

**DESIGN AND CONSTRUCTION OF A THREE-PHASE INDUCTION MOTOR
PROTECTION SYSTEM AGAINST PHASE FAILURE AND OVERHEATING**

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**A PROJECT SUBMITTED TO THE DEPARTMENT OF ELECTRICAL
AND ELECTRONIC DEPARTMENT, FACULTY OF ENGINEERING,
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REQUIREMENT OF THE AWARD OF BACHELOR OF ENGINEERING (B.
ENG) DEGREE IN ELECTRICAL AND ELECTRONIC ENGINEERING.**

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CERTIFICATION

This is to formally acknowledge that the project work presented herein was collaboratively undertaken by **ONOSHEFE SILAS OGHENETEGA**, bearing matriculation number **ENG2002310** and **FAVOUR EDWIN OSAGIE** bearing matriculation number **ENG2002312** . Both students are of the Department of Electrical/Electronic Engineering, Faculty of Engineering, University of Benin. The project was carried out as part of the academic requirements for the successful completion of the Bachelor of Engineering (B.Eng.) degree in Electrical/Electronic Engineering. It reflects the students' effort, knowledge, and commitment in partial fulfillment of the conditions necessary for the award of the said degree.

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Date

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(Head of Department)

Date

DEDICATION

We gratefully dedicate this project, first and foremost, to God Almighty, whose grace and guidance have been a constant source of strength in our lives.

We also extend our heartfelt dedication to our families, whose unwavering financial, emotional, and intellectual support has been instrumental throughout our academic journey.

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ABSTRACT

Induction motors, though robust, are prone to electrical and thermal stresses that can cause costly failures, while traditional protection devices are either too slow, prone to nuisance trips, or too expensive for small industries. The problem therefore lies in the lack of an affordable, reliable, and adaptable protection system that integrates both electrical and thermal monitoring. The aim of the project is to design a micro-controller-based protection system for three-phase induction motors to detect faults such as single-phasing, under voltage, and overheating.

A functional protection system was built using the PIC16F877A micro-controller to achieve real-time monitoring and automatic motor isolation. The design employed ZMPT101B voltage sensors, an ACS712 current sensor, a DS18B20 temperature sensor, LM7805 regulator, ULN2003 driver, relay/contractor, and a 16×2 LCD. The methodology involved circuit design and simulation, hardware assembly, and programming in Embedded C to process sensor data, and control the relay for fault response for phase failure or for temperature above 60 degrees.

The performance of the system was rigorously evaluated through testing in both faulty and normal operating conditions. During fault simulation, the system accurately identified phase loss, displaying "Phase Failure" on the LCD followed by the specific faulty phase voltages. When the motor temperature exceeded 60°C, the display indicated "Over Temp" and subsequently showed the actual real-time temperature measurement. Conversely, once the faults were cleared and the system was restored to normal operation (with phases at 220V and temperature below 60°C), the LCD confirmed that the Relay was switched ON, reconnecting the motor to the power source. Following this restoration, the system resumed its standard monitoring mode, displaying the actual temperature and operational parameters, thereby proving the system's reliability in managing transitions between fault detection and safe recovery.

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CHAPTER 1

INTRODUCTION

Three-phase induction motors are fundamental to industrial operations because of their simplicity, reliability, and high efficiency. Despite these advantages, they are vulnerable to electrical anomalies such as single-phasing, phase unbalance, over-current, and voltage deviations, as well as thermal stress that can lead to insulation failure and winding damage. Protecting motors against these faults is essential to prevent catastrophic failure, reduce downtime, and lower maintenance costs.

This project develops a micro-controller-based protection system using the PIC16F877A to provide fast, reliable detection and isolation of electrical and thermal faults. The system continuously acquires analog signals from current transformers and voltage dividers to monitor individual phase currents, neutral (residual) current, and phase voltages, while an onboard temperature sensor measures motor winding or ambient temperature. Signal conditioning, ADC scaling, and calibrated thresholds convert raw measurements into actionable protection decisions.

The protection strategy combines threshold-based detection with persistence timing and startup delays to distinguish transient disturbances from sustained faults and to avoid false trips during inrush. On confirmed fault conditions, the micro-controller actuates a relay or contractor to disconnect the motor and displays the fault type and status on an LCD. A manual reset facility enables safe restoration after inspection and corrective action.

