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Analysis of No-Load Test on a Power Transformer: Case Study of 2.5MVA 33/11KV Transformer Located in Harmony Estate, Nigeria

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ABSTRACT

This research addresses a significant research gap in the study of no-load test on power transformers. Despite the widespread utilization of no-load tests for assessing core losses and excitation characteristics in power transformers, there is a lack of comprehensive studies exploring the impact of various specific factors, including frequency characteristics, load conditions, instrument conditions, and design parameters, on the accuracy and reliability of no-load test results. Furthermore, the evolution of transformer technologies and materials has introduced new challenges that may affect the validity of traditional no-load test methodologies. To bridge this gap, this study employs MATLAB-Simulink simulations to enhance the analysis by integrating conditional factors and parameters, offering higher accuracy compared to traditional calculations and laboratory experiments. The research will yield two sets of results: one from mathematical equations and another from MATLAB simulations, enabling a thorough comparison and the derivation of valuable recommendations in the power generation industry.

Keywords: Power transformers, No-load test, Load conditions, MATLAB-Simulink simulation, Analysis and testing

INTRODUCTION

Background of Study

Transformers are vital components in electrical power systems, responsible for transferring electrical energy between circuits at different voltage levels. In more technical terms, a transformer can be said to be a static device, used in electrical power systems to transfer electrical power between two circuits through the principle of electromagnetic induction, without a change in operating frequency.

Electromagnetic induction mentioned above; is the process by which a changing magnetic field induces an electric current in a conductor – when an AC current flows through the primary winding of a transformer, it creates a changing magnetic field in the core. This changing magnetic field induces a voltage in the secondary winding according to Faraday's law. The ratio of the number of turns in the primary winding to the number of turns in the secondary winding determines the voltage transformation ratio of the transformer. This principle is utilized in transformers to transfer electrical energy between two or more coils of wire (Agena *et al.*, 2014).

Wiranto (2016) noted that a power transformer basically consists of two electrical coils of wire, one called the “Primary Winding” and another called the “Secondary Winding” These two coils are not in electrical contact with each other but are instead wrapped together around a common closed magnetic iron circuit called the “core”. This soft iron core is not solid but made up of individual laminations connected together to help reduce the core’s losses.

The two coil windings are electrically isolated from each other but are magnetically linked through the common core allowing electrical power to be transferred from one coil to the other. When an electric current passed through the primary winding, a magnetic field is developed which induces a voltage into the secondary winding as shown in Figure 1 below.

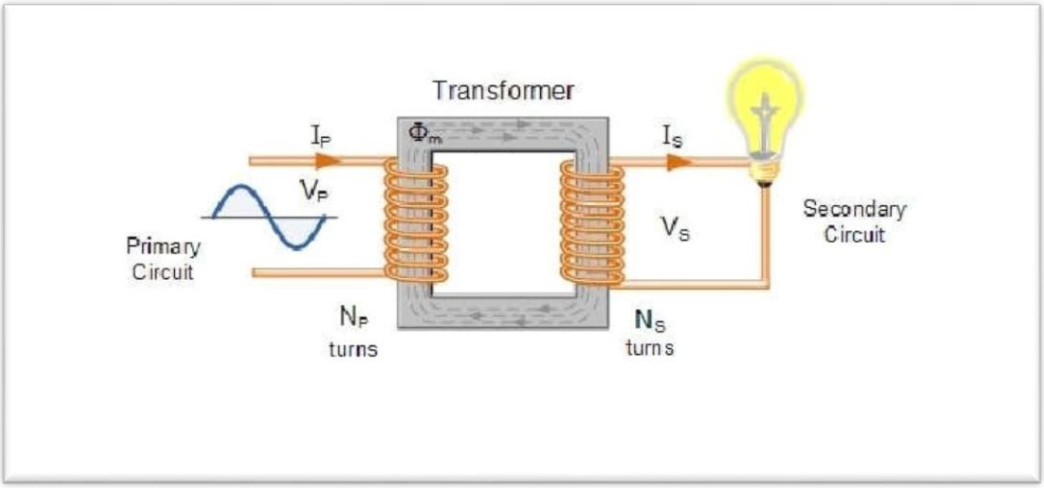


Figure 1: A Simple Power Transformer

The input winding to a transformer is called the primary winding. The output winding is called the secondary winding. If there are more turns of wire on the primary than on the secondary, the output voltage will be lower than the input voltage. For a step-down and a step-up transformer. Notice that the winding with the greater number of turns has the higher voltage. One winding has twice as many turns as the other. In one case the voltage is stepped down to half, while in the other the voltage is stepped up to double (Patil & Patil, 2015).

For the purpose of this research, a no-load test is conducted to evaluate the performance of a transformer when no load or minimal load is connected to its secondary side. The primary objective of this test is to determine the core losses, exciting current, and magnetizing characteristics of the transformer.

During a no-load test, the primary side of the transformer is energized with the rated voltage while the secondary side is left open-circuited or connected to a very small load. The following parameters are typically measured during the test:

1. Core Losses: The no-load test helps determine the iron or core losses in the transformer. These losses consist of hysteresis and eddy current losses, which occur due to the alternating magnetic field in the core.
2. Exciting Current: The test also allows measurement of the exciting current or the no-load current drawn by the primary winding. This current is required to establish the magnetic field in the core and is generally small compared to the full-load current.
3. Magnetizing Characteristics: By gradually increasing the primary voltage during the no-load test, the magnetizing characteristics of the transformer can be determined. This includes measuring the voltage required to establish the magnetic flux in the core. The data obtained from the no-load test is crucial for transformer design and operation. It helps in assessing the efficiency, losses, and voltage regulation of the transformer under actual operating conditions.

In addition, to analyze transformers, it is essential to understand the different classifications of them. Transformers can be classified into various categories, application being the most important classification, and others are as follows;

1. Based on Application

a) Step-up Transformer: Which increases the voltage level from the primary winding to the secondary winding. This type of transformer is used in power generation stations and transmission systems to step up the voltage for long-distance transmission, reducing transmission losses.

b) Step-down Transformer: It decreases the voltage level from the primary winding to the secondary winding. Step-down transformers are commonly used in distribution systems to reduce the high-voltage power to lower levels suitable for commercial and residential use (Popescu & Mastorakis, 2009).

2. Based on Number of Phases

a) Single-Phase Transformer: A single phase transformer is a type of transformer which operates on single-phase power supply. It consists of two highly inductive coils called winding of transformer wound on a core made up of iron or steel material. A single-phase transformer is a high-efficiency piece of electrical equipment, and its losses are very low because there isn't any mechanical friction involved in its operation.

b) Three-Phase Transformer: A three phase transformer or 3φ transformer can be constructed either by connecting together three single-phase transformers, thereby forming a so-called three phase transformer bank, or by using one pre-assembled and balanced three phase transformer which consists of three pairs of single-phase windings mounted onto one single laminated core. In three phase transformers, windings are connected such that the three primary windings are placed in delta or star and similarly the secondary windings are also connected in star or delta depending upon the application of area.

3. Based on construction

a) Core type Transformer: type of transformer in which the magnetic circuit consists of two vertical sections called limbs and two horizontal sections called yokes and the windings placed on the limbs. The primary and secondary windings are uniformly distributed on two adjacent limbs of the core. Both the windings are of cylindrical shape and they are arranged in a concentric manner the Low voltage (LV) winding is place near the core and high voltage (HV) winding is on over it.

b) Shell type Transformer: A shell type transformer consists of one central limb and two outer limbs. In the shell type transformer, both primary and secondary windings are placed on the central limb. The function of the two outer limbs is to complete the path of low reluctance for magnetic flux. This type of core provides double magnetic circuit and it provides a better mechanical support and protection for the windings. The material used for making core is same as core type transformer.

