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Load Variation Effects on Power Transformer Efficiency: A MATLAB Simulation

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Abstract: This project investigates the impact of varying electrical loads on the efficiency of power transformers through MATLAB-based simulation. Power transformers play a vital role in electrical power systems, and their efficiency is significantly influenced by the nature and magnitude of the connected load. Using transformer equivalent circuit modeling, the study incorporates essential parameters such as winding resistance, leakage reactance, and core magnetizing inductance. Simulations are conducted by varying both resistive and inductive loads to analyse how these changes affect input and output power, ultimately determining the transformer's efficiency under different operating conditions. The results demonstrate that transformer efficiency varies with load magnitude, reaching peak performance under optimal loading conditions while declining under light or excessive loads. Inductive loads, which introduce reactive power components, were also shown to reduce overall efficiency compared to purely resistive loads. These findings underscore the importance of effective load management for achieving energy savings, extending the operational lifespan of transformers, and ensuring efficient power distribution. The project concludes by suggesting future advancements involving real-time monitoring and adaptive control systems that could dynamically regulate transformer parameters in response to load variations, thereby maintaining optimal performance across diverse electrical

Keywords: Transformer, Efficiency, MATLAB Simulation, Loads variation.

I. INTRODUCTION

Power transformers are essential components in electrical power systems, responsible for stepping voltage levels up or down to facilitate efficient transmission and distribution of electricity. Their performance, particularly efficiency, plays a crucial role in ensuring reliable and cost-effective power delivery. Efficiency in a transformer is defined as the ratio of output power to input power, and it is influenced by several factors, among which the connected electrical load is one of the most significant.

As the load on a transformer changes, so does its efficiency. Under light loads, core losses dominate, leading to reduced efficiency, while under heavy loads, copper losses become significant. This dynamic behaviour makes it critical to understand how transformers respond to different loading conditions, both resistive and inductive. A detailed study of this relationship can provide valuable insights into designing more energy-efficient systems and developing load management strategies that optimize transformer performance.

In this project, MATLAB simulation is used as a powerful tool to model the transformer's equivalent circuit and observe its performance under varying load scenarios. By simulating a range of resistive and inductive load conditions, we aim to analyse the resulting changes in input power, output power, and overall efficiency. The objective is to generate efficiency curves that reflect real-world transformer behaviour and highlight the implication of load variations. This knowledge is particularly important for engineers and utility operators seeking to enhance power system reliability, reduce operational losses, and extend equipment lifespan.

II. LITERATURE REVIEW

Power transformers are a fundamental part of the electrical infrastructure, serving to transfer electrical energy between circuits through electromagnetic induction. Their ability to step voltage levels up or down with minimal losses makes them indispensable in generation, transmission, and distribution networks. However, the efficiency of transformers is not constant and varies with loading conditions.

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Transformer losses are generally categorized into two types: core (iron) losses, which are relatively constant, and copper (I^2R) losses, which depend on the load current. As such, the load profile significantly affects a transformer's operating efficiency.

Numerous studies have explored transformer behaviour under different loading conditions. Traditional research has focused on analytical methods to estimate losses and efficiency, often based on nameplate data or empirical models. More recent approaches utilize computational tools such as MATLAB/Simulink to simulate transformer performance using equivalent circuit models. These models incorporate key parameters like winding resistance, leakage reactance, and core magnetizing reactance, providing a more realistic representation of transformer operation under dynamic load conditions. In particular, studies have shown that resistive loads primarily influence copper losses, while inductive loads introduce reactive power, affecting both voltage regulation and efficiency. The role of reactive power has become increasingly important, especially with the integration of renewable energy sources and non-linear loads, which complicate transformer loading profiles.

Recent advancements have emphasized the need for real-time monitoring and adaptive control of transformer loading. Technologies like smart grid systems and IoT-based sensors now enable dynamic load tracking and performance optimization. Despite these developments, simulation-based analysis remains a vital step in understanding load-related effects before implementing real-time solutions.

This project builds on existing research by simulating both resistive and inductive loading conditions using MATLAB. The aim is to provide a detailed analysis of how these conditions influence transformer efficiency and to highlight potential strategies for improving transformer operation in variable load.