The system is designed to be low-cost, configurable for different motor ratings through simple calibration of ADC scaling and threshold values, and scalable for industrial deployment. By integrating both electrical and thermal protection layers, the design enhances motor safety, prolongs service life, and provides a practical solution for improving reliability in diverse three-phase motor applications.

1.1 BACKGROUND OF STUDY

Three-phase induction motors have powered industrial progress for more than a century, tracing their practical emergence to the late 19th and early 20th centuries when advances in alternating-current generation and poly-phase distribution enabled efficient, rugged electric drives. Early pioneers transformed the theoretical concepts of rotating magnetic fields into commercially viable motors that displaced steam and direct-current drives across manufacturing, pumping, and transportation sectors. Over time the squirrel-cage induction motor became the dominant general-purpose machine because of its simple construction, low maintenance, and favorable efficiency under a wide range of loads (Fitzgerald, A. E., Kingsley, C., & Umans, S. D, 2003) .

Despite their mechanical simplicity, modern three-phase induction motors remain vulnerable to several electrical and thermal faults that threaten reliability and safety. Supply-side problems such as phase loss (single-phasing), phase unbalance, under-voltage, and over-voltage produce abnormal currents and negative-sequence components that increase winding heating and reduce developed torque. Load-side problems and mechanical issues (bearing failures, shaft misalignment, blocked rotor conditions) can also raise current draw and internal temperature. When these

abnormal conditions persist they accelerate insulation ageing, degrade magnetic materials, and can lead to catastrophic winding failure and extended downtime in industrial plants.

Traditional protective devices—thermal overload relays, electromagnetic over-current relays, and fixed-ratio phase-failure relays—offer essential defense but have limitations. Thermal overloads react slowly and can miss rapid electrical transients; simple phase-failure relays may not discriminate between transient disturbances and sustained single-phasing; and many electromechanical solutions are not easily adjustable for differing motor ratings or modern diagnostic needs. These shortcomings create two recurring problems in practice: nuisance trips during startup or brief transients, and late detection of damaging conditions that permit irreversible thermal or dielectric damage to progress.

Integrating electrical measurements (phase currents, residual/neutral current, and phase voltages) with direct thermal sensing and programmable logic provides a layered protection approach that addresses these gaps. Micro-controller-based systems can implement calibrated ADC scaling, persistence/timing windows to reject short transients and handle startup inrush, and flexible thresholds tailored to specific motor ratings. Adding continuous temperature monitoring of winding or key bearing zones captures overheating from electrical and mechanical causes, enabling earlier intervention and reducing insulation failure risk. This combined electrical-plus-thermal strategy delivers a practical, cost-effective solution for modern industrial installations seeking both reliable protection and clear diagnostic feedback (IEEE Power & Energy Society ,2011).

1.2 STATEMENT OF PROBLEM

Three-phase induction motors are widely used in industrial and commercial applications due to their robustness and efficiency. However, they are highly susceptible to electrical faults such as single-phasing, phase unbalance, over-current, and voltage fluctuations. These faults, if not detected promptly, can lead to excessive heating, insulation breakdown, and eventual motor failure, causing significant production losses and costly downtime (Shivpuje & Patil, 2017). The absence of effective monitoring and protection systems in many installations makes these motors vulnerable to premature damage.

Traditional protection devices such as thermal overload relays and simple phase-failure relays provide only limited coverage. They often fail to discriminate between transient disturbances and sustained faults, leading either to nuisance tripping or delayed fault detection. This limitation reduces system reliability and increases maintenance costs, as motors may either trip unnecessarily during startup or continue operating under harmful conditions (Journal of Aquatic Science, 2023). The lack of integrated thermal monitoring further compounds the problem, as overheating from mechanical faults or poor ventilation may go unnoticed until severe damage occurs. Furthermore, many existing protection systems are expensive, complex, or not easily adaptable to different motor ratings. Small and medium-scale industries, in particular, struggle to afford advanced digital relays, leaving their motors inadequately protected. There is therefore a pressing need for a low-cost, micro-controller-based protection system that integrates electrical and thermal monitoring, provides accurate fault detection with minimal false trips, and offers clear diagnostic feedback for

operators (Shivpuje & Patil, 2017). Such a system would enhance motor reliability, reduce downtime, and improve overall safety in industrial environments.

1.3 AIM AND OBJECTIVES

1.3.1 AIM

The principal aim of this project is to design, implement and construct a functional three phase induction motor protection system against phase failure and overheating using PIC16F877A micro-controller.

1.3.2 OBJECTIVES

1. To design and develop a three phase protection system against phase imbalance and overheating.
2. To integrate an PIC16F877A micro-controller for processing sensor data and controlling the response mechanisms.
3. To implement an audible alarm system that alerts users immediately when there is a fault in the system
4. To incorporate relays for motor isolation and protection for phase failure and overheating

1.4 METHODOLOGY

The project follows a structured approach, consisting of the following steps:

1. System Design and Circuit Simulation- The hardware architecture is designed and validated using a simulation of Proteus Design Suite. This stage involves integrating ZMPT101B voltage sensors for phase monitoring and the DS18B20 digital sensor for thermal detection.
2. Firmware Development and Programming- C language is used in programming MikroC Pro for PIC compiler. The firmware is flashed onto the PIC16F877A micro-controller. The code is programmed with specific logic to initiate a trip command if the temperature exceeds 60 degrees Celsius or for any phase failure.
3. Fault Notification and Interface Setup- An interface is established between the micro-controller and a 16x2 LCD to provide real-time status updates, including live temperature and voltage readings. A piezoelectric buzzer is integrated into the circuit to serve as an audible alarm, which is triggered by the micro-controller the moment the processed data indicates a temperature above 60 degrees or a voltage irregularity.
4. Hardware Assembly and Power Isolation- The physical circuit is constructed on a PCB, incorporating a ULN2003 driver IC to manage the power requirements of the switching unit. This isolation occurs automatically the instant the micro-controller detects a thermal breach at 60 degrees or a loss of phase voltage, preventing motor winding burnout.

1.5 SIGNIFICANCE OF THE STUDY

The protection of three-phase induction motors is highly significant because these machines are the backbone of industrial processes worldwide. They are widely used in manufacturing, pumping, and automation due to their robustness and efficiency, yet they remain vulnerable to faults such as single-phasing, over-current, and overheating. If left undetected, these faults can cause insulation breakdown, winding failure, and costly downtime. Developing a micro-controller-based protection system therefore ensures longer motor lifespan, reduced maintenance costs, and improved reliability of industrial operations (IRJET, 2019).

Another important contribution of this study is its role in enhancing workplace safety. Electrical and thermal faults not only damage equipment but also pose risks such as fire hazards and electrical accidents. By integrating both electrical and thermal monitoring, the system provides a more comprehensive protection strategy compared to conventional relays, which often fail to detect overheating or discriminate between transient and sustained faults. This integrated approach reduces the likelihood of catastrophic failures and promotes safer working environments (IJRAR, 2024).

Finally, the study is significant because it offers a cost-effective and adaptable solution. Many advanced motor protection relays are expensive and inaccessible to small and medium-scale industries. The proposed micro-controller-based design provides programmable thresholds, startup delay logic, and clear diagnostic feedback at a lower cost, making it suitable for a wider range of applications. Furthermore, it lays the foundation for future improvements such as remote monitoring and predictive maintenance, contributing to the advancement of smart industrial systems (IRJET, 2019; IJRAR, 2024)

1.6 SCOPE AND LIMITATION

1.6.1 SCOPE

This project focuses on the design and implementation of a micro-controller-based protection system for three-phase induction motors using the PIC16F877A. The system is designed to monitor key parameters such as phase currents, neutral current, phase voltages, and motor temperature. It provides protection against common electrical faults including single-phasing, phase unbalance, over-current, under-voltage, and over-voltage, as well as thermal faults caused by overheating. The project also incorporates persistence timing and startup delay logic to minimize false trips, while fault conditions are displayed on an LCD for quick diagnostics. A relay or contractor is used to isolate the motor during fault conditions, and a manual reset option ensures safe restoration after inspection. The system is intended to be low-cost, adaptable to different motor ratings through calibration, and suitable for small to medium industrial applications.

1.6.2 LIMITATIONS

Despite its effectiveness, the project has certain limitations. The system is primarily designed for low to medium power motors and may not be directly applicable to very high-power industrial machines without additional scaling or protective hardware. It relies on the accuracy of sensors (CT's, voltage dividers, and temperature sensors), which may introduce errors if not properly calibrated or if subjected to noise and interference. The design does not include advanced communication features such as

remote monitoring, data logging, or integration with SCADA systems, which are common in modern industrial protection relays. Additionally, the system is limited to detecting predefined faults and does not incorporate predictive maintenance capabilities such as vibration analysis or advanced fault diagnostics. Finally, the prototype is intended for educational and demonstration purposes, and further industrial hardness would be required for deployment in harsh industrial environments.

1.7 ORGANIZATION OF THE PROJECT

The many stages involved in the creation of this project has been divided into five different chapters as follows:

Chapter one is the introduction of the project.

Chapter two is literature review of three phase induction motor protection system.

Chapter three is on design and methodology.

Chapter four is construction, testing and results.

Chapter five is on conclusion and recommendation.

CHAPTER 2 : LITERATURE REVIEW

2.1 BACKGROUND ON INDUCTION MOTOR FAULTS AND PROTECTION PRINCIPLES

The operational reliability of three-phase induction motors is frequently compromised by thermal and electrical faults, with overheating and phase failure being the most critical. In industrial settings, the thermal limits for these motors are governed by standards such as NEMA MG 1 and IEC 60034-1, which categorize motors into insulation classes like B, F, and H. For most standard industrial applications, a motor operating under healthy conditions typically maintains a surface temperature between 40°C and 60°C (NEMA 2021). These standards define the allowable temperature rise above a 40°C ambient reference; for instance, a Class F motor is rated for a total maximum internal temperature of 155°C (IEC 2022). Overheating occurs when the motor's internal temperature exceeds these rated insulation limits due to prolonged overloading or restricted ventilation. According to Fitzgerald, Kingsley and Umans (2003), for every 10°C rise above the rated limit, the functional life of the motor's insulation is approximately halved.

Phase failure, often referred to as single-phasing, occurs when one of the three supply lines is interrupted due to a blown fuse, a broken conductor, or contact failure. This condition is particularly hazardous because the motor may continue to run using only the remaining two phases, but it will experience a dramatic increase in current (approximately 1.73 times the normal value) to maintain the load (Rashid 2017). This surge leads to rapid localized heating in the winding, which can cause total insulation breakdown in minutes. To prevent such damage, industry standards for three-phase systems typically standardized at 415V in many regions or 460V according to NEMA require that the voltage remains balanced. IEEE (2011) suggests that a voltage unbalance of even 3% can lead to a 20% increase in temperature, necessitating protection systems that can detect phase loss or significant voltage asymmetry immediately.

The protection principles discussed in this section focus on the integration of sensing technologies to detect these critical temperature shifts and phase irregularities before catastrophic failure occurs. By utilizing digital sensors like the DS18B20 for thermal tracking and voltage monitoring circuits for phase detection, the system provides real-time defense against the industry-standard limits established by NEMA and IEC. In the event of a phase failure or if the sensed temperature surpasses the predefined safety margin of 60°C to 65°C, the control logic initiates a trip command. This disconnects the power supply through a relay mechanism, thereby ensuring the longevity of the machine and maintaining strict industrial safety standards (Shivpuje and Patil 2017).

2.2 EXISTING MOTOR PROTECTION TECHNIQUES AND DEVICES

Over the years, a variety of devices and methods have been developed to protect induction motors from electrical and thermal faults. The most basic form of protection is the fuse, which interrupts the circuit when excessive current flows. While fuses are inexpensive and effective against short circuits, they cannot provide selective protection against gradual overloads or phase imbalances (Electrical4U, 2024). Similarly, circuit breakers offer reset-table protection and can respond to both overloads and short circuits, but they are not sensitive enough to detect subtle

unbalances or single-phasing conditions that can damage motor winding over time (Electrical Technology, 2020).

Another widely used device is the thermal overload relay, which relies on a bi-metallic strip that bends under heat generated by current flow. This mechanism provides protection against sustained overloads by disconnecting the motor when excessive heating occurs. However, thermal relays are slow to respond and may not adequately protect against rapid fault conditions such as sudden phase loss or severe voltage dips. Moreover, they lack the ability to integrate multiple fault parameters, limiting their effectiveness in modern industrial environments (ETechnoG, 2024).

In more advanced systems, electronic and digital relays have been introduced to overcome these limitations. These devices use sensors and microprocessors to monitor current, voltage, and sometimes temperature, enabling faster and more accurate fault detection. They can be programmed with adjustable thresholds and provide diagnostic information, making them more versatile than traditional relays. Nevertheless, their relatively high cost and complexity often make them inaccessible to small and medium-scale industries, particularly in developing countries such as Nigeria, where affordability and ease of maintenance are critical considerations (Electrical Technology, 2020).

The literature therefore shows that while conventional devices provide basic protection, they are often inadequate for comprehensive motor safeguarding. This gap has motivated research into micro-controller-based protection systems, which combine the affordability of simple devices with the intelligence and flexibility of digital relays. Such systems can integrate multiple fault detection methods, reduce nuisance tripping, and provide user-friendly interfaces, making them a promising solution for industrial applications.

2.3 MICROCONTROLLER-BASED PROTECTION SYSTEMS

The advancement of micro-controller technology has transformed the design of motor protection systems, offering low-cost, flexible, and intelligent alternatives to conventional relays. Unlike electromechanical devices, micro-controllers can simultaneously monitor multiple parameters such as current, voltage, and temperature, process them in real time, and execute complex decision-making algorithms. This makes them particularly suitable for induction motor protection, where faults often manifest in subtle variations across several electrical and thermal variables (Shivpuje & Patil, 2017).

Several studies have demonstrated the effectiveness of micro-controller-based systems in providing comprehensive protection. For example, a PIC micro-controller-based design was shown to reliably detect single-phasing, over-current, and overheating, while also providing user feedback through an LCD interface (IJLRET, 2019). Similarly, research by IJIRT (2020) highlighted how low-cost micro-controller platforms could integrate current, temperature, and speed monitoring to trip relays under fault conditions, thereby reducing the risk of catastrophic motor failure. These systems not only improve accuracy but also allow for programmability, enabling engineers to adjust thresholds and timing parameters to suit different motor ratings and operating environments.

Micro-controller-based protection also supports additional features that enhance usability and reliability. Persistence timing and startup delay logic can be implemented in software to avoid nuisance tripping during motor inrush currents. Non-volatile memory, such as EEPROM, allows calibration data and fault history to be stored, ensuring consistent performance across power cycles. Furthermore, micro-controllers can be interfaced with communication modules, enabling remote monitoring and integration into supervisory control and data acquisition (SCADA) systems (IJRAR, 2024). These capabilities demonstrate the scalability of micro-controller-based solutions, making them adaptable to both small-scale industries and larger industrial plants.

Despite these advantages, the literature also identifies some limitations. Many prototypes remain at laboratory scale and are not rugged for harsh industrial environments. Issues such as electromagnetic interference, sensor calibration errors, and inadequate isolation between high-voltage and low-voltage sections can affect reliability. Moreover, while advanced digital relays are commercially available, their cost remains prohibitive for small and medium enterprises in developing countries such as Nigeria. This gap underscores the importance of research into affordable, locally adaptable micro-controller-based protection systems that combine accuracy, safety, and cost-effectiveness (IJLRET, 2019; IJIRT, 2020).

2.4 RELEVANT CASE STUDIES AND IMPLEMENTATIONS

Several case studies and experimental implementations have demonstrated the practicality of micro-controller-based induction motor protection systems. For instance, a study by IJIRT (2020) developed a PIC18F452-based protection circuit that monitored current and voltage variations to detect faults such as over-voltage, under-voltage, and over-current. The system successfully isolated the motor during abnormal conditions, proving that micro-controllers can provide reliable and low-cost protection in real-time industrial scenarios (IJIRT, 2020).

Similarly, IJLRET (2019) presented a PIC micro-controller-based embedded system for three-phase induction motor protection. Their design integrated current and voltage sensing with LCD display feedback, enabling operators to quickly identify fault conditions. The study highlighted the advantages of being programmable, which allowed the system to be adapted to different motor ratings without hardware changes. This adaptability is particularly important in small and medium-scale industries where motors of varying capacities are used (IJLRET, 2019).

Another case study by ER Publications (2021) focused on real-time fault identification in induction motors using a micro-controller platform. The researchers demonstrated that integrating current, voltage, and temperature monitoring significantly improved fault detection accuracy compared to conventional relays. Their findings emphasized that micro-controller-based systems not only enhance reliability but also reduce maintenance costs by preventing catastrophic failures (ER Publications, 2021).

In the Nigerian context, where power quality issues such as frequent voltage fluctuations and phase imbalances are common, these case studies are highly relevant. They show that micro-controller based solutions can be tailored to address local challenges by providing comprehensive protection at a fraction of the cost of

advanced digital relays. However, most of these implementations remain at prototype or laboratory scale, underscoring the need for further research into being rugged, field testing, and adaptation for harsh industrial environments.

2.5 GAPS, LIMITATIONS, AND MOTIVATIONS FOR THE PROJECT

Although numerous studies have demonstrated the feasibility of micro-controller-based induction motor protection systems, several gaps and limitations remain. Many prototypes are developed and tested only under laboratory conditions, without sufficient validation in real industrial environments where noise, dust, and fluctuating power quality are common. This lack of being rugged means that while the systems perform well in controlled settings, their reliability in harsh operating conditions is uncertain (IJIRT, 2020).

Another limitation is the narrow scope of protection in many designs. Some systems focus primarily on current-based faults such as over-current or single-phasing, while neglecting thermal monitoring or voltage imbalance detection. Others implement only basic threshold-based algorithms without persistence timing or startup delay logic, leading to nuisance tripping during motor inrush currents. These shortcomings reduce the practicality of such systems in industries where both electrical and thermal stresses must be addressed simultaneously (IndusEdu, 2021).

Cost and accessibility also remain significant challenges. Advanced digital relays and commercial motor protection units are often too expensive for small and medium-scale industries, particularly in developing countries such as Nigeria. While micro-controller-based solutions are more affordable, many published designs still rely on imported components or lack clear guidelines for local adaptation. This creates a gap between academic prototypes and deployable solutions that can be manufactured, maintained, and scaled within the Nigerian industrial context (IJLRET, 2019).

The motivation for this project therefore arises from the need to design a low-cost, adaptable, and comprehensive protection system that integrates electrical and thermal monitoring, incorporates persistence logic to reduce false trips, and provides clear diagnostic feedback through LCD and LED indicators. By using the PIC16F877A micro-controller, the system leverages multiple ADC channels, EEPROM storage, and flexible programming to deliver reliable protection tailored to local industrial needs. This approach directly addresses the limitations identified in the literature and contributes to safer, more efficient motor operation in Nigerian industries.

2.6 CONCEPTUAL FRAMEWORK AND SUMMARY

The reviewed literature highlights that while induction motors are indispensable in industrial applications, they remain vulnerable to a range of electrical and thermal faults. Conventional protection devices such as fuses, circuit breakers, and thermal overload relays provide only partial coverage, often failing to detect subtle or combined fault conditions. More advanced digital relays offer comprehensive protection but are costly and less accessible to small and medium-scale industries, particularly in developing contexts such as Nigeria (Electrical Technology, 2020; ETechnoG, 2024).

Micro-controller-based protection systems have emerged as a promising alternative, combining affordability with flexibility. Studies demonstrate that micro-controllers can integrate multiple sensing inputs—current, voltage, and temperature—while executing intelligent algorithms such as persistence timing, startup delay, and trip latching (Shivpuje & Patil, 2017; IJIRT, 2020). Case studies further show that these systems can provide real-time monitoring and user feedback through LCD and LED, enhancing both reliability and usability (IJLRET, 2019). However, implementations remain at prototype level, lacking industrial-grade durability for deployment and insufficient adaptation to local challenges such as poor power quality and cost constraints (IndusEdu, 2021).

The conceptual framework for this project is therefore built on integrating sensor inputs (current transformers, potential transformers, and temperature sensors) with the PIC16F877A micro-controller, which processes the data using programmed protection algorithms. The micro-controller then drives output actuators (relay/contractor) to isolate the motor during fