



FACULTY OF ENGINEERING AND TECHNOLOGY

DEPARTMENT OF ELECTRONICS AND ELECTRICAL ENGINEERING

FINAL YEAR PROJECT REPORT

DESIGN OF AN AUTOMATIC FORWARD AND REVERSE STARTER

FOR THREE PHASE INDUCTION MOTOR.

BY

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**A FINAL YEAR PROJECT REPORT SUBMITTED TO THE DEPARTMENT OF
ELECTRICAL ENGINEERING IN PARTIAL FULFILMENT OF THE AWARD OF A
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ABSTRACT:

This project designs and implements an automated forward and reverses starter system for a three-phase induction motor to replace high risk manual switching mechanisms. Industrial and workshop environments heavily rely on these motors for conveyor belts, cranes, and machining equipment where directional changes are constantly required. Traditional manual phase reversal switches expose operators to high voltages and introduce severe mechanical and electrical stress to the motor due to abrupt directional changes. By integrating magnetic contactors, overload relays, and time delay mechanisms, this design ensures smooth transitions between forward, stop, and reverse states. Crucially, the system features both hardware and electrical interlocking mechanisms to prevent the forward and reverse contactors from engaging simultaneously, effectively eliminating the risk of catastrophic line to line short circuits.

To enhance precision and monitoring, the system integrates an Arduino microcontroller platform for sensor-based automation. The Arduino acts as the central control unit, processing inputs from operational switches or position sensors and managing output signals to the relay modules that drive the heavy duty contactors. Thermal overload relays are embedded within the power circuit to continuously monitor current draw, immediately cutting power if an overcurrent or fault condition is detected. Furthermore, the microcontroller enforces programmed time delays during direction switches, ensuring the motor rotor comes to a complete rest before reversing. The resulting prototype offers a highly reliable, safe, and cost-effective motor control solution that significantly reduces maintenance downtime and improves operator safety in small-scale industrial and micro workshops.

DECLARATION:

I, MUGWE SIMON, solemnly declare that this Final Year project report is entirely my own original work. It is being presented in partial fulfillment of the academic requirements necessary for the conferral of a Diploma in industrial Electronics and Electrical Engineering offered at Busitema University. The contents of this report are derived from my first final year project at the Faculty of Engineering and Technology, where I underwent a six months project engagement across various schedules within the Semester. I further affirm that this report has not been previously submitted in whole or in part to any other institution for the purpose of obtaining an academic award.

Sign: 

Name: Mugwe Simon

Date: 17th /06 / 2026.....

APPROVAL:

The undersigned supervisor, hereby certify that have reviewed this project report and confirm that it meets all the necessary academic standards and examination requirements for the award of a Diploma in industrial Electronics and Electrical Engineering at Busitema University.

Project supervisor.

Name: Mr. Mbabaali Frank

Signature:  Date: 11...../06...../2026.....

DEDICATION

First and foremost, I give thanks to God Almighty for His countless blessings, guidance, and strength throughout the completion of this Final Year Project Report and in every aspect of my life.

I dedicate this report to my mother, Alice Malime, and my father, Goerge Kirya, whose unwavering dedication, boundless love, steadfast support, and heartfelt prayers have been a source of endless encouragement and inspiration.

I also dedicate this work to Rev. Fr Martin Joseph Kibeti and Bro. Waki Moses, whose extraordinary leadership and compassionate service have touched many lives. Their commitment to their wonderful cause has been a beacon of hope and a testament to the power of faith in transforming communities and I will always be inspired by their legacy and become that Godly Transformational leader they inspired me to be.

ACKNOWLEDGEMENTS:

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I'm deeply grateful to the entire management and staff of Electrical department. Their willingness to share knowledge, answer my questions, made this project experience truly worthwhile. I also appreciate my university for giving me this opportunity to gain practical skills in my field of study.

A special thank you goes to my Mentor, for his professional advice mentorship and for helping me navigate through this learning process successfully.

I can't forget my fellow project mates – Ogwang Ronald, Mujungu Ronald, Mabinda Wycliffe, and Natule Ben - who became like a second family during these intense months of project work. Our teamwork, shared challenges, and mutual support made every task more manageable and every success more meaningful.

Most importantly, I give all glory to God Almighty, whose guidance and blessings have been evident throughout this entire journey.

LIST OF ACRONYMS

ABBREVIATION	FULL NAME
MCB	Miniature Circuit Breaker
MPCB	Motor Protection Circuit Breaker
MCCB	Molded Case Circuit Breaker
NC	Normally Closed
NO	Normally Open
OLR	Over Load Relay
PLC	Programmable Logic Controller
EMF	Electromotive force
PF	Power Factor
HP	Horse Power
IDE	Integrated Development Environment

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CHAPTER ONE: INTRODUCTION

1.0: Background.

In modern industrial and workshop environments, electric motors serve as the primary prime movers driving critical mechanical systems. Industrial applications such as conveyor belts, hoists, overhead cranes, elevators, and automated machine tools heavily rely on these motors to perform repetitive tasks. A distinct operational requirement across these applications is the frequent change in the direction of rotation (clockwise and counterclockwise). For decades, this directional reversal was achieved using manual switches or basic push-button starters operated entirely by human personnel.

However, relying on manual intervention introduces significant operational inefficiencies. Manual switching is inherently time-consuming, relies heavily on operator vigilance, and introduces a high probability of human error. If an operator mistakenly toggles the reverse direction while the motor is still spinning forward at high speed a phenomenon known as plugging the motor experiences massive electrical current spikes and severe counter-torque. This abrupt switching leads to rapid insulation degradation, mechanical gear shearing, and premature motor failure. To mitigate these hazards, this project proposes the design and construction of an Automatic Forward and Reverse Starter. This system shifts control from human operators to an automated framework utilizing magnetic contactors, time-delay relays, and robust interlocking mechanisms. By automating the sequence, the starter eliminates timing errors, enforces mandatory deceleration periods, safeguards the hardware, and ensures smooth transitions between operating states.

Furthermore, three-phase induction motors are the undisputed workhorses of the modern manufacturing sector. Their widespread industrial adoption stems from their highly desirable physical and economic characteristics: they are simple in construction, rugged, low priced, reliable, and exceptionally easy to maintain. In operation, they run at an essentially constant speed from no load to full load conditions. However, because their synchronous speed is strictly dependent on the supply frequency and the number of stator poles, three-phase induction motors are historically difficult to adapt to precise, wide-range speed control without expensive variable frequency drives (VFDs). In engineering scenarios where

massive, continuous speed variations are mandatory, direct current (DC) motors are traditionally preferred.

Nevertheless, because three-phase induction motors can be manufactured with specialized torque characteristics to suit most rugged industrial demands, they remain the optimal choice for the majority of heavy duty applications. Since speed modulation is not required for standard transport and lifting tasks, optimizing these motors through intelligent, automated directional control offers a highly cost effective alternative to expensive drive systems. Implementing an automated control topology leverages the rugged durability of the three phase induction motor while introducing modern safety and efficiency standards to small-scale industrial and workshop environments.

1.1: PROBLEM STATEMENT

In many industrial and mechanical systems such as conveyor belts, cranes, and automated machining tools there is a critical need for electric motors that can operate in both forward and reverse directions to enable bidirectional motion. However, most of these systems in small-scale environments still rely heavily on manual control networks, which require an operator to physically switch the direction of rotation. This manual intervention introduces severe operational bottlenecks, including human error, delayed response times, and heightened safety risks. These issues become particularly pronounced when the manufacturing system is subjected to frequent, rapid directional changes. Additionally, improper or un-timed switching between forward and reverse modes introduces acute phase-sequence conflicts, leading to catastrophic electrical short circuits, devastating mechanical stress on the motor shaft, and permanent thermal damage to the contactors or stator windings.

