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Optimisation of Transformer Design Parameters Using Altair Flux

K V Bharadwaj Karthik[1], V. Abhilash Naik[2],V Kowshik Chavali[3], G Suresh Babu[4]
Chaitanya Bharathi Institute of Technology, Hyderabad , India,,

Abstract- This project focuses on the analysis of a three-phase star–delta step-down transformer using Altair Flux with emphasis on the no-load test and short- circuit test. The objective is to accurately evaluate core (iron) losses and copper (Joule) losses through finite element electromagnetic simulation. In the no-load test, rated voltage is applied to the primary winding while the secondary is kept open, enabling determination of magnetizing current, flux distribution, and core losses. The Bertotti loss model is employed within Altair Flux to separate hysteresis, eddy current, and excess losses in the core. Flux density distribution is examined to ensure operation below saturation limits. In the short-circuit test, the secondary winding is shorted and a reduced voltage is applied to circulate rated current, allowing evaluation of winding resistance, leakage reactance, and copper losses. The simulation accurately captures current density and I^2R losses in both primary and secondary windings. The star–delta connection is properly modeled to obtain correct phase relationships and loss values. Results from Altair Flux demonstrate realistic loss estimation consistent with transformer theory. The study confirms that core losses remain nearly constant with load, while copper losses vary with the square of current. Overall, the work validates Altair Flux as an effective tool for detailed electromagnetic analysis of transformer performance using standard no-load and short-circuit test procedures.

Keywords – Three-phase transformer, star–delta connection, Altair Flux, finite element analysis, core losses, copper losses, Bertotti model, no-load test, short-circuit test, electromagnetic simulation.

I. INTRODUCTION

Transformers are fundamental components of modern electrical power systems, enabling efficient transmission and distribution of electrical energy by stepping voltage levels up or down. With increasing demand for high-capacity and energy-efficient equipment, accurate analysis of transformer performance has become essential. Even small reductions in losses in large power transformers can lead to significant energy savings over their operating lifetime. Traditionally, transformer performance was evaluated using analytical calculations and experimental testing. However, these methods often involve simplifying assumptions and may not capture the detailed electromagnetic behavior inside the core and windings.

The advancement of Finite Element Analysis (FEA) tools has greatly improved the accuracy of transformer modeling and loss prediction. Altair Flux is one such powerful electromagnetic simulation software widely used for detailed analysis of electrical machines and transformers. It enables precise computation of flux distribution, current density, and losses under various operating conditions. In practical transformer evaluation, the no- load test and short-circuit test are the two most important standard tests.

The no-load (open-circuit) test is performed to determine the core or iron losses and magnetizing current when rated voltage is applied with the secondary winding open. These losses mainly consist of hysteresis, eddy current, and excess losses caused by alternating magnetic flux in the core. The short-circuit test is conducted by shorting the secondary winding and applying a reduced voltage to circulate rated current, allowing accurate estimation of copper (Joule) losses and leakage impedance.

Since the applied voltage is low, core losses during this test are negligible. In this project, a 259.3 MVA three-phase star–delta step-down transformer is modeled and analyzed using Altair Flux. The objective is to simulate no-load and short-circuit conditions to obtain realistic estimates of core losses, copper losses, flux density, and current distribution. The Bertotti loss model is used for detailed separation of core loss components. The study demonstrates the effectiveness of FEA-based simulation in validating transformer performance and provides a reliable foundation for further optimization and design improvement.

II. LITERATURE REVIEW

Key Authors
These are commonly cited in transformer loss and optimization research.

1. G. Bertotti (1988)
Introduced the Bertotti three-term iron loss separation model II(hysteresis, eddy, excess).
Widely used in modern FEA tools including Altair Flux.

2. S. V. Kulkarni and S. A. Khaparde (2004)
Provided comprehensive analytical methods for transformer design and performance evaluation.

Their work forms the theoretical basis for loss and flux calculations.

3. J. Faiz and B. M. Ebrahimi (2010)
Applied finite element analysis to improve accuracy of transformer electromagnetic modeling.

Demonstrated benefits over classical equivalent circuit methods.

4. R. K. Gupta and S. K. Singh (2019)
Investigated multi-objective optimization of transformers using FEA tools.

Highlighted reduction of copper and core losses through parametric variation.

5. P. K. Jain (2019)
Used NSGA-II algorithm for transformer parameter optimization.

Showed effectiveness of Pareto-based multi-objective approaches.

6. S. Das (2020)
Performed magnetic and thermal analysis of power transformers using Altair Flux.

Validated FEA results with practical transformer data.