4. Based on cooling

a) Dry type transformer: This is a type of transformer that uses only air as the cooling medium to dissipate heat. Instead of using liquid cooling, the windings and core of the transformer are insulated and encapsulated in a solid epoxy resin or other suitable insulating material. This encapsulation ensures that the windings are protected from environmental influences like moisture, dust, and chemical contaminants.

b) Wet type transformer: A wet type transformer, also known as a liquid-immersed transformer, uses a liquid coolant, typically mineral oil, to provide cooling for the transformer's windings and core. The windings and core are immersed in the cooling liquid, which helps dissipate heat generated during operation.

5. Based on location

a) Indoor type Transformer: An indoor type transformer is designed and installed inside a building or an enclosed structure. These transformers are used when the available space for installation is indoors or when there is a need to protect the transformer from external environmental factors like weather, moisture, and dust. Indoor transformers are commonly used in residential, commercial, and industrial applications where the facility has designated spaces or substations indoors.

b) Outdoor type Transformer: An outdoor type transformer is designed and installed in an open-air environment, typically on a concrete pad or a metal platform. These transformers are often used in utility substations, power distribution stations, and other outdoor power infrastructure applications. Outdoor transformers are built to withstand various weather conditions, and they come with weatherproof enclosures to protect the internal components from rain, snow, and other environmental elements.

c) Station Transformer: A station transformer is a type of transformer used in electrical substations to step voltage levels up or down between different voltage levels in the power transmission and distribution network. These transformers are generally larger and more powerful than distribution transformers and are located in substations.

Considering the different classifications of transformer, the construction of some may vary over the other, however, there are important components always present in all transformers irrespective of the class, size and applications. These components are explained below.

Core: The core is a laminated structure made of high-permeability materials such as silicon steel. It provides a low reluctance path for the magnetic flux generated by the primary winding, allowing efficient energy transfer between the primary and secondary windings.

Windings: Transformers have two sets of windings - the primary winding and the secondary winding. The primary winding is connected to the input voltage source, while the secondary winding is connected to the output load. The number of turns in each winding determines the voltage transformation ratio of the transformer.

Insulation: Insulation is used to electrically isolate the different windings and prevent short circuits. It ensures that there is no direct contact between the windings or between the windings and the core.

Tank (Enclosure): The tank is a protective enclosure that houses the core and windings. In larger transformers, it also contains the cooling system. The tank is typically made of steel and provides mechanical support and protection to the internal components.

Cooling System: Transformers generate heat during operation due to energy losses. The cooling system dissipates this heat to maintain the transformer's temperature within acceptable limits. Common cooling methods include air cooling (dry type transformers) and liquid cooling using mineral oil (wet type transformers)

Conservator (for Oil-Filled Transformers): Large oil-filled transformers have a conservator, which is a cylindrical tank connected to the main tank by a pipe. The conservator allows for expansion and contraction of the cooling oil as the transformer temperature varies during operation.

Bushings: Bushings are insulating components that provide a means for external connections to the transformer windings. They are used to connect the transformer to the electrical power system.

According to de Melo *et al.* (2019), the power transformer represents the most strategic and expensive equipment of the power transmission system. Failure in a transformer can lead to power outages, with inconvenience and damage to consumers, this is why it is necessary to carry out safety checks and periodic maintenance activities on the transformer to prevent this from happening, and this project aims to analyze a typical power transformer in a software-based environment (MATLAB), and discuss the results based on industrial regulations and standards.

Statement of Problem

The no-load test is conducted to assess the behavior of a transformer when no load or minimal load is connected to its secondary side. This test helps in determining core losses, exciting current, and magnetizing characteristics, providing critical insights into the transformer's operation.

Aim of the Study

The aim of the study is to investigate and understand the performance characteristics and operational parameters of the transformer under no-load conditions.

Objectives of the Study

The aim of this study shall be achieved through the following objectives:

i. Collect data from the 2500KVA 33/11KV power transformer.
ii. Develop mathematical relationships that describe the no load test for power transformers.
iii. Solve the mathematical equations and determine the no-load magnetizing reactance, core-loss resistance, and the fixed power loss of the transformer (core-loss).
iv. Analyze the results of mathematical equations.
v. Simulate the model using MATLAB and compare results.

Scope of Study

This research study is to be concerned with characterization of a 2.5MVA 33/11KV transformer, using the no-load or open circuit test, through the modeling of relevant mathematical equations, and simulation of models using MATLAB. Its major contribution will be provided with transformer parameters without the need for an experimental method.

Significance of the Study

The significance of this project is essential for achieving efficient operation of transformers in electrical power systems as it allows for the evaluation of no-load current in relation to the rated current, core losses, assessment of voltage regulation, validation of design specifications, diagnostic capabilities, and compliance with industry standards made be IEC or IEEE.

Overview of project

This project contains four chapters. Chapter one contains the introduction, chapter two shows the materials and method used for the project, chapter three contains the result and discussion of the project and finally, chapter four brings about the conclusion and recommendations.

MATERIALS AND METHODS

This chapter contains a comprehensive account of the materials employed and the methodologies adopted in the process of analyzing the no-load test on a 2.5 MVA power transformer through MATLAB simulation. An essential phase in this research, this chapter explains the systematic approach we followed to investigate the intricate behavior of power transformers under no-load conditions. The successful execution of this research project depends upon the accurate selection of materials and the application of suitable methods which in this case is MATLAB simulation.

Materials

i. The materials used in this project include:
ii. No. 2.7KVA, 400V mobile generator set
iii. High voltage multimeter
iv. Recording templates
v. Live tester
vi. Fastening toolbox
vii. Testing lamps

Safety Gadgets used in this project include:

i. Hard Hat
ii. Safety gloves
iii. Safety boot
iv. Safety googles
v. Overall jacket

Transformer under Test

The transformer under test is a three-phase unit rated 250KVA, 33/11KV operating at 50HZ frequency.

The no-load circuit is shown in Figure 2 below.

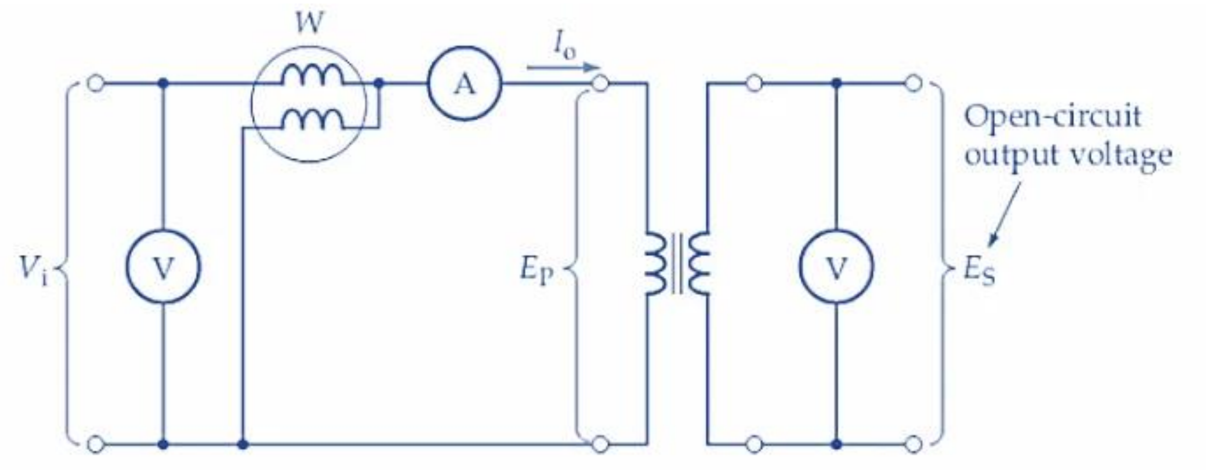


Figure 2: No-load Test Circuit

In the figure above, Vi is the AC source voltage on the voltmeter, V is the supply voltage on the primary side, W is the power reading on the primary side, Io is the input current, Ep is the open-circuit input voltage, Es is the open-circuit output voltage.