The primary operational challenge arises when both the forward and reverse circuits are accidentally engaged simultaneously, or when the motor is reversed abruptly without a sufficient time delay to allow the rotor to fully decelerate. Such operational errors cause instant line-to-line short circuits due to the overlapping of opposing phase sequences, resulting in explosive electrical faults, tripped main circuit breakers, and extensive system breakdowns. Moreover, conventional manual starter systems completely lack integrated automation features such as automated time delay reversal, thermal overload protection, and precise sequential control. These missing features are mathematically and operationally crucial for maintaining system efficiency, dampening harmful counter-torque, and protecting the inner stator windings from destructive overcurrent surges.

Despite the development of advanced motor starters, a review of current systems reveals the following critical research gaps:

1. **The Cost-Accessibility Gap for Small-Scale Enterprises:** While advanced, commercially available automatic motor control systems exist on the market such as industrial Programmable Logic Controllers (PLCs) or Variable Frequency Drives (VFDs), their high procurement costs, complex programming curves, and specialized maintenance requirements make them economically non-viable and highly inaccessible to small scale

2. industries and micro workshops as manual back and forth starters or basic time-of-flight (TOF) relays, still rely on physical.
3. **The Timing and Human Error Vulnerability Gap:** Current low cost alternatives, such human intervention or static hardware timers that lack real-world adaptability. They do not feature dynamic, sensor-based feedback loops to safely verify that a motor rotor has reached absolute standstill before initiating phase reversal.
4. **The Multi-Fault Protection Integration Gap:** Traditional manual starters are purely reactive, dangerous, and error-prone. There is a distinct gap in existing low-cost starter topologies regarding the seamless integration of simultaneous safety interlocks both physical and software-driven , real-time thermal overcurrent protection, and intelligent position sensing within a singular, low-cost microcontroller framework.

This project directly addresses these gaps by developing a low-cost, automatic, microcontroller-driven solution using readily available solid-state and embedded components, explicitly tailored to withstand the economic and operational constraints of small-scale industrial and workshop applications.

1.2: PROJECT OBJECTIVES

1.2.1: MAIN OBJECTIVE.

To design an automatic forward and reverse starter for a three-phase induction motor.

1.2.2: SPECIFIC OBJECTIVES.

- 1: To design an automatic forward and reverse control circuit and power circuit capable of operating a three-phase induction motor in both directions safely and efficiently without manual intervention.
- 2: To incorporate interlocking and protection mechanisms both electrical and mechanical to prevent simultaneous operation of forward and reverse circuits, protect the motor from overloads, and ensure reliable performance during direction changes.
- 3: To develop a system with combination of sensors that is to say; Arduino, load cell (single point) and proximity sensor (capacitive).

- 4: To test and evaluate the performance of the designed system by analyzing its operational reliability, response time, and safety efficiency under different load and switching conditions, ensuring it meets industrial automation standards.

1.3 RESEARCH QUESTIONS:

- 1: How can an automatic forward and reverse control circuit be designed to operate an induction motor safely and efficiently without manual switching?
- 2: What interlocking and protection mechanisms can be implemented to prevent simultaneous forward and reverse operations and protect the motor from overloads?
- 3: How can a combination of sensors be applied to achieve a desired automation control in the presence of given parameters?
- 4: How can the designed system be tested and evaluated to ensure reliable performance and compliance with industrial automation standards?

1.4: JUSTIFICATION OF THE PROJECT.

Small-scale industries and workshops rely heavily on manual or semi-automatic motor controls, which frequently lead to operational downtime, mechanical wear, and electrical hazards due to operator error. Developing an automatic forward and reverse starter specifically for these settings justifies itself by offering an affordable, compact, and fail-safe automation solution that directly enhances workplace safety, protects equipment from costly damage, and boosts overall productivity. In the contemporary manufacturing landscape, the financial viability of small-scale workshops depends on optimizing machinery uptime and eliminating unnecessary repair overheads. Manual phase-reversal switching methods expose internal contact components to intense electric arcing and transient voltage spikes. Over time, this degradation triggers severe phase-to-phase insulation faults, which are a leading cause of catastrophic stator breakdown in three-phase machinery according to technical findings published in **Nature Scientific Data**. By introducing an embedded microcontroller architecture that automates the directional cycle, this project completely eliminates human error from the physical switching loop. The automated system replaces unpredictable manual timing with rigid, software-enforced cooling states, justifying the design as an essential, high-utility asset protection mechanism for resource-constrained enterprises.

Furthermore, this engineering design bridges a critical economic and technological divide that leaves micro enterprises vulnerable. While modern industrial facilities rely on highly sophisticated Variable Frequency Drives (VFDs) or heavy duty Programmable Logic Controllers (PLCs) to manage directional changes, the steep procurement and programming costs of these systems render them entirely inaccessible to small workshops. The development of a low cost alternative using an open-source Arduino platform paired with standard electromagnetic contactors democratizes automation. It replicates the core protective functions of premium industrial starters such as simultaneous engagement protection and thermal overload mitigation at a fraction of the market price. This strategic choice of hardware lowers the financial entry barrier for local workshops seeking modernization, turning what was once an expensive luxury into an accessible workshop safety standard.

1.5: Significance of the Study

The significance of this study lies in its multi layered contributions to occupational safety, engineering literature, and the financial sustainability of small scale industrial applications. On a technical level, this research provides a practical blueprint for integrating low cost solid state electronics with traditional high voltage electrical distribution networks. By detailing the construction of a dual-layer interlocking mechanism where the forward and reverse contactors are isolated through both physical cross wiring and algorithmic code blocks this study demonstrates a highly dependable method for preventing line-to-line faults. Standard reference materials on **BC Campus Open Text Basic Motor Control** emphasize that simultaneous coil engagement in a reversing starter results in a severe dead short circuit across the main three phase supply lines. This study advances small scale industrial engineering by proving that open source microcontrollers can reliably execute these rigorous interlocking routines without experiencing timing lags or system freezes.

Beyond its technical architecture, this project holds immense practical value for occupational safety and health management in micro-workshops. Manual starters frequently require operators to stand in close proximity to main electrical panels, exposing them to catastrophic arc flash incidents, thermal burns, and lethal electrical shocks during a switching fault. Implementing this automated starter isolates the human operator from high-voltage components by routing control commands through low-voltage to sensor interfaces. According to research on motor faults compiled by the **National Center for Biotechnology Information**, unmitigated phase sequence errors generate severe thermal overloads that

degrade motor health rapidly. By introducing integrated monitoring loops, this starter mitigates these hidden operational risks. Consequently, this study acts as a vital resource for small business owners looking to optimize throughput, lower insurance liabilities, and foster a secure, incident-free manufacturing environment.

1.6: SCOPE OF THIS STUDY.

- Design of the power circuit and control circuit for forward and reverse motor operation.
- Use of magnetic contactors and interlocking systems to prevent simultaneous energizing of forward and reverse contactors.

Incorporation of overload protection to safeguard the motor against excessive current and electrical faults.

- Automatic switching between forward and reverse directions using timing or control mechanisms.
- Use of combination of sensors i.e. Arduino, load cell(strain gauge) and proximity sensor(capacitive) to enhance safety

1.6.1: Technical scope.

The automation system focuses on protecting the motor from mechanical stress and electrical stress and also eliminates switching errors by the use of interlocking mechanisms, use of timers, forward and reverse contactors and auxiliary contactors for safety and control.

The project utilizes Arduino Uno microcontroller, a relay module acting as an interface between the control power panel and the Arduino for sending signals to the contactors, proximity sensor capacitive type for detection of the presence of human beings and other objects enhancing improved safety, load cell sensor to detect the weight of the load supposed to be lifted by the system.

1.6.2: Geographical scope.

