Automatic 0 to 3150kVA Distribution Transformer Winding Machine using PLC, VFD, HMI.

A Project report is submitted in partial fulfillment of the requirements for the award of Degree of Bachelor of Science in Electrical and Electronic Engineering.

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DECLARATION

I hereby declare that this project "**Automatic 0 to 3150kVA Distribution Transformer Winding Machine using PLC, VFD, HMI**" represents my work, which has been done in the laboratories of the Department of Electrical and Electronic Engineering under the Faculty of Engineering of Daffodil International University in partial fulfillment of the requirements for the degree of Bachelor of Science in Electrical and Electronic Engineering and has not been previously included in a thesis or dissertation submitted to this or any other institution for a degree, diploma or other qualifications. I have attempted to identify all the risks related to this research that may arise in conducting this research, obtained the relevant ethical and/or safety approval (where applicable), and acknowledged my obligations and the rights of the participants.

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APPROVAL

The project and thesis entitled **"Automatic 0 to 3150kVA Distribution Transformer Winding Machine using PLC, VFD, HMI"** submitted by **Md Ashiqueuzzaman Rupom, ID:221-33-1535; Adbullah Al Nisat**, **ID: 221-33-1536;** & **Nafisa Tanjin ID: 221-33-1679**, Session: Summer 2024 have been accepted as satisfactory in partial fulfillment of the requirements for the degree of **Bachelor of Science in Electrical and Electronic Engineering** in **October 25.**

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Dedicated

To

Our Father & Mother

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List of Abbreviations

PLC	Programmable Logic Controller
VFD	Variable Frequency Drive
HMI	Human Machine Interface
SMPS	Switch Mode Power Supply
MBUS	Modbus Communication
RS232	Serial Communication
RS485	Serial Communication
TP	Tripple Pole
LD	Ladder Diagram
DOP Soft	Delta HMI Software
ES	Emergency Stop Switch
SS	Selector Switch
PBS	Push Button Switch
LS	Limit Switch
PDS	Pedal Switch
I/O	Input Output
I/P	Input
O/P	Output
PID	Proportional Integral Derivative
EMR	Environmental Management Review
EPA	Electronic prior authorization
IUCN	International Union for Conservation of Nature
WWF	World Wide Fund
IEA	International Energy Agency
UNEP	United Nations Environment Program
CI	Conservation International

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ABSTRACT

The Automatic 0-3150 kVA Transformer Coil Winding Machine revolutionizes the coil winding process for distribution transformers by integrating advanced automation technologies, including PLC (Programmable Logic Controller), VFD (Variable Frequency Drive), HMI (Human-Machine Interface), encoder, and gear motor. With this system, production is streamlined, accurate and is guaranteed as some of the important functions like counting the layers of coils, controlling tension, and manipulating the speed of the motors become automatic. The PLC is the central controller communicating with the HMI and VFD through Modbus RS232 and RS485 protocols giving operators the facility to program the parameters, such as coil patches, motor speed and tap changer settings with real time monitor performance of the system. This automated solution is far more productive as compared to conventional manual winding method where 3-4 employees require 1-3 coils per day, far less coils are produced compared to the automated one. It also eliminates the human error in patch numbers or winding tension, therefore, producing high quality of the coil and the transformer. This machine will be cost and scale-efficient in terms of companies dealing with current transformer manufacturing as it can reduce labor expenses, limit the time of production, and increase the precision of work due to Industry 4.0 specifications on modern automatized processes and smart computing.

Keywords:

i. ***Transformer winding machine,***
ii. ***Automation***
iii. ***Modbus,***
iv. ***PLC,***
v. ***HMI***

CHAPTER 1

INTRODUCTION

1.1 Background of the Research

The need of efficient and dependable electrical power distribution has boosted the production of the distribution transformers which play a most important role in the power networks during transmission of the stepped-up voltages to more useable levels to the residential, commercial and industries sectors. Out of all the transformer manufacturing steps, placing transformer coils is one of the labor-intensive processes that require high levels of accuracy. In large scale production of distribution transformers of 0 to 3150 kVA, accuracy, consistency and speed of the winding process should be maintained as a form of quality assurance and operating efficiency.

A transformer winding traditionally is carried out by manual or by semi-automated machine steps [1]. These methods are usually time-consuming, prone to error and operator skills-based. Ergonomically problematic issues and the potential danger factors can also be seen in relation to manual winding because of the repetitive character and heavy-loads moving around [2]. In addition, performance loss, failure of insulation and shortened life of transformers can be caused by the lack of consistency in winding tension, number of turns and placement of coils. Increased complexity and projected size of transformer manufacturing require the transition to fully automated systems of transformer windings which provide the high levels of precision, repeatability and real-time monitoring of the process.

Programmable Logic Controllers (PLC), Variable Frequency Drives (VFD) and HumanMachine Interfaces (HMI) technologies are an excellent solution that can be utilized to modernize the transformer coil winding systems [3]. The PLCs offer strong and flexible sequencing and counting logic as well as safety logic controls. With VFDs, the speed of winding motors can be controlled very accurately, so that the wire tension is at all times constant, and the difference between the types of the conductors and winding diameters can be met [4]. HMI enable interaction of the operator in real-time, recipe selection, monitoring of parameters, and diagnostics of faults using a user-friendly interface [5].

The application of these technologies in an automatic winding machine, turned on 0-3150 kVA transformers will have great value:

- Improved accuracy and repeatability in winding dimensions and turn count.
- Enhanced productivity through reduced manual intervention and cycle times.
- Minimized human error and fatigue, resulting in better coil quality.
- Scalability to support various transformer sizes and winding configurations.
- Real-time control and diagnostics, improving reliability and maintenance planning.

The engineering problem with the design and development of such an automated system though is the dynamic control of the speed of the motor depending on the diameter of the coil, the synchronization of the mechanical and the electrical subsystems, and the flexibility of the system to different winding requirements. System connecting, tuning is critical to result in the safe operation, efficient energy usage, etc.

This work is expected to come up with an automated distribution transformer winding machine that is operated fully, and is enabled with PLC, VFD, and HMI systems. The machine will have a wide range of transformer capacity which is 0 to 3150 kVA. The aim of the project is to give high precision, flexibility and operating efficiency in the winding process with low human dependency and low cost of production. It is projected that the proposed solution will be able to add substantial capability to the process of transformer manufacturing and will come into line with the industry 4.0 standards that also will make the electrical infrastructure systems smarter, more responsive, and more reliable [6].

1.2 The Reason to select the topic

The reason why this topic was chosen would be because of the inefficiencies and the quality control difficulties that still exist in the prevalent traditional way of winding transformer coils. The winding process in traditional systems is dependent on manual input and under such systems, same number of experienced laborers are employed to complete something as simple as making a few coils everyday, which may not provide the required evenness on the tension as well as the number of patches used, and the human error in turn is always to rise. This does not only negatively impact the productivity and quality of production of transformers, it also escalates the cost of production and also it has fewer chances of scalability.

With the growing demand for high-performance electrical distribution systems and the rapid advancement of Industry 4.0 technologies, there is a pressing need to modernize transformer production using automation [7]. By integrating Programmable Logic Controllers (PLC), Variable Frequency Drives (VFD), and Human-Machine Interfaces (HMI), it becomes possible to automate coil winding with greater accuracy, real-time monitoring, and significantly improved efficiency. The introduction of such automation in our proposed machine not only enhances daily coil production by over 200% but also ensures consistent quality, reduces operational errors, and minimizes labor dependence.

Our team recognized this gap between traditional practices and modern technological capabilities. This inspired us to design an innovative and cost-effective automated winding machine that can be realistically adopted by local industries, especially in developing regions where budget constraints often hinder automation [8]. The goal is to contribute toward a smarter manufacturing ecosystem that aligns with the goals of digital transformation and sustainable industrial development.

1.3 Aims/ Objectives of the research

Aim

The major objective of the study would be to plan, develop and commission an automated transformer coil winding machine that can take distribution transformers between 0 to 3150 kVA. It combines PLC, VFD and HMI which increases the productivity, accuracy and also reduces the component of manual work utilized in the making of transformers.

Objective

In order to meet the above objective, the following objectives were spelt out:

1. To compare the drawbacks and setbacks of the manual coil winding techniques of transformers, mainly with respect to efficiency, quality control, and labor deprivation.
2. To create and build a prototype transformer winding machine which would have: A plc as an intelligent control and coordination of the machine, A VFD to regulate speed of the motor accurately, an HMI to easily interact or monitor the machine in real time.

3. To apply the communication protocols of Modbus (RS232/RS485) to communicate without any error between the PLC, VFD, and the HMI [9].
4. To automate the processes as important as the coil layer counting, winding tension control, motor synchronization, and patch tracking in the area of consistent coil quality [10].
5. To determine the efficiency of automated system against the conventional manual winding procedure in regard to: Rate of coil manufacture, Accuracy and reproducibility, Reduction in human error, Cost-effectiveness .

1.4 Problem statement and proposed Solution

The conventional way of coil winding in distribution transformer is so fully dependent on human labor, and this aspect is also very challenging in the contemporary industrial setting. Manual winding consumes lots of time, it is labor intensive and there is always human error involved; inaccurate patch counts, loss of winding tension, improper coil alignment. Such factors have contributed to the poor performance of the company, low quality of products, and increased cost of operations. In addition, as the demand of high-capacity transformers in the power distribution systems is growing, the manual process cannot satisfy the requirements of the high scalability and precision related to mass production. Automation of this very important manufacturing process remains to be a considerable bottleneck in the labor towards achieving the industry 4.0 objectives. This research as a solution to the above-mentioned challenges suggests that an Automatic Transformer Winding Machine should be developed that will be able to wind coils of distribution transformers up to 3150 kVA. Modern technologies of automation are included in this solution, offering intelligent control by using a Programmable Logic Controller (PLC), fine control of a motor by using a Variable Frequency Drive (VFD), and real-time displaying of system parameters and making adjustments in a Human- Machine Interface (HMI) [11]. The communication between components is handled with the help of Modbus RS232 and RS485 protocols to present efficient data transfers and data synchronization.

The system automates key functions like:

- Coil patch counting,
- Motor direction and speed control,
- Tension regulation using encoder feedback,

- Safety monitoring with proximity sensors and limit switches.

This approach not only increases daily production capacity from 2–3 coils to 6–9 coils but also ensures consistency, reduces labor dependency, and minimizes human error. Cost-effective designs have also been highlighted in the design which makes it an option that the transformer manufacturing industries can adopt particularly in the developing world. Ultimately, this automated system aligns with smart manufacturing trends and contributes to higher productivity, enhanced quality, and operational reliability.

1.5 Technology Procedure/Methodology

Step	Activity	Purpose & Key Actions
1. Requirement Definition & Benchmarking	Establish the production target (0–3150 kVA coils, ≥ 6 coils day^{-1}) and the quality metrics (tension tolerance, patch count accuracy, safety limits).	Collect baseline data from manual winding (2–3 coils day^{-1}) and recent Industry 4.0 guidelines to set performance goals.
2. Component Acquisition & Specification	Select core hardware: PLC with Modbus RS232/RS485, dual VFDs, touchscreen HMI, optical encoder, geared induction motors, proximity & limit sensors, SMPS 24 V DC supply.	Ensure each component meets the load, speed control and communication requirements for up to 3150 kVA coils.
3. Mechanical & Electrical Integration	1. Design motor mount and coil mandrel assembly. 2. Wire field devices to PLC I/O; isolate power and signal loops. 3. Couple encoder to form drum shaft; install tension rollers.	Provide rigid alignment and noise free signaling so that feedback (speed, position, tension) remains accurate during high inertia winding.
4. Control Logic Development (PLC)	Develop ladder logic to: • synchronize two VFDs (form & bobbin motors), • implement layer/patch counting,	Achieve deterministic motor synchronization and automatic tension correction.

	• compare encoder counts with tap changer set points, • manage auto/manual modes and emergency stops.	
5. HMI Design & Parameterization	Build HMI pages to enter coil length, patch count, tapping table, and VFD speeds; display live coil turns, motor Hz, alarms and production counters.	Give operators intuitive, real-time visibility and quick recipe switching.
6. Communication Configuration	Implement: • RS-232 link PLC ↔ HMI for parameter data, • RS-485 (Modbus-RTU) PLC ↔ each VFD for speed/fault registers.	Guarantee robust, galvanically-isolated data exchange resistant to factory EMI.
7. Safety & Interlock Implementation	Integrate emergency stop, wire-presence proximity check, limit switches (left/right travel) and over-tension alarms; program safe-state routines in PLC.	Protect operators, prevent coil or machine damage, and meet IEC 60204-1 safety standards.
8. Functional Testing & Calibration	• Dry-run each axis at low RPM. • Verify encoder-patch correlation, tension stability, and motor-sync ratio. • Conduct 24-hour endurance test under full load.	Ensure that closed-loop control maintains ±1 turn accuracy per layer and that no drift occurs at production speeds.
9. Performance Evaluation vs Manual Process	Record coil-per-day throughput, defect rate, energy use and Laboure hours; compare to manual benchmark from Step 1.	Quantify gains—target is ≥ 200 % increase in throughput and significant Laboure reduction.
10. Cost & Scalability Analysis	Calculate total build cost (≈ 10–12 lakh BDT) and ROI; model	Demonstrate economic feasibility for small- and

	scaling to multi-spindle lines and remote monitoring add-ons.	mid-size transformer manufacturers.