III. SYSTEM MODELLING

The MATLAB/Simulink model used in this study is designed to simulate the performance of a power transformer under different loading conditions and analyse its efficiency. The model includes all essential components of a practical transmission and distribution system.

1. Three-Phase Voltage Source (500 kV, 50 Hz): This block provides a balanced high-voltage supply, representing the primary side of a typical transmission system. It delivers a 500 kV, 50 Hz three-phase AC signal to the transformer system.
2. Source Impedance (R-L Network): To emulate the real-world conditions of a power system, a resistive-inductive series network is used to represent the internal impedance of the supply system. This affects voltage drop and power loss in the system.
3. Two-Winding Transformer (150 MVA, 289/133 kV): A three-phase, two-winding transformer block is used to step down the high-voltage input to a usable medium-voltage level. The transformer parameters are configured to match practical transmission equipment, allowing for accurate loss and efficiency calculations.
4. Load Block (Resistive Load): A purely resistive load is connected at the low-voltage side of the transformer to represent varying industrial demand. The resistance value is altered across simulations to observe changes in power flow and transformer efficiency.
5. Voltage and Current Measurement Blocks: Measurement blocks are placed on both primary and secondary sides of the transformer. These blocks provide real-time data on voltage and current, which are used for computing input and output power.
6. Power Calculation Blocks:
    a. The system calculates:
        i. Input Power (Pin) using the product of primary voltage and current,
        ii. Output Power (Po) using the product of secondary voltage and current,
        iii. Efficiency (%) = (Po / Pin) × 100
7. Scope Blocks: Oscilloscope blocks are used to display the voltage and current waveforms at different points in the circuit, allowing for visual monitoring of system behaviour under varying load conditions.
8. Display Block: A display block is used to show the transformer efficiency in real time during the simulation The entire model is executed with a discrete solver using a fixed time step of 2e-5 seconds for a simulation duration of 0.2 seconds. This ensures accurate waveform resolution and power calculation.

IV. METHODOLOGY

A MATLAB/Simulink model was developed to investigate the impact of load variation on the performance of a power transformer, specifically focusing on its efficiency.

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1. The simulation system comprises a three-phase, 500 kV, 50 Hz AC source, connected to a two-winding power transformer rated at 150 MVA, 289/133 kV.
2. To accurately reflect practical operating conditions, the internal impedance of the source is modeled using a series R-L network.
3. The transformer steps down the high voltage to a usable level (133 kV) for industrial loads, enabling a detailed analysis of efficiency under varying load conditions.
4. A resistive load is connected to the secondary side of the transformer, and its value is systematically varied to study its effect on power flow and system losses.
5. Voltage and current measurement blocks are placed at both primary and secondary sides of the transformer. These measurements are used to compute:
    a. Input power (Pin)
    b. Output power (Po)
    c. Transformer efficiency = (Po / Pin) × 100
6. Scope blocks are used to visualize the voltage and current waveforms, allowing for real-time assessment of waveform integrity and phase relationships.
7. A display block is included to continuously show the calculated efficiency during the simulation.
8. The simulation runs for a duration of 0.2 seconds using a fixed-step discrete solver with a sample time of 2e-5 seconds, ensuring accurate tracking of transients and power flow.
9. The simulation is repeated for various load resistance values to observe the change in current, voltage, and efficiency. Results are recorded and analysed to understand the relationship between loading conditions and transformer.