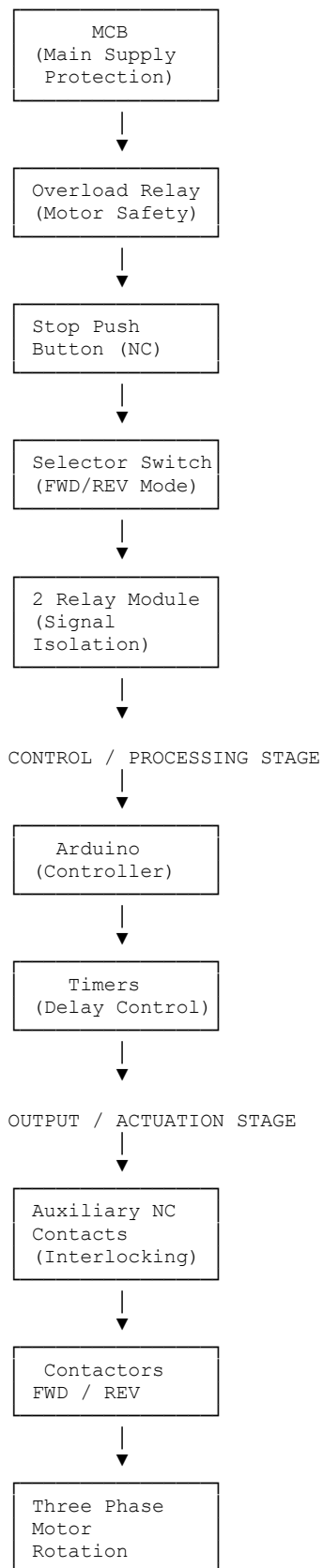
The developed system is deployed in small scale industries and small workshop environments.

1.6.3: Time scope.

The system took me 6 months to design and develop.

1.7: Conceptual frame Work.

INPUT / PROTECTION STAGE
↓
▼



Explanation of the Framework

1. MCB (Miniature Circuit Breaker)

- Acts as the first protection device.
- Provides short circuit and overcurrent protection.
- Supplies power to the control and power circuits.

2. Overload Relay

- Protects the motor from excessive current.
- Trips the control circuit when motor overload occurs.

3. Stop Push Button (NC)

- Provides emergency stopping.
- Normally closed contact opens when pressed, disconnecting the control circuit.

4. Selector Switch

- Allows selection between:

Forward operation

Reverse operation

Automatic/manual control depending on design

5. 2 Relay Module

- Interfaces the low-power Arduino output with high-power contactor coils.
- Provides electrical isolation.

6. Arduino Controller

- Acts as the brain of the system.
- Receives inputs from switches and protection devices.
- Sends commands for forward and reverse operation.

7. Timers

- Introduce delay between forward and reverse commands.
- Prevents sudden direction change which can damage the motor.

8. Auxiliary NC Contacts

- Provide electrical interlocking.

CHAPTER TWO: LITERATURE REVIEW

Introduction:

This chapter presents a comprehensive and critical review of historical and contemporary literature concerning the control, automation, and protection of three-phase induction motors. By examining peer-reviewed journals, textbooks, and foundational electrical engineering manuals, this section provides an analytical overview of the technological trajectory from manual mechanical starters to programmable solid-state systems. The primary objective of this review is to contextualize the development of the automated forward and reverse starter within the broader scope of industrial machine control. Each reviewed system is evaluated based on its architectural design, efficiency, operational reliability, and safety standards. Through this rigorous comparative analysis, this chapter highlights the distinct contributions, technical limitations, and systemic research gaps within existing methodologies, reinforcing the academic and practical necessity of this project.

The structural evaluation of existing knowledge focuses heavily on the electrical and mechanical stresses induced during phase-reversal routines. Standard industrial control principles established by textbook resources like demonstrate that reversing a three-phase motor requires the physical swapping of any two incoming supply lines . While this process reverses the stator's rotating magnetic field, performing this operation without precise timing parameters leads to plugging faults. According to motor degradation studies published in **Nature Scientific Data**, unmitigated plugging faults subject the stator windings to extreme transient currents and high counter-torque spikes, accelerating insulation breakdown and mechanical gear shearing. Consequently, the literature review explores how advanced protective frameworks mitigate these phenomena.

Furthermore, this chapter scrutinizes the specific hardware and software tools selected for this design, comparing their industrial efficiency against traditional automated methods. Conventional automated solutions traditionally leverage Industrial Programmable Logic Controllers (PLCs) or Variable Frequency Drives (VFDs) to establish directional switching. Research documentation from the **Arab Academy for Science, Technology and Maritime Transport (AAST) Portal** demonstrates that while PLC-based control circuits successfully eliminate human timing errors through programmed interlocking networks, their high market costs create an economic barrier for micro-enterprises. Conversely, emerging research from platforms like ResearchGate explores the application of low-cost open-source microcontrollers (such as Arduino) to handle motor startup and fault protection sequences. By reviewing these

diverse approaches, this introduction establishes a clear theoretical baseline, showing how this project synthesizes low-cost embedded systems with heavy-duty electromagnetic power components to fill an existing research loophole in affordable workshop automation.

2.1: Key aspects

2.1.1: Forward and reverse starter for three phase induction motor.

A Forward or Reverse Starter is a control circuit used to change the rotational direction of a 3-phase induction motor. In automation, this is achieved by swapping any two of the three-phase supply lines connected to the motor, which reverses the phase sequence and the magnetic field.

How it Works

Forward Direction: The motor runs with the standard phase sequence e.g., L1, L2, L3.

Reverse Direction: The controller energizes a separate set of contacts that swap two of the phases e.g. changing it to L2, L1, L3.

Direction Change: The motor must be brought to a complete stop before changing direction to prevent extreme mechanical and electrical stress.

2.1.2: Interlocking Mechanism.

This involves Incorporation of protection and interlocking.

Materials: Auxiliary contacts, interlocking bar ,overload relay, circuit breakers and timers.

System Design: there are two interlocking mechanism which include;

Electrical Interlocking: An auxiliary contact on the Forward contactor physically prevents the Reverse contactor from energizing (and vice versa) at the same time. This prevents a dead short.

Mechanical Interlocking: A physical/mechanical barrier between the two contactors that serves as a backup to the electrical interlock, ensuring both cannot be pushed closed simultaneously.

2.1.3: Automation.

Automation is the creation and application of technologies to produce goods and services with minimum human involvement to a minimum. The implementation of automation technologies,

techniques and processes improve the efficiency, reliability and/or speed of many tasks that were previously performed by humans. This technique is applied in homes, industries, offices and others. Automation makes not only an efficient use but also an economical use of the electricity and time.

2.2.4: Timers and a selector switch.

2.2.4.1: Timers;

This involve both the reverse and forward timer.

A forward and reverse timer is an automation control device that automatically switches a motor's rotation direction. It eliminates the need for manual push-buttons by cycling between forward run, pause, and reverse run states based on preset times.

The Operation Cycle

The timer continuously repeats a four-step sequence to protect the equipment:

Forward Run: The timer energizes the forward contactor for a set duration.

Pause/Dwell Time: The motor stops and coasts to a complete rest.

Reverse Run: The timer energizes the reverse contactor for a set duration.

Pause/Dwell Time: The motor stops completely before starting the forward cycle again.



Figure 1: showing timer

2.2.4.2: A selector Switch

In an automatic forward and reverse starter, a selector switch acts as the **master mode controller**. It allows an operator to choose how the system behaves manually overriding the system, putting it into a completely automated timed cycle, or shutting it down safely.

Working Principle

Rotary Contact Mechanism: Turning the physical knob rotates an internal cam. This cam mechanically opens or closes specific sets of electrical contacts based on the chosen position.

Maintained Contact Behavior: Unlike a push-button that springs back, a selector switch stays in its turned position until an operator manually moves it again.

Circuit Path Redirection: It works like a railroad switch, physically routing the control voltage for example 24V DC or 110V AC down entirely different wiring paths depending on the selected mode.



Figure 2: showing a selector switch

2.2.5:Arduino

Arduino is a microcontroller board that enables interaction between sensors and actuators. This board is powered by an Atmel 8-bit AVR chip for programming and cooperate with electronic circuit. Arduino board also able to control output such as lights for the relay module signals and proximity sensor capacitive and load cell sensor. Programming on Arduino works with Arduino software which is compatible with most of common operating system such as

Windows, Linux and Macintosh. The programming on Arduino uses C language and simple for user to change the code.

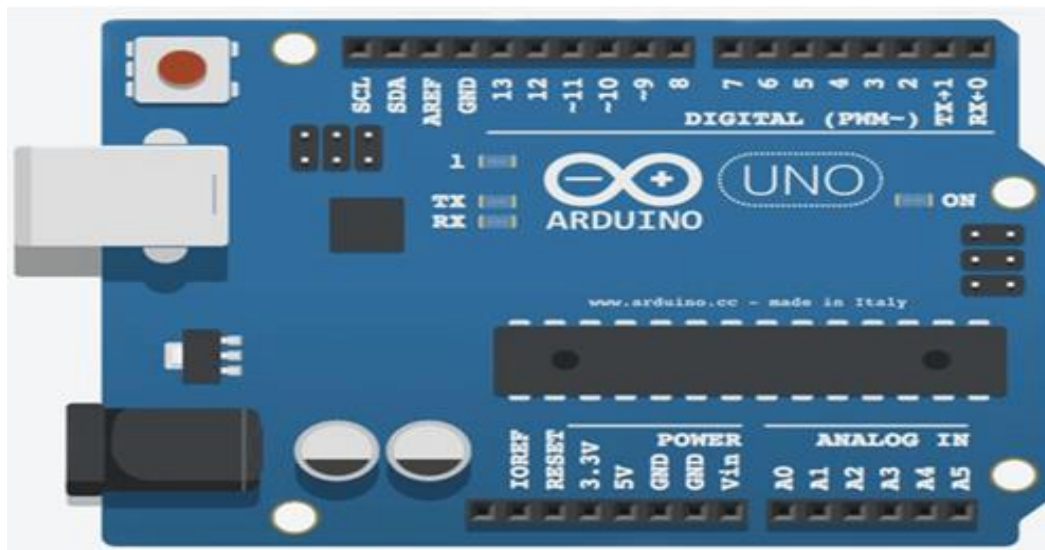


Figure 3 showing Arduino

2.2.6: Relay module;

In this automated starter project, the relay module acts as the **isolated bridge** between the low-voltage control logic (like a PLC, microcontroller, or digital timer) and the high-voltage power circuit of the three-phase motor. It allows a low-power signal to safely switch the heavy electrical currents needed to trigger the motor contactors.

2. Working Principle

Signal Input: The control system (e.g., PLC or automatic timer) sends a low-voltage signal (usually 5V, 12V, or 24V DC) to the relay module's input pins.

Electromagnetic Activation: This signal flows through an internal copper coil inside the relay, creating a magnetic field.

Contact Switching: The magnetic field pulls a mechanical armature down. This moves the internal switch contacts from their resting position to their active position.

Circuit Isolation: There is no physical electrical connection between the low-voltage input control side and the high-voltage output switching side.



Figure 4 showing relay module

2.2.7: Proximity sensor capacitive.

Sensor Selection Principle

To differentiate humans from other materials, the system uses a **Capacitive Proximity Sensor** calibrated precisely for a **1500mm sensing range**. Unlike inductive sensors (which only see metal), capacitive sensors detect changes in dielectric constant, allowing them to distinguish between dense organic tissue (humans) and lighter raw materials.

Operational Logic

Material Detection (Normal Operation): When metals or non-metal lifting materials pass within 1500mm, the sensor ignores them or filters them as normal cargo. The control circuit remains closed, and the forward/reverse automated cycle continues uninterrupted.

Human Detection (Emergency Stop): Because the human body has a high dielectric constant (due to water content), crossing the 15mm boundary causes a massive shift in the sensor's electrostatic field.



Figure 5 showing proximity sensor

2.2.8: Load cell sensor:

A **load cell** is a transducer that converts mechanical force (the load) into an electrical signal. As weight is applied, the internal strain gauges flex, altering their electrical resistance. This change is measured and converted into a highly accurate weight reading.



Figure 6 showing load cell

For an automatic forward/reverse starter addressing small-scale industry applications, the recommended weight sensing range for this design is 50kg to 500kg. that is to say , ideal for small hoppers, conveyors, or material sorting.

2.2.9: Magnetic contacts and inductor lamps.

2.2.9.1: Magnetic contactors for both forward and reverse:

Magnetic Contactor Operation

A magnetic contactor uses an electromagnetic coil to open or close electrical contacts, switching heavy motor currents on and off.

The forward and reverse magnetic contactors are critical to this automated system for several key reasons:

1. High-Power Automation

Eliminates Manual Labor: It removes the need for human operators to manually flip heavy phase-reversal switches or swap physical wires to change direction.

Safe Low-Voltage Control: It allows a low-voltage, low-current signal from your automated controller like a 5V microcontroller or 24V PLC to safely switch the high-voltage 415V three-phase industrial power running to the motor.

2. Equipment and System Protection

Prevents Short Circuits: The built-in mechanical and electrical interlocking ensures that both contactors can never close simultaneously, preventing a catastrophic phase-to-phase dead short circuit.



Figure 7 showing magnetic contactor

2.2.9.2: Indicator lamps.

This involved the use of two green indicator lamps, one for forward direction and the other to indicate the reverse movement, one orange indicator lamp and red indicator lamp.

Indicator lamps are critical for visual monitoring, system diagnostics, and operator safety in a small-scale automated industrial environment. They provide immediate, real-time feedback on what the system is doing without requiring the operator to open the high-voltage control panel.

The specific importance of each lamp color in this design includes:

1. Two Green Indicator Lamps (Direction Status)

Visual Confirmation: Each lamp corresponds to a specific direction of rotation ,one for **Forward** and one for **Reverse**.

Process Tracking: They inform the operator exactly which phase of the automated cycle is active for example Forward lamp lights up when a conveyor is loading; Reverse lamp lights up when it is automatically backing up or discharging.

Contactors Verification: They confirm that the control system has successfully energized the respective magnetic contactor coil.

2. Red Indicator Lamp (System Stopped or Danger)

Safe to Work Signal: It illuminates when the motor is completely stationary or when the system is in Standby mode, letting workers know it is safe to load materials.

Emergency Stop (E-Stop) Indicator: In many industrial designs, this lamp turns on or flashes if a worker hits the Emergency Stop button, indicating that the system is frozen and requires a manual reset.

3. Orange Indicator Lamp (Fault or Weight Overload)

Load Cell Warning: It lights up when the load cell detects an weight condition outside the safe operating range for example exceeding the maximum 500 kg limit.

Thermal Overload Trip: It indicates that the motor's thermal overload relay has tripped due to drawing too much current, protecting the motor from burning out.

Troubleshooting: It instantly tells the maintenance team that the system stopped due to a fault rather than a normal operational pause, reducing factory downtime.

2.2: System Operation

2.2.1: Load detection:

The load cell verifies that the material weight falls within the safe 50–500 kg range to unlock the system. The controller then automatically switches power between cross-wired forward and reverse magnetic contactors to change motor direction safely without manual phase intervention.

2.2.2: Signal detection.

The Arduino constantly reads the analog voltage signal from the load cell's amplifier module to calculate the precise weight of the load. Once the weight falls within the programmed limits, the Arduino sends a low voltage digital signal to trigger the relay module, automatically activating the corresponding high-power magnetic contactor.

2.2.3: Contactor energization.

The Arduino activates the relay module, which closes the control circuit to send main coil voltage to the designated contactor. This creates a magnetic field that pulls the heavy power contacts shut, automatically starting the three-phase motor.

2.2.4: Sensor detection.

The load cell measures material weight to ensure it falls within the safe 50–500 kg range before operation begins. Simultaneously, the capacitive proximity sensor detects the physical presence or fill-level of the object to automatically trigger the next phase of the motor cycle.

2.2.5: De-energization duration:

When a stop or fault is triggered, the Arduino instantly cuts power to de-energize the active contactor coil within milliseconds. A programmed safety delay of 8 to 10 seconds then follows, ensuring the motor completely stops spinning before the reverse direction can activate.

2.3: Existing systems comparison Table

System Name	Advantages	Disadvantages	Examples
VFD with Integrated PLC & Load Cell	• Precise speed control • Smooth	• Very high initial cost • Complex	Siemens SINAMICS V20 / S120

	acceleration • High energy savings	programming • High harmonic distortion	• ABB ACS380 Drive
Soft Starter with Digital Weighing Controller	• Reduces mechanical wear • Smooth current ramps • Medium cost profile	No speed regulation • Fixed operating frequency • Bulky component footprint	Schneider Altistart 22 • Eaton S811+ Soft Starter
Smart Motor Control Centers (Smart MCC)	• Advanced remote monitoring • Detailed fault diagnostics • High network integration	• Extremely expensive • Complex troubleshooting • Excessive for small shops	• Allen-Bradley CENTERLINE 2100 • Siemens SIMOCODE pro
SCADA-Controlled Conveyor Systems	• Centralized data logging • Real-time graphical UI • Excellent safety tracking	• Requires dedicated PC / Server • High software licensing fees • High maintenance needs	• Rockwell FactoryTalk View • Ignition SCADA by Inductive

Table showing comparison of the existing 1

Conclusion:

The literature review highlights the Operation of induction motor in both forward and reverse direction as a fundamental requirement in many industrial applications such as conveyor belts, cranes , elevators and automated machines.

- ❖ Studies show automatic starters improve safety and performance. According to Eze et al (2019), automation not only eliminates human error but also enhances safety and precision in industrial operations.

- ❖ Automated systems reduce down time and human error.(for example can introduce time delay between forward and reverse switching)
- ❖ In addition, literature on motor starter design highlights the growing shift from conventional electro mechanical system to intelligent motor control system.

CHAPTER THREE:METHODOLOGY

INTRODUCTION

The methodology explains the various methods, procedures, and strategies that are to be employed along with techniques to be used to meet the above-mentioned objectives of designing

Data Collection

A number of research mechanisms were used in collecting the kind of data that is needed to know the requirements of the project and these included:

Research: This involved reviewing textbooks, and articles related to automatic forward and reverse motor starter systems. The information got from this documentation was necessary for the identification and analysis of the requirements that were needed to accomplish the design of the system.

Questionnaires: A set of printed questions were prepared and distributed to some small scale industrial workers and small workshop environments. These helped in collecting user-specific needs, challenges, and suggestions regarding the reverse and forward motor starter. Interviews were conducted with industrial motor operators , technicians, industrial managers concerning the reverse and starter operations and isolated problems.

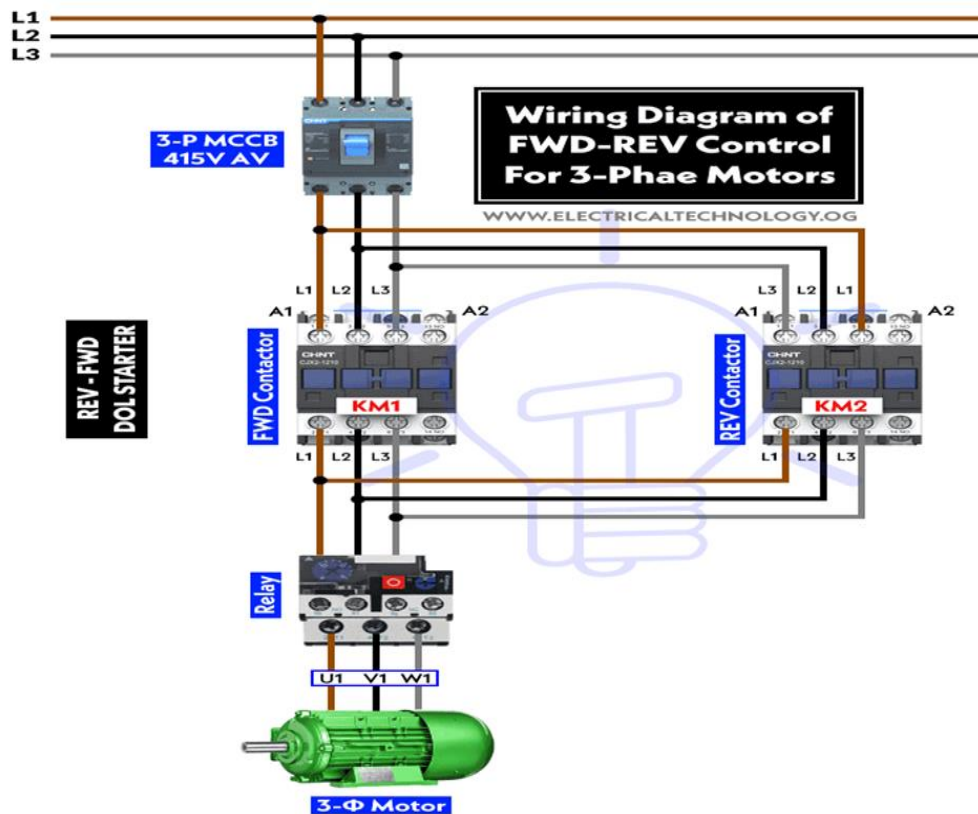
3.1:METHODOLOGY.

3.1.1:Design of an automatic forward and reverse control circuit and power.

The foundational architecture of this project involves developing a dual-stage electrical topology consisting of a high-power distribution circuit and a low-voltage automation control circuit. The primary engineering goal is to establish an automated phase-reversal system that safely alters the physical rotation of a three-phase induction motor without requiring manual phase switching.

Materials: Three-Phase Magnetic Contactors (Forward and Reverse units), Thermal Overload Relay (TOR), Industrial Push Buttons (Start/Stop/Reverse), and a Three-Phase Miniature Circuit Breaker (MCB).

Power circuit: breaker → overload relay → forward/reverse contactors → motor.



Figure

8 showing wiring diagram for forward and reverse control

Control circuit: push buttons, relays, timers, auxiliary contacts for interlocking.

Data Analysis Techniques: Simulation in ekts software to test circuit logic, timing delays, and fault scenarios.

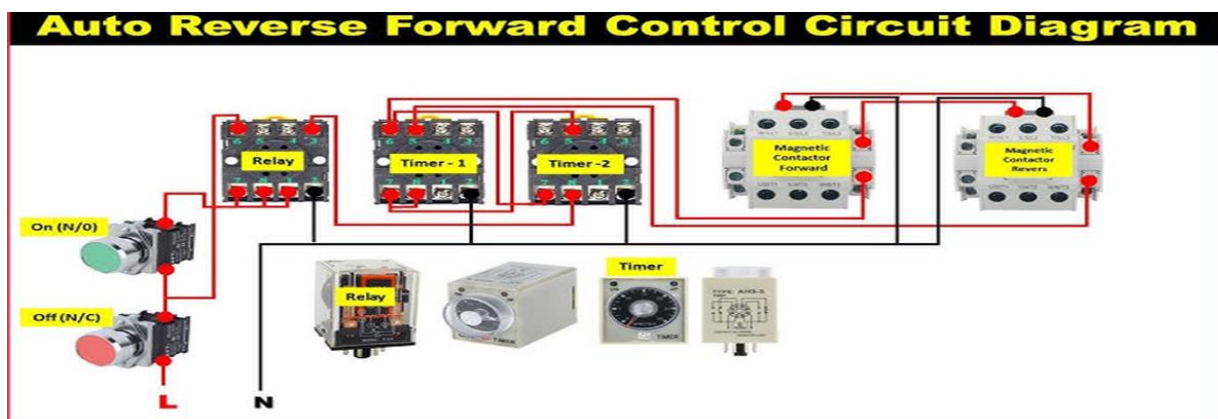


Figure 9 control circuit

3.1.2. Incorporation of protection and interlocking.

To guarantee operational safety and completely eliminate the structural vulnerabilities found in manual starter panels, this stage focuses exclusively on embedding redundant, multi-layered protective frameworks into the physical and electrical architecture of the starter.

Materials: Normally Closed (N.C.) and Normally Open (N.O.) Auxiliary Contact Blocks, Mechanical Interlocking Bars, Bi-metallic Thermal Overload Relays, and Main Line Miniature Circuit Breakers.