7. Y. Zhou et al. (2020)
Applied Hyper Study-based optimization to electrical machines and transformers.

Demonstrated automated DOE and sensitivity workflows.

8. **M. R. Badr (2018)**
Used genetic algorithms to optimize transformer efficiency and reduce losses.

Compared conventional and evolutionary optimization techniques.

III. EXISTING PROBLEMS

In traditional transformer design and analysis, engineers primarily relied on analytical calculations and experimental testing methods. These conventional approaches often involve simplifying assumptions, which may not accurately capture the complex electromagnetic behavior inside transformer cores and windings. One major limitation is the inability of classical methods to visualize flux distribution and local saturation effects within the core. As a result, designers may overlook hotspots and localized loss concentrations that affect efficiency and thermal performance.

Another significant problem without advanced simulation tools is the difficulty in accurately separating core losses into hysteresis, eddy current, and excess components. Manual calculations typically use approximate empirical formulas, which can lead to deviations from actual performance. Additionally, evaluating leakage flux and stray losses using traditional equivalent circuit methods is often inaccurate for large power transformers. Prototype-based validation is also time-consuming, expensive, and not suitable for rapid design iterations.

Without Altair Flux, performing parametric studies becomes cumbersome because each design change requires manual recalculation or physical testing. Sensitivity analysis and multi-objective optimization are particularly challenging with conventional approaches. Designers may also struggle to predict current density distribution in windings, which is critical for estimating Joule losses and thermal limits. Furthermore, coupling between electromagnetic and thermal effects is difficult to analyze using purely analytical methods.

Altair Flux overcomes these limitations by providing a robust Finite Element Analysis (FEA) environment for detailed electromagnetic modeling. It enables precise visualization of flux lines, magnetic saturation, and field distribution inside the transformer. The software accurately computes core losses using advanced models such as the Bertotti formulation, improving loss prediction reliability. Joule losses in windings are automatically calculated based on actual current density distribution.

Another key benefit is the ability to simulate standard tests such as no-load and short-circuit conditions without building physical prototypes. Altair Flux also integrates seamlessly with HyperStudy for Design of Experiments, sensitivity analysis, and multi-objective optimization using algorithms like NSGA-II. This significantly reduces design time and development cost while improving transformer efficiency and reliability. Overall, the use of Altair Flux enables more accurate, faster, and optimization driven transformer design compared to traditional methods.

IV. SPECIFICATIONS OF TRANSFORMER

Table 1:- Transformer specifications

Power	259.3 MVA
Primary voltage(L-L)	228.63 KV
Secondary Voltage (L-L)	73.3 KV
Primary current	655 A
Secondary current	3537 A
Frequency	50 Hz
No of phases	3
Connection type	Delta Star

Table 2:-Input Parameters

HV Windings	
No of turns	432
HV Thickness(mm)	95
HV resistance(ph)	0.15
Internal radius(mm)	665
LV Windings	
No of turns	80
LV Thickness(mm)	75
LV resistance(ph)	0.0037
Internal radius(mm)	520
Core	
Diameter of core(mm)	820
Height of core(mm)	2175
Distance between legs(mm)	1395
No of steps	3

V. METHODOLOGY

The methodology is same for No load test and Short circuit test;

Geometry

Geometry creation in Altair Flux involves building the physical model of the transformer, including the core, windings, air region, and tank if required. Accurate geometry is essential because electromagnetic field distribution depends strongly on dimensions and layout. Flux provides both manual sketching and parametric modeling tools, allowing easy modification of dimensions during optimization. Proper geometric symmetry (such as using a 2D or sector model) helps reduce computation time. A clean and well- defined geometry ensures reliable simulation results.

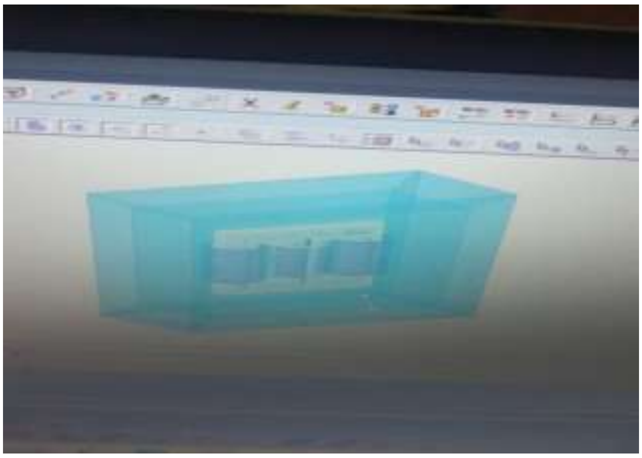


Fig 1:- Geometry

Meshing

Meshing is the process of dividing the geometry into small finite elements where the field equations are solved. In Altair Flux, finer mesh is typically applied in regions with high field variation, such as air gaps, winding edges, and core corners. Proper mesh quality directly affects solution accuracy and convergence.