Table 1: Rating of 2500KVA 33/11KV Transformer under Test

2500KVA 33/11KV Transformer	
Model	ABB
Rated power (KVA)	2500
Rated frequency (HZ)	50
Rated primary voltage (V)	33000
Rated primary current (A)	43.739
Rated secondary voltage (V)	11000
Rated secondary current (A)	131.216

Methods

Computer simulation provides a simplification of reality due to its role in the design, analysis and evaluation of systems. A variety of software tools are available to simulate engineering applications. The most popular software is MATLAB which was used to carry out the analysis in this project. Mathematical equations were also used to solve for the Core loss resistance, Magnetizing reactance and efficiency of the transformer.

The circuit arrangement for the open-circuit test of a transformer is shown in Figure 2, where the high voltage side of the transformer is left open, i.e., the no-load test is to be performed on the low-voltage side of the transformer. This test is conducted to determine the core or iron losses and the no-load circuit parameters R_c and X_m of the transformer.

The steps involved:

1. The circuit shown above is connected
2. The applied voltage is slowly increased from zero to normal rated value of the LV side with the help of a variac
3. The input voltage, input current and input power are measured and recorded
4. The power supply is returned to zero and switched off
5. Calculate R_c and X_m of the transformer from readings recorded.

With a very small primary current, and near-zero secondary current (i.e., the voltmeter current), the copper loss in the windings can be assumed negligible. The input power measured on the wattmeter is then the total transformer core losses, and the ammeter indicates the no-load primary current (I_o). From the measured values of input voltage, current, and power, the components of the no-load equivalent circuit can be determined (Ahmed, 2022).

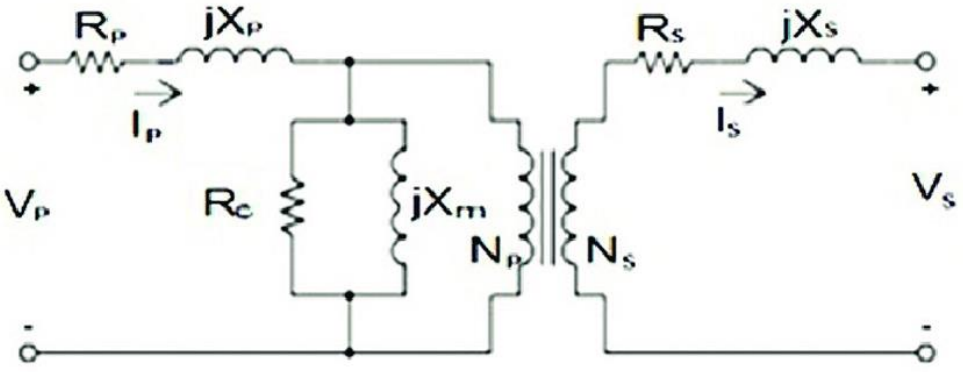


Figure 3: Transformer Exact Equivalent Circuit Open-Circuited

Where the parameters of this transformer are as follows:

Primary side: a. Primary voltage terminal (Vp) b. Primary current (Ip) c. Primary resistance (Rp) d. Primary leakage reactance (Xp) e. Core-loss resistance (Rc) f. Magnetizing reactance (Xm) g. Number of turns (Np).

Secondary side: a. Secondary voltage terminal (Vs) b. Secondary current (Is) c. Secondary resistance (Rs) d. Secondary leakage reactance (Xs) e. Number of turns (Ns).

Sometimes, a high resistance voltmeter is connected across the HV winding. Though, a voltmeter is connected, HV winding can be treated as open circuit as the current through the voltmeter is negligibly small. This helps in to find voltage transformation ratio (K) (Daware, 2014).

From the circuit, the no-load current (Ip) has two components given as

$$I_\mu = I_0 \sin\Phi \text{ and } I_w = I_0 \cos\Phi \qquad (1)$$

Where I_μ= Magnetizing component of no-load current

I_w = Core loss component of no-load current
CosΦ = no-load power factor

$$\text{Cos}\Phi = \frac{W}{Vp*Io} \qquad (2)$$

Where W = wattmeter reading

The shunt parameters (Ro and Xo) can be calculated using the two components of current in the equivalent circuit given as:

$$\text{Xo} = \frac{Vp}{\text{I}\mu} \qquad (3)$$

$$\text{Ro} = \frac{Vp}{Iw} \qquad (4)$$

Where Xo = purely inductive resistance
Ro = non-inductive resistance
Real power P of the circuit is given as:

$$\text{P} = \frac{Vp^2}{Rc} \qquad (5)$$

Apparent power S of the system is given as:

$$\text{S} = \text{Vp*Io} \qquad (6)$$

Where Rc = Core losses resistance. The real power and input voltage can be used to calculate these core losses, and the equation is given as:

$$\text{Rc} = \frac{Vp^2}{P} \qquad (7)$$

The current Ic flowing through the resistor Rc can be calculated using ohms law as shown

$$\text{Ic} = \frac{Vp}{Rc} \qquad (8)$$

The no-load current I_0 is the vectorial sum of the magnetizing current Im and core loss or working component current Ic, Function of Im is to produce flux Φm in the magnetic circuit and the function of Ic is to satisfy the no load losses of the transformer. Thus,

$$\text{Ip} = \sqrt{Ic^2} + Im^2 \qquad (9)$$

From this expression, the magnetizing reactance Xm can be calculated by extracting Im from equation (9),

It can be written as:

$$\text{Im} = \sqrt{Ip^2} + Ic^2 \qquad (10)$$

And using ohms law, Xm can be calculated as:

$$\text{Xm} = \frac{Vp}{Im} \qquad (11)$$

The efficiency of the transformer can also be obtained by the equation:

$$\text{Efficiency} = \frac{OUTPUT\ POWER}{INPUT\ POWER} \times 100\% \qquad (12)$$

Where

Input power = Output power + core losses + copper losses (13)

The efficiency of the transformer under no load should be zero as there is no power output available.

MATLAB

The name MATLAB stands for matrix laboratory. MATLAB was originally written to provide easy access to matrix operations, and over the years it has evolved into a high-level programming language and numeric computing environment designed for engineers and scientists. MATLAB supports matrix multiplications, plotting of functions and data, implementation of algorithms and creation of models and applications (Houcque, 2005).

MATLAB supports two-way integration with other programming languages, allowing the user to use other high-level languages in creating applications and performing functions.

Aside from programming languages, MATLAB integrates with Simulink, which is a MATLAB-based graphical programming environment for modeling, simulating and analyzing multidomain dynamical systems. Its primary interface is a graphical block diagramming tool and a customizable set of block libraries.

Simulink is a design and simulation focused software, used in a variety of applications ranging from control systems, telecommunication systems, signal processing, robotics, Artificial Intelligence, mechanical modeling and in this case, power system analysis. Using its graphical user interface, the various electrical components are represented and used to design virtual systems in the Simulink environment, this interactive feature enables the power engineers to test systems using a range of values, and obtain accurate results which can then be applied in the practical sense. MATLAB and Simulink together enable an efficient environment to execute both textual and graphical programming parameters.