V. SIMULATION MODEL

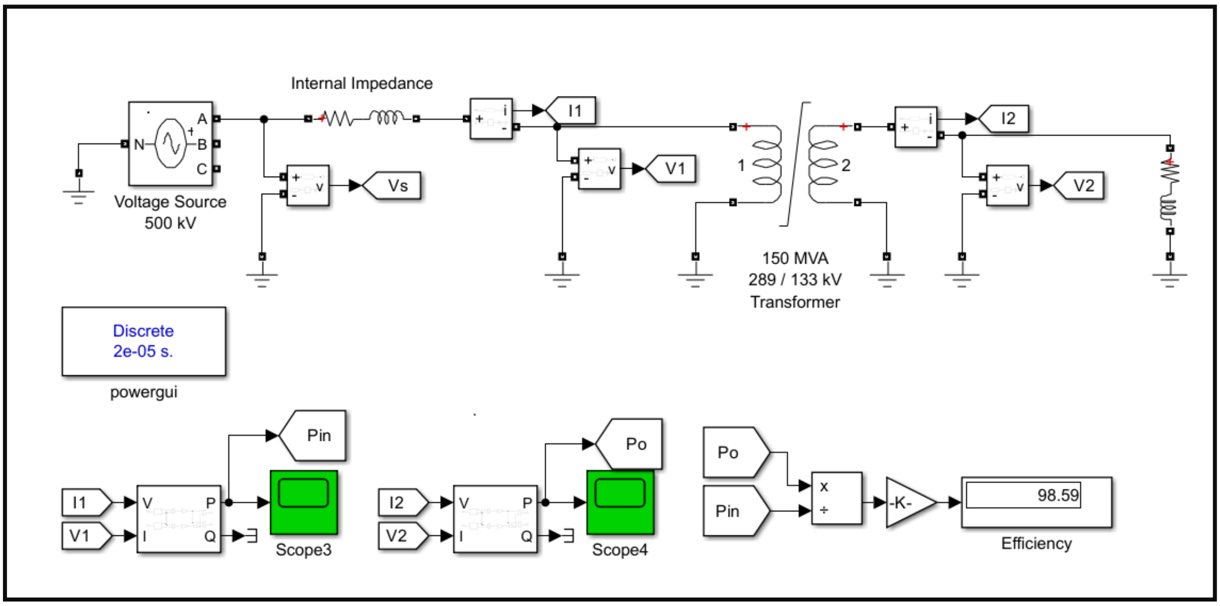

Fig 1. Block diagram

Table 1. Analysis Of load and Efficiency On Power Transformer

Load on Transformer	Efficiency
120e6	98.59
15e6	91.50
135e6	98.60

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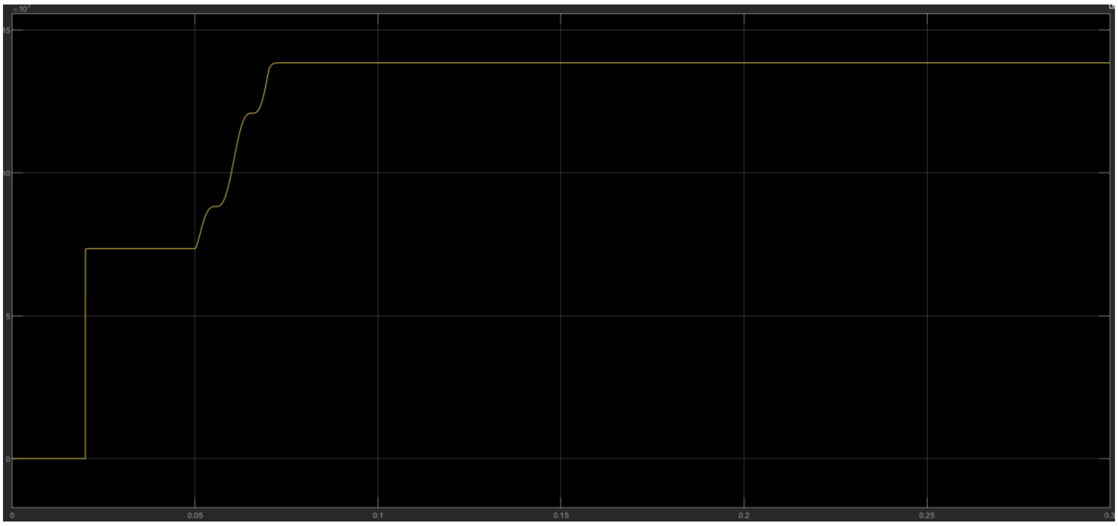