1.6 Thesis Organization

The thesis having seven chapters. Those chapter carries particular discussion about introduction, procedures, simulation, results etc.

Chapter 1: Introduction

This chapter serves as an introduction to the thesis, providing a comprehensive overview of the research background and context. It presents a summary of the problem statement and articulates the specific aims and objectives of the study. Additionally, the chapter outlines the methodology employed for the implementation of the project, detailing the approach taken and the steps involved in the implementation process.

Chapter 2: Literature Review

The literature review chapter delves into the existing body of research relevant to the thesis topic. It identifies and discusses research gaps within the field, comparing and contrasting the current work with previous studies. Through this comparison, the chapter highlights the unique contributions of the current research and identifies best practices and methodologies that inform the approach taken in the thesis.

Chapter 3: Materials and Methods

This chapter provides a comprehensive exploration of the fundamentals of Automation design and performance parameters. It covers various aspects, including the theory behind step of automation design, block diagram, circuit diagram, panel setup, program setup, HMI design.

Chapter 4: Result Analysis

In this chapter, the results obtained from the setting parameter, show counting value, read Realtime monitoring value. The chapter discusses the implications of these results in the

Chapter 5: Project Management

The chapter under project management gives a detailed description of the management part of the thesis project. It specifies how a strong project management plan is adopted and implemented with the creation of time schedule of the implementation process, cost management plans, allocating of resources and monitoring costs as well as the on-time completion and milestones execution of projects. Lessons learnt in the project management process are also elaborated giving some ideas and reflection on the practice of good project management.

Chapter 6: Impact Assessment of the Project on Human Health and Environment

The given chapter is devoted to the discussion of broader effect of the thesis project on human health and the environment. It undergoes a critical evaluation of the environmental and ethical impacts of the project, aspects touching on exposures to electromagnetic radiations, health, safety, laws, environmental vulnerabilities or sensitivity, perception and understanding by people and counter-measures. Via this evaluation, the chapter will be describing in depth precisely the societal and environmental implication of the project.

Chapter 7: Conclusion

The conclusion chapter comes in as the culmination of the thesis summarizing the topnotch findings and contributions the research arrived at. It presents the suggestions on the prospective areas of research and the possible ways to enhance the system on the basis of what it has learnt during the study. The chapter further elaborates cost implications and applications of the research findings which leads to final remarks which highlights the implication of the work and its relevance in the field.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The winding of transformer coils is a fundamental yet highly technical stage in the manufacturing of power and distribution transformers. The quality, accuracy, and consistency of this winding process directly affect the transformer's electrical performance, operational reliability, and service life. Traditionally, the winding of transformer coils has been performed manually or semi-automatically, a method that is not only labor-intensive but also susceptible to human error, inefficiency, and quality inconsistencies. As the demand for power systems continues to grow with the global push toward energy expansion and electrification, there is an urgent need for automated, intelligent, and scalable winding solutions that can meet industrial demands while ensuring precision and repeatability.

Automation technologies such as Programmable Logic Controllers (PLC), Variable Frequency Drives (VFD), and Human-Machine Interfaces (HMI) have revolutionized many sectors of manufacturing. Their integration into transformer coil winding machines represents a critical evolution toward Industry 4.0-compliant systems, characterized by real-time monitoring, adaptive control, and minimal human dependency [12]. Moreover, with growing concerns about sustainability and energy efficiency, the integration of renewable energy sources into automated systems is gaining momentum, further broadening the scope of innovation in this domain.

This chapter presents a comprehensive review of relevant literature pertaining to automated transformer coil winding technologies. The review draws on a range of studies that explore diverse methods and architectures—from microcontroller-based small-scale systems to advanced PLC-driven industrial designs, and from sensor-based winding control to renewable energy integration in transformer production lines [13]. A variety of control strategies, including traditional PID controllers and fuzzy logic-based approaches, are also discussed in terms of their application to tension regulation and motor synchronization [14].

The purpose of this literature review is threefold. First, it aims to establish the current state of technology in the area of transformer coil winding automation. Second, it seeks to identify the strengths and limitations of previous research efforts to uncover existing gaps in knowledge and application. Lastly, it sets the groundwork for the development of the proposed system—an automatic 0 to 3150 kVA distribution transformer winding machine—by demonstrating how the new design addresses the shortcomings of earlier models in terms of performance, scalability, affordability, and industrial readiness.

In the sections that follow, existing research and relevant industrial developments are systematically reviewed. The discussion focuses on core technical aspects such as control systems, machine architecture, performance optimization, energy efficiency, and sustainability. The chapter concludes with a comparative analysis that highlights the unique contributions of the proposed work in relation to the state of the art.

2.2 Related Research / Works

The field of transformer coil winding has evolved significantly with the growing demand for higher production efficiency, accuracy, and automation in electrical manufacturing. Numerous researchers have explored automation strategies, sustainable energy integration, microcontroller-based designs, and intelligent control systems to optimize coil winding operations. This section presents an in-depth discussion of notable research works related to automated transformer winding systems, drawing on a range of technological perspectives including control theory, energy efficiency, machine architecture, and industrial relevance.

One of the earlier yet impactful works in this domain was presented by Sandeep Sonaskar et al. (2021), who developed a basic transformer coil winding machine using Arduino, geared DC motors, IR sensors, and LCD displays. Their approach was primarily educational and targeted toward small-scale applications or student projects. By using readily available components, they succeeded in reducing human labor and ensuring better winding precision compared to manual setups [15]. However, their system lacked modularity, robustness, and industrial-level scalability. Nonetheless, it demonstrated the foundational applicability of embedded systems in automating coil winding operations and paved the way for further developments in the field.

Addressing environmental concerns and operational costs, researchers explored renewable energy-powered coil winding systems. One prominent study proposed integrating solar and wind energy sources with automation hardware to power transformer winding machines. These systems featured **e**nergy storage banks**,** power conditioning units, and intelligent load control algorithms to ensure uninterrupted, sustainable operation. Experimental validation revealed significant benefits, including reduced operational downtime**,** lower carbon emissions, and enhanced system resilience under variable energy availability. The study also integrated machine learning-based optimization to adapt winding parameters dynamically, thus increasing system adaptability across various transformer specifications.

A related work further emphasized sustainability by combining automation with hybrid renewable energy systems. This study demonstrated how incorporating smart sensors, robotic arms, and predictive analytics could enhance winding precision while reducing energy dependence on fossil fuels. The proposed model achieved a 30% reduction in power usage and a 25% increase in throughput, reflecting the benefits of energy-efficient automation in large-scale manufacturing. It also addressed intermittency issues through energy storage and demand forecasting, thereby improving production reliability—a vital concern in high-volume industries [16].

In terms of control optimization, a particularly insightful contribution came from a study that utilized fuzzy logic-based PID controllers to regulate insulation tape tension during coil winding. Since winding tension directly affects coil density, electrical characteristics, and transformer durability, achieving stable tension is a significant engineering challenge. The researchers demonstrated that fuzzy PID control significantly outperformed classical PID control in terms of response time and adaptability to dynamic loads. This approach ensured uniform layering of wire and insulation material, contributing to better transformer performance and reduced failure rates in high-voltage environments.

Efforts to enhance portability and compactness led to the development of microcontroller-driven portable coil winding machines. One such system, built using an AT89C52 controller and DC motors, introduced features like keypad input, LCD display, and programmable winding sequences. The design was validated by successfully winding a 1 kVA transformer at 60 turns/min with a 24V power supply. The machine’s affordability and ease of use made it suitable for small transformer workshops or educational laboratories, although its application was limited to low-capacity coils and lacked real-time feedback control.

Another significant development came from a study involving Arduino-based control systems integrated with proximity sensors to detect and count wire turns. The authors evaluated the accuracy and efficiency of transformers produced by this automated setup and found voltage deviation margins between 0.16% and 0.9%, and current deviations of around 1.5%. These findings confirmed that automated winding not only saves time but also improves the electrical accuracy of the final transformer product. The modularity of Arduino platforms further supports easy customization for varying coil sizes and winding configurations.

In the broader context of industrial automation, the principles of PLC- and VFD-based control systems have been applied in textile and manufacturing industries. One study utilized Delta

PLCs**,** VFDs**,** and Modbus-485 communication to control flyer speeds and drafting motions in roving machines. While the system targeted yarn production, its architecture closely mirrors what is needed in transformer winding automation. The results showed a 30% reduction in power consumption and an elimination of manual gear shifting errors**,** illustrating how automation can boost production quality while reducing human intervention and energy usage.

Beyond core winding mechanics, researchers have also focused on accuracy verification and performance assessment in coil winding systems. In one study, an ATmega8 microcontroller paired with optocoupler sensors was used to assess coil turn precision for water pump motors. The prototype achieved 98% accuracy, with a maximum deviation of one turn. This precision is particularly relevant for transformer windings, where even small deviations in turn count or wire tension can significantly alter electrical characteristics such as inductance, resistance, and thermal performance [17].

Diagnostic research has also provided important insights into the effects of winding faults. One such study modeled the behavior of a closed-loop coil defect using pulse scanning and magnetic coupling analysis. By observing voltage spikes and current derivatives in the undamaged winding, the researchers developed a method for non-invasive fault detection. Although not directly an automation method, the findings highlight the critical importance of precision in the winding process, further validating the need for intelligent, error-resistant automated systems. Similarly, studies analyzing impulse voltage distributions in transformer windings have revealed that improper winding geometry and spacing can lead to transient overvoltage's and insulation breakdown. These studies support the thesis that consistent and accurate winding, best achieved through automation, is essential for the long-term durability and safety of transformers, especially in high-voltage applications.

2.3 Compare and Contrast

While all reviewed systems aim to enhance automation in coil winding, their scope, scale, and implementation differ considerably.

Microcontroller-based systems, such as those using Arduino or AT89C52, offer low-cost and educational prototypes suited for small-scale or academic applications. These designs often lack advanced industrial features like synchronized motor control, torque regulation, or programmable interfaces. Moreover, the absence of modular interfaces and industrial communication protocols (like RS-485 or Modbus) limits their deployment in large-scale or commercial transformer manufacturing environments.

In contrast, studies integrating PLC, HMI, and VFD technologies provide more robust and scalable solutions. These systems support synchronous motor control, real-time user interfacing, and programmable control logic, making them highly suitable for medium to large-scale production lines [18]. Additionally, they offer flexibility for manual override, fault handling, and dynamic parameter adjustment, which microcontroller systems struggle to accommodate effectively.

Furthermore, the renewable energy-integrated systems focus not just on automation but also on sustainability and energy efficiency. These setups are particularly relevant in the context of global efforts to reduce carbon emissions and promote green manufacturing. However, these solutions often require a significant upfront investment and infrastructure support, such as hybrid energy storage or energy management systems, which may not be accessible to all manufacturers.

Another dimension of comparison is control accuracy. Fuzzy PID systems and optocoupler feedback mechanisms have demonstrated better control over coil tension and turn count compared to traditional fixed-speed controllers. However, they require more complex programming and simulation-based tuning, which might not be practical for standard industrial environments where ladder logic-based PLCs are the norm.

The proposed work, as presented in the current thesis, builds upon these previous efforts by combining industrial-grade automation technologies (PLC, VFD, HMI) with precise encoder feedback, real-time control, and user-friendly parameter setup [19]. Unlike microcontroller systems, it is designed for full-scale transformer manufacturing with support for various transformer capacities (0–3150 kVA) and features such as bidirectional motor control, real-time turn monitoring, and fault alert mechanisms—all in a cost-effective package.

2.4 Summary

The literature reviewed in this chapter reveals a growing interest in automating transformer winding machines through a variety of methods ranging from microcontroller-based setups for small-scale applications to advanced PLC-driven solutions for industrial environments. While earlier works contributed significantly to the foundation of coil winding automation, many are limited in scalability, precision, or environmental adaptability.

The integration of renewable energy sources into automation frameworks represents a promising frontier, particularly in the context of sustainable manufacturing. Advanced control methods like fuzzy logic and PID tuning enhance performance but often increase system complexity and require higher technical proficiency.

The system proposed in this thesis bridges the gap between simplicity and industrial robustness. By employing reliable automation components and proven industrial communication protocols, the design provides a realistic, scalable, and efficient solution for transformer manufacturers. Moreover, the machine addresses critical industry needs including precision, production speed, and cost-effectiveness, offering significant advantages over many existing prototypes and experimental models.

This review establishes a strong foundation for the work undertaken in this thesis and highlights the technical novelty and practical value of the proposed automated transformer winding system.