How MATLAB is Used for No-Load Test

The MATLAB system initially operates under the assumption of receiving specific design specifications. Considering this assumption, a set of mathematical expressions are derived to efficiently compute the values of parameters in the magnetic circuit of the power transformer to be tested.

Subsequently, an algorithm is created to enable the software application to effectively utilize these derived mathematical expressions. This algorithm automates the computation process, facilitating the accurate determination of various parameters within the magnetic circuit of the power transformer.

To streamline this workflow, a MATLAB-based software solution is developed. This software exhibits the capability to ingest the design specifications as input and seamlessly perform the required computations, subsequently presenting the computed parameters of the transformer's equivalent circuit in a comprehensible visual representation. The development of the MATLAB software for transformer design and analysis entails the following key components:

1. MATLAB inherently supports the creation of applications with advanced graphical user interface (GUI) features, thereby enabling a user-friendly interface for interaction.
2. The GUI development environment in MATLAB, known as GUIDE (GUI Development Environment), is leveraged extensively to design and implement the visually appealing and functional GUIs required for the software.
3. Notably, MATLAB supports graph-plotting capabilities, utilizing the software's analytical capabilities by offering enhanced visualization of relevant data and results.

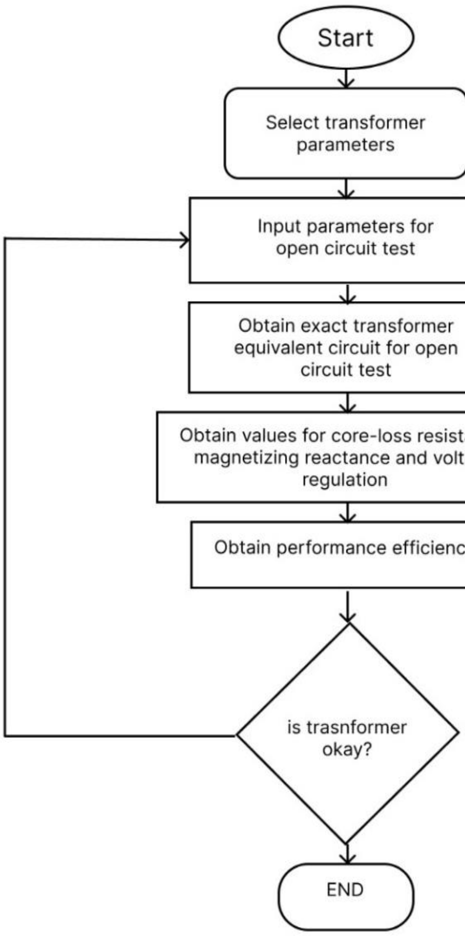


Figure 4: Flow Chart for MATLAB Operation

MATLAB Model for No-load Test

The open-circuit test is performed to determine exciting branch parameters (i.e., RC and XM) of the equivalent circuit, the no-load loss, the no-load exciting current, and the no-load power factor. As shown in Figure 3, while one of the windings is open-circuited (in our case secondary winding is the input voltage, VOC; input current, IOC; and input power, POC, to the transformer is measured.

Figure 5 shows the Simulink/Sim Power Systems realization of the open-circuit test where a single-phase transformer model whose equivalent circuit parameters could be specified using a transformer dialog box. An AC voltage source is applied to the primary side. Since in the Simulink environment, all elements must be electrically connected, the secondary side of the transformer cannot be left open, and a voltmeter and RMS mask are connected to view the secondary voltage.

On the primary side, current, and voltage measurement blocks are used to measure the instantaneous current and voltage. The output of each meter is connected to a root mean square (RMS) block/ mask to determine the RMS values of primary current and voltage. The

RMS block computes the RMS value of its input signal over a running window of one cycle of the fundamental frequency. The display boxes read these RMS values of the open-circuit Current, loc, and Voltage.

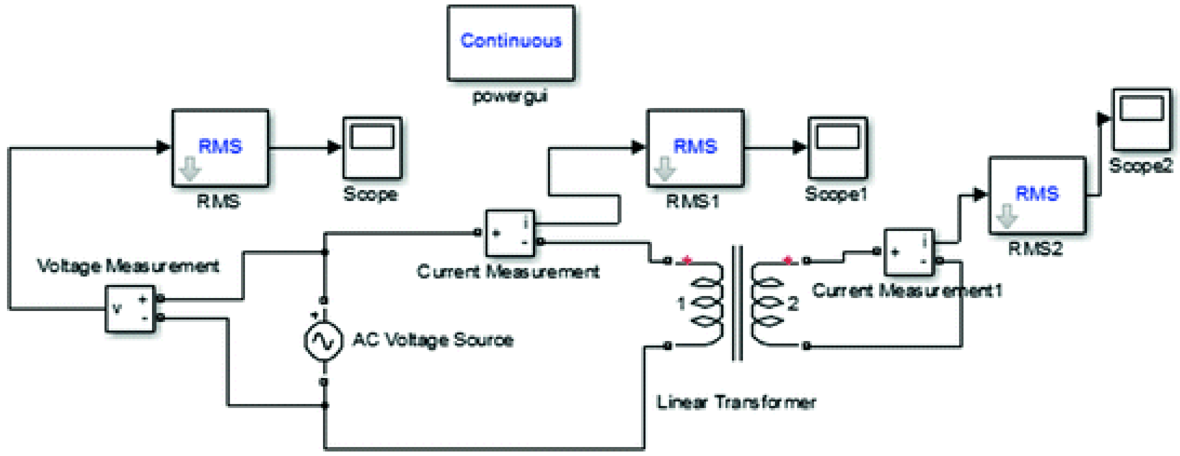


Figure 5: Simulink Model of the Open-Circuit Test

The outputs of the current and voltage measurement blocks are connected to a power measurement block that measures the apparent power, active power, Poc, and reactive power, Qoc, of the primary side. The output of this block is connected to a display box to read Poc and Qoc.

The output of the open circuit voltage, Voc, is connected to a math function block which squares the value of the Voc and divides it by the active power, Po. The value is multiplied by 4 to get the magnetization resistance.

The output of the open circuit voltage, Voc, is connected to a math function block which squares the value of the Voc and divides it by the active power, Qoc. The value is multiplied by 4 and the product is divided by a constant (2ntf) to get the magnetization inductance.

RESULTS AND DISCUSSION

This chapter contains a comprehensive analysis of the results obtained and the subsequent discussions arising from the Analysis of No-Load Test on a 2.5MVA Power Transformer project. It explains and discusses the findings and observations acquired through the execution of no-load tests on power transformers using MATLAB Simulink Simulation. These results will be presented, analyzed, and interpreted to provide a deeper understanding of the transformer's performance under no-load conditions. Additionally, this chapter will address any notable trends, anomalies, or insights that have emerged during the investigation, aiming to contribute to the broader body of knowledge in the field of electrical engineering and power distribution systems.

Results

Figure 6 shows the graphical representation of the MATLAB Simulink circuit used in simulating the no load test on the Power Transformer in view. The model was run for ten (10) seconds and various data values were recorded which will be shown consequently. Nahidul (2021) designed the basic structure of a single-phase transformer for No-load simulation.

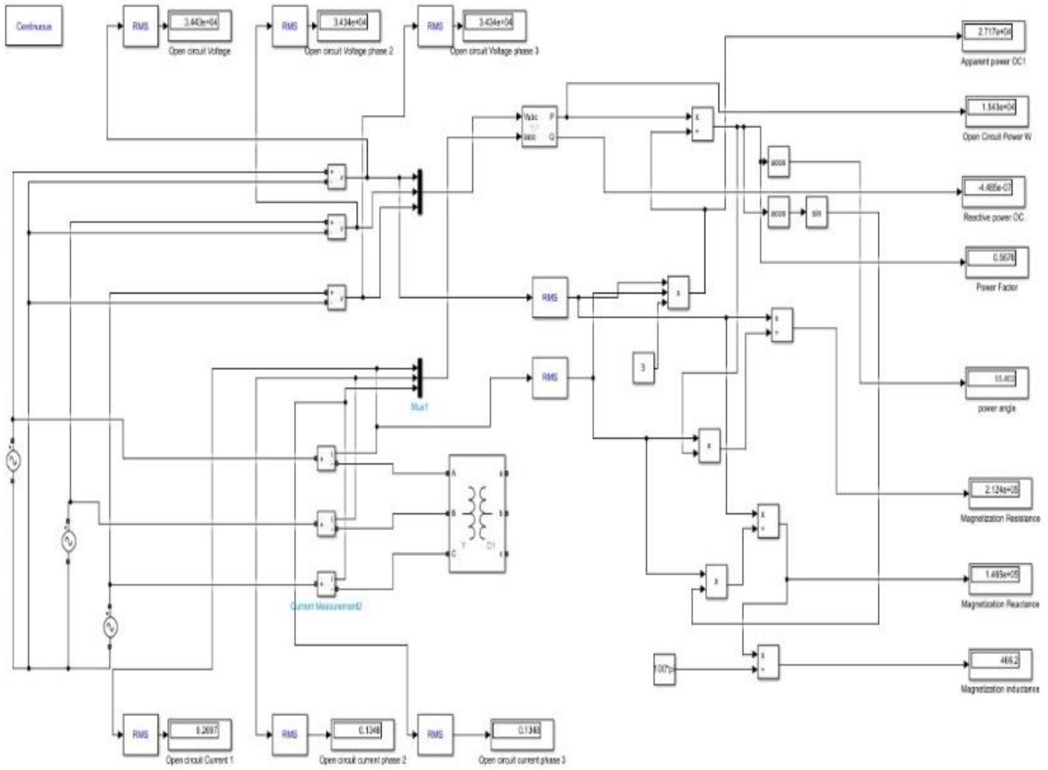


Figure 6: Actual Simulink model of the Open Circuit Test

The results of this simulation were recorded in the form of graphs, and numerical values. The graphs contained below report the results for the four basic parameters; Primary voltage, secondary voltage, open circuit current, open circuit Power. And the tables included in this chapter reports all numerical values gotten from the simulation, Physical transformer readings and mathematical calculation.

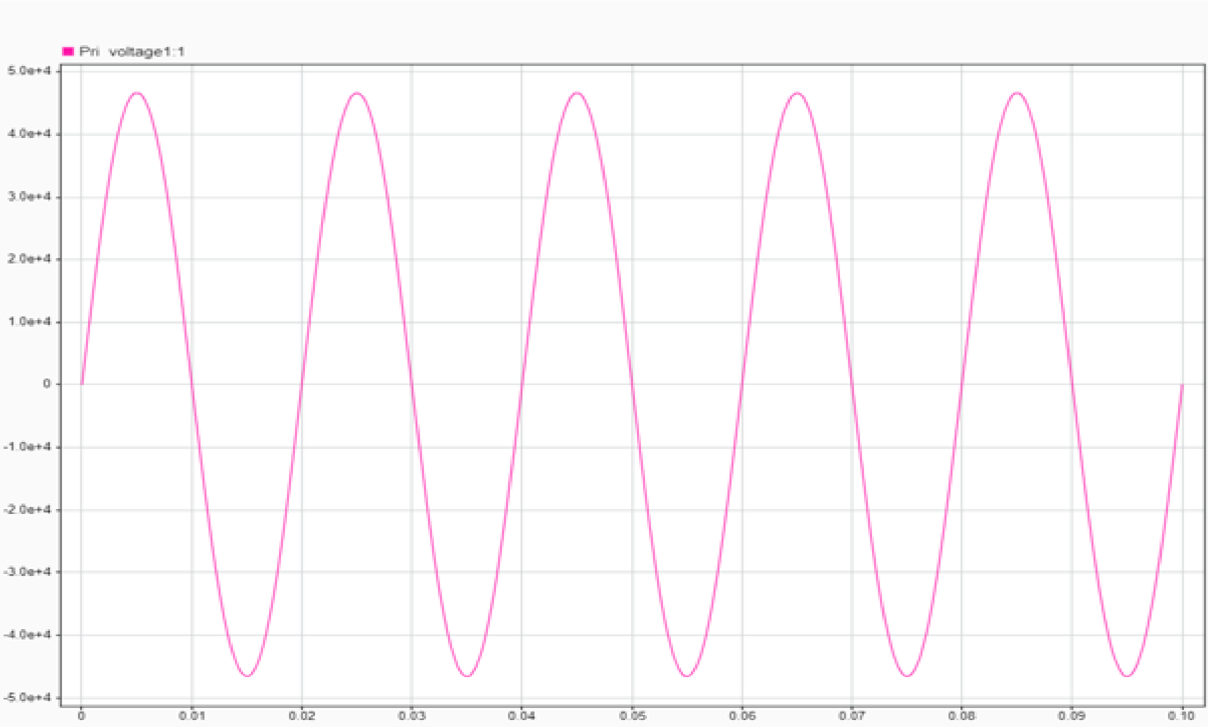


Figure 7: Graph of Primary voltage

In the MATLAB Simulink model designed for the analysis of the no-load test on the power transformer in study, the graph representing the primary voltage exhibits a consistent and unvarying supply voltage throughout the entire duration of the simulation with an average value of 3.3e4V or 33KV. This outcome aligns with the fundamental principles of the no-load test, where the primary winding, connected to a sinusoidal AC voltage source, remains energized without any attached load. This absence of load ensures that the primary voltage, characterized by parameters like RMS voltage and frequency, remains steady, adhering to its rated value. Any deviations observed in this graph would necessitate a more in-depth investigation, possibly involving measurements of the primary winding resistance, insulation quality, or supply voltage stability, and accounting for factors such as magnetic saturation in the core material.