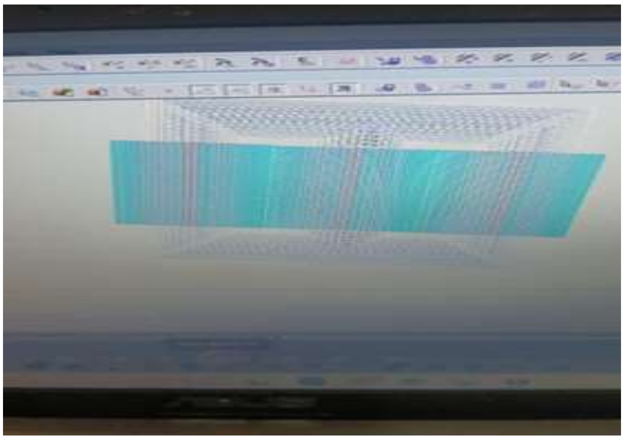


Fig 2:- Meshed Model

Physics

The physics setup defines the electromagnetic behavior of the transformer in Altair Flux. It includes assigning material properties (like B–H curve for the core and conductivity for windings), excitation sources, and boundary conditions. For transformer analysis, AC magnetic or transient magnetic physics is commonly used. The software then solves Maxwell’s equations over the meshed geometry to compute flux distribution, induced voltages, and losses. Correct physics definition is crucial for obtaining realistic no-load and short-circuit test results.

Post Processor

The post-processor in Altair Flux is used to visualize and analyze simulation results such as flux density, field lines, current density, voltages, and losses. It provides contour plots, vector plots, and graphs to help interpret transformer performance under no-load and short-circuit conditions. It also allows computation of derived quantities like Joule losses, core losses, and efficiency for detailed evaluation.

VI. CIRCUIT DIAGRAMS

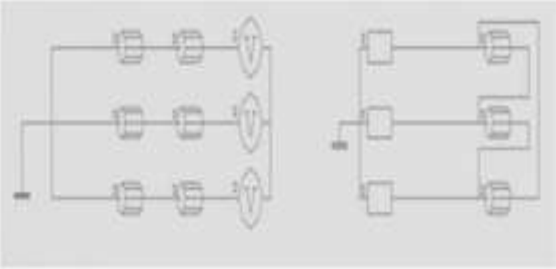


Fig 3:-No load test Circuit in Altair Flux

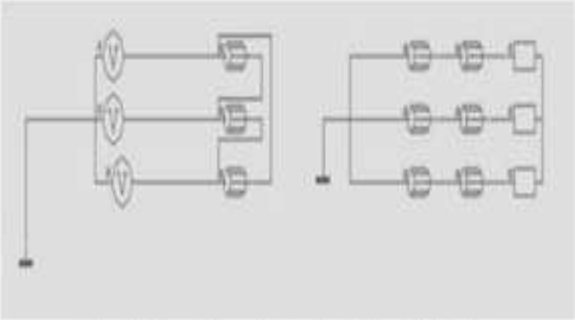


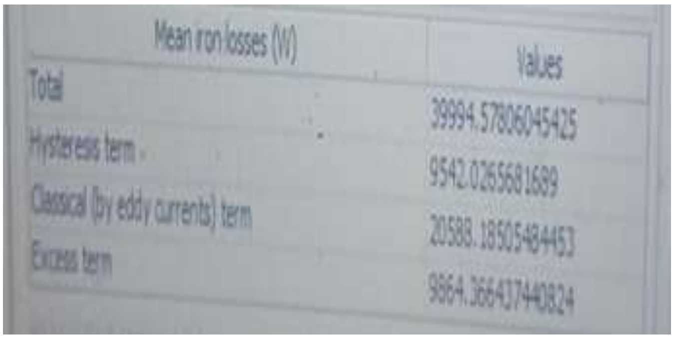
Fig 4:-Short Circuit test Circuit in Altair Flux

VII. Result Analysis

No Load Test:

In this No load test the HV winding is opened and test is performed on LV side . On LV side rated phase voltage 42.32 KV is applied .