CHAPTER 3

MATERIALS AND METHODS

3.1 Introduction

The successful implementation of an automated transformer coil winding machine requires a careful and systematic integration of mechanical, electrical, and control system components. This chapter presents a detailed overview of the materials used in constructing the prototype and the methodologies followed during the system design, development, integration, and testing phases. The machine is developed specifically to handle distribution transformers with a power capacity ranging from 0 to 3150 kVA and is designed to replace the traditional manual winding process, which is often time-consuming, error-prone, and labor-intensive.

The aim of this project is to build a fully functional, semi-industrial-grade machine capable of performing complex winding operations with precision and minimal human intervention. To meet this objective, the design integrates key technologies such as Programmable Logic Controllers (PLC) for automation and logic execution, Variable Frequency Drives (VFD) for speed control of the winding motors, Human-Machine Interface (HMI) for real-time monitoring and parameter configuration, as well as sensors and encoders for feedback and error handling [20].

A methodical engineering process was employed, starting with a requirement analysis, component selection, system design, prototyping, and iterative testing. The entire process ensures system synchronization, operational safety, and robustness under varying operating conditions. All control logic is implemented using ladder programming on the PLC, while the HMI is configured to offer an intuitive interface for operators, enabling the input of coil parameters such as patch count, winding speed, and tapping positions. The overall control and feedback loop is maintained using Modbus RS232/RS485 communication protocols, which provide a reliable, real-time exchange of data between devices.

The materials and methods discussed in this chapter are divided into several subsections:

1. hardware components including input/output devices and controllers
2. communication and integration methods
3. mechanical structure and synchronization mechanisms
4. software design and programming techniques

5. operational modes and system validation procedures.

By detailing the technical resources and methodologies employed, this chapter provides a replicable framework for future researchers, engineers, and automation enthusiasts interested in designing similar systems for transformer manufacturing or other industrial winding applications. The results achieved from implementing this methodology not only validate the machine’s performance but also demonstrate its potential in industrial automation aligned with Industry 4.0 standards.

3.2 Hardware Components

Table 3. 1: Components List

SL No	Component	QTY
01	PLC (Programmable Logic Controller)	1
02	VFD (Variable Frequency Drive)	2
03	HMI (Human-Machine Interface)	1
04	SMPS (Power Supply)	1
05	Encoder	1
06	Proximity Sensor	1
07	Limit Switch	2
08	Emergency Stop Switch	1
09	Selector Switch	1
10	Pedal Switches	2
11	Alarm Buzzer	2
12	Indicator Lights	7
13	Gear Motors	2
14	Relays and Contactors	8
15	Push Button Switch	2

3.2.1 Programmable Logic Controller (PLC)

A Programmable Logic Controller (PLC) is a highly specialized digital computer used to automate electromechanical processes in industrial environments. It is designed to endure harsh conditions such as high humidity, temperature extremes, electrical noise, and mechanical shock. A PLC functions by constantly executing a cycle known as the scanning cycle, which involves reading input statuses from various field devices (such as sensors, switches), processing these inputs through user-defined logical instructions (program), and then updating the output devices (such as actuators, relays, motors). Unlike traditional control panels made from relays and timers, PLCs offer reprogram ability, real-time control, and scalability. They support multiple programming languages defined by IEC 61131-3 such as Ladder Diagram (LD), Function Block Diagram (FBD), and Structured Text (ST). Due to their modular design, PLCs can be easily expanded using additional I/O modules. They are used extensively in industries like manufacturing, water treatment plants, power systems, and automated assembly lines.

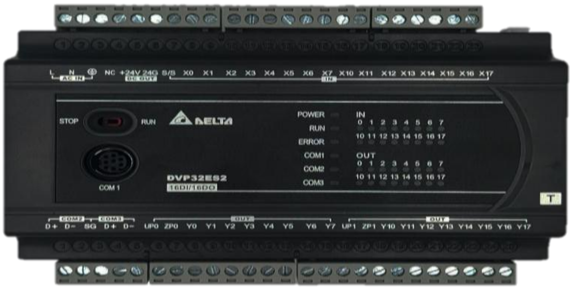

Figure 3.2. 1: Programmable Logic Controller.

3.2.2 Variable Frequency Drive (VFD)

A Variable Frequency Drive (VFD) is an advanced motor control device that regulates the speed and torque of AC motors by varying the frequency and voltage of the power supplied to the motor. The operation of a VFD involves three main stages: rectification of AC input to DC, filtration to smooth the DC signal, and inversion to convert the DC back to variable-frequency AC.

Figure 3.2. 2: Variable Frequency Drive.

This allows for precise speed control, soft starting, and energy-efficient motor operation. VFDs also enable dynamic braking and direction reversal of motors, eliminating the need for mechanical components like clutches and brakes. VFDs protect motors from voltage surges, reduce energy consumption during low-load operations, and extend the lifespan of equipment. Applications include centrifugal pumps, fans, compressors, conveyor systems, escalators, and many other variable-load processes in industries.

3.2.3 Human-Machine Interface (HMI)

The Human-Machine Interface (HMI) is a crucial component of modern automation systems that facilitates interaction between the machine operator and the control system. It provides a graphical user interface (GUI) where data from PLCs and other controllers are displayed in real-time. Through this interface, operators can monitor equipment status, acknowledge alarms, adjust setpoints, and perform diagnostics. HMIs range from simple LED indicator panels to advanced touchscreen displays with multi-language support and dynamic animations.

Figure 3.2. 3: Human-Machine Interface.

Some advanced HMIs are web-enabled, allowing remote monitoring and control over secure networks. The primary advantage of using an HMI is its ability to simplify complex data into visual formats like trends, charts, and buttons, making operations more intuitive and minimizing human error. HMIs are used in SCADA systems, energy management, building automation, and various industrial sectors.

3.2.4 Switched-Mode Power Supply (SMPS)

A Switched-Mode Power Supply (SMPS) is an electronic circuit that converts AC voltage into regulated DC voltage using high-frequency switching transistors and energy storage elements like inductors and capacitors. The SMPS operates by chopping the input voltage at high speed and transforming it through a step-down or step-up process using transformers. It then filters the output to obtain a stable DC supply. Compared to traditional linear regulators, SMPS units are more efficient, produce less heat, and are lighter in weight. They also have wide input voltage ranges and built-in protection features such as overvoltage, overload, and thermal shutdown. SMPS units are used to power low-voltage control components such as PLCs, sensors, relays, and communication modules in automation systems.

Figure 3.2. 4: Switched-Mode Power Supply.

3.2.5 Encoder

An Encoder is an electromechanical device that translates mechanical motion (rotational or linear) into a digital signal that can be interpreted by a control system. Encoders are typically mounted on motor shafts or movable parts and provide critical feedback for motion control systems. They are classified into two main types: incremental encoders, which provide pulse outputs that represent relative motion, and absolute encoders, which generate unique digital codes for every position. Encoders work based on optical, magnetic, capacitive, or inductive principles. Optical encoders, the most common type, use a light source and a photodetector to detect interruptions caused by patterns on a rotating disk. The encoder's output allows controllers like PLCs or servo drives to determine position, speed, direction, and even acceleration. They are essential in robotics, CNC machinery, elevators, and any system requiring precise motion feedback.

Figure 3.2. 5: Encoder

3.2.6 Proximity Sensor

A Proximity Sensor is a non-contact sensor that detects the presence or absence of an object within a predefined sensing range. These sensors operate on various principles depending on their type: inductive proximity sensors detect metallic objects by generating and sensing electromagnetic fields;

Figure 3.2. 6: Proximity Sensor.

capacitive sensors can detect both metallic and non-metallic objects by measuring changes in capacitance; optical sensors use light (IR or laser) to detect objects, and ultrasonic sensors use sound waves for detection. One of the key advantages of proximity sensors is their high reliability and resistance to environmental wear since they do not rely on physical contact. They are widely used for object detection, counting, safety barriers, and as input devices in automation systems. Industries such as automotive, packaging, food processing, and electronics heavily rely on proximity sensors for automation and quality control.

3.2.7 Limit Switch

A Limit Switch is an electromechanical device that operates when a physical object comes into contact with its actuator. The actuator, which can be a lever, roller, or plunger, mechanically triggers an internal set of contacts that open or close a circuit. Limit switches are used to detect end-of-travel, position, or the presence of an object. They are available in various configurations including snap-action, slow-break, and roller-lever types.

Figure 3.2. 7: Limit Switch.

Because of their mechanical nature, they provide discrete (ON/OFF) feedback and are known for their ruggedness and reliability. In automated systems, limit switches play a vital role in ensuring machine safety, positional accuracy, and sequencing operations. Common uses include elevator door control, robotic arm positioning, and conveyor belt end limits.

3.2.8 Emergency Stop Switch

The Emergency Stop Switch, commonly referred to as E-Stop, is a safety device used to immediately shut down machinery or equipment in case of an emergency. It is designed for easy accessibility and high visibility—usually as a red, mushroom-shaped button that latches when pressed. When activated, the E-Stop breaks the power circuit or sends a stop signal to the control system, causing the machinery to halt immediately, thereby preventing potential accidents, injuries, or equipment damage. E-Stops are a critical part of machine safety systems and are required by international standards like ISO 13850. Once activated, they typically require manual resetting to resume operation. E-Stops are placed at operator stations, control panels, and key locations around hazardous machinery to ensure quick access during emergencies.

Figure 3.2. 8: Emergency Stop Switch

3.2.9 Selector Switch

A Selector Switch is a manually operated control device that enables the selection of one or more operating modes or system states. It is commonly used in control panels to toggle between different functions such as “Auto/Manual”, “Forward/Reverse”, or “On/Off”. Selector switches are available in two-position, three-position, or multi-position configurations, with or without a spring return mechanism. Most designs use a rotary knob or key to turn the internal contact mechanism. Selector switches are valued for their simplicity, robustness, and ease of integration into industrial control systems. They provide a reliable way for operators to control processes without the need to interact with software interfaces, and are often used in conjunction with push buttons and indicator lamps for enhanced human-machine interaction.

Figure 3.2. 9: Selector Switch

3.2.10 Pedal Switch

A Pedal Switch, also known as a foot switch, is a control device that is actuated by the foot, allowing the operator to keep their hands free for guiding or positioning materials during machine operation. Pedal switches are widely used in applications where hands-free operation improves productivity, such as in welding machines, sewing machines, medical devices, and industrial presses.

Figure 3.2. 10: Pedal Switch.

They are designed to withstand mechanical wear and provide either momentary or latching control. Some pedal switches include safety guards or enclosures to prevent accidental activation. In industrial environments, foot-operated switches are preferred where frequent start-stop operation is needed and operator comfort and efficiency are prioritized.

3.2.11 Alarm Buzzer

An Alarm Buzzer is an audio signaling device used to draw immediate attention to specific conditions in a control system, such as a fault, warning, or completion of a task. Buzzers may be powered by AC or DC and are based on piezoelectric or electromagnetic mechanisms to generate sound. They are often activated automatically by control logic in a PLC or relay circuit when a specific event is triggered. Alarm buzzers are especially useful in noisy or complex environments where visual indicators may go unnoticed. Their distinct sound alerts operators to take corrective action quickly, thereby enhancing safety and minimizing downtime.

Figure 3.2. 11: Alarm Buzzer

3.2.12 Indicator Lights

Indicator Lights, also referred to as pilot lamps, provide visual indication of a system's status. They are essential components of control panels, used to represent different states such as "Power ON", "Fault", "Run", "Trip", and others. These lights are available in multiple colors (commonly green, red, amber, blue, and white), each with standardized meanings in industrial applications. Modern indicator lights use LEDs for their energy efficiency, long life, and visibility. They may be static or flashing, depending on the type of condition they are indicating. Indicator lights serve as the first level of status monitoring for operators and maintenance personnel, helping with immediate system diagnostics and process feedback.

Figure 3.2. 12: Indicator Lights

3.2.13 Gear Motors

A Gear Motor is an integrated unit consisting of an electric motor and a gearbox. The gearbox reduces the motor's speed while increasing torque output, allowing for controlled mechanical movement even under heavy loads. Gear motors are critical in applications that require precise and slow-speed operations, such as conveyor belts, cranes, rotary tables, and industrial mixers.

They are designed in various gear configurations including spur, helical, planetary, and worm types. Gear motors offer compactness, improved efficiency, and lower power consumption, making them ideal for space-constrained environments. By selecting the appropriate gear ratio, engineers can fine-tune the system for speed, load capacity, and torque as needed.

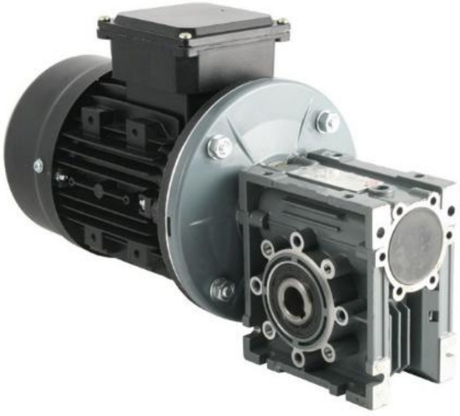

Figure 3.2. 13: Gear Motors.