Fig. 1.1(a): Simulated Efficiency of (120e6) Pin waveform

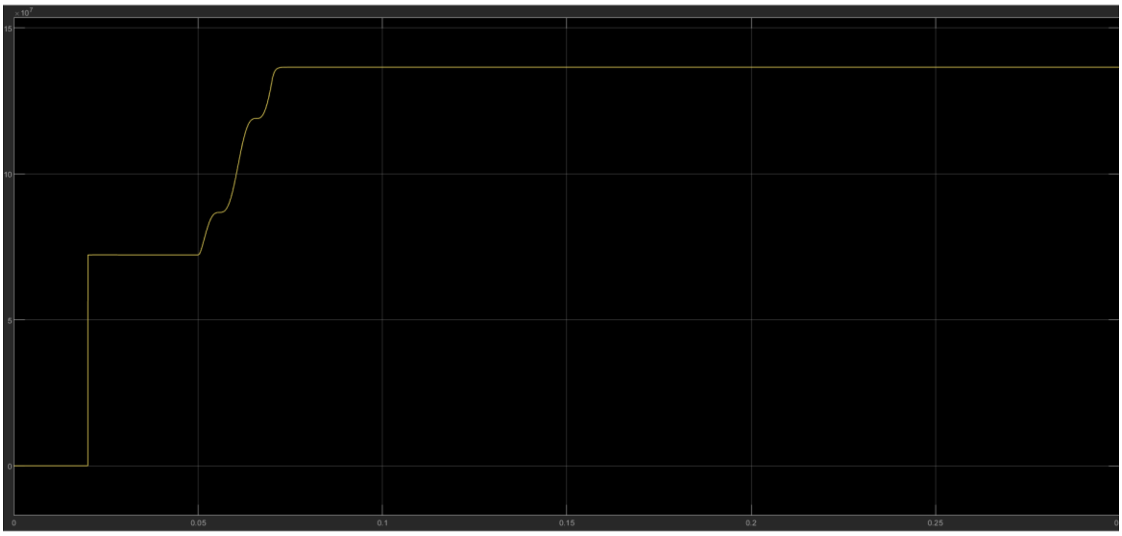

Fig. 1.1(b): Simulated Efficiency of (120e6) Po waveform

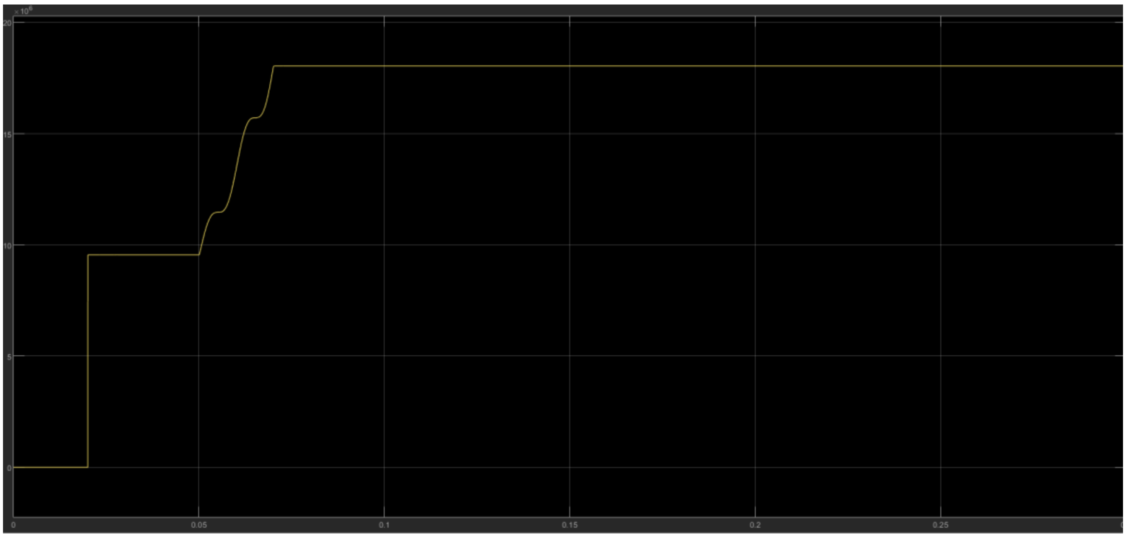

Fig. 1.2(a): Simulated Efficiency of (15e6) Pin waveform

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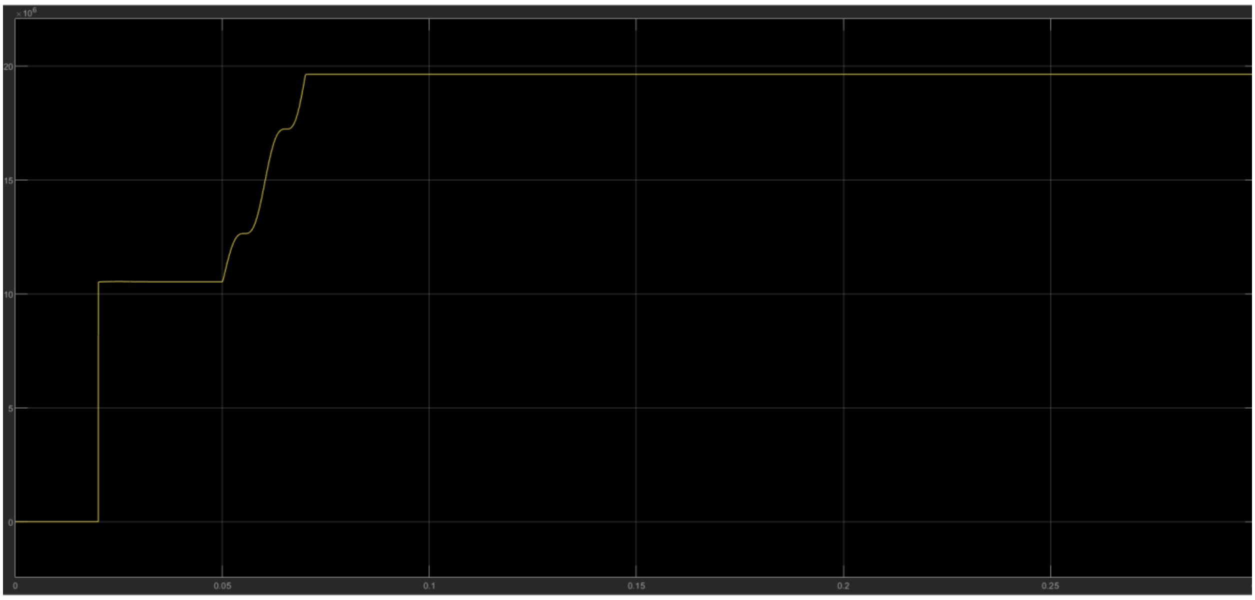

Fig. 1.2 (b): Simulated Efficiency of (15e6) Po waveform

VI. CONCLUSION

The simulation study effectively demonstrates how varying the load resistance impacts the performance and efficiency of a power transformer. Using MATLAB/Simulink, it was observed that as the load increases, both the input and output power levels change, affecting the overall efficiency of the system. The measurements showed that transformer efficiency remains high under optimal loading conditions but tends to decline as the load deviates significantly from its rated value due to increased losses.

The scope waveforms confirmed the voltage and current behaviour under different loading scenarios, while the real-time efficiency display provided a clear quantitative measure of performance. This simulation highlights the importance of proper load matching in transformer-based power systems to maintain high efficiency and minimize losses.

The model proves to be a valuable tool for engineers and designers to evaluate transformer performance under variable loads and reinforces the need for load management strategies in power system design and operation.

REFERENCES

[1] IEEE Std C57.12.00-2015, “IEEE Standard for General Requirements for Liquid-Immersed Distribution, Power, and Regulating Transformers,” IEEE, 2015.
[2] A. Greenwood, Electrical Transients in Power Systems, 2nd ed., Wiley-Interscience, 1991.
[3] R. C. Dugan, M. F. McGranaghan, H. W. Beaty, Electrical Power Systems Quality, 3rd ed., McGraw-Hill, 2012.
[4] MathWorks Documentation, “Three-Phase Transformer Modeling in Simulink,” MATLAB R2023b. Available: https://www.mathworks.com/help/sps/
[5] P. Kundur, Power System Stability and Control, McGraw-Hill, 1994.
[6] A. Bendre, G. Venkataramanan, D. Divan, and T. Degner, “Observations on Impacts of Distributed Generators on Power Quality,” IEEE Power Electronics Letters, vol. 2, no. 1, pp. 25–29, Mar. 2004.