

DESIGN AND CONSTRUCTION OF TRANSFORMER CIRCUIT TRAINER

BY

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HND/23/EEE/FT/0029

SUBMITTED TO

**THE DEPARTMENT OF ELECTRICAL/ELECTRONIC
ENGINEERING, NSTITUTE OF TECHNOLOGY,**

KWARA STATE POLYTECHNIC, ILORIN.

**IN PARTIAL FUFILMENT OF THE REQUIREMENTS FOR THE AWARD OF
HIGHER NATIONAL DIPLOMA (HND)
CERTIFICATE IN ELECTRICAL/ELECTRONIC ENGINEERING**

JULY, 2025.

CERTIFICATION

This is to certify that this project work was carried out and submitted by **ADEGOKE DAMILOLA RICHARD** of matric number **HND/23/EEE/FT/0029** to the department of Electrical/Electronic Engineering is accepted having confirmed with the requirements for the award of Higher National Diploma (HND) in the department of Electrical/Electronic Engineering, Institute of Technology, Kwara State Polytechnic, Ilorin.

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DEDICATION

This project is dedicated to God and to my family.

ACKNOWLEDGEMENT

I am deeply grateful to God for the strength, wisdom, and grace that carried me through the course of this project.

I sincerely thank my Mum Rev. Mrs. Joanna Yinka Laoye and the rest of my family for their unwavering support, emotionally, financially, and spiritual. Your prayers, encouragement, and life advice has kept me going.

My special appreciation goes to my supervisor, **ENGR. KAREEMJIMOH JEKIDERO** for his mentorship and support to see that this project work is successful.

I am equally grateful to the Head of Department, **ENGR. DR. LAWAL AHMED O.** and the entire staff of Electrical/Electronic Department, Kwara State Polytechnic, Ilorin, for their contribution towards the successful completion of this work.

ABSTRACT

This project presents the Design and Construction of a Transformer Circuit Trainer aimed at enhancing practical learning in Electrical and Electronics engineering education. The trainer serves as an instructional tool that allows students to gain hands-on experience in understanding transformer operations, circuit behavior, and safety practices.

The project followed a structured design methodology involving requirement analysis, component selection, system integration, and rigorous testing. Key components such as transformers, circuit breakers, voltmeters, and ammeters were carefully chosen for their functionality, safety, and reliability. The final prototype was assembled and tested under various conditions to evaluate its performance, efficiency, and compliance with safety standards.

Results from the testing phase demonstrated that the trainer met the design specifications and performed as expected in educational demonstrations. It successfully illustrated key transformer principles such as voltage transformation, current distribution, and power measurements under different load conditions.

The transformer circuit trainer is a valuable educational tool that bridges the gap between theoretical knowledge and practical skills. It promotes active learning, enhances problem-solving abilities, and supports the development of technical competence in students. While the trainer met its objectives, recommendations for future improvements include expanding its functionalities and incorporating digital monitoring features to broaden its application in modern electrical training environments.

TABLE OF CONTENTS

| | |
|-------------------|-----------|
| Title Page | I |
| Certification | II |
| Dedication | III |
| Acknowledgements | IV |
| Abstract | V |
| Table of Contents | VI - VIII |

CHAPTER ONE – Introduction

| | |
|--|------|
| 1.0 Introduction | 1- 2 |
| 1.1 Background of the Study | 2 |
| 1.2 Statement of problem | 2-3 |
| 1.3 Aim of the project | 3 |
| 1.4 Objectives of the project | 3 |
| 1.5 Significance of the study | 4 |
| 1.6 Scope and Limitations of the Project | 4-5 |

CHAPTER TWO – Literature Review

| | |
|--------------------------------------|-----|
| 2.0 Literature Review | 6 |
| 2.1 Overview of Transformer Circuits | 6 |
| 2.1.1 Historical Development | 6 |
| 2.1.2 Principle of Operation | 6-7 |

| | |
|--|--------|
| 2.1.3 Real and Ideal Transformers | 7 |
| 2.1.4 Classification of Transformers | 7-8 |
| 2.2 Existing Training Methods for Transformer Circuits | 8 |
| 2.2.1 Limitations of Existing Methods | 8 |
| 2.3 Design Considerations for Training Equipment | 8-9 |
| 2.3.1 Safety | 9 |
| 2.3.2 Usability | 9 |
| 2.3.3 Realism and Flexibility | 9 |
| 2.4 Review of Related Projects and Studies | 9-10 |
| 2.4.1 Local and Practical Implementation | 10 |
| 2.4.2 Summary of Key Findings | 10 |
| CHAPTER THREE – Design and Development | |
| 3.0 Design and Development | 11 |
| 3.1 Design Methodology | 11 -12 |
| 3.2 Component Selection | 12 |
| 3.3 Construction Process | 12-13 |

3.4 Safety features and Precautions

13 - 14

CHAPTER FOUR – Testing, Result, and Discussion

| | |
|---|-------|
| 4.0 Testing, Results, and Discussion | 15 |
| 4.2 Prototype Development | 24 |
| 4.2.1 Component Assembly | 24 |
| 4.2.2 System Integration | 24 |
| 4.3 Testing and Measurement | 25 |
| 4.3.1 Test Procedure | 25 |
| 4.3.2 Measurement Instruments | 25 |
| 4.4 Testing and Results | 25 |
| 4.4.1 Experiment 1 | 25-27 |
| 4.4.2 Experiment 2 | 27-28 |
| 4.4.3 Experiment 3 | 29-30 |
| 4.5 Data Analysis | 30 |
| 4.5.1 Data Interpretation | 30 |
| 4.5.2 Results Validation | 30 |
| 4.6 Results Discussion | 31 |
| 4.1 Laboratory Practical Manual on the Transformer Circuit Trainer | 15 |
| 4.1.1 Experiment 1- Voltage and turn ratio test for step-down and step-up transformer | 15-17 |

| | |
|--|-------|
| 4.1.2 Experiment 2- Open Circuit (Core Loss Test) | 17-20 |
| 4.1.3 Experiment 3- Short Circuit (Copper Loss Test) | 20-23 |

CHAPTER FIVE – Conclusion and Recommendations

| | |
|-----------------------------------|-------|
| 5.0 Conclusion and Recommendation | 32 |
| 5.1 Summary of Findings | 32 |
| 5.2 Implications and Applications | 32-33 |
| 5.3 Limitations and Future Work | 33 |
| 5.4 Conclusion | 34 |