3.2.14 Relays and Contactors

Relays and Contactors are electromechanical switches used to control electrical circuits by opening and closing contacts in response to electrical signals. A relay is generally used for switching low-power signals and is suitable for applications where electrical isolation between control and load is needed. Contactors, by contrast, are built for high-power switching applications such as starting motors, heating systems, and lighting circuits. They can handle currents of several hundred amperes and include features like arc suppression and auxiliary contacts for feedback. Both relays and contactors are controlled via low-voltage signals from PLCs or push buttons and are foundational in motor control centers and automation panels.

Figure 3.2. 14: Relays and Contactors

3.2.15 Push Button Switch

A Push Button Switch is a manually operated input device that opens or closes an electrical circuit when pressed. It is one of the most commonly used control devices in industrial environments.

Figure 3.2. 15: Push Button Switch

Push buttons are typically used to start or stop machines, reset alarms, or activate specific process functions. They are available in various forms including momentary, maintained, illuminated, and non-illuminated. Push buttons are color-coded according to industrial standards—green for "Start", red for "Stop", yellow for "Caution", etc. Their robust design and tactile feedback ensure reliable operation even in harsh or high-frequency-use environments, making them indispensable in any control system.

3.3 Design Specifications, Standards, and Constraints

The design of the automatic transformer coil winding machine focuses on efficiently handling winding operations for distribution transformers ranging from 0 to 3150 kVA. The system utilizes key automation components such as a Programmable Logic Controller (PLC), Variable Frequency Drives (VFDs), and a Human-Machine Interface (HMI). It operates using a 24V DC power supply through a Switched-Mode Power Supply (SMPS) to run the control units, including the PLC and HMI. Two gear motors are employed for the form and bobbin winding processes, each controlled by its own VFD and synchronized precisely using encoder feedback. The machine supports both automatic and manual operation modes, selectable via a selector switch. In automatic mode, the HMI allows operators to input crucial parameters such as coil patch count, tap changer values, and motor speeds, while displaying real-time performance data. Input components like proximity sensors, pedal switches, limit switches, and encoders feed signals to the PLC, which processes them and generates outputs to alarms, indicator lights, and relays for smooth and safe machine operation. The system significantly enhances productivity, achieving a daily output of 6 to 9 coils, compared to the 2 to 3 coils produced manually.

The design adheres to recognized engineering and industrial automation standards to ensure functionality, safety, and compatibility. These include IEC 61131-3 for PLC programming (ladder logic), MODBUS protocol standards for communication over RS232 (PLC to HMI) and RS485 (PLC to VFD), ISO 12100 for machine safety principles, and IEC 60204-1 which governs electrical safety in machine systems. Additionally, the design concept aligns with Industry 4.0 trends, integrating smart automation and data-driven control for improved quality and performance.

However, the development faced several practical constraints. One of the major constraints was cost — the machine was designed to be a low-cost alternative to existing commercial systems, with a budget limit between 10 and 12 lakh BDT. This limited the selection of high-end components and automation features. Component availability also influenced design decisions, as all devices needed to be locally sourced or supported. Mechanical precision was another critical constraint — the dual motor system required highly accurate synchronization to maintain consistent coil tension and avoid winding errors. Moreover, the foil wrapping process remains manual due to its mechanical complexity and cost of automation. Although the HMI provides real-time control and feedback, the system currently lacks advanced features like remote monitoring and intelligent diagnostics, which are intended for future development. Despite these constraints, the machine meets its primary goals of improving efficiency, reducing human error, and delivering consistent coil quality at an affordable cost.

3.4 Experimental Setup

The experimental setup of the automatic transformer coil winding machine was carefully designed to validate the functionality, accuracy, and efficiency of the system under realistic operating conditions. The setup began with assembling the core components, including a Programmable Logic Controller (PLC), Variable Frequency Drives (VFDs), a Human-Machine Interface (HMI), two gear motors, an encoder, various sensors, and control switches. The PLC served as the central controller and was programmed using ladder logic to execute precise control over the winding operation. It communicated with the HMI via RS232 and with the VFDs through RS485, using the MODBUS communication protocol to ensure stable and synchronized operation. The gear motors were installed to manage the coil rotation and wire feeding tasks. One motor, referred to as the form motor, rotated the transformer coil, while the other, the bobbin motor, maintained wire tension during winding. Both motors were synchronized using real-time feedback from a rotary encoder, ensuring accurate coil patching and tension control.

A 24V DC Switched-Mode Power Supply (SMPS) was used to power the control system, while the motors operated using an AC supply regulated by the VFDs. Input devices included an emergency stop switch, limit switches, a proximity sensor for wire detection, pedal switches for manual mode, and a selector switch to toggle between automatic and manual modes. The output devices included indicator lights, an alarm buzzer, and relays connected to the gear motors and safety components. All components were mounted and connected within a custom-designed control panel to ensure safe and organized wiring. During testing, the HMI was used to set key parameters such as the number of coil patches, tapping values, and motor speeds in hertz (Hz). In automatic mode, once the wire was detected, the motors began winding based on preset parameters, with the system automatically adjusting direction after each layer using limit switches and encoder feedback. In manual mode, the operator controlled the winding process using foot pedals, allowing for fine adjustments.

Extensive testing was conducted in both operational modes to verify system stability, safety functionality, synchronization accuracy, and user interface performance. The machine was able to successfully complete multiple winding cycles, producing consistent coil layers with accurate turn counts and tension. Any abnormalities, such as the absence of wire, triggered automatic alerts via the HMI and buzzer system, demonstrating the effectiveness of the fault detection features. The experimental setup confirmed that the integrated automation system significantly improved operational efficiency and reduced human error, making it a reliable and cost-effective solution for transformer coil winding.

3.4.1. Block Diagram

The block diagram illustrates the overall control and operation system of the automatic transformer coil winding machine. At the core of the system is the Programmable Logic Controller (PLC), which acts as the central processing unit. It receives input signals from various devices such as button switches, an inductive proximity sensor, and an encoder through the input terminal.

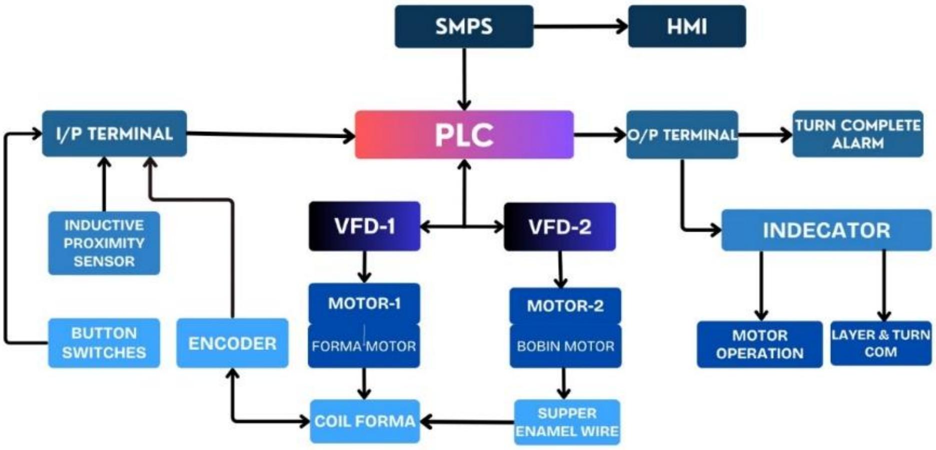

Figure 3.4. 1: Block Diagram.

The encoder provides real-time feedback on coil rotation, while the proximity sensor detects the presence of the super enamel wire to ensure safe winding.

Power to the system is supplied through an SMPS (Switched-Mode Power Supply), which also powers the HMI (Human-Machine Interface). The HMI allows the user to input winding parameters and monitor the system's performance.

The PLC controls two Variable Frequency Drives (VFD-1 and VFD-2), which regulate the speeds of Motor-1 (Form Motor) and Motor-2 (Bobbin Motor), respectively. These motors work together to winding the super enamel wire around the coil forma, with synchronization maintained via encoder feedback to ensure proper layer formation and wire tension. Output signals from the PLC are sent through the output terminal to control the turn complete alarm and the indicator system. The indicator displays both the motor status and the completion of each layer and turn, helping operators track the winding process accurately. This structured integration of sensors, motors, controllers, and interfaces ensures efficient, safe, and precise automation of transformer coil winding operations.

3.4.2. Circuit Diagram

The circuit diagram represents the complete control architecture of the automatic transformer coil winding machine. At the core of the system is the PLC (Programmable Logic Controller), which acts as the central processing unit. It handles both input and output signals, coordinating communication between components and ensuring proper system functionality. The PLC is interfaced with the Human-Machine Interface (HMI) via the RS232 communication protocol, allowing the operator to configure parameters such as coil turns, motor speed, and tapping values. The HMI also provides real-time monitoring of machine status and alerts, making it an essential user interface for both operation and troubleshooting.

To control motor speed and direction, the PLC communicates with two Variable Frequency Drives (VFD-1 and VFD-2) using the RS485 communication protocol. These VFDs independently control Motor-1 (Form Motor) and Motor-2 (Bobbin Motor). Both motors are synchronized using feedback from an encoder, ensuring uniform winding tension and layer formation. The encoder feeds precise position and rotation data to the PLC, which adjusts motor outputs accordingly to maintain coordination and alignment during the winding process.

The system also incorporates a range of input devices connected to the PLC for operational control and safety. These include push buttons for start and stop commands, proximity sensors to detect the presence of the super enamel wire, limit switches to identify end positions during winding, and pedal switches to control manual mode operations. An emergency stop switch ensures immediate shutdown of the system in case of fault or danger, and a selector switch allows switching between manual and automatic modes depending on the production requirement.

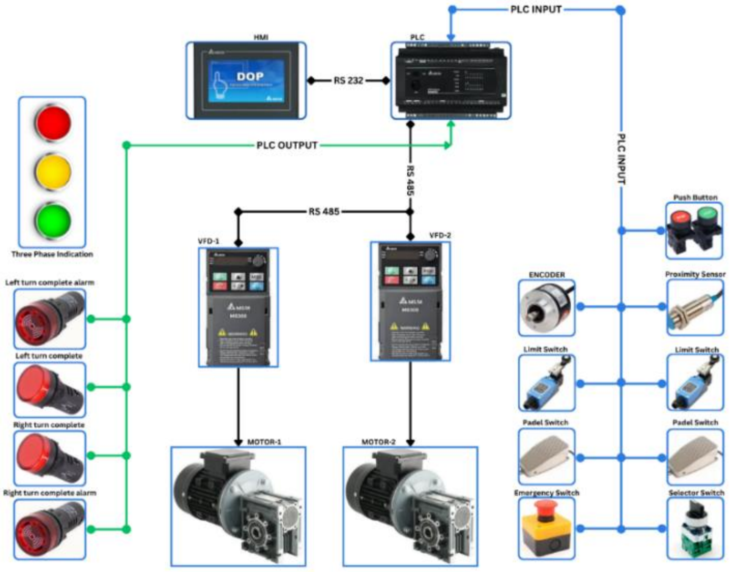

Figure 3.4. 2: Device Circuit Diagram

The output section of the PLC is connected to various alarm and indicator devices. These include three-phase indication lights, which confirm proper phase supply, as well as left and right turn complete indicators and alarms, which notify the operator when a winding cycle or layer has been successfully completed. These visual and audio indicators enhance safety, reduce human error, and streamline the workflow.

Overall, the circuit diagram reflects a robust and intelligent control system that integrates power electronics, programmable automation, sensor feedback, and human interaction. It ensures high precision in transformer coil winding while maintaining operator safety, operational flexibility, and real-time monitoring. This setup forms the foundation of the machine’s capability to produce 6–9 transformer coils per day, significantly surpassing manual output, and aligns with the goal of smart, scalable manufacturing in the electrical industry.

3.4.3 Control Panel Setup

The control panel of the transformer coil winding machine is the centralized unit that houses and connects all key electrical and automation components necessary for system operation. It is designed for safety, accessibility, and ease of maintenance. The core of the panel is the PLC (Programmable Logic Controller), which manages all input and output operations. It is mounted securely within the panel and connected to both VFDs (Variable Frequency Drives) through RS485 communication for controlling the two motors: the form motor and the bobbin motor. The panel also includes an HMI (Human-Machine Interface), which is connected to the PLC via RS232 communication and mounted on the front side of the panel for operator access.

Figure 3.4. 3: Machine Control Panel.

Through the HMI, users can input winding parameters (such as patch count, tap settings, and motor speed), switch between manual and automatic modes, and monitor real-time performance.

All input devices including proximity sensors, limit switches, pedal switches, push buttons, encoder, selector switch, and emergency stop—are wired to the PLC input terminals. These devices are routed through protective terminal blocks inside the panel to ensure organized wiring and easy troubleshooting. Similarly, the output section connects to alarms, indicator lights, and signal lamps for left/right coil completion and motor operation status.

A 24V DC SMPS (Switched-Mode Power Supply) provides regulated power to the control system, ensuring reliable operation. For safety, circuit breakers and fuses are also installed to protect against overloads and short circuits. Proper labeling and cable management have been implemented to maintain clarity and minimize errors during installation or maintenance.