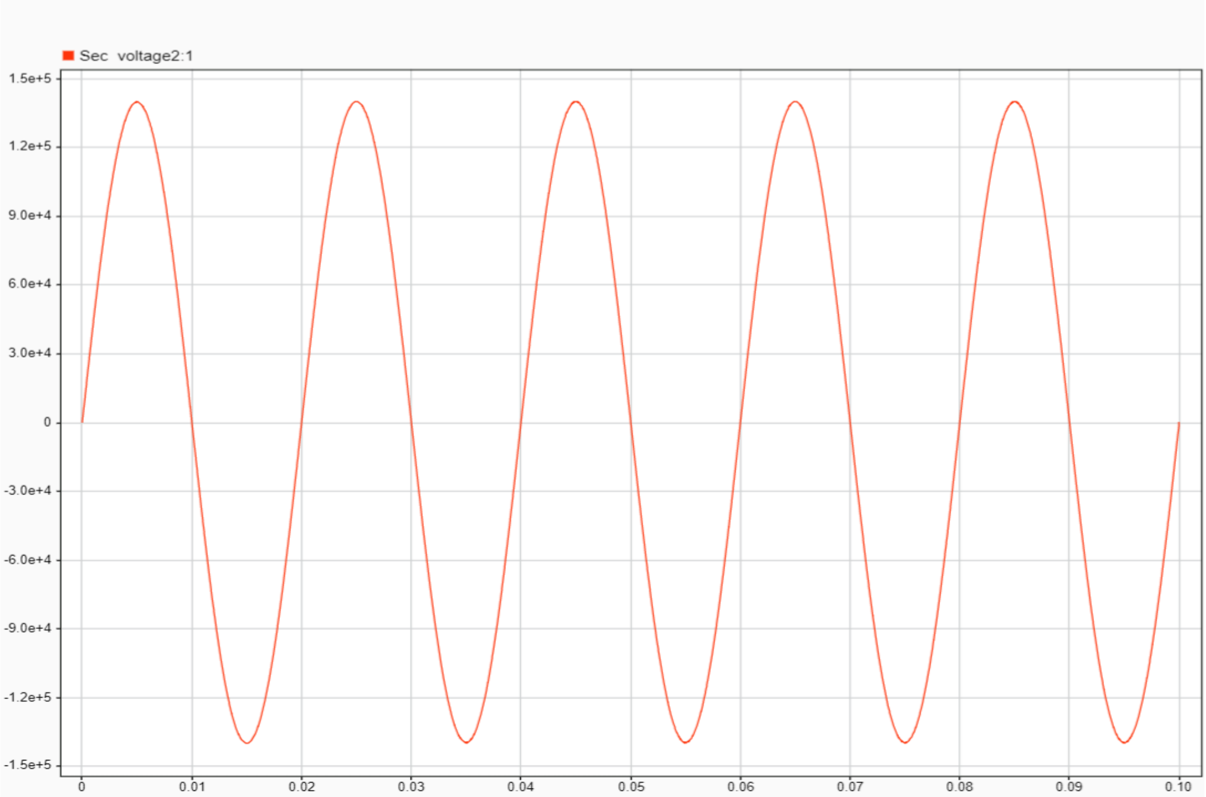


Figure 8: Graph of Secondary voltage

Within the MATLAB Simulink environment, the graph portraying the secondary voltage provides a clear insight into the transformer's performance during the no-load test. This graph illustrates a proportional and stable relationship between the secondary and primary voltages, a fundamental characteristic of a well-designed and functioning power transformer also with an average value of 1.1e4V or 11KV. As the primary voltage, characterized by its phasor representation, remains constant, the secondary voltage, governed by the turn's ratio, maintains an expected reduction in line with the transformer's specifications. Minor variations, may be attributed to negligible winding losses, core losses, or the inherent modeling precision in the simulation. In practice, such deviations are generally insignificant and remain well within acceptable limits, ensuring the transformer operates within its rated voltage parameters.

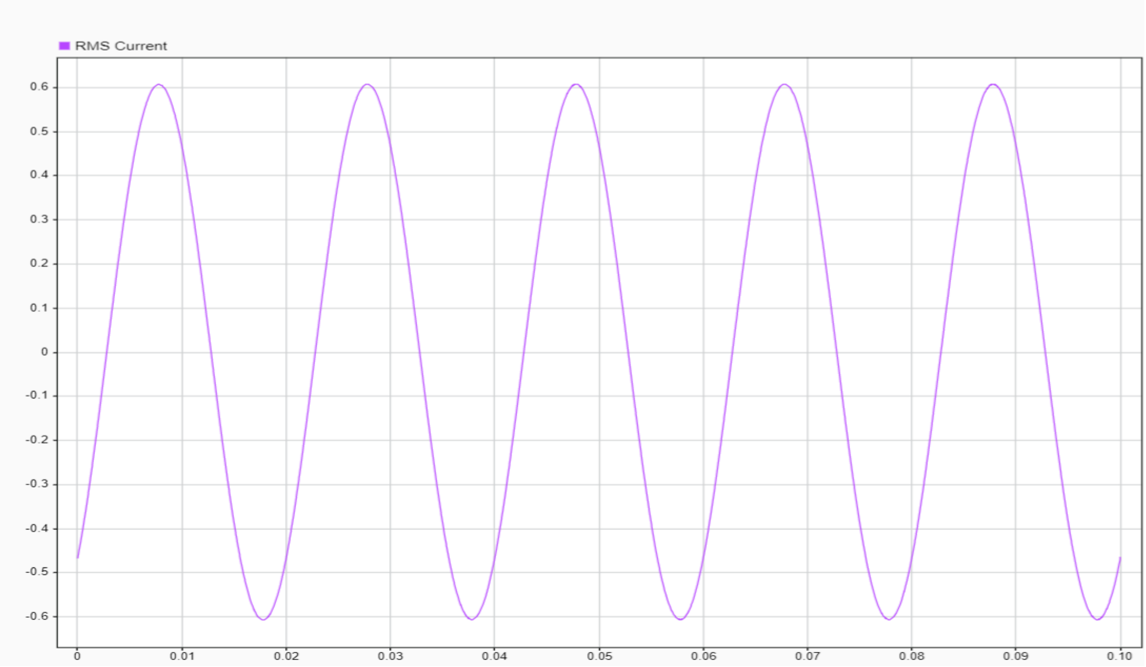


Figure 9: Graph of Open circuit current

In the context of the no-load test, the open circuit current graph generated through MATLAB Simulink reveals a near-zero and constant current flow, precisely as anticipated in this testing phase. The open circuit current, often referred to as the excitation current or magnetizing current, is a crucial parameter to assess the transformer's core magnetization and overall performance under no-load conditions. This current, characterized by its phase angle and magnitude, remains minimal due to the absence of load impedance in the secondary winding. Any deviations from this expected behavior might prompt an investigation into the core material properties, such as magnetic permeability, winding configurations, or any potential magnetic imbalances within the transformer, which could affect core saturation and hence excitation current.

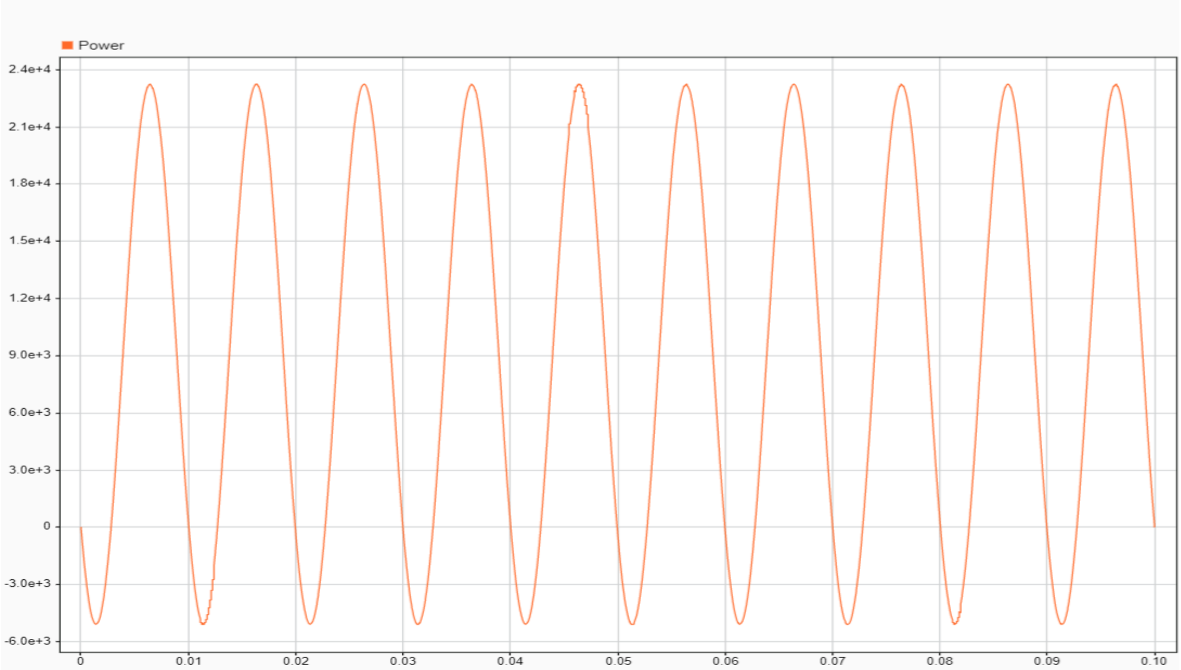
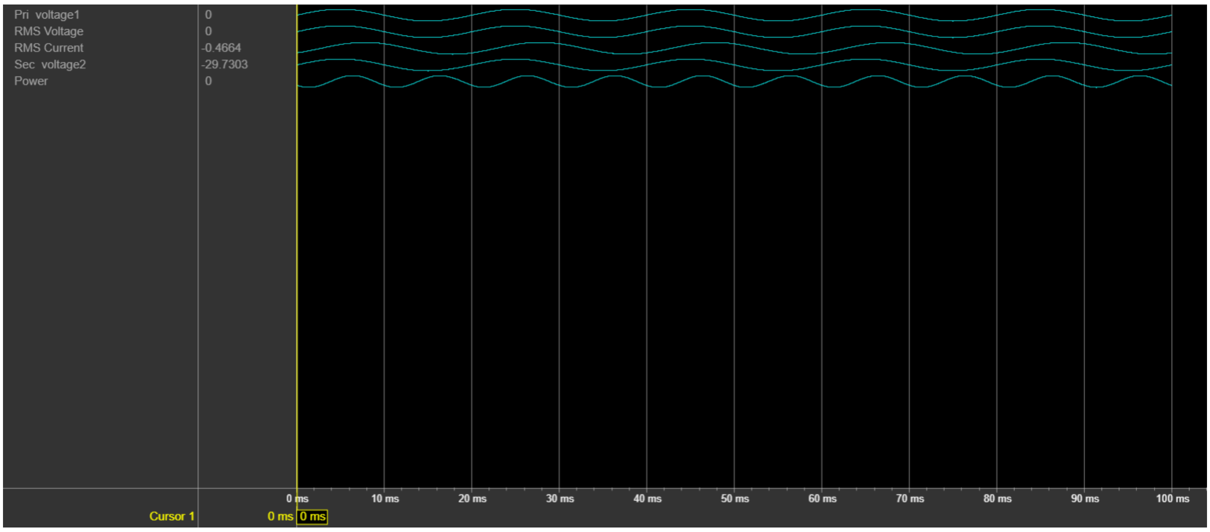


Figure 10: Graph of Open circuit power

In this model, the open circuit power graph depicts minimal and consistent power consumption by the transformer throughout the test. This outcome adheres to the theoretical expectations, where an ideal transformer should exhibit negligible losses when operating without a load. These losses primarily include core hysteresis, eddy current losses, and minimal winding resistance. The open circuit power, characterized by its active and reactive power components, serves as a critical indicator of transformer efficiency under no-load conditions. If the open circuit power values significantly deviate from this norm, it is imperative to inspect the transformer's core material, winding quality, and insulation, as these factors can influence power losses during the no-load test, potentially indicating areas for improvement or maintenance and considering effects like stray losses and harmonics.



Pri voltage1 0
RMS Voltage 0
RMS Current -0.4664
Sec voltage2 -29.7303
Power 0

Figure 11: Logic analyzer

Incorporating a logic analyzer graph into the MATLAB Simulink simulation provided a comprehensive view of the transformer's performance during the 10-second duration of the no-load test. The logic analyzer graph displayed key parameters in real-time, offering valuable insights into the transformer's behavior. The primary voltage, marked by its constant amplitude and frequency, remained stable throughout the test, in line with the ideal characteristics of a well-designed power transformer. Correspondingly, the secondary voltage, reflecting the turns ratio, exhibited a proportional reduction without any discernible fluctuations. The RMS open circuit voltage, calculated as the square root of the mean of the squared instantaneous voltage values, maintained a consistent value, affirming the reliability of the transformer's voltage regulation. Simultaneously, the RMS open circuit current, calculated similarly for current, remained nearly zero, attesting to the absence of load and the core's magnetization effects. Lastly, the open circuit power, computed from the instantaneous voltage and current, remained minimal and steady, indicating efficient core operation with minimal losses under no-load conditions. The logic analyzer graph thus provided a detailed snapshot of the transformer's performance, ensuring that critical parameters aligned with expected values, thereby confirming the transformer's suitability for its intended application.

Table 2: Simulated results for No-load Test

	No-load current	No-load Voltage	Power factor	Power Angle	Active power	Reactive power	Apparent power	Magnetizing Resistance	Magnetizing Reactance	Magnetizing Inductance
Transformer					2.5e6			2.178e5		577.73
Simulation	0.2697	3.443e4	0.5678	55.403	1.543e4	-4.485e-7	2.717e4	2.12e5	1.465e5	466.2

From the simulation result in Table 2:

The No-Load current is 0.2697. Taking the percentage of the simulated no-load current from the nominal current of the transformer from Table 2,

No-Load current = 0.2697 A

Rated current = 43.739 A

Taking the percentage,

0.2697/43.739 × 100 = 0.616%

From the data collected from the transformer:

Table 3: Measurement of No-load Losses and Current

Applied Voltage (V)		Secondary voltage (V)	No load current (A)			Wattmeter (W)			Instrument			Avg. Current
HV	LV		A	B	C	A	B	C	W	V.T	C.T	
100	50	11,000	2.072	1.911	1.698	66.74	194.14	88.26	1	5	1	1.893

Table 2 shows the ammeter reading of the no-load current lo. As no load current I is quite small compared to the rated current of the transformer, the voltage drops due to this current can be taken as negligible.

According to Chukwuma (2022), since the voltmeter reading Vi can be considered equal to the secondary induced voltage of the transformer, the input power during the test is indicated by the watt-meter reading. As the transformer is open-circuited, there is no output, hence the input power here consists of core losses in the transformer and copper loss in the transformer during no load condition. But as said earlier, the no-load current in the transformer is quite small compared to the full load current, so copper loss due to the small no-load current can be neglected. Hence, the wattmeter reading can be taken as equal to core losses in the transformer.

Consequently, we can safely assume that the wattmeter reading directly corresponds to the core losses within the transformer during this no-load condition. This insight is vital for accurately assessing the transformer's efficiency and performance characteristics.

The results of the developed model for transformer testing are shown in Table 4 below.

Table 4: Calculated Results for No Load Test Result

	1st Reading	2nd Reading	3rd Reading
theta	89.8322	89.4708	89.7293
Iu	1.9814	1.9070	1.6662
Iw	-0.6060	0.1233	-0.3271
Xo	5.5517e+3	5.768e+3	6.601e+3
Ro	1.81e+4	8.922e+4	3.362e+4
Rc	1.810e+6	6.232e+5	1.370e+6
Ic	0.006	0.017	0.008
Im	43.7390	43.7390	43.7390
Xm	251.4918	251.4918	251.4918

Efficiency	1.1720	0.1796	1.2260
No load loss	1750	1750	1750

From the result, the current lags the input voltage at approximately 90°. The efficiency of the no-load test is greater than zero, which means that power is being lost hence the transformer needs to be checked on, even though small, the efficiency is expected to be zero since the load is not connected across the secondary of the transformer.

Discussion

In this simulation of the no-load test for a three-phase transformer, it is important to note that the analysis primarily focused on a single-phase value, representing one of the phases. This approach was adopted based on the assumption that the electrical characteristics and performance of each phase are highly similar under no-load conditions. In practice, three-phase transformers are designed and manufactured with balanced windings and equivalent electrical parameters across all phases, making it reasonable to infer that the behavior observed in one phase is representative of the transformer's performance as a whole. By concentrating the analysis on a single phase, computational efficiency was enhanced, and the complexity of the simulation reduced while maintaining the accuracy of the results. This streamlined approach is a common practice in the analysis of three-phase transformers and aligns with the understanding that variations among phases are minimal during the no-load test, where load imbalances are absent.

