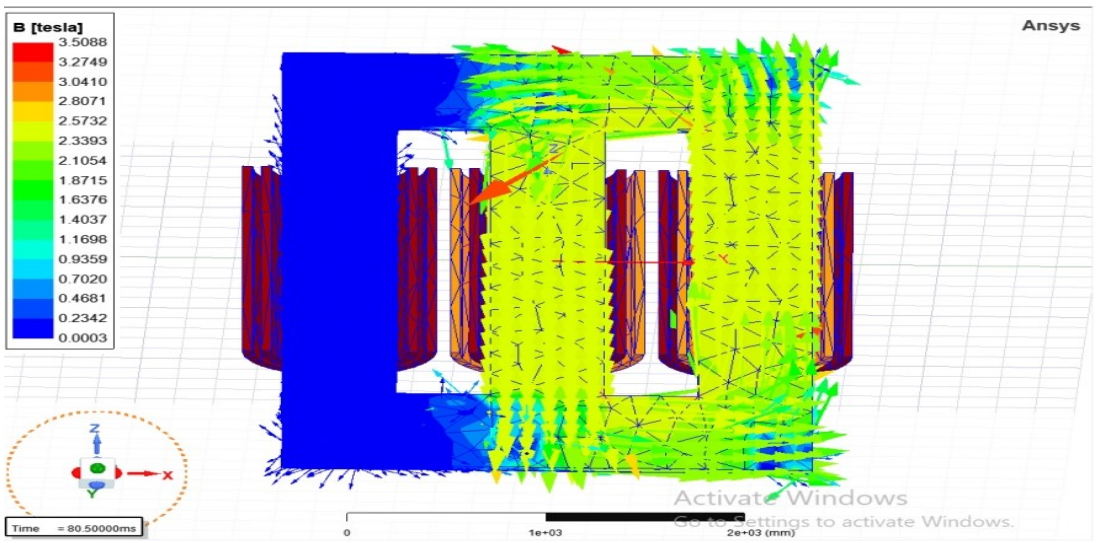

Figure 25 Magnetic vector flux distribution

Figures 24 and 25 shows the magnetic field distribution as well as magnetic vector flux distribution the core of power transformer. It can be seen that the magnetic field density is more prominent on the corner of the core. This is due to the fact that losses at the corner are more, as the flux lines turns at an angle from limb towards the yoke leading to higher losses in this area Difficulties have occurred in the winding insulation, especially first and third phase. Excessive strain may cause the insulation material to deteriorate or even perforate. After the simulation, it can be seen from the B field graphic the nonlinear behavior of the transformer, with a minimum of 0.2023 T and a maximum of 1.84T, for 132 kV.