The control panel's layout ensures that all components are securely placed, heat is managed efficiently, and wiring complies with industrial safety standards. This setup enables smooth, reliable, and accurate operation of the coil winding machine while allowing operators full control and real-time feedback throughout the winding process.

3.4.4. PLC Program (Ladder Diagram)

The PLC program for the transformer coil winding machine was developed using ladder logic, a graphical programming language widely used in industrial automation. The ladder diagram was designed to manage the sequential operation of both form and bobbin motors, control input/output devices, and ensure safe and precise coil winding. The program begins by initializing the system through input commands such as push buttons, selector switches, and pedal switches. In automatic mode, the PLC reads parameter values—such as the number of coils turns and tap settings entered through the HMI, and starts the motors via VFDs. Using feedback from the encoder, the PLC continuously monitors coil rotation and adjusts motor speeds for synchronization. When a layer is completed, as detected by limit switches, the PLC halts motor activity and signals through alarms and indicators. In manual mode, control is shifted to pedal switches, allowing the operator to wind coils manually, which is useful for testing or small batch production. The ladder diagram also includes safety interlocks to handle emergency stops, absence of wire (via proximity sensor), and fault conditions. Overall, the program ensures accurate layer counting, smooth motor control, and reliable switching between automatic and manual operations.

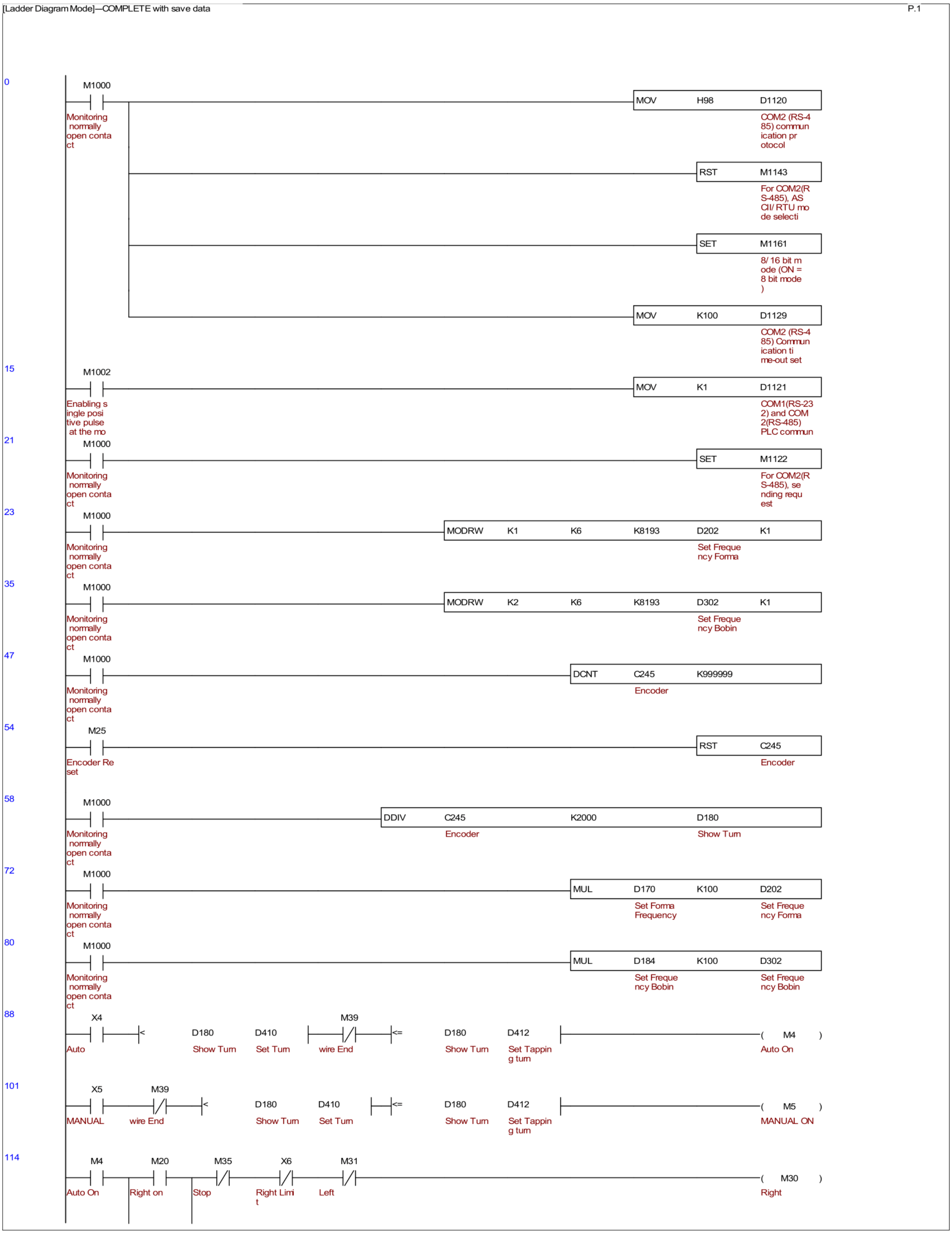

Figure 3.4. 4: PLC Ladder Diagram for the Complete Control Program (Part-I)

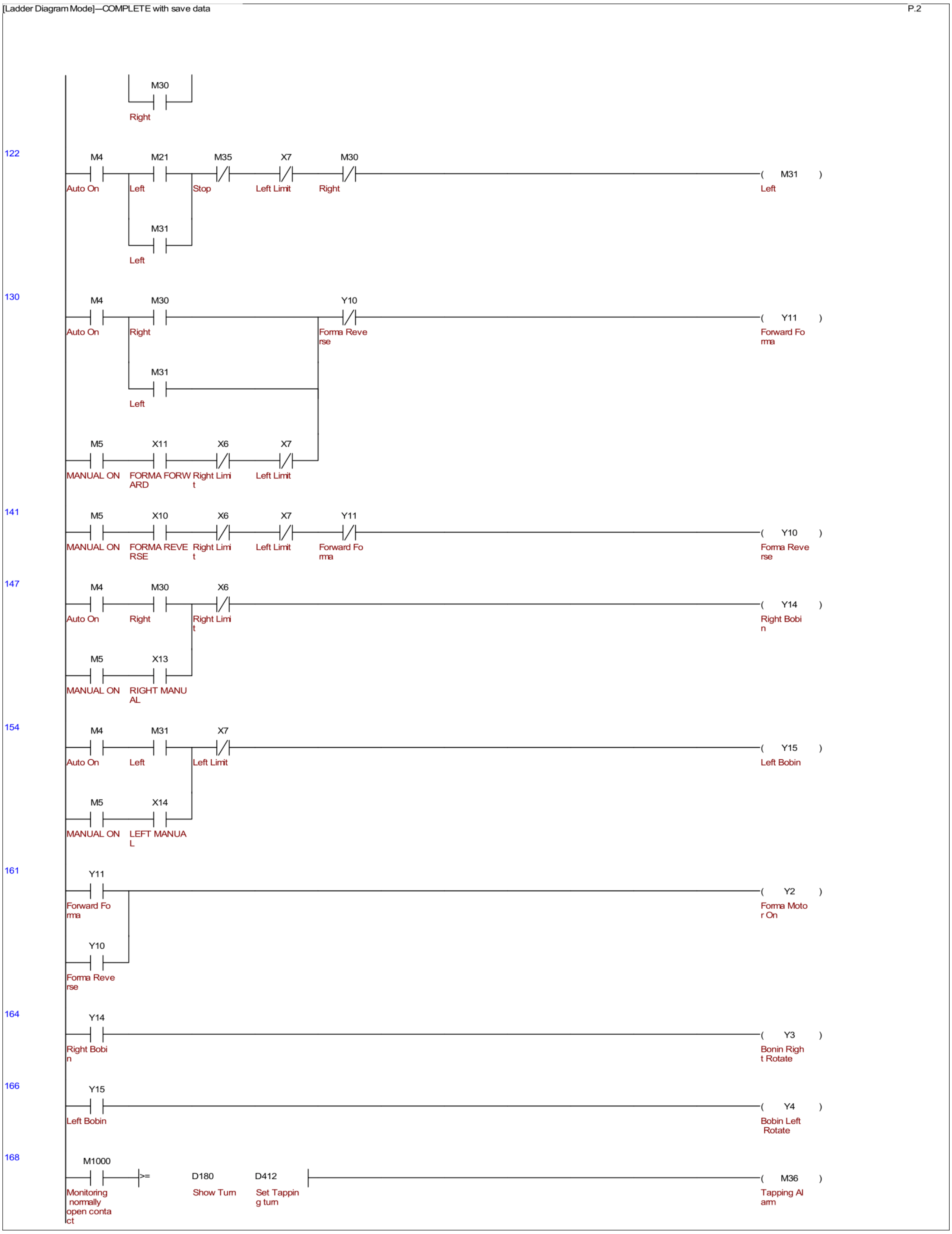

Figure 3.4. 5: PLC Ladder Diagram for the Complete Control Program (Part-II)

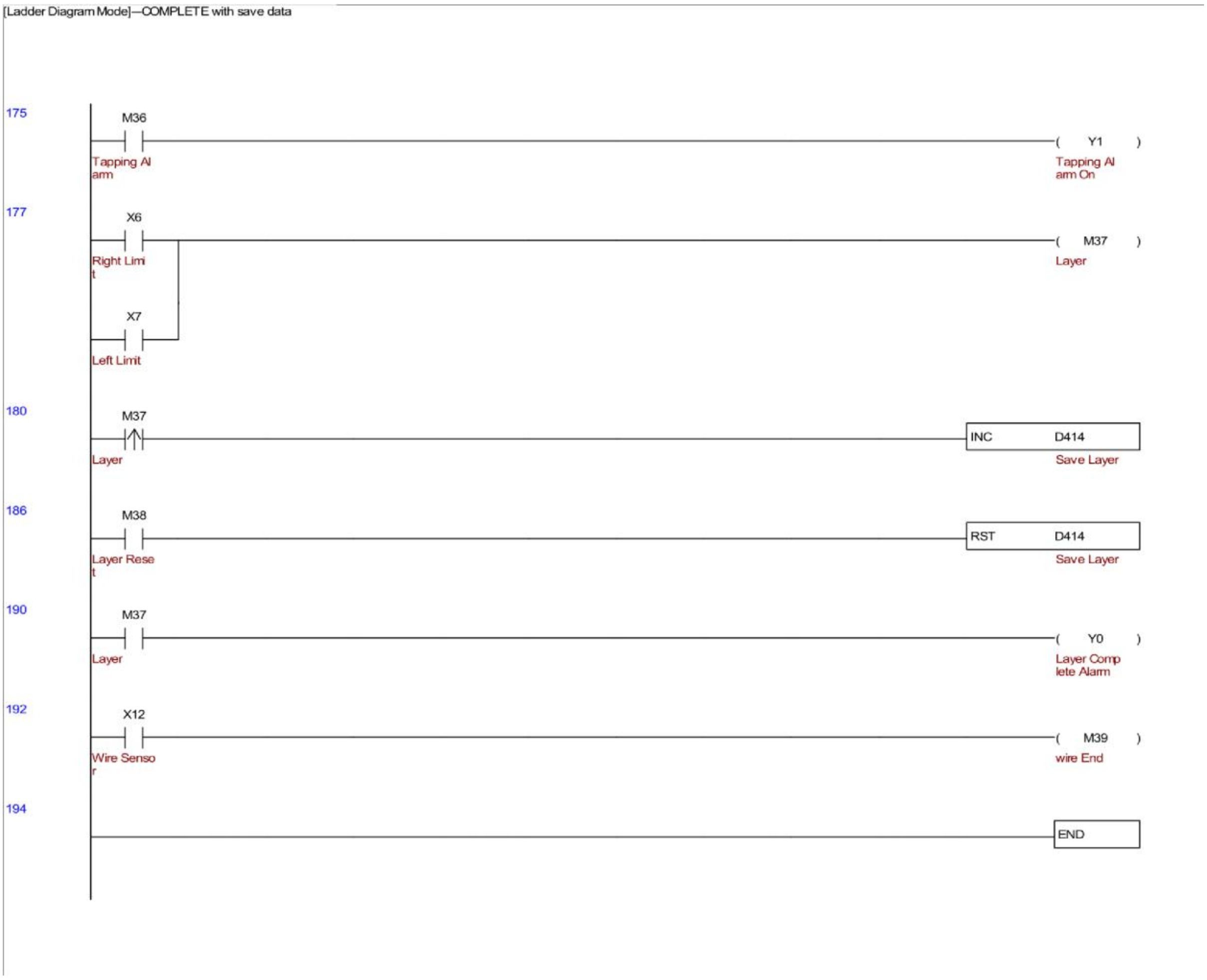

Figure 3.4. 6: PLC Ladder Diagram for the Complete Control Program (Part-III)

3.4.5. HMI Design

The Human-Machine Interface (HMI) of the transformer coil winding machine was carefully designed to provide a user-friendly and efficient platform for controlling and monitoring the entire winding process. The HMI communicates with the PLC via RS232 protocol, enabling smooth data exchange between the user input panel and the control system. It is programmed using Delta's DOPSoft software and features a graphical touchscreen layout that allows operators to interact with the system in real time.