Computation results:



Mean iron losses (W)	Values
Total	39994.57806045425
Hysteresis term	9542.0265681689
Classical (by eddy currents) term	20588.18505484453
Excess term	9864.366437440824

Fig 5:- Total core losses(Hysterisis+eddy+excess term)

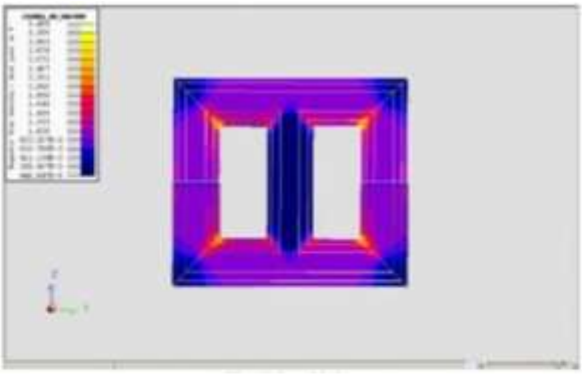


Fig 6 :Iso values:- It shows the magnetic flux density throughout the core

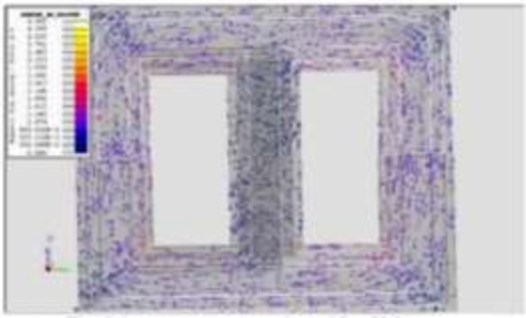


Fig 7:- Arrows representing isovalues 2 Short circuit test

In Short circuit test ,the LV side is short circuited and test is performed on HV side . The rated curremt on HV side is 655

Name of the result *

SENSORVALUE_2

Comment

Current value of SENSOR_2

Validity of the result

Results | Description

Real scalar

Fig 8:- SC losses

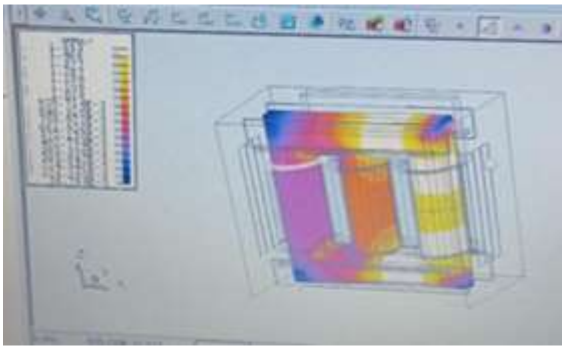


Fig 9:- Isovalues(Magnetic Flux density)

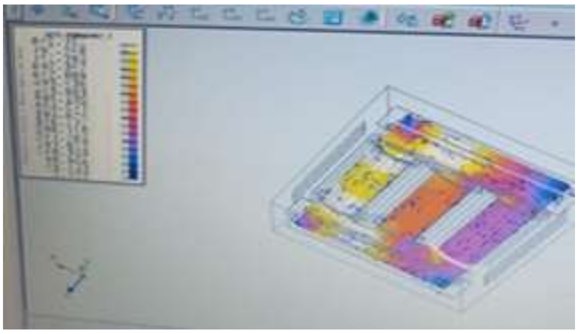


Fig 10 :- Arrows representing isovalues

VIII. CONCLUSION

This project successfully demonstrated the electromagnetic analysis of a three-phase star–delta step-down transformer using Altair Flux under no-load and short-circuit test conditions. The finite element model accurately predicted core losses using the Bertotti loss formulation and evaluated copper losses through current density distribution in the windings. The study confirmed that core losses remain nearly constant with load, while Joule losses vary with the square of current. Flux density distribution obtained from the simulation verified that the transformer operates within acceptable magnetic limits. The short-circuit analysis provided realistic estimation of winding losses and leakage behavior. Overall, the results validate Altair Flux as an effective and reliable tool for transformer performance evaluation without extensive physical testing. The methodology improves accuracy compared to conventional analytical approaches and provides deeper insight into internal electromagnetic behavior.

IX. FUTURE SCOPE

For future scope, the model can be extended to include thermal analysis to study temperature rise and cooling performance. Integration with Hyper Study can enable multi-objective optimization to minimize losses and material cost simultaneously. The approach can also be applied to different core materials such as amorphous or nano-crystalline steels for further efficiency improvement.

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