System Design:

Electrical Interlocking: The control circuit routes the activation power of the forward contactor coil through the Normally Closed (N.C.) auxiliary contact of the reverse contactor. Conversely, the reverse contactor coil power is routed through the N.C. auxiliary contact of the forward contactor. This cross-wired logic mathematically ensures that energizing one coil instantly breaks the power pathway of the opposing coil, making simultaneous activation impossible.

Mechanical Interlocking: A physical, mechanical interlocking bar is wedged between the armatures of the forward and reverse contactors. This hardware restraint physically jams one contactor open if the opposing contactor is closed, acting as a final line of defense if an auxiliary contact suffers an electrical weld fault.

Overload Protection: A bi-metallic thermal overload relay is integrated directly into the main power line to monitor the continuous current draw, featuring an adjustable current trip curve tailored to the motor's full-load amperage rating.

Data Analysis Techniques: System defenses are validated through targeted fault simulations within a controlled electrical tested. These stress tests include initiating direct phase-to-phase short circuits, executing high-current overload injections, and trying to force simultaneous forward/reverse button presses to verify the response of the interlocking mechanisms.

3.1.3. Develop a system with sensors (Arduino, load cell, proximity sensor)

This stage introduces intelligent, sensor-driven automation into the starter by interfacing an open source Arduino microcontroller with industrial sensory modules, replacing human operators for cyclical production tasks.

Materials: Arduino Uno Microcontroller Board, Strain Gauge Load Cell, HX711 Weight Amplifier Module, and a Capacitive Proximity Sensor.

System Design: The Arduino board serves as the centralized logic controller and is programmed via C++ scripts to process incoming digital and analog sensory inputs. A strain gauge load cell monitors structural weight thresholds to prevent mechanical over hoisting. Simultaneously, a capacitive proximity sensor is positioned near the motor's operational field to detect human operators or materials entering the hazard zone. The Arduino reads these real-time data inputs and manages the 5V DC relay modules that drive the heavy-duty AC contactor coils. .

Data Analysis Techniques: Empirical data processing techniques are used to calibrate the strain gauge load cell via the HX711 library, measure sensor signal propagation response times using an oscilloscope, and conduct integration testing to align sensor triggers with the motor's electrical stop/start thresholds.

3.1.4: Evaluation of Efficiency and System Performance

The complete system underwent systematic performance testing to measure its operating efficiency, structural thermal stability, and switching response profiles under varying load profiles. The starter is tested across a spectrum of operational states including no-load, partial-load, and full-rated load conditions while executing rapid directional switching routines. This process helps measure the transient voltage drops, current surges during plugging states, and the overall reliability of the software-enforced deceleration timers.

3.2: System Testing

Testing was done at various stages to ensure its functionality and performance.

3.2.1: Unit testing

Each component was tested individually to confirm it performs as expected.

3.2.2: Integration Testing

Components were then all together integrated and tested to ensure they work well and produce the desired outcomes.

3.2.3:General System Testing

Complete system was tested under real-life scenarios to ensure it reliably detects presences of human and other materials like metals and non-metals, and stops automatically once the human being is detected and continues running other materials are detected by the capacitive proximity sensor .

3.2:4: Validation.

Validation was carried out to confirm that the system meets its intended purpose providing real-time safety detection alerts to human presence. The effectiveness of the proximity sensor detection was verified through repeated tests and user feedback.

3.3: System Design

System Block Diagram

Entity Relationship Diagrams (ERDs)

The system was designed as illustrated in the figure below

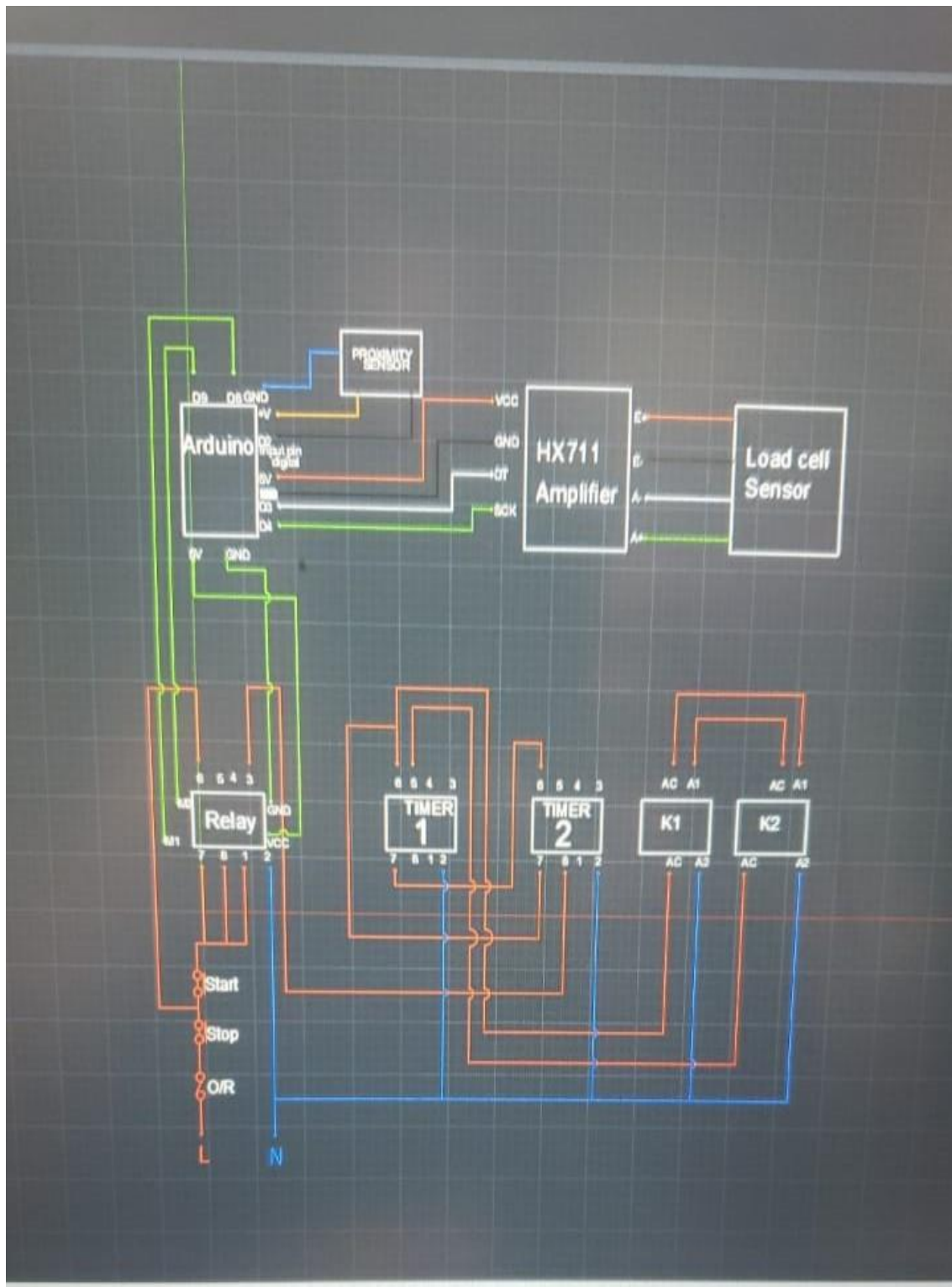


Figure 10 showing system design

3.4: Tools

The tools that were used to develop the system included;

3.4.1: Software tool

Arduino IDE was used to write and upload the code to the Arduino Uno.

3.4.2: Hardware tools

1. Arduino Uno microcontroller
2. Proximity capacitive sensor
3. Magnetic contactors and auxiliary contacts
4. Selector switch
5. Load cell sensor
6. Relay module
7. Over load relay
8. Timers
9. Bread board for prototype.
10. Power supply (battery or an adaptor)
11. Connecting wires
12. Jumper connectors / wires
13. Indicator lamps and push buttons.
14. Cable ties

3.5: Data Analysis

The data collected was analyzed based on the objectives set to generate relevant insights and system requirements. After analysis and interpretation of the information, this report was documented, highlighting all the research findings which support the development process and also identify potential challenges.