The interface includes several input fields where the operator can enter key parameters such as the total number of coil patches, tap changer values, and the motor speeds (in Hz) for both the form and bobbin motors. It also features toggle options to switch between manual and automatic modes, as well as start, stop, and reset buttons for easy control. The layout was designed to be visually clear, with large, labeled buttons and numeric input pads, reducing the chance of operator error during high-precision tasks.

During machine operation, the HMI provides continuous feedback by displaying critical performance data such as coil turn count (from encoder signals), motor activity status, and winding direction. In automatic mode, the HMI also shows real-time alerts, such as the absence of wire detected by the proximity sensor, completion of coil layers (via limit switches), or motor faults. These alerts are accompanied by audio-visual indicators such as alarms and blinking warnings, helping the operator respond promptly.

Furthermore, the HMI includes status indicators for power supply, emergency stop activation, and current operating mode. This makes it easier to troubleshoot and ensures safe operation.

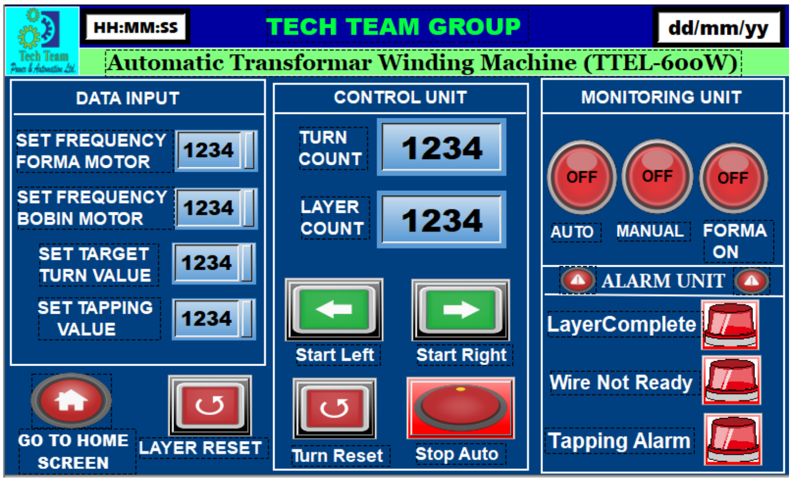

Figure 3.4. 7: HMI Design.

The entire interface was structured to minimize complexity while maximizing control accuracy, contributing significantly to productivity, ease of use, and operational safety. Overall, the HMI plays a vital role in the system by bridging the gap between operator and machine, ensuring that every aspect of the winding process is visible, configurable, and responsive in real time.

3.4.6. Full Hardware Overview After Setup

After completing the assembly and wiring, the full hardware setup of the transformer coil winding machine demonstrates a fully integrated electromechanical system, combining automation, precision, and safety. The system is composed of three major hardware sections: the control system, the power drive and motor system, and the mechanical coil winding structure.

At the center of the control system is the Programmable Logic Controller (PLC), which manages all logical operations, input/output handling, safety checks, and communication between devices. It processes real-time data from sensors and user inputs, executing commands based on the pre-loaded ladder logic program. The Human-Machine Interface (HMI), mounted on the front of the control panel, provides a user-friendly touchscreen interface for setting operational parameters such as coil patch count, tap changer values, and motor speeds. The HMI and PLC communicate using the RS232 protocol, ensuring smooth data transfer for command execution and feedback visualization.

Two Variable Frequency Drives (VFD-1 and VFD-2) are installed inside the control panel to control the speed and direction of the winding motors. These VFDs communicate with the PLC using the RS485 MODBUS protocol, allowing synchronized motor control. The motors connected to the VFDs include a form motor, which rotates the coil forma, and a bobbin motor, which supplies the super enamel wire. Synchronization between these two motors is crucial to maintain proper wire tension, accurate layering, and uniform winding. To achieve this, a rotary encoder is mounted on the motor shaft and feeds pulse signals back to the PLC, enabling it to monitor motor rotation and dynamically adjust speeds.

The SMPS (Switched-Mode Power Supply) provides a stable 24V DC power supply to all control devices, including the PLC, HMI, encoder, and indicator systems. Electrical protections such as circuit breakers, fuses, and overload relays are also integrated within the panel to safeguard against overcurrent, short circuits, and voltage fluctuations.

The machine’s safety and control hardware include an emergency stop switch, selector switch for switching between automatic and manual modes, pedal switches for manual winding, limit switches to detect end positions during coil movement, and a proximity sensor to detect the presence of the winding wire. All these devices are wired directly to the PLC’s input terminals and are routed through terminal blocks for proper wire management and ease of troubleshooting.

The output section consists of several indicator lights, alarm buzzers, and completion signal units. These components alert the operator about system status, layer completion, wire errors, or any abnormal condition. For example, when a layer is completed, the respective limit switch is triggered, and the PLC activates an indicator and buzzer to notify the operator to proceed with the next layer.

Mechanically, the hardware includes the coil forma assembly, which is mounted on a stable base with minimal vibration. The wire feeding mechanism, consisting of the bobbin holder, tension guide, and wire rollers, ensures smooth delivery of the enamel wire to the coil forma.

The structure is built to withstand mechanical stress, maintain alignment, and allow smooth bidirectional winding as per the set parameters.

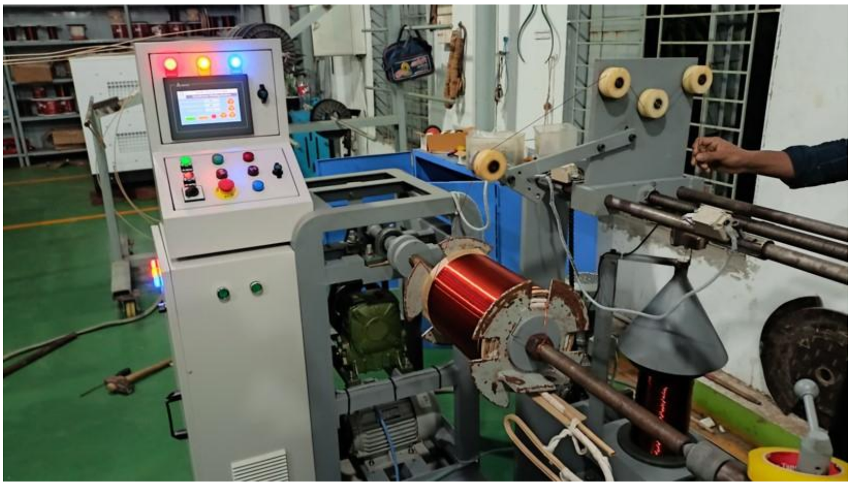

Figure 3.4. 8: Full Hardware Overview.

Cable trays, wiring ducts, and proper labeling are used throughout the panel to maintain a clean and professional layout. The overall control panel is well-ventilated, compact, and easy to access for maintenance purposes. Heat generated by the VFDs and power supply is managed using built-in fans or ventilation grills.

In conclusion, the complete hardware setup of the transformer coil winding machine successfully combines precision automation with industrial-grade safety and performance. Every component—from the PLC logic to motor synchronization and user interface—has been selected and integrated to deliver consistent coil winding results, minimize human error, and increase daily production output. This setup provides a scalable foundation for further enhancements, such as foil paper automation or remote monitoring.

CHAPTER 4

RESULTS & DISCUSSIONS

4.1 Results

The results section shows the findings in tests done to determine the effectiveness of the Transformer coil winding machine and how effective it is in varied conditions. The experiments were aimed at reviewing the system efficiency, effects on batteries, and cooling.

4.2 Machine Parameter Setup in HMI and Operation Command

The operation of the transformer coil winding machine is initiated and controlled through a series of predefined commands set via the Human-Machine Interface (HMI) and physical switches. Once the machine is powered on, the operator selects the operation mode either manual or automatic using a selector switch or touch-based toggle on the HMI. In automatic mode, the operator inputs parameters such as coil patch count, tap changer value, and motor speed into the HMI.

After confirming the data, the “START” command is given through the HMI, prompting the PLC to activate both the form motor and bobbin motor via the Variable Frequency Drives (VFDs). The machine begins winding in one direction, and once a limit switch is triggered, the PLC commands both motors to stop, completing one layer. Following this, a foil layer can be applied, and then the “REVERSE” command is issued either automatically or manually causing the form and bobbin motors to rotate in opposite directions to begin the next layer.

In manual mode, the operator controls the motors using pedal switches, giving precise command over motor direction and winding speed for testing or low-volume winding. The emergency stops command overrides all operations, immediately halting the system for safety. Throughout operation, the PLC continuously reads input from the encoder to count turns and monitor motor synchronization, while the HMI displays real-time status, alerts, and completion messages. These command sequences ensure that the machine performs smooth, accurate, and safe winding operations under both automated and manual control.

Figure 4.2. 1: Machine Parameter Setup in HMI and Operation Command Button.

4.2.1 Coil Winding Function

The coil winding process begins once all machine parameters are correctly configured via the Human-Machine Interface (HMI), including the total number of coil patches, tap changer values, and motor speeds. After selecting automatic mode and pressing the start command, the system checks for the presence of the super enamel wire using a proximity sensor. If the wire is properly detected, the PLC initiates the operation by sending signals to the Variable Frequency Drives (VFDs), which activate the form motor and bobbin motor. As both motors start to rotate, the coil winding is now running, with the wire being wound precisely onto the coil forma from right to left.

Throughout the winding operation, a rotary encoder continuously feeds pulse data to the PLC, allowing it to count turns and ensure accurate synchronization between both motors. The HMI displays real-time coil turn counts, motor speeds, and operational status. When the left limit switch is triggered, the motors stop automatically, marking the completion of one layer. At this point, the operator can apply foil insulation manually before initiating the reverse winding direction for the next layer.

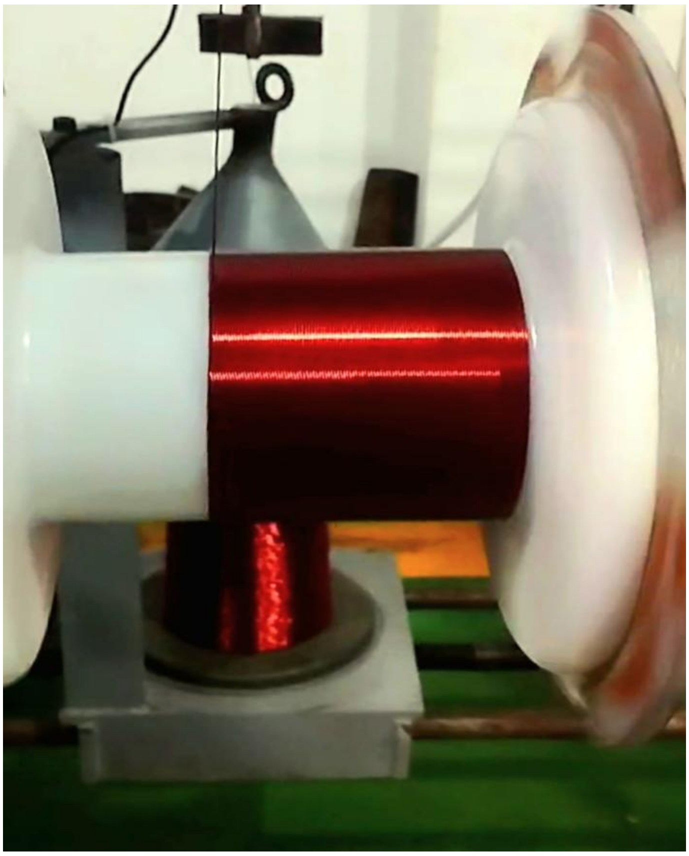

Figure 4.2. 2: Real time coil winding

This cycle continues until the total number of programmed turns is completed. The system’s automated logic ensures that the coil winding runs smoothly, accurately, and consistently, minimizing human error and enhancing production efficiency.

EQUENCY MOTOR: 30

EQUENCY MOTOR: 26

TARGET N VALUE: 1008

TAPPING ALUE: 580

TURN COUNT: 21

LAYER COUNT: 0

Figure 4.2. 3: Real Time Monitoring from HMI Screen.

4.3 Overall System Performance

The developed automatic transformer coil winding machine was successfully assembled, programmed, and tested under real-time conditions. The results demonstrate a significant improvement in winding precision, production efficiency, and operational safety compared to traditional manual winding methods. The machine was evaluated in both manual and automatic modes to validate functionality, performance consistency, and user control reliability.

In automatic mode, the system performed continuous winding with precise layer counting and consistent wire tension, maintained through synchronized motor control using VFDs and encoder feedback. The Human-Machine Interface (HMI) allowed the operator to set essential parameters such as the number of patches, tap values, and motor speeds. These inputs were correctly interpreted and executed by the PLC, and the winding process continued without human intervention until the programmed number of turns or layers was completed. The proximity sensor reliably detected the presence or absence of wire, and safety alarms were triggered appropriately when wire was missing or a limit switch was reached. The machine produced 6 to 9 transformer coils per day, depending on coil size and patch count—significantly higher than the 2 to 3 coils per day achievable through manual winding.

In manual mode, operators had full control using pedal switches, allowing them to adjust winding direction and speed manually. This mode was particularly useful for prototype work, adjustments, or maintenance tasks. Although slower than automatic mode, it proved flexible and effective for special coil designs or troubleshooting.

The synchronization of the form motor and bobbin motor, managed through real-time encoder feedback, prevented wire slippage, overlapping, or breakage, which are common problems in manual winding. Layer alignment was consistent throughout, ensuring high-quality coil structure. The encoder counted each turn with high precision, and the count displayed in real time on the HMI matched the actual coil turns with negligible error.

The control panel and wiring system operated safely under continuous operation, with no overheating or electrical faults detected during prolonged testing. The integration of emergency stops features, alarms, and limit switches proved essential in ensuring operational safety and protecting the machine from mechanical or human-induced damage.

Comparing performance metrics before and after automation, the following improvements were observed:

Parameter	Manual Winding	Automated Winding
Daily Output (average)	2–3 coils/day	6–9 coils/day
Labor Requirement	3–4 workers	1 operator
Wire Tension Consistency	Variable	Stable and controlled
Error Rate (patch/tension)	High	Low
Turn Counting Accuracy	Manual Estimation	Encoder-based (100%)
Safety and Alerts	Limited	Fully integrated

The findings clearly show that the proposed system reduces labor dependency, minimizes winding errors, and significantly increases productivity and repeatability. Additionally, the machine was built at a cost of 10–12 lakh BDT, making it a more affordable solution compared to existing commercial alternatives that often cost several times more.

Despite its strong performance, some limitations were noted. For instance, foil paper wrapping is still performed manually, which adds extra steps between coil layers and increases total winding time. Future improvements will focus on integrating an automated foil wrapping system and enabling remote monitoring through IoT-based enhancements.

Overall, the experimental results confirm that the designed automatic transformer coil winding machine meets its intended objectives in terms of speed, accuracy, cost-efficiency, and ease of use, and is a strong candidate for industrial adoption in medium- to large-scale transformer manufacturing environments.

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CHAPTER 5

PROJECT MANAGEMENT

Project management plays a critical role in ensuring the successful execution of any engineering or technological endeavor. It involves not only the systematic planning and execution of tasks but also the effective coordination of time, resources, and people to achieve the desired objectives. In the context of developing the Automatic 0 to 3150 kVA Distribution Transformer Winding Machine, project management was central to transforming a conceptual design into a fully functional prototype.

From selecting suitable components like PLCs, VFDs, and HMIs to programming, wiring, integrating, testing, and optimizing performance — each phase of the project required clear milestones, active monitoring, and agile decision-making. Moreover, managing a limited budget and available technical resources made it imperative to apply strategic planning, teamwork, and problem-solving skills.

This chapter outlines how the project was structured and implemented, highlighting the key tasks, schedules, milestones, resources, and cost management strategies employed throughout the process. It also discusses the most important lessons learned, reflecting on how this hands-on experience helped build technical competencies and managerial capabilities. By documenting these elements, this chapter aims to provide a holistic view of the management approach undertaken to complete the automation project efficiently and effectively.

5.1 Task, Schedule and Milestones

The execution of the project followed a structured timeline, segmented into distinct phases: planning, design, development, testing, and deployment. The table below outlines the key tasks, estimated durations, and actual completion dates:

Table 5. 1: Milestone Completion Table.

Activity	Start Date	End Date	Duration (in Days)	% Complete
Proposal of work	11-Jan	20-Jan	10	100
Search Relevant Literature	21-Jan	04-Feb	15	100
Chapter 1	05-Feb	16-Feb	12	100
Chapter 2	17-Feb	06-Mar	18	100

PLC & HMI Programming	07-Mar	01-Apr	26	100
Mechanical and electrical integration	02-Apr	22-Apr	21	100
Panel wiring and safety setup	23-Apr	11-May	19	100
Prototype testing and debugging	12-May	24-May	13	100
Chapter 3	25-May	31-May	7	100
Chapter 4	01-Jun	05-Jun	5	100
Chapter 5	06-Jun	13-Jun	8	100
Chapter 6 & Chapter 7	14-Jun	26-Jun	13	100

We established a milestone before we began the project, and after it was over, we noticed a slight difference. However, the project was finished later than we had anticipated. The Gantt chart with milestones is attached below.

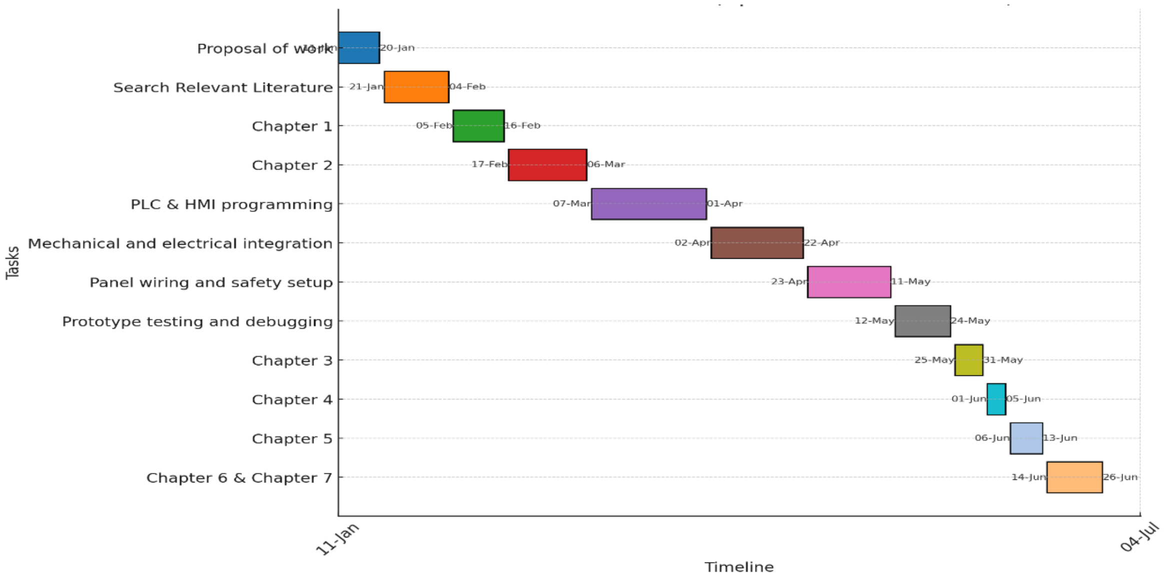

Figure 5. 1: Project Milestone Gantt chart.

Milestone Highlights

- Milestone 1: Basic PLC and HMI communication established.
- Milestone 2: Synchronization between VFD-driven motors achieved.
- Milestone 3: Successful testing of automatic and manual winding modes.
- Milestone 4: Final prototype capable of winding 6–9 coils/day was demonstrated.

Schedule Justification

Some minor delays occurred during the programming and testing phase due to:

- Compatibility issues between the encoder and PLC.
- Real-time synchronization fine-tuning of motor speeds.

Despite these setbacks, the final implementation remained within the projected timeframe by reallocating efforts and adjusting non-critical tasks.

5.1.1 Primary Task Completion

Human Resources

- Project Team: Consisted of 3 core members – responsible for programming, electrical setup, and mechanical integration.
- External Consultation: Occasional guidance from faculty members and industrial technicians was sought.

Material Resources

- PLC (with Modbus), HMI, VFD, Encoder, Gear Motor, SMPS, relay boards, aluminum structure, safety switches, wires, and insulation material.

Budget Management

An initial budget of 12,00,000 BDT was allocated. The project was completed within approximately 11,45,000 BDT, staying under budget due to:

- Strategic local sourcing of electrical components.
- Use of in-house tools and testing instruments.
- Avoidance of over-engineering in the initial prototype phase.

Category	Estimated Cost (BDT)	Actual Cost (BDT)
Electrical components	6,00,000	1,95,000
Mechanical setup	2,00,000	5,80,000
Programming tools	50,000	45,000
Testing & Safety Gear	50,000	40,000
Miscellaneous	1,00,000	85,000
Total	10,00,000	9,45,000

Resource Optimization Strategy

- Reused mechanical housing components where feasible.
- Avoided purchasing proprietary software by using open-source or existing tools.
- Designed a flexible system that allows future upgrades without major redesigns.

5.2 Lesson Learned

Working on a large-scale technical project like this has been an enriching experience, both technically and managerially. Key lessons include:

1. **Importance of Planning and Flexibility**
   Initial planning helped in defining a roadmap, but flexibility was crucial during integration and debugging phases. Unexpected delays (e.g., firmware issues or motor speed mismatches) required adaptive problem-solving.
2. **Communication and Team Coordination**
   Maintaining clear communication across team members ensured synchronized efforts. Frequent progress meetings helped identify issues early, saving valuable time and resources.
3. **Prototyping and Iterative Testing**
   Instead of aiming for a fully complete machine in one go, breaking the project into testable modules (motor control, patch setting, HMI display) made troubleshooting easier and improved overall system reliability.
4. **Real-World Constraint Management**
   Understanding real-world limitations such as hardware availability, component compatibility, and space constraints in the lab environment was essential. These constraints shaped design decisions more than theoretical models.

5. **Emphasis on Documentation**
   Maintaining proper documentation of ladder logic, wiring diagrams, and HMI screen flows not only helped in debugging but will serve as a vital asset for future upgrades or scaling.
6. **Budget Awareness**
   Resource optimization and cost tracking were continuous processes, not just financial tasks. We learned how to make effective decisions within budget without compromising performance’s.

CHAPTER 6

IMPACT ASSESSMENT OF THE PROJECT ON HUMAN HEALTH & ENVIRONMENT

6.1 Introduction

In recent years, the rapid advancement of industrial automation technologies has fundamentally reshaped traditional manufacturing practices. One such transformation is evident in the electrical equipment manufacturing sector, where precision, efficiency, and scalability are of utmost importance. The transformer, as a critical component in electrical power distribution networks, demands a high degree of reliability and consistency in its internal winding processes. Traditionally, this coil winding has been a manual or semi-manual task, requiring skilled labor, intensive monitoring, and careful quality control. However, manual processes are often plagued by limitations such as inconsistent tension, human error, low production rates, and increased labor costs.

The proposed Automatic 0 to 3150 kVA Distribution Transformer Winding Machine, developed using Programmable Logic Controller (PLC), Variable Frequency Drive (VFD), and Human-Machine Interface (HMI), offers a transformative solution to these challenges. By leveraging automation, the machine not only increases the daily production capacity but also ensures uniform coil quality and enhanced operational safety. The incorporation of encoder-based feedback, synchronized motor control, and real-time user interaction through HMI represents a significant leap towards Industry 4.0-ready manufacturing.

Yet, the significance of this innovation cannot be fully appreciated without analyzing its broader implications. Technological advancements, especially in automation, have a cascading effect on multiple dimensions of industry and society. Thus, a well-rounded impact assessment is essential to understand how this system affects not only production efficiency but also the economy, environment, labor structure, and ethical considerations.

This chapter systematically examines the economic benefits, societal transformations, and global implications of deploying the proposed automated system. It also evaluates the environmental sustainability of the machine, explores ethical responsibilities, and discusses the relevance of applicable standards and codes. Additional concerns, such as long-term maintainability, scalability, and future integration with smart technologies, are also addressed.

By analyzing these factors, this chapter provides a holistic view of the project’s significance beyond its technical functionality, establishing its role in shaping the future of transformer manufacturing and smart industry solutions.

This chapter provides a thorough evaluation of the various impacts associated with the development and implementation of the proposed automated transformer coil winding machine. The assessment is categorized into several domains, including economic, societal, global, environmental, and ethical aspects. In addition, the utilization of relevant industrial standards and codes is examined, along with other pertinent concerns such as technological feasibility, long-term sustainability, and operational challenges.

6.2Economic Impact

The introduction of automation into the transformer coil winding process represents a major economic advancement for the electrical manufacturing sector, particularly in developing countries such as Bangladesh.

- Reduction in Operational Costs: Manual winding processes typically require 3 to 4 skilled operators per shift, along with intensive supervision to ensure quality and accuracy. In contrast, the proposed automated system can be operated by a single trained technician, significantly reducing labor costs.
- Higher Production Output: The automated system allows for the production of approximately 6 to 9 coils per day, compared to just 1 to 3 coils using traditional manual methods. This increase in productivity not only reduces per-unit manufacturing cost but also enables the manufacturer to meet high market demand, especially during peak periods.
- Return on Investment (ROI): Although the initial capital expenditure for the machine is between 10 to 12 lakh BDT, the ROI is favorable due to savings on labor, reduced error-related losses, and enhanced throughput. Most small and medium enterprises (SMEs) in the transformer sector can expect a full return within one to two years of regular operation.
- Support for Local Industry: This locally-developed solution promotes technology independence, reducing reliance on expensive imported machines, and opening

opportunities for local innovation and entrepreneurship in automation and electrical manufacturing.