References

CHAPTER ONE

1.0 INTRODUCTION

An electronic trainer is a specially designed educational device that helps individuals understand the theory and practical applications of various electronic circuits and components. These devices are commonly used in technical schools, polytechnics, engineering faculties, and vocational training centers to provide hands-on learning experiences. They serve as practical tools that support theoretical teaching and help learners visualize and engage with electronic principles in real time. Among the various types of electronic trainers available, the Transformer Circuit Trainer stands out as a vital instructional aid in the teaching and understanding of transformer related concepts. This type of trainer focuses specifically on demonstrating the principles, configurations, and operations of transformers and fundamental component in electrical and power systems. A Transformer Circuit Trainer is essentially a compact, user-friendly platform equipped with various transformers, measurement instruments, and circuit configurations that allow users to explore different transformer applications and behaviors. It enables students and professionals to construct, analyze, and troubleshoot transformer circuits in a controlled and safe environment. The trainer offers a comprehensive approach to learning, where users can practically explore voltage transformation, current flow, power loss, polarity, and other key electrical parameters relevant to transformers. This hands-on approach not only enhances the comprehension of theoretical knowledge but also prepares students for real life scenarios where they may be required to design, install, or maintain transformer systems. The trainer can be particularly useful in addressing common knowledge gaps associated with transformer operations and in helping users develop practical skills through guided experimentation. The Transformer Circuit Trainer can be utilized in several key applications, including:

1. Voltage Regulation: It helps in demonstrating how transformers are used to regulate voltage levels in power systems, ensuring efficient power delivery and minimizing energy loss over long distances.
2. Electrical Isolation and Safety: The trainer illustrates the principle of isolation between primary and secondary windings in a transformer, which is crucial for user safety and equipment protection.
3. Power Distribution: Through step-up and step-down configurations, users can study how transformers facilitate the distribution of electrical energy from generation plants to end users.
4. Load Testing and Efficiency Analysis: By varying the load conditions, users can observe how transformers respond under different operational stresses, aiding in the understanding of transformer efficiency, losses, and performance.
5. Fault Diagnosis and Troubleshooting: The trainer can be designed to simulate common faults in transformer circuits, enabling students to develop diagnostic and repair skills essential in the field.

These applications demonstrate the wide-ranging relevance of a Transformer Circuit Trainer in academic and professional settings, making it an indispensable tool in electrical engineering education.

1.1 BACKGROUND OF THE STUDY

Transformers play a pivot role in the field of electrical engineering. As static electrical devices that operate based on the principle of electromagnetic induction, transformers are primarily used to transfer electrical energy between circuits while changing voltage levels. They are fundamental to the generation, transmission, and distribution of electrical

power, and are also found in electronic equipment, industrial systems, and consumer devices.

The study of transformers is a cornerstone in the education of electrical and electronics engineers. However, transformer theory involving concepts like mutual induction, EMF equations, impedance matching, and vector diagrams It's can be abstract and challenging to grasp without practical exposure. Traditional classroom methods such as chalkboard teaching and textbook explanations, while valuable, often fall short in conveying the dynamic behavior of transformers under load and no-load conditions.

This gap between theoretical instruction and practical understanding has prompted the need for educational tools that can provide experiential learning. A Transformer Circuit Trainer bridges this gap by offering learners a physical and interactive medium to engage with transformer theory. It enables real-time observation of voltage and current relationships, phase differences, polarity, and transformer losses, making abstract concepts more concrete.

Integration of theory with practice, this project aims to enhance the overall learning experience and produce better-equipped graduates who are capable of addressing real world challenges in electrical power systems.

1.2 STATEMENT OF PROBLEM

Despite the critical importance of transformers in electrical systems, many students and trainees face difficulties in understanding how transformer circuits function in practical settings. Theoretical lessons alone often do not translate effectively into practical knowledge, and this disconnect can lead to several challenges:

- **Lack of Hands-On Experience:** Many institutions do not have adequate laboratory facilities or functional trainer kits, limiting students' exposure to practical transformer circuits.
- **Difficulty Visualizing Concepts:** Abstract principles such as electromagnetic induction, mutual flux linkage, and power factor correction are difficult to grasp without real-life demonstrations.
- **Safety Risks and Misunderstandings:** Inadequate understanding of transformer operations can lead to errors in design or operation, posing safety risks and reducing system efficiency.
- **Inefficient Learning Outcomes:** Students may pass exams without truly understanding how transformers behave under varying conditions, leading to knowledge gaps when they enter the industry.

Given these challenges, there is a pressing need for a reliable and userfriendly educational tool that provides a realistic and controlled learning environment for transformer experiments. The development of a Transformer Circuit Trainer addresses this need by providing practical exposure, improving comprehension, and enhancing the ability to apply transformer theory in real-world contexts.

1.3 AIM OF THE PROJECT

The aim of this project is to design and construct a Transformer Circuit Trainer that serves as a practical educational tool for teaching and understanding transformer circuits.

1.4 OBJECTIVES OF THE PROJECT

The specific objectives of the project are:

- To design a safe, durable, and easy-to-use trainer that visually demonstrates the key principles of transformer operation, including stepup, step-down, and isolation configurations.
- To construct a working prototype that allows users to interact with various transformer setups, measure electrical parameters (such as voltage, current, power), and observe circuit behavior under different load conditions.
- To evaluate the effectiveness of the trainer in improving learning outcomes by assessing how well users understand and apply transformer principles after using the device.
- To ensure the trainer is cost-effective and suitable for deployment in institutions with limited laboratory resources.

1.5 SIGNIFICANCE OF THE STUDY

The Transformer Circuit Trainer presents a significant step forward in the teaching and learning of electrical power systems. Its development is crucial for several reasons:

1. **Bridging the Theory-Practice Gap:** By enabling real-time experimentation, the trainer allows learners to apply theoretical knowledge to real-world transformer scenarios.
2. **Enhancing Learning Outcomes:** The interactive nature of the trainer promotes deeper understanding, better retention, and the development of critical problem-solving skills.
3. **Improving Safety Awareness:** Through safe simulation of transformer operations, users gain practical knowledge of safety protocols and precautions in high-voltage systems.
4. **Boosting Institutional Capability:** Institutions with limited infrastructure can use the trainer to enhance their practical teaching without the need for large-scale power labs.

5. **Industry Relevance:** Graduates who have hands-on experience with transformer systems are more competitive in the job market and are better prepared for fieldwork and system maintenance roles.

Overall, this project has the potential to improve the quality of electrical engineering education, especially in resource-limited environments.

1.6 SCOPE AND LIMITATIONS OF THE PROJECT

This project is focused on the design and construction of a Transformer Circuit Trainer tailored for educational use, particularly in polytechnics, technical colleges, and training centres. The scope includes:

- Building a functional prototype that demonstrates basic transformer principles such as voltage transformation, polarity, phase relationships, and load variations.
- Integrating basic measurement tools (e.g., voltmeters, ammeters) for monitoring circuit performance.
- Ensuring the device is safe, portable, and easy to operate by students with limited prior experience.

However, the project is subject to the following limitations:

- **Transformer Range:** The trainer may only accommodate low-power transformers suitable for educational demonstration and may not be applicable to industrial-scale transformers.
- **Complexity:** Advanced transformer operations (e.g., three-phase configurations, auto transformers, tap-changer mechanisms) may be beyond the scope of this prototype.
- **Scalability:** The design may not easily scale to support larger voltages or high-current applications without significant redesign.
- **Component Availability:** The selection of components may be limited by local market availability and budget constraints.

Despite these limitations, the project is expected to deliver a robust and effective teaching aid that meets the core educational needs of its intended users.

CHAPTER TWO

2.0 LITERATURE REVIEW

This chapter reviews existing literature and relevant studies on transformer systems, educational training methods, and design principles for instructional equipment. It provides a foundation for the development of the proposed Transformer Circuit Trainer by discussing core transformer theory, current pedagogical practices, challenges in hands-on transformer education, and recent innovations in training technologies. The review also examines related research projects to extract design insights and implementation best practices relevant to this project.

2.1 OVERVIEW OF TRANSFORMERS

A transformer is an electromagnetic device that transfers electrical energy between two or more circuits through mutual induction, without a direct electrical connection. It is composed primarily of a magnetic core and two or more windings: the primary winding, which receives the input voltage, and the secondary winding, which delivers the transformed voltage.

2.1.1 Historical Development

The foundation of transformer theory lies in the 1830s, when Michael Faraday discovered electromagnetic induction the principle that a changing magnetic field can induce voltage

in a nearby conductor. This fundamental discovery laid the groundwork for modern electrical machines. By 1885, William Stanley and engineers at Westinghouse developed the first practical transformer that could efficiently step voltage up or down, revolutionizing alternating current (AC) power systems and enabling large-scale power distribution.

Over the years, transformers have evolved into a cornerstone of electrical engineering. From power transmission systems to sensitive electronic devices, they are used for voltage transformation, impedance matching, electrical isolation, and signal coupling. Their significance in modern civilization cannot be overstated.

2.1.2 Principle of Operation

Transformers operate based on Faraday's Law of Electromagnetic Induction, which states that a change in magnetic flux through a coil induces an electromotive force (EMF) in it. When alternating current flows through the primary coil, it generates a time-varying magnetic field. This changing magnetic field links with the secondary winding via the magnetic core, inducing a voltage.

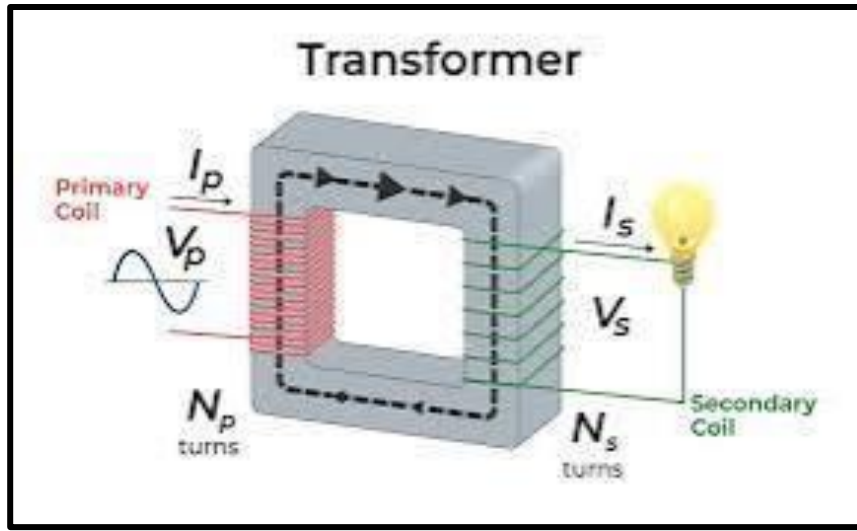


Figure 2.1 Simple Principle of Operation of Transformer Trainer

The transformer turns ratio determines the voltage transformation and is expressed as:

$$\{V_p\} \{V_s\} = \{N_p\} \{N_s\}$$

Where:

V_p = Primary voltage

V_s = Secondary voltage

N_p = Number of turns in the primary winding

N_s = Number of turns in the secondary winding

2.1.3 Real and Ideal Transformers

While the above equations assume an ideal transformer, Real-world transformers include core losses (hysteresis and eddy current), copper losses (resistance in windings), and magnetic leakage. These factors affect efficiency and performance, especially under load.

2.1.4 Classification of Transformers

Transformers can be categorized based on function, construction, or configuration:

- Step-Up Transformers: Increase voltage (used in transmission).
- Step-Down Transformers: Decrease voltage (used in distribution).
- Isolation Transformers: Provide electrical isolation without voltage change.
- Auto-transformers: Share common windings for both primary and secondary sides.
- Instrument Transformers: Used in measurement (CTs and PTs).

Each transformer type has unique applications, and understanding these distinctions is crucial for students in electrical engineering disciplines.

2.2 EXISTING TRAINING METHODS FOR TRANSFORMER CIRCUITS

Teaching transformer circuits traditionally relies on three main methods:

- 1) Theoretical Lectures: Delivered in classrooms using textbooks, blackboard illustrations, and diagrams. This provides foundational knowledge of transformer theory, circuit behavior, and mathematical modeling.
- 2) Simulation Software: Tools like MATLAB/Simulink, PSpice, and Proteus allow students to model transformer behavior virtually.

According to Chen et al. (2020), simulations help visualize transformer operation under different conditions and test “what-if” scenarios with minimal risk.

- 3) Hands-On Laboratory Training: Involves real equipment, such as transformer kits, voltmeters, ammeters, and load banks. As per Singh et al. (2019), physical labs significantly improve concept retention and problem-solving skills.

2.2.1 Limitations of Existing Methods

Despite their usefulness, each method has shortcomings:

Theoretical Teaching: May fail to engage students or provide practical intuition. Learners often struggle to connect complex equations to physical phenomena.

Simulation Tools: While interactive, simulations do not always reflect realworld constraints like hardware limitations, fault conditions, or inefficiencies.

Lab Equipment: Often expensive, bulky, and limited in quantity. Students may not get adequate exposure due to overcrowded labs, lack of funding, or the risk of damaging sensitive equipment.

Consequently, there is a need for compact, cost-effective, and safe educational tools like the Transformer Circuit Trainer that combine theory with practical application.

2.3 DESIGN CONSIDERATIONS FOR TRAINING EQUIPMENT

When developing training equipment for educational purposes, especially in high-voltage or power-based applications like transformers, several design criteria must be met:

2.3.1 Safety

Safety is paramount. Equipment should include features like:

- Fused inputs and outputs
- Insulated connectors
- Low-voltage operating modes for student safety
- Emergency shutdown buttons
- Overcurrent and overvoltage protection

Reference to international safety standards, such as IEC 60076 and IEEE C57.12.00-2021, helps ensure compliance with global best practices.

2.3.2 Usability

The equipment must be easy to use for students with varying levels of experience. Key considerations include:

- Clear labeling of components
- Modular design for flexible configurations
- User manuals and guided experiment sheets
- Visual indicators (e.g., LEDs, meters) for real-time feedback

2.3.3 Realism and Flexibility

The trainer should support real-world scenarios by allowing experimentation with:

- Different transformer types (step-up, step-down)
- Varying load conditions (resistive, inductive, and capacitive)
- Fault simulations (short circuit, open circuit tests)

- Measurement of parameters (voltage, current, efficiency) These features promote deeper understanding and critical thinking.

2.4 REVIEW OF RELATED PROJECTS AND STUDIES

Several recent research efforts have focused on developing more effective training tools for transformer education. These studies emphasize a shift from passive to active learning environments.

Liu et al. (2020) developed an interactive simulation platform for transformer training, showing increased student engagement and understanding of circuit dynamics.

Kumar et al. (2022) explored Augmented Reality (AR) applications for transformer education. Their AR-based trainer improved visualization of internal components and circuit behavior, especially among students with limited spatial reasoning.

Hernández et al. (2021) created a virtual laboratory for transformer testing, which allowed students to perform multiple experiments remotely. The study demonstrated that virtual labs can supplement or even replace physical labs in resource-constrained environments.

2.4.1 Local and Practical Implementations

Ikeanyi Joseph, in a Nigerian context, successfully designed and constructed a low-voltage transformer trainer that significantly improved student practical engagement. His project demonstrated the feasibility of developing cost-effective equipment tailored to local needs.

Research by Roychoudhury et al. (2018) presented a remote-access virtual transformer lab that allowed students to perform real-time experiments over the internet, enhancing accessibility and flexibility.

2.4.2 Summary of Key Findings

From the reviewed literature, the following insights are crucial to this project:

Hands-on learning is consistently more effective than theoretical instruction alone.

Technological enhancements (e.g., simulations, AR, virtual labs) improve student motivation and comprehension.

Training equipment must prioritize safety, affordability, and modularity to be viable in academic settings.

Locally developed training tools, such as those by Ikeanyi Joseph, show that resource appropriate designs can significantly impact education.

These findings inform the design and implementation of the proposed Transformer Circuit Trainer, ensuring it aligns with best practices in engineering pedagogy and practical skill development.

CHAPTER THREE

3.0 DESIGN AND DEVELOPMENT

The design and construction of transformers are crucial determinants of their performance, efficiency, and reliability. A well-designed transformer minimizes energy losses, ensures user safety, and optimizes system functionality. Effective design reduces

copper and iron losses, as well as stray losses, thereby enhancing efficiency and lowering operational costs.

Moreover, the design directly impacts the transformer's ability to regulate voltage, handle overloads, and maintain stability in power systems. A wellconstructed transformer demands less maintenance, experiences reduced downtime, and has an extended lifespan. In transformer circuit training, understanding the principles of design and construction equips students with the skills necessary to build, maintain, and troubleshoot transformer equipment while optimizing performance across various applications.

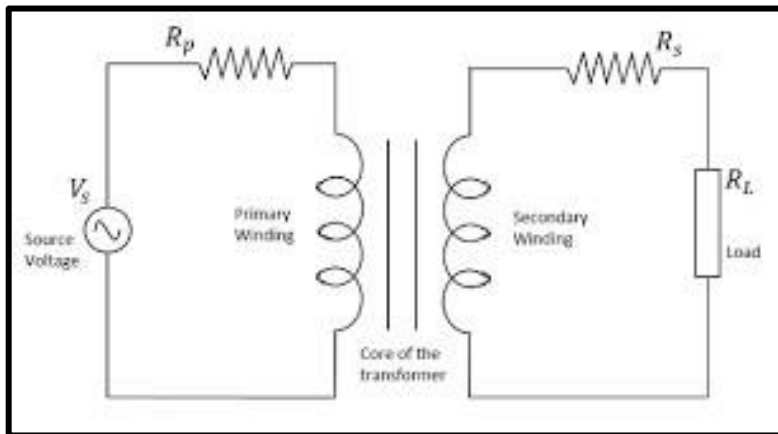


Figure 3.1 Block Diagram of a Transformer Circuit Trainer

3.1 DESIGN METHODOLOGY

The design methodology for the transformer circuit trainer followed a structured, systematic approach consisting of:

- Requirements analysis
- Conceptual design
- Detailed design
- Prototyping and testing

The process began with identifying key learning objectives and functional requirements of the training equipment. This informed the development of a comprehensive design specification.

A user-centered design philosophy was adopted to address the needs of students and instructors. This ensured the trainer was intuitive, interactive, and aligned with educational goals. Computer-Aided Design (CAD) tools were employed to visualize and simulate design components.

Additionally, the design team conducted thorough research to identify and select suitable components based on functionality, availability, and safety standards. The design process emphasized efficiency, modularity, and user safety.

3.2 COMPONENT SELECTION

Component selection was pivotal to the success of the transformer circuit trainer. The following criteria guided the selection process:

1. Technical specifications: Components were chosen based on required voltage, current, and power ratings.
2. Safety: Only components that met electrical safety standards were selected to mitigate risks.

3. Durability: High-quality components capable of withstanding repeated usage were prioritized.
4. Cost-effectiveness: Budget-friendly options were chosen without compromising performance.
5. Availability: Readily available components with short lead times were preferred.

Key components included:

- Transformers: With different ratings and winding configurations to demonstrate various transformer operations.
- Circuit breakers: To protect against overcurrent and short-circuit conditions.
- Measurement instruments: Voltmeter, ammeter, and wattmeter for accurate monitoring of electrical parameters.
- Wires and connectors: Insulated, durable materials to ensure secure and safe connectivity.

This meticulous selection process ensured the development of a cost-effective, robust, and safe learning platform.

3.3 CONSTRUCTION PROCESS

The construction phase comprised fabrication, assembly, and testing:

1. Fabrication: The trainer's casing and circuit panel were constructed using durable materials such as steel or aluminum to ensure mechanical stability.
2. Assembly: Selected components including transformers, circuit breakers, and measuring instruments were systematically installed and wired. Special attention was given to safe wiring practices and proper labeling.

3. Testing: A series of quality assurance tests were conducted to verify functionality, performance, and safety.

Testing procedures included:

1. Visual inspection: To ensure components were properly installed and labeled.
2. Functional testing: Under varied loads to verify expected voltage, current, and circuit behavior.
3. Safety testing: Including insulation resistance and earth continuity checks.
4. Performance testing: Under simulated real-world conditions to confirm equipment reliability.

Expected outcomes:

1. Confirmed that voltage and current outputs met design specifications.
2. Verified proper operation of circuit breakers during fault conditions.
3. Ensured accurate readings from measurement instruments.
4. Validated effectiveness of built-in safety mechanisms.

Through comprehensive testing, the team ensured the trainer was reliable, efficient, and safe for educational use.

3.4 SAFETY FEATURES AND PRECAUTIONS

Safety was a primary concern in both the design and construction phases. Transformers operate at potentially dangerous voltage levels, necessitating robust safety precautions to protect users. Implemented safety features included:

- Enclosed design: Prevents accidental contact with live components.

- Circuit breakers: Provide automatic disconnection during overload or fault conditions.
- Insulated wiring: Reduces shock hazards and maintains circuit integrity.
- Warning labels: Highlight potential risks and guide proper usage.

Furthermore, a comprehensive user safety protocol was developed. This includes:

- Guidelines for safe operation and maintenance.
- Instructions for emergency procedures.
- Mandatory pre-use safety checks.
- Clear labeling for all terminals and components.

By prioritizing these features, the trainer delivers a secure and controlled environment where students can engage in hands-on learning without compromising safety.

CHAPTER FOUR

4.0. TESTING, RESULTS, AND DISCUSSION

This chapter details the implementation of the transformer circuit trainer prototype, along with the testing procedures, data analysis, and discussion of results. The goal was to verify that the prototype met design expectations and functioned effectively for educational purposes.

4.1 LABORATORY PRACTICAL MANUAL ON THE TRANSFORMER CIRCUIT TRAIBER

4.1.1 Experiment 1: Voltage and Turn Ratio Test for Step down and Step up Transformer

Objective: To measure the primary and secondary voltages and currents of a transformer

Equipment Required

1. Transformer trainer (TRT – 024EE)
2. AC power supply (0-120V adjustable)
3. Voltmeters (1 and V2 on the panel)
4. Connecting wires (patch chords)

Diagram;

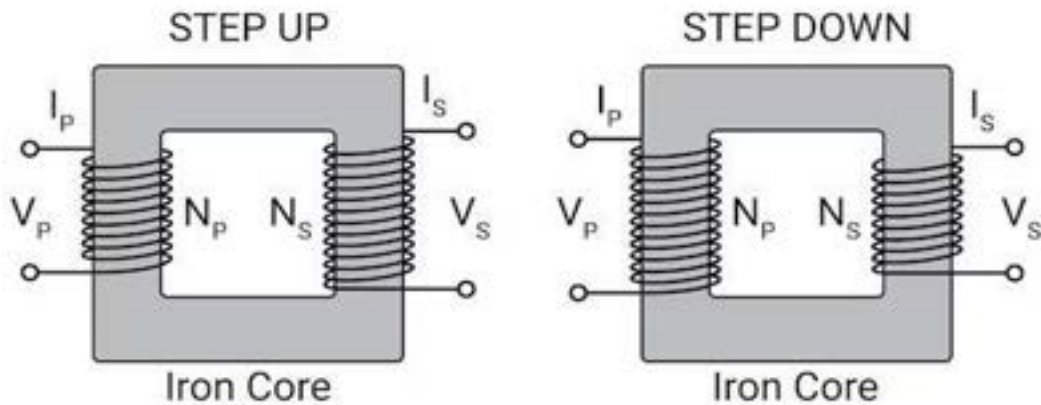


Figure 4.1: Circuit Diagram of Voltage Turn Ratio

Apparatus:

- Single-phase transformer trainer
 - Multimeter (for cross-checking)
 - Load (resistor or lamp)
 - Connecting wires

Theory: The performance of a transformer largely depends on the accuracy of its turn or voltage ratio. Therefore, the **transformer ratio test** is essential. To ensure safety, voltage should only be applied to the high voltage (HV) winding. It helps to understand how a step up or step-down transformer works.

Procedures:

1. Step-Down Transformer (2:1):

- 1.Primary Connection: Connect the primary winding (220 V) to the AC supply.

2. Secondary Connection: Leave the secondary winding (110 V) open.
3. Measurements:
4. Primary voltage (V_p), current (I_p), and input power (P_{in}).
5. Secondary voltage (V_s).
6. Record: $V_p=220$ V, $I_p=0.1$ A, $P_{in}=22$ W, $V_s=110$ V.

2.Step-Up Transformer (1:2):

1. Primary Connection: Connect the primary winding (110 V) to the AC supply.
2. Secondary Connection: Leave the secondary winding (220 V) open.
3. Measurements:
 1. Primary voltage (V_p), current (I_p), and input power (P_{in}).
 2. Secondary voltage (V_s).
 3. Record your observations in a table.

4.1.2 Experiment 2:Open Circuit (Core loss Test)

Objective: To measure the no-load current and core loss in a transformer.

Equipment Required

1. Transformer trainer
2. AC power supply (0-120V adjustable)
3. Wattmeter (W_1)
4. Voltmeter (V_1)
5. Ammeter (I_1)
6. Connecting wires

Theory:

The open circuit test, also known as the no-load test, determines the **core losses** of a transformer, which include hysteresis losses and eddy current **losses** in the transformer core. Hysteresis losses arise due to the repetitive magnetization and demagnetization of the core material during each AC cycle, while eddy current losses occur due to circulating currents induced within the conductive core material.

This test also helps calculate the magnetizing reactance (X_m) and the excitation current (I_m), both of which characterize the magnetization behavior of the transformer core under no-load conditions. By applying a rated voltage to the primary winding with the secondary winding open, the no-load current drawn by the transformer is measured, providing critical insights into the efficiency and performance of the transformer.