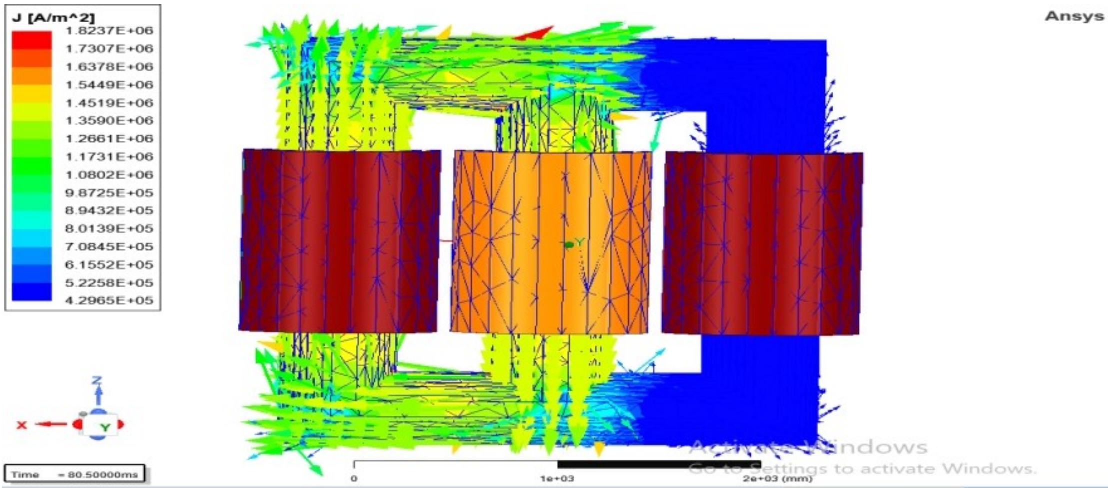

Figure 26 Current density distributions

From the result of figure 26, the obtain result of half 3D is in closed agreement with assume current density of 2.3A/mm^2.

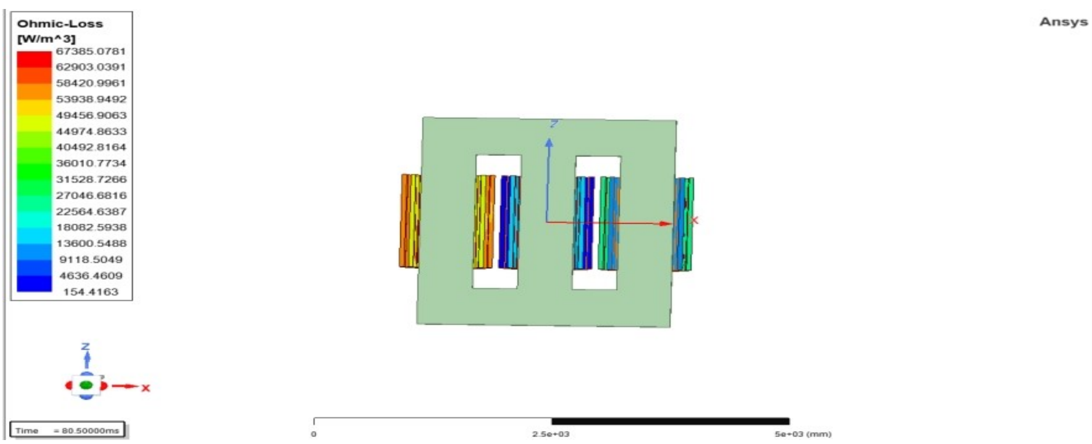

Figure 27 Ohmic loss

Furthermore, modeling of transformer was done with H.V winding to analyze the winding loss. Figure 27 shows the winding loss of the transformer in watts/meter cube is 67385. The volume of winding is 1.46 meter cube. Multiplying them gives the winding loss of transformer which is 98.4kW

Conclusion

Finite element analysis method as applied to power transformer model been examined in this research. During the research, it was noted that reasonable number of research data are available in this domain, though most of them are based on adaptive FEM and standard coarse mesh FEM. In this research the application of adaptive finite element analysis method, which is a FEM scenario was examined. And double discretization algorithm or model developed in this research was applied to simulate the winding, insulation, thermal and electromagnetic model of the same transformer, finer mesh was obtained and hence better results. In summary, the double discretization result for winding loss 98.4kW, and that of core loss was 19.63kW, produced a magnetic flux density of 1.87T. For electrodynamic model computation, the result showed 652.69kN is the axial force along the high voltage side and 1.25kN radial force along for the low voltage winding section during the short circuit condition, translating to 94.72°C as the hot spot temperature for the thermal model and 10.48kV/mm as stress between high voltage and low voltage winding for electrostatic model. When the numerical and analytical results are compared, the accuracy of the developed thermal, winding, insulation and electromagnetic models were revealed. In addition, it was observed that the developed models gave better results than the analytical. Designers can achieve optimum designs using the appropriate core magnetic material by reducing or increasing the distance between the core and the coils. Different solutions can be developed using methods such as FEM to reduce losses. This type of calculation is very practical, and can be done by applying an adequate software model of every machine, including the transformer.

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