Proper data analysis was crucial in defining both the functional and non-functional requirements of the automatic forward and reverse motor system.

CHAPTER FOUR: RESULTS AND DISCUSSIONS.

4.0: Introduction:

Chapter presents the results obtained from the design, construction, and testing of the Automatic Forward and Reverse Starter for a Three-Phase Induction Motor. The results are discussed in relation to the project objectives and compared with findings from previous studies on automatic motor control systems. The purpose of the discussion is to evaluate the effectiveness, reliability, and suitability of the developed system for industrial applications.

4.1: Analysis of Results for Objective One: Design of Automatic Forward and Reverse Control and Power Circuit

Results Obtained:

The developed control and power circuit successfully achieved automatic forward and reverse operation of the three-phase induction motor. During testing, the forward contactor energized first, supplying the motor with the normal phase sequence and causing clockwise rotation. After receiving a control signal from the Arduino-based control system, the forward contactor was de-energized and the reverse contactor energized, reversing two phases and causing the motor to rotate in the opposite direction.

The power circuit effectively supplied electrical energy to the motor while the control circuit coordinated switching operations. The motor responded correctly to all programmed control commands, demonstrating stable forward and reverse operation without abnormal interruptions.

The control circuit also maintained proper separation between power and control sections, thereby improving safety and simplifying troubleshooting.

4.1.1: Discussion of Results

The successful operation of the developed control and power circuit indicates that the selected design methodology was appropriate for automatic motor direction control. The use of contactors to interchange motor phases proved effective in reversing motor rotation while maintaining continuous motor functionality.

The control circuit demonstrated a high level of operational reliability because switching occurred in the correct sequence without simultaneous activation of opposing contactors. This confirms that the designed circuit was capable of controlling motor direction accurately and safely.

Furthermore, the integration of Arduino-based control improved automation compared to traditional manual forward and reverse starters. The microcontroller enabled automatic decision-making based on programmed instructions and sensor inputs, reducing dependence on human operators.

4.1.2: Comparison with Previous Research Studies

Previous studies on automatic motor control have commonly utilized contactor-based forward and reverse circuits because of their simplicity and reliability. Similar studies reported that phase reversal through contactor switching is one of the most effective methods for changing the direction of rotation of a three phase induction motor.

Researchers who developed timer based automatic forward and reverse starters reported successful motor direction reversal through sequential energization of forward and reverse contactors. The results obtained in this project agree with those findings since the developed system also achieved smooth directional switching without affecting motor performance.

Studies involving PLC controlled motor starters demonstrated improved automation and operational flexibility. However, PLC systems generally require higher installation costs and greater programming complexity. In contrast, the Arduino based system developed in this project achieved similar automatic control functions using relatively inexpensive hardware, making it more suitable for small scale industrial applications and educational laboratories.

Research involving microcontroller based motor control systems has shown that microcontrollers improve control accuracy, reduce response time, and enhance automation capabilities. The results obtained in this project support these findings because the Arduino controller successfully managed switching operations and sensor integration while maintaining reliable motor performance.

Compared to conventional manually operated starters, the developed system offered several improvements including:

Reduced human intervention.

Faster directional switching.

Improved operational consistency.

Enhanced automation.

Better integration with sensor-based control systems.

4.2: Other results and discussions;

4.2.1: Development of platforms.

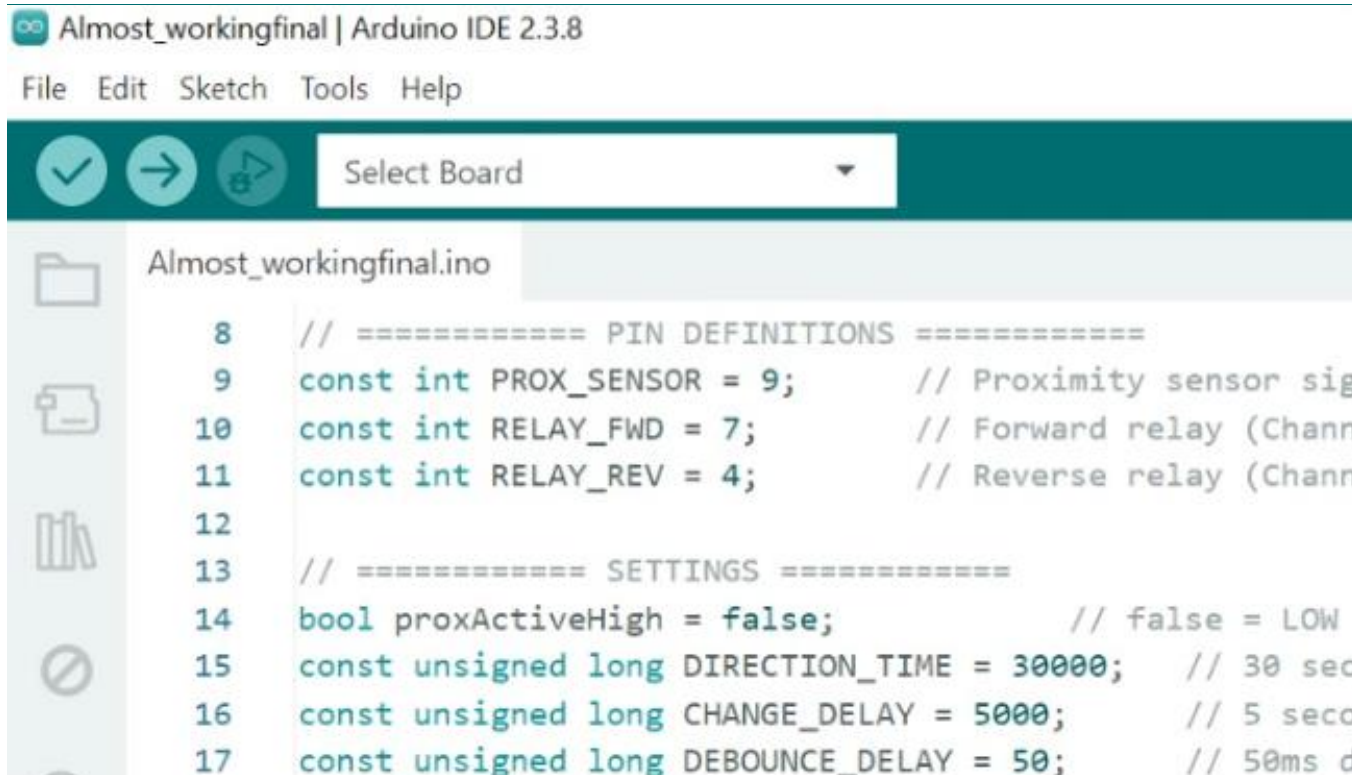
Before the development begun, it was necessary to have an integrated development environment with which the system would be coded.

4.2.2: Arduino

Arduino is an open-source platform that uses hardware and software. Arduino consists of both a physical programmable circuit board (microcontroller) and a piece of software, IDE (Integrated Development Environment) that runs on a computer, these were used to write and upload hardware code to the microcontroller through the Arduino UNO physical board.

4.2.3: Code Designs.

The system and program were written in the Arduino Platforms. The design codes are :



```
Almost_workingfinal | Arduino IDE 2.3.8
File Edit Sketch Tools Help

Select Board

Almost_workingfinal.ino
8 // ===== PIN DEFINITIONS =====
9 const int PROX_SENSOR = 9; // Proximity sensor sig
10 const int RELAY_FWD = 7; // Forward relay (Chanr
11 const int RELAY_REV = 4; // Reverse relay (Chanr
12
13 // ===== SETTINGS =====
14 bool proxActiveHigh = false; // false = LOW
15 const unsigned long DIRECTION_TIME = 30000; // 30 sec
16 const unsigned long CHANGE_DELAY = 5000; // 5 secc
17 const unsigned long DEBOUNCE_DELAY = 50; // 50ms d
```

Figure 11 showing programming code

4.2.4: Testing

Testing was carried out to determine whether the system could achieve the required functionality by meeting the specified requirements. The different components of the system were tested against the requirements and then integrated to ensure that they achieve system's goal. It was done at the unit level and integrated level.