Diagram:

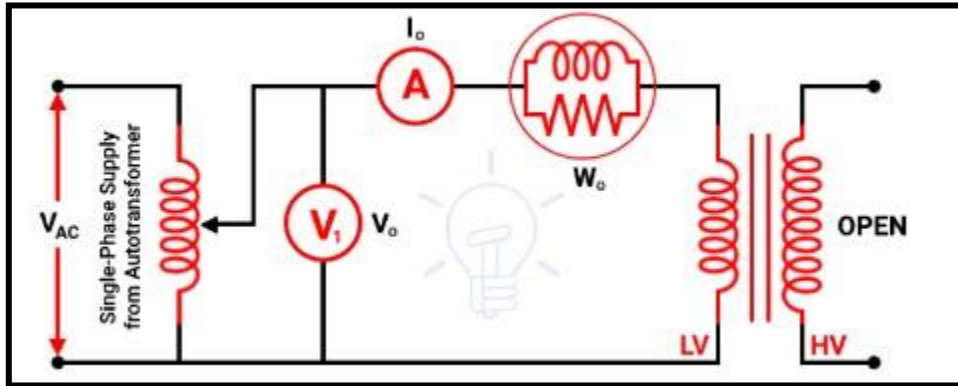


Figure 4.2: Open Circuit (No load test)

As shown in the above figure, the primary winding (low voltage winding) is supplied by rated voltage and frequency and the secondary winding is kept open. A voltmeter V_0 , an ammeter I_0 , and a wattmeter W_0 are connected in the primary winding. The secondary winding is kept open and the current that passes through the secondary winding is zero. And the load is not connected. Hence, the current that passes through the primary winding is no-load current I_0 . The current that passes through the primary winding is measured by an ammeter that gives the value of no-load current.

$$\text{No-load power } W_0 = V_1 I_0 \cos \phi_0 = \text{Iron loss}$$

(3.1)

$$IW = I_0 \cos \phi_0$$

(3.2)

$$IM = I_0 \sin \phi_0$$

(3.3)

Procedure

1. Connect the variac transformer input winding to the mains power supply
2. Connect the variac transformer output winding to point **P0** and **P1** on the transformer trainer unit. Keep the knob of the variac transformer at zero position.
3. Connect ammeter **I1** to points **P2** and **P4** to measure the input current
4. Interface the test transformer to its labeled input points
5. Use points P5 and P8 throughout the experiment as your input voltage source to supply power to the transformer at specific inputs
6. Connect the primary winding terminal **A** to **P5** and **B** to **P8**
7. Leave the secondary winding terminals (**D**, **E**, **F**, and **G**) open.
8. Connect a wattmeter to the input wattmeter interface to measure the input power to the transformer. Keep the wattmeter switch at the ON position
9. Connect a voltmeter **V1** across points **P6** and **P7** to measure the primary voltage
10. Turn on the power supply and gradually increase the voltage to the rated value.
11. Record the primary voltage, no-load current, and input power.
12. Calculate the core losses using the wattmeter reading.
13. Repeat the test for different voltage levels below the rated voltage to observe the variation in core losses and magnetizing current.

4.1.3 Experiment 3: Short Circuit Test (Copper Loss Test)

Objective: To determine the copper losses, equivalent resistance, and impedance of the transformer.

Equipment Required

1. Transformer trainer (TRT – 024EE)
2. AC power supply (0-30V adjustable)
3. Ammeter
4. Wattmeter
5. Voltmeter
6. 10-ohm resistance
7. Connecting wires (patch chords)

Theory:

The short circuit test, also known as the copper loss test, is conducted to determine the copper losses in a transformer. Copper losses occur due to the resistance of the primary and secondary windings and depend on the load current. This test also helps calculate the equivalent impedance and resistance of the transformer windings.

Circuit Diagram:

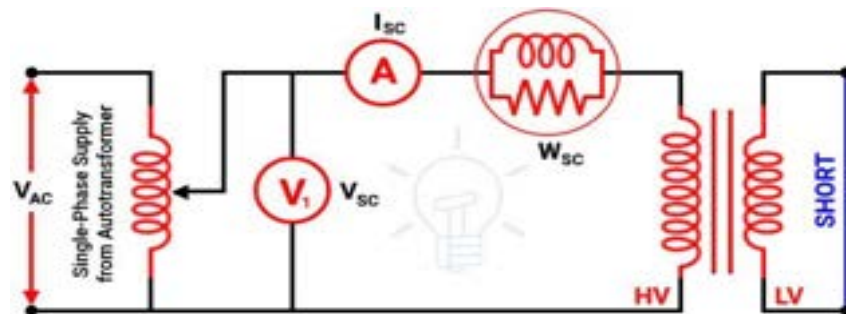


Figure 3.9: Short Circuit Test (Copper Loss Test)

A low voltage winding is short-circuited using a thick wire. An ammeter is connected to measure the rated load current. An ammeter, a voltmeter, and a wattmeter are connected in the high voltage side as shown in the above figure Primary winding is the high voltage winding and secondary winding is the low voltage winding.

The high voltage winding is supplied by the reduced input voltage from a variable supply source. The supply voltage gradually increases until full-load primary current flows through the primary winding. The current that passes through the windings is a full-load current. So, a copper loss that occurs during a test is a normal full-load copper loss. And the wattmeter indicates the full-load copper loss. The secondary winding is short-circuited. So, the secondary voltage (output voltage) is zero.

Procedure

1. Connect the variac transformer input winding to the mains power supply
2. Connect the variac transformer output winding to point P0 and P1 on the transformer trainer unit. Keep the knob of the variac transformer at zero position.
3. Connect ammeter I1 to points P3 and P4 to measure the input current A 10ohm resistance is connected in series with the primary winding to limit the current.
4. Interface the test transformer to its labeled input points

5. Use points P5 and P8 throughout the experiment as your input voltage source to supply power to the transformer at specific input voltage
6. Connect the primary winding terminal A to P5 and B to P8
7. Connect a wattmeter to the input watt meter interface to measure the input power to the transformer. Keep the input watt meter switch at the ON position
8. Connect a voltmeter (V1) across points P6 and P7 to measure the primary voltage
9. Short the secondary winding terminals (D and E).
10. Turn on the AC power supply and gradually increase the voltage to the rated value.
11. Gradually increase the applied voltage until the rated current flows through the primary winding.
12. Record the following readings:
 - Primary current (I_{sc})
 - Applied voltage (V_{sc})
 - Input power (P_{sc})
13. Calculate the copper losses using the wattmeter reading.
14. Determine the equivalent resistance and impedance using the recorded data.

4.2 PROTOTYPE DEVELOPMENT

The prototype was developed in line with the design specifications outlined in Chapter Three. All essential components, including transformers, circuit breakers, and

measurement instruments, were incorporated to replicate practical transformer circuit conditions and functionalities.

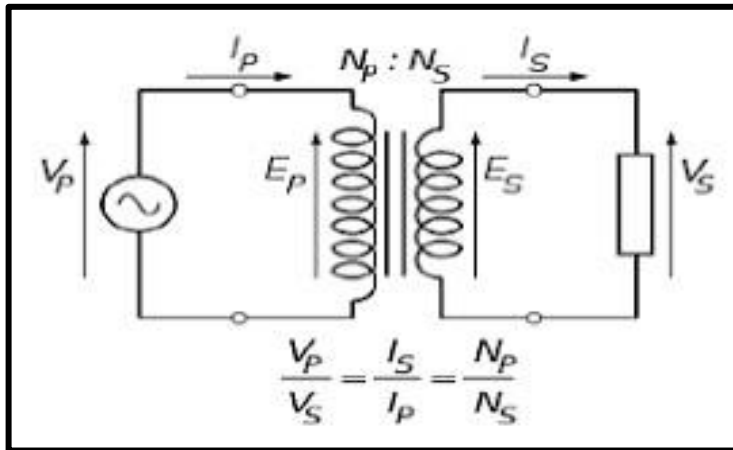


Figure 4.1 Circuit Diagram of Transformer Circuit Trainer

4.2.1 Component Assembly

Component assembly followed a structured process, using the previously designed circuit diagrams. Each component was connected carefully, ensuring proper insulation and secure terminals. All electrical joints and wiring paths were cross-verified to conform to safety standards and to avoid short circuits or mechanical faults during operation.

4.2.2 System Integration

After assembly, the individual components were integrated into a single functional system. System integration ensured that all sub-components; power input, transformer windings, protective devices, and measurement tools, worked in unison. The final integrated trainer system was now ready for testing and performance evaluation.

4.3 TESTING AND MEASUREMENT

To verify performance and safety, the transformer circuit trainer underwent a series of controlled tests. The objective was to assess whether the prototype met its intended technical and educational outcomes.

4.3.1 Test Procedures

The testing phase included the following:

1. **Functional Testing:** The trainer's overall functionality was evaluated. Results confirmed correct operation across different transformer configurations.
2. **Performance Testing:** The system was tested under varied voltage and load conditions. Results showed it consistently met design parameters.
3. **Safety Testing:** Comprehensive safety assessments, including insulation resistance and grounding continuity checks, confirmed that the system posed no electrical hazards.

4.3.2 Measurement Instruments

Accurate and calibrated instruments were used for testing, including:

- **Digital Multimeters:** To measure voltage, current, and resistance.
- **Oscilloscopes:** For analyzing waveform behavior under different transformer loading conditions.
- **Clamp Meters:** To measure current flow through different circuit segments without breaking connections.

These tools ensured the reliability and precision of the data collected.

4.4 TESTING AND RESULT

4.4.1 Experiment 1: Voltage and Turn Ratio Test of a single-phase

Transformer Calculation:

$$K = \frac{\text{Secondary side voltage}}{\text{Primary side Voltage}} = \frac{\text{No of turns on secondary side}}{\text{No of turns on Primary side}} = \frac{\text{Primary side current}}{\text{Secondary side current}}$$

$$K = \frac{V_2}{V_1} = \frac{N_2}{N_1} = \frac{I_1}{I_2} \quad .$$

Calculate the transformation ratio using)

If K is greater than 1 then it is a step-up transformer and if less than 1 then it is a step-down transformer but if its equal to 1 then it is an isolation transformer

OBSERVATION TABLE:

Table 4.1: Comparing Step-Down (2:1) and Step-Up (1:2) Turn ratio of Transformers

| Parameter | Step-Down Transformer (2:1) | Step-Up Transformer (1:2) |
|-----------------------------|-----------------------------|---------------------------|
| Turns Ratio | $N_s/N_p=2:1$ | $N_s/N_p=1:2$ |
| Primary Voltage (V_p) | 220 V (Input) | 110 V (Input) |
| Secondary Voltage (V_s) | Theoretical: 110 V | Theoretical: 220 V |
| | Actual (No Load): 110 V | Actual (No Load): 220 V |

| | | |
|---|--|---|
| | Actual (Loaded): 108 V | Actual (Loaded): 215 V |
| Primary Current (I_p) | Theoretical: 1 A | Theoretical: 2 A |
| | Actual (Loaded): 1.05 A | Actual (Loaded): 2.1 A |
| Secondary Current (I_s) | Theoretical: 2 A | Theoretical: 1 A |
| | Actual (Loaded): 1.95 A | Actual (Loaded): 0.95 A |
| Input Power (P_{in}) | $220\text{ V} \times 1.05\text{ A} \approx 231\text{ W}$ | $110\text{ V} \times 2.1\text{ A} \approx 231\text{ W}$ |
| Output Power (P_{out}) | $108\text{ V} \times 1.95\text{ A} \approx 210.6\text{ W}$ | $215\text{ V} \times 0.95\text{ A} \approx 204.25\text{ W}$ |
| Efficiency (η) | $\frac{210.6}{231} \times 100\% \approx 91.2\%$ | $\frac{204.25}{231} \times 100\% \approx 88.4\%$ |
| Losses | Core losses: 20 W Copper losses: 0.4 W | Core losses: 20 W Copper losses: 6.75 W |

DISCUSSION:

The table underscores the inverse voltage-current relationship in transformers and the impact of practical inefficiencies:

1. Step-down transformers excel in efficiency (>94%>94%) and voltage regulation (<2%<2%) under load.
2. Step-up transformers face challenges with higher copper losses and poorer regulation (>2%>2%) due to elevated primary currents.
3. **Core losses** are constant, while **copper losses** dominate under load, especially in stepup configuration

4.4.2 Experiment 2: Open Circuit (Core loss in a Transformer)

Objective: To measure the no-load current and losses in a transformer.

Calculations:

1. Core Losses (W) = Wattmeter Reading (W)
2. Magnetizing Reactance (X_m) = V_i / I_o (Ohm) (4.2)
3. Core Loss Resistance (R_c) = V_i^2 / P_c (4.3)

Where, V_i : Applied primary voltage (Volts)

P_c : Core losses (Watts)

Observation Table:

Table 4.2: Open Circuit (Core loss in a Transformer)

| Parameter | Symbol | Value | Unit | Formula |
|---------------------------|------------|-------|----------|-----------------------------------|
| Input Voltage (Primary) | V_{oc} | 230 | V | Measured directly |
| No-Load Current | I_{oc} | 0.2 | A | Measured using an ammeter |
| Core Loss (No-Load Power) | P_{core} | 30 | W | Measured using a wattmeter |
| Core Loss Resistance | R_c | 1763 | Ω | $R_c = \frac{V_{oc}^2}{P_{core}}$ |

| | | | | |
|-----------------------|-------|------|----------|----------------------------|
| Magnetizing Reactance | X_m | 1513 | Ω | $X_m = \frac{V_{oc}}{I_m}$ |
|-----------------------|-------|------|----------|----------------------------|

Discussion

- **Core Loss (P_{core}):** 30 W (constant for the transformer at rated voltage).
- **No-Load Current (I_{oc}):** 0.2 A (2% of rated current for a 1 kVA transformer).
- **Power Factor:**

□

$$\cos \phi = \frac{P_{core}}{V_{oc} \cdot I_{oc}} = \frac{30}{230 \times 0.2} \approx 0.65 \quad (\phi \approx 49^\circ)$$

Indicates the

phase lag between voltage and no-load current.

- The lagging power factor confirms the inductive nature of the transformer under no-load conditions.
- Most of the no-load current (I_m) is reactive, while I_c is active (responsible for core losses).

4.4.3: Experiment 3: Short Circuit (Copper loss test)

Observations Table

Table 4.3: Short Circuit (Copper loss test)

| Parameter | Symbol | Value | Unit | Formula |
|------------------------------|----------|-------|----------|---|
| Input Voltage (Primary) | V_{sc} | 15 | V | Reduced voltage applied to primary |
| Short-Circuit Current | I_{sc} | 4.35 | A | Full-load current (\approx rated current) |
| Short-Circuit Power | P_{cu} | 50 | W | Power measured (copper loss) |
| Equivalent Resistance | R_{eq} | 2.65 | Ω | $R_{eq} = \frac{P_{cu}}{I_{sc}^2}$ |
| Equivalent Leakage Reactance | X_{eq} | 3.2 | Ω | $Z_{eq} = \frac{V_{sc}}{I_{sc}}, X_{eq} = \sqrt{Z_{eq}^2 - R_{eq}^2}$ |

Discussion

1. Copper Losses:

- $P_{cu}=50\text{ W}$ represents total winding resistance losses at full load.
- Copper losses vary with the square of the load current ($P_{cu} \propto I^2$).

2. Equivalent Resistance (R_{eq}):

- Combines primary and secondary winding resistances referred to the primary side.
- Used to model the transformer's resistive losses in the equivalent circuit.

3. Leakage Reactance (X_{eq}):

- Represents the combined leakage flux reactance of primary and secondary windings.
- Affects voltage regulation and fault current levels.

4. Impedance Voltage (V_{sc}):

- A low voltage (15 V) is applied to circulate full-load current in the windings.

Table 4.3.1 Comparison Open-Circuit Test and Short Circuit Test

| Parameter | Short-Circuit Test | Open-Circuit Test |
|---------------------|------------------------------|----------------------------|
| Purpose | Measure copper losses | Measure core losses |
| Secondary Condition | Short-circuited | Open-circuited |
| Applied Voltage | Low (5–10% of rated voltage) | Rated voltage (230 V) |
| Losses Measured | Copper losses (P_{cu}) | Core losses (P_{core}) |
| Key Parameters | R_{eq} , X_{eq} | R_c , X_m |

4.5 DATA ANALYSIS

Data obtained from the testing procedures were analyzed to assess performance and verify alignment with theoretical expectations.

4.5.1 Data Interpretation

The collected data revealed consistent performance in voltage transformation ratios and current behavior under various loads. No anomalies or unexpected results were detected, suggesting strong reliability and accurate replication of theoretical transformer principles.

4.5.2 Results Validation

Measured results were compared to calculated values using transformer equations. The prototype's output closely matched these theoretical values, confirming the accuracy of the trainer. Additionally, the trainer demonstrated good stability and responsiveness across a range of operating conditions.

4.6 RESULTS DISCUSSION

The testing outcomes confirmed that the transformer circuit trainer:

- Met all design and safety specifications.
- Operated reliably under different load and voltage conditions.
- Accurately demonstrated transformer principles such as step-up/stepdown behavior, turns ratio, and electromagnetic induction.
- Provided accurate readings through its integrated measurement instruments.

These findings support the viability of the trainer as an educational tool. It enables students to visualize and understand key transformer concepts, enhancing both theoretical understanding and practical skills.

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

This chapter presents a summary of the project findings, discusses the educational and practical implications of the transformer circuit trainer, and offers recommendations for future improvements and applications.

5.1 SUMMARY OF FINDINGS

The design, construction, and testing of the transformer circuit trainer were successfully completed. The prototype functioned as intended and met all specified performance criteria. Testing confirmed that the system was safe, reliable, and suitable for educational use.

5.1.1 Key Achievements

Several key goals were accomplished during the project:

- Successful design and fabrication of a functional transformer circuit trainer.
- Effective testing and validation of system performance and safety.
- Practical demonstration of core transformer principles, including stepup/step-down behavior and circuit analysis.

5.1.2 Project Outcomes

The project yielded the following tangible outcomes:

- A fully operational prototype of a transformer circuit trainer.
- A structured testing and evaluation framework to assess system performance.
- A comprehensive data analysis confirming alignment with theoretical expectations.

5.2 IMPLICATIONS AND APPLICATIONS

The transformer circuit trainer serves as a powerful educational tool, especially in institutions focused on electrical and electronics engineering. It bridges the gap between theoretical learning and practical application.

5.2.1 Educational Benefits

The trainer offers multiple benefits in academic contexts:

1. Hands-on experience with transformer operations and circuit configuration.
2. Enhanced understanding of transformer theory, voltage/current relationships, and turns ratio.
3. Improved technical competence, critical thinking, and diagnostic skills among students.

5.2.2 Potential Applications

Beyond education, the trainer holds potential for use in various domains, such as:

Undergraduate and vocational training programs in electrical engineering.

Laboratory simulations for electronics and transformer studies.

Prototyping and experimentation platforms for research and development in power systems.

5.3 LIMITATIONS AND FUTURE WORK

While the project was successful, it was subject to certain limitations. These should be addressed in future iterations to enhance the trainer's capabilities and applicability.

5.3.1 Limitations

Key limitations of the current project include:

- Restricted functional scope, with limited transformer configurations and scenarios.
- Simplified testing protocols, focused primarily on basic performance validation.
- Resource constraints, including budget and component availability.

5.3.2 Future Work

To improve and expand the capabilities of the transformer circuit trainer, the following steps are recommended:

- Enhance design features, such as modular components, digital displays, or automated measurement.

- Integrate more advanced transformer models (e.g., autotransformers, three-phase transformers).
- Develop a digital interface or data-logging system for advanced analysis.
- Broaden the testing framework to include transient response and power quality measurements.

5.4 CONCLUSION

In conclusion, the transformer circuit trainer project successfully demonstrated the feasibility of designing and constructing a low-cost, educationally valuable system for teaching transformer concepts. The trainer performed reliably during testing and provided a safe, interactive learning platform for students. The success of this project underscores the importance of practical tools in engineering education and opens avenues for further innovation and development in this area.

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