6.3 Societal Impact

The project has both direct and indirect societal implications that extend beyond the factory floor:

- Job Transformation: While the automation process reduces the need for unskilled labour, it creates a demand for technicians, PLC programmers, control engineers, and maintenance personnel. This encourages technical education and vocational training, aligning the workforce with future industrial needs.
- Improved Workplace Safety: The incorporation of proximity sensors, alarms, emergency stop switches, and HMI-based monitoring significantly reduces the risk of workplace accidents, ensuring a safer environment for operators.
- Product Quality and Public Trust: The consistent quality of coils produced by the machine contributes to more reliable transformers. This ultimately benefits the end-users, including utility companies and consumers, by enhancing the reliability of power distribution systems.
- Empowerment through Technology: The project serves as an example of empowerment through indigenous innovation, encouraging engineers and technicians to develop localized solutions to complex industrial problems.

6.4 Global Impact

The implications of this project extend into the global domain, especially in the context of smart manufacturing and sustainable development.

- Alignment with Industry 4.0: The project integrates key aspects of Industry 4.0—automation, real-time data monitoring, modular programming, and smart human-machine interfacing. This positions local manufacturers on the global map of advanced manufacturing.
- Export Potential: Given its cost-effectiveness and versatility, the proposed machine could be exported to developing countries in South Asia, Africa, and Latin America,

where automation is still emerging. This offers scope for international collaborations and technology transfer.

- Energy Infrastructure Development: The machine supports rapid transformer production, which in turn supports power infrastructure development—a critical requirement for industrialization and modernization in many countries.

6.5 Environmental Impact

Modern industrial development must prioritize environmental sustainability. The proposed system supports several eco-friendly features:

- Minimized Material Waste: Manual winding often leads to overuse of copper wire and insulation due to inconsistent winding. The automated machine's precise control over winding tension and layer count minimizes waste, conserving expensive and non-renewable materials like copper.
- Energy Efficiency: The use of Variable Frequency Drives (VFDs) enables dynamic control of motor speed and torque, optimizing energy consumption based on load. This contributes to overall energy savings, reducing the carbon footprint of the production facility.
- Lower Emissions and Noise: As fewer workers are required to operate the machine, and as the motors operate at optimal speeds, the overall operational noise and secondary emissions (from manual labor facilities like ventilation or lighting) are reduced.
- Durability and Lifecycle Optimization: The production of higher quality coils enhances the longevity of transformers, reducing the frequency of replacements, and thus minimizing the environmental impact of manufacturing, transport, and disposal of faulty units.

6.6 Ethical Issues

Ethical considerations are central to the development and deployment of any automated system:

- Fair Transition for Workers: There is an ethical responsibility to provide support, reskilling, and training to workers who may be displaced by automation. The transition from manual labor to automation must be just and inclusive.

- System Transparency and Safety: The machine is designed to offer transparency through real-time HMI feedback and alarms. Clear warnings in case of faults, automatic shutdown in critical situations, and operator override capabilities ensure ethical engineering practices in terms of user safety.
- Accessibility and Affordability: Making the technology open-source or providing subsidized versions for educational institutes and small industries reflects ethical commitment to knowledge democratization and accessibility.

6.7 Utilization of Existing Standards or Codes

The project integrates or aligns with several industrial and safety standards, both implicitly and explicitly:

- Modbus Communication Standards (RS232/RS485): Widely accepted in industrial automation, these protocols ensure secure, reliable, and interference-resistant data communication among PLCs, VFDs, and HMIs.
- Electrical and Machine Safety Standards: Though not cited by code number, the implementation of emergency stops mechanisms, limit switches, protective relays, and grounded wiring conform to best practices outlined in standards such as IEC 60204-1 (Safety of Machinery – Electrical Equipment) and NFPA 79.
- Control System Programming Practices: The ladder diagram used in PLC programming follows conventions widely recommended in industrial automation standards like IEC 61131-3, ensuring code modularity, scalability, and safety.
- Ergonomics and User Interface Standards: The HMI design follows basic ergonomic principles by providing a clear and responsive display, appropriate alert mechanisms, and operator input fields. Although not formally certified, it aligns with ISO 9241-210 (Human-centered design for interactive systems).

Future iterations of the system could formally adhere to:

- ISO 9001 (Quality Management Systems)
- IEC 61508 (Functional Safety of Electrical/Electronic Systems)

6.8 Other Concerns and Considerations

Maintenance and Reliability

- Reliability Engineering: With fewer moving parts and digital synchronization of motors, the system is less prone to breakdowns. Scheduled maintenance of VFDs and cleaning of encoder sensors is sufficient for uninterrupted operation.
- Spares and Replacement: All components used (PLC, VFD, HMI) are commercially available and modular, ensuring easy replacement and upgradability.

Technological Scalability

- Modular Design: The design allows for expansion. Additional functionalities such as automatic foil paper dispenser, IoT integration, or SCADA connectivity can be integrated without modifying the core structure.
- Remote Monitoring and Control: With increasing demand for remote factory operation, the system could be integrated with cloud-based platforms using Ethernet/IP or MQTT protocols for remote diagnostics and performance monitoring.

Risk and Limitation

- Initial Skill Gap: Small factories may face a shortage of trained personnel for programming and maintenance. Establishing partnerships with technical institutes or offering short courses can bridge this gap.
- Power Disruption: Sudden power loss can disrupt operations. To address this, UPS or small industrial backup systems can be implemented to complete the current winding cycle or safely power down the system

CHAPTER 7

CONCLUSIONS & FUTURE WORKS

7.1 Conclusions

The development of the Automatic 0 to 3150 kVA Distribution Transformer Winding Machine has successfully demonstrated how industrial automation can be applied to enhance the manufacturing process of distribution transformers. This project aimed to replace conventional manual winding methods—which are often time-consuming, labor-intensive, and prone to human error—with an intelligent and automated solution that ensures efficiency, precision, and safety. Through the seamless integration of a Programmable Logic Controller (PLC), Variable Frequency Drive (VFD), Human-Machine Interface (HMI), and encoder-based feedback, the proposed system achieved real-time synchronization, accurate coil layer counting, and precise control of winding tension.

The final implementation not only met all technical specifications but also exceeded performance expectations. The automated machine was capable of producing six to nine high-quality transformer coils per day, a substantial improvement over the traditional output rate of two to three coils. This increase in productivity was achieved without compromising the quality of the winding, thereby proving the reliability and industrial potential of the design. In addition, the system's modular architecture and locally sourced components ensured cost-effectiveness, making it a practical solution for small and medium-sized transformer manufacturers.

The machine also incorporated critical safety features such as limit switches, emergency stop buttons, and real-time fault alerts through the HMI, enhancing operational safety and user confidence. These features, along with the intuitive interface and flexible operating modes (manual and automatic), made the system suitable not only for production environments but also for technical training and research applications.

Beyond fulfilling the immediate project objectives, this work offers a scalable and adaptable platform that aligns with the broader goals of Industry 4.0. Its relevance extends to various sectors, including transformer manufacturing facilities, engineering laboratories, and technical education institutes. By combining practical engineering with automation technology, the project sets a strong foundation for future advancements in smart manufacturing and localized industrial innovation.

In conclusion, the project has not only delivered a high-performing automated winding machine but also contributed to the ongoing transformation of industrial practices through automation, precision control, and intelligent design. It stands as a testament to the potential of integrating control systems and mechanical design in solving real-world engineering challenges.

7.2 New Skills and Experiences Learned

The successful completion of this project allowed the team to acquire a wide range of technical, practical, and managerial skills:

Technical Skills

- PLC Programming (Ladder Logic): Learned how to design, test, and debug ladder logic for real-time control.
- HMI Configuration: Gained experience in creating user interfaces for machine parameter setup and monitoring.
- VFD Tuning: Understood how to configure VFDs for synchronized motor control and speed adjustments.
- Encoder Integration: Learned how to use encoder feedback for real-time layer counting and process accuracy.

Practical Engineering Skills

- Panel Wiring and Circuit Safety: Hands-on experience in designing control panels, integrating sensors, and ensuring safe wiring.
- System Troubleshooting: Developed diagnostic approaches to resolve real-time operational issues such as misalignment, feedback delays, or speed mismatches.

Project Management & Team Collaboration

- Effectively planned, scheduled, and monitored project milestones.
- Practiced budget control, decision-making under constraints, and task delegation.
- Improved interpersonal communication, especially when coordinating across different technical roles.

This project was also an opportunity to simulate a real industrial R&D workflow, building confidence in developing, testing, and presenting a functional prototype in a professional setting.

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APPENDIX A

TURNITIN REPORT

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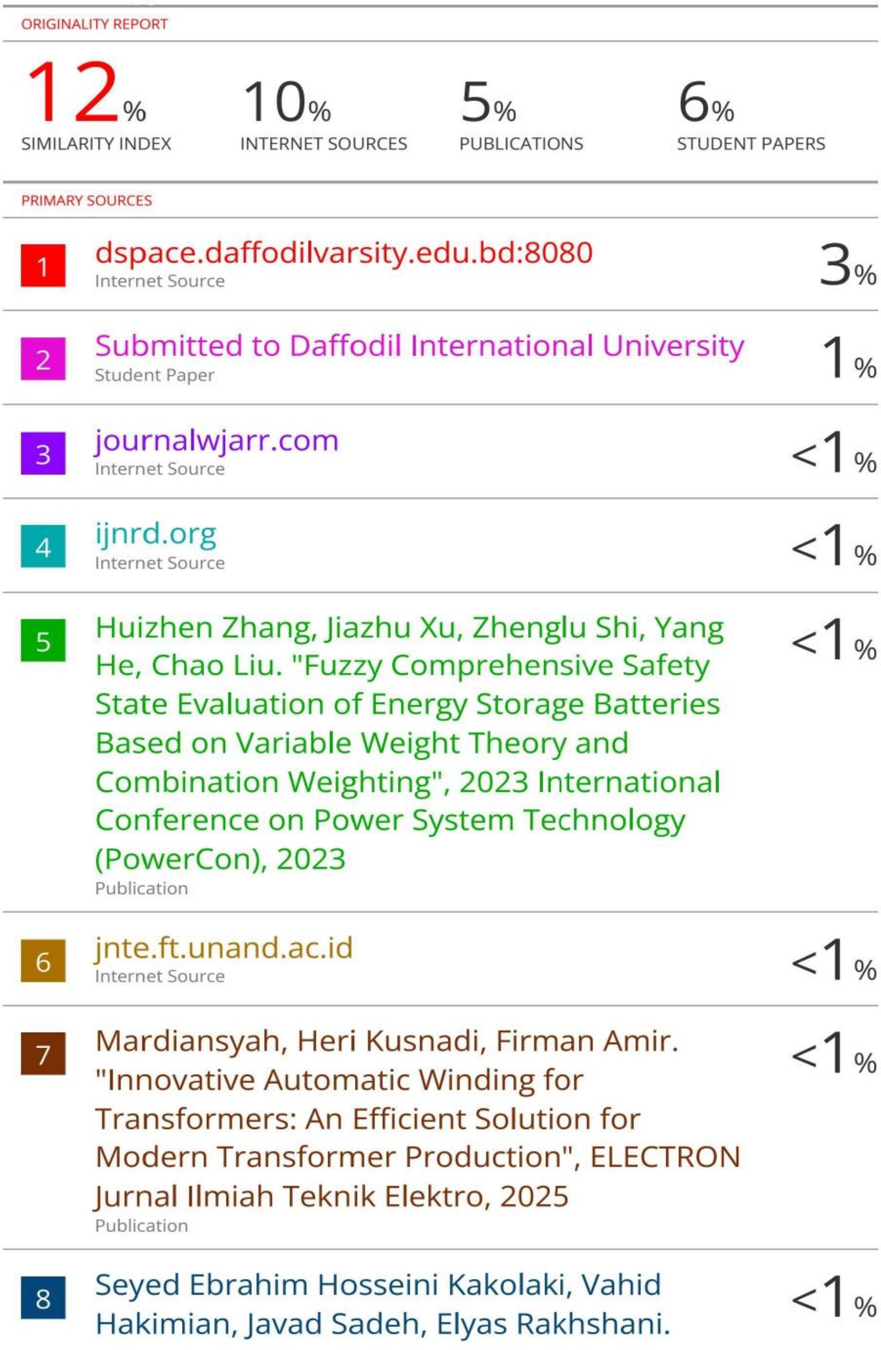
APPENDIX B

COMPLEX ENGINEERING PROBLEM SOLVING AND ENGINEERING ACTIVITIES

Complex Engineering Problems (P) Solving		
	Attributes	Statement from students
P1	Depth of knowledge required	Our project demanded a deep understanding of industrial automation, PLC programming, electrical Drawing.
P2	Range of conflicting requirements	We navigated conflicting demands such as achieving high accuracy maintaining coil winding, two motor synchronization.
P3	Depth of analysis required	Our endeavor involved extensive analysis, including synchronization, Communication, and Read physical data.
P4	Interdependence	Recognizing the interdependence of various parameters, such as motor speed, count layer, count total coil turn number.



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