4.2.5: Unit testing

This involved testing individual components or units of the system to ensure they function correctly in isolation. These included;

1. Relay module

This required first setting it with a certain code for it to start operation or blink, on the Arduino board it is interfaced with the control panel and Arduino.

2.cantactors and timers

Contactors and timers were tested and implemented by first verifying their performance through powering them separately by the power supply ,continuity tests and then by integrating

them into the system, including code designing and assigning transition timing between the contactors and

timers. The implementation process involved understanding the contactors and timers' output, using appropriate circuits to condition the signal, and analyzing the collected data to detect and diagnose contactor energization.

3. indicating lamps.

These are used for indication of any action that has taken place, there are two green indicator lamps, one indicates the forward movement and the other indicates reverse movement, one orange indicator lamp which lights once there is fault in the system, our system also has one red indicator lamp which lights red color indicating that the system has been supplied with power. There are interfaced with the auxiliary contacts which acts as control after receiving command signals from the relay module.

4. proximity sensor.

This was first powered by the external source using the USB to connect to its power out let terminals to change for its performance before integration. After concerning its functionality, its signal terminal was then connected to the Arduino signal side. It was initially calibrated by varying its length range by using a code. The proximity sensor used in this project is capacitive type, its detective range is 15mm.

It operates corresponding to the system when it receives commands from the microcontroller as long as all the conditions are true.

4.3: Integration Testing.

Different parts of the system and code were brought together to analyze how well they work once they are integrated. This helped to know whether the combined units of the system work. Test data and inputs were carefully taken to facilitate testing, covering diverse user interactions and real-world scenarios. Each test scenario was meticulously documented, specifying the sequence of actions, expected outcomes, and required inputs.

During test execution, interactions, timing, and responses were monitored while ensuring the system correctly handled errors and safety protocols. This process helped identify any compatibility or communication issues between system components, ensuring that the automatic forward and reverse starter operates cohesively, reliably, and safely.

4.4: System Testing.

This was carried out to ensure the system aligned with the specified requirements. It took place on the overall integrated system.

System testing marks a critical phase in our automatic forward and reverse motor project, where we assessed the complete system's overall functionality, performance, and reliability. This comprehensive evaluation encompassed all system components working in unison to ensure the fulfillment of user requirements and safety standards.

The process began with defining detailed test cases covering various user scenarios, from issuing sensor signal commands to the microcontroller. Realistic test data was carefully prepared to mimic practical user interactions and environmental conditions. The system was subjected to a series of rigorous tests, focusing on scenarios involving sensor signal command recognition by the microcontroller and the way the microcontroller responds to the data after interpretation.

Closely monitored and documented the system's behavior, scrutinizing its ability to perform correctly and safely under diverse conditions.

System testing was pivotal in confirming that automatic forward and reverse starter met all specifications, adhered to safety standards, and provided users with a dependable and efficient safety solution.

4.5: System Verification

This involved examining all predetermined system specifications such as documents, code, design and program to ensure the system meets the specified functional and non-functional requirements. System verification was done at every stage of development before any feature is implemented.

This phase encompassed a comprehensive evaluation of the system's functionality, safety, and performance. It began by rigorously examining each system requirement against the implemented features, confirming that every aspect was addressed effectively. Real-world scenarios were simulated to validate that the system behaved as intended, from recognizing threats to the motors through the sensors' functionality commands to executing precise responses by the proximity capacitive sensor responding to emergencies.

4.6: System Validation

System validation occurred after the system had been completely built. Its main intent was to ensure that the modules of the system were performing to yield the desired and expected goals. System validation marked the pivotal phase where the Automatic forward and reverse motor system rigorously assessed to ensure that it met the specified requirements and aligned with the real world needs and expectations of users. The validation process aimed to verify that the system, as a whole, was fit for its intended purpose. This entailed extensive testing under diverse conditions, including real-world environments and user scenarios. The system responses were validated to signal detection commands, executed precise responses, and handled emergency situations. The validation process reaffirmed that an automatic forward and reverse motor starter not only met project objectives but also enhanced the quality of life for users by providing them with a reliable and efficient operation and safety aid.

4.7: System Operation.

The system is powered by cable connected to the board that drives the system by a suitable DC power of 5V that is fed to on board devices and integrated circuits. While as the control panel components receives a suitable AC power of 230-240V through the cable connected to the socket power outlet.

The user begins by providing power for the system through a power cable. The system is programmed to send signal commands to the relay module interfacing the control system panel . When the Arduino sends signals t to the relay module, the relay module decodes the signal and provides commands for both the forward and reverse contactors and timers to execute productively depending on the contactor and timer signal sent respectively.

4.8: Comparison of this project and other existing solar security systems.

The Automatic forward and reverse starter that I developed is cost efficient because it is at a reliably low cost of purchase at 700,000/= while the other existing security systems for example Advanced automatic systems like VFD cost 2,000,000/=. This makes the system more affordable for the target market who here fair-income small scale industrial users.

CHAPTER FIVE: RECOMMENDATIONS AND CONCLUSION.

5.1: Limitations of the project.

- 1) **.Sensor Reliability:** Harsh industrial environments expose capacitive sensors to dust and moisture, leading to false proximity triggers and unsafe reversing sequences.
- 2) **Relay Contact Wear:** Frequent mechanical switching of heavy inductive motor loads causes electrical arcing, which rapidly pits and welds relay contacts.
- 3) **Arduino Processing Limits:** The 8-bit microcontroller lacks real time operating system (RTOS) capabilities, creating dangerous execution delays during emergency stop commands.
- 4) **Load Cell Drift:** Continuous vibration from the three-phase motor introduces mechanical noise, distorting load cell voltage data and corrupting weight based decisions.
- 5) **Component Scaling Gaps:** Using low cost hobbyist electronics fails to meet rigid industrial safety standards, limiting the system's actual adoption in commercial small scale factories.

5.2: Conclusion.

This project successfully bridges the technology gap between small scale industries and local workshop environments by delivering an automated, low cost forward and reverse motor starter. By replacing expensive, rigid industrial PLCs with an accessible Arduino microcontroller, the design democratizes smart automation for budget constrained operations. Integrating proximity and load cell sensors adds critical safety and material handling intelligence previously unavailable at this price point. Ultimately, this scalable system proves that small workshops can significantly boost productivity, reduce operator error, and improve machine safety without requiring prohibitive capital investment.

Furthermore,

Although advanced automatic motor starters exist , they are costly and inaccessible to small industries. Current manual starters are unsafe , error prone and lack automation

features . There is a clear gap , automated forward and reverse starter designs that integrate safety, reliability , and sensor based control. This project addresses that gap by developing low cost,

automatic solution using readily available components ,tailored for small-scale industries and small work shop applications.

To address these challenges, this project aims to design an automatic forward and reverse induction motor control system that operates efficiently, safely, and without manual intervention. The proposed design will employ contactors, timers, overload relays, and interlocking mechanisms to ensure that only one direction is active at a time. Furthermore, the system will incorporate a control circuit based on relays or programmable logic controllers (PLC) to automate switching sequences, reduce operational errors.

The main objective of this project was to design an automatic forward and reverse control circuit and power circuit capable of operating a three-phase induction motor in both directions safely and efficiently without manual intervention.

5.3:Recommendations.

- ❖ Industries and workshops that frequently require motor direction changes should adopt automatic forward and reverse starters to improve efficiency and safety.
- ❖ Proper maintenance and regular inspection of contactors, relays, and wiring should be carried out to ensure long term reliable operation.
- ❖ Electrical engineering students and technicians should use similar projects for practical learning in industrial motor control and automation systems.
- ❖ Adequate training should be provided to operators and technicians on the safe handling and operation of motor control systems to prevent accidents and equipment damage.

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