In a MATLAB simulation of a three-phase transformer's no-load test, the choice to focus on a single phase was made using the symmetry, efficiency, and application of specific electrical rules as guiding factors. This strategy in electrical engineering is supported by a number of elements:

Equilibrium and operation

For each phase, symmetrical winding arrangements and virtually similar electrical properties are used in the construction of three-phase transformers. With this symmetry, steady-state functioning is balanced. Kirchhoff's Current Law states that the total current at a node is zero. The currents in each phase of a balanced three-phase system are 120 degrees apart and add up to zero at any given time. It is acceptable to believe that an individual's behavior will follow this natural balance because it lowers the complexity of analysis.

Equivalence from phase to phase

According to the Law of Electromagnetic Induction, a change in magnetic flux causes a coil to develop a voltage. Each phase's magnetic field in a three-phase transformer interacts with the core material in a similar way. Because of this, the voltage created in each phase is equal in amplitude and phase shift, which causes all three phases to behave very similarly (Glover, Sarma & Overbye, 2008).

Symmetry with no load

The transformer performs with little excitation and little losses during the no-load test. The lack of load guarantees that the core losses and magnetizing current are largely the same across phases. The simulation effectively captures these common traits by focusing on a single phase because phase imbalances that could happen under load are hardly noticeable.

Resource Efficiency

It can take a lot of time and calculation to simulate all three phases in their entirety. By concentrating on a single phase, the simulation can be made simpler, with less computing work and faster simulation times while still accurately simulating the transformer's no-load behavior.

In summary, the simulation methodology was developed, considering electrical parameters, core characteristics, and circuit connections, ensuring precision and reliability.

Emphasis was placed on adherence to industry standards and regulations, ensuring safe, reliable operation in real power systems. This detailed analysis yields a profound understanding of no-load test behavior, offering valuable insights for electrical engineering and power system design.

CONCLUSION AND RECOMMENDATIONS

Conclusion

The percentage deviation observed in the no-load current, which remains below the industry-accepted threshold of 10% in relation to the nominal or rated current, confirms the transformer's efficiency and reliability. This permissible margin ensures that the transformer operates within safe and efficient parameters, minimizing the risk of over-excitation and undue stress on the transformer windings.

Recommendations

In the pursuit of safe and standardized transformer design and utilization within the electrical industry, the no-load test emerges as a cornerstone for validation and assessment. This test, conducted under conditions devoid of external load, offers invaluable insights into a transformer's core characteristics, efficiency, and overall performance. To ensure the utmost reliability and adherence to industry standards, it is essential to couple the utilization of the no-load test with a comprehensive set of recommendations and best practices. These guidelines not only enhance transformer efficiency and longevity but also contribute to the seamless operation of power distribution systems. In this regard, the following recommendations are put forth as essential considerations for achieving safe and standardized transformer design and utilization:

Optimize Core Materials and Design:

Select advanced core materials with low hysteresis and eddy current losses, coupled with an efficient core design to minimize core losses during no-load testing.

Enhance Winding Techniques and Insulation:

Employ precision winding techniques and high-quality insulating materials to minimize stray losses and ensure the integrity of windings.

Implement Regular Testing and Maintenance:

Establish a rigorous testing and maintenance schedule that includes periodic no-load tests to proactively identify deviations and address potential issues.

Incorporate Advanced Monitoring and Diagnostics:

Integrate real-time monitoring and diagnostic systems to continuously assess transformer health, enabling early detection and remediation of problems.

Adhere to Industry Standards and Regulations:

Maintain strict compliance with industry standards and regulations governing transformer design, manufacturing, and operation, and update designs to align with the latest standards.

Prioritize Load Profile Assessment:

Conduct a thorough load profile assessment during the design phase to optimize transformers for specific applications, thereby minimizing losses.

By applying these recommendations, the electrical industry can fortify its commitment to safe and standardized transformer design and utilization, ultimately contributing to the reliability and sustainability of power distribution systems.

REFERENCES

Abanihi, K. V., Aigbodion, D. O., Kokoette, E. D. & Diarah, R. S. (2014). Analysis of load test, transformation, turns ratio, efficiency and voltage regulation of single phase transformer. *International Journal of Science, Environment and Technology, 3*(5), 1657-1667.

Agena, K., Razmiko, A., Darwin, A., Jonas, A., Caesar, B. J., Kevin, B. M., Ellaine, B. V., Pamela, B., Marivette, B. & Sherlyn, C. (2014). Transformer Core and Transformer Winding. *Academi*a. https://www.academia.edu/5666402/Transformer_Core

Ahmed, A. (2022). Open-Circuit and Short-Circuit Tests in Transformers. *EE Power*, Technical Article.

Balci M. (2014). *On the no-load loss of power transformers under voltages with sub-harmonics.* Turkish Republic Ministry of Science, Industry and Technology. Project 01008.STZ.2011-2, pp. 3-7.

Dasgupta, I. (2002). *Design of Transformers.* McGraw-Hill Education.

Daware, K. (2014). Open Circuit and Short Circuit Test On Transformer. *Electrical Easy.* https://www.electricaleasy.com/2014/04/open-and-short-circuit-test-on-transformer.html

de Melo, A. G., Benetti, D., de Lacerda, L. A., Peres, R., Floridia, C., Silva, A. D. A., & Rosolem, J. B. (2019). Static and dynamic evaluation of a winding deformation FBG sensor for power transformer applications. *Sensors*, *19*(22), 4877. https://doi.org/10.3390/s19224877

Glover, J. D., Sarma, M. S., & Overbye, T. J. (2008). *Power System Analysis and Design*. Thomson Learning, Part or the Thomson Corporation. ISBN: 10: 0-534-54884-9.

Houcque, D. (2005). *Introduction To MATLAB For Engineering Students*. Northwestern University.

Koprivica, B. & Koprivica, S. M. (2017). No-load Operation of Single-Phase Transformer at Low Frequencies. *International Scientific Conference "UNITECH 2017" – Gabrovo.*

Nahidul, I. (2021). Transformer Open Circuit Test Using Simulink. *Mathworks, Matlab Central File Exchange*. Model - R2014a.

Patil, N., & Patil, J. H. (2015). Design and Analysis of Transformer using MATLAB. *International Journal of Science Technology and Engineering*, *1*(12), 23-28. https://www.doi.org/10.36106/ijsr

Popescu, M. C. & Mastorakis, N. (2009). Modelling and simulation of step-up and step-down transformers, *World Scientific and Engineering Academy and Society, 1*(6), 23-34.

Ramamurthy, J. R., Chiesa, N., Høidalen, H. K., Mork, B. A., Stenvig, N. M., & Manty, A. C. (2017). Influence of voltage harmonics on transformer no-load loss measurements and calculation of magnetization curves. *Electric Power Systems Research*, *146*, 43-50. https://doi.org/10.1016/j.epsr.2017.01.022

Uzoamaka, C. (2022). Analysis of No-Load Test on Power Transformer: Case Study 2.5MVA 33/0.415KV Transformer in Law School Rivers State.

Waldi, T. (2002). *Electrical Machines, Drives, and Power Systems* (5th ed.). Prentice Hall.

Wiranto, A. (2016). Transformer Basics a Typical Voltage Transformer. *Academia*. https://www.academia.edu/36956457/Transformer_Basics_A_Typical_Voltage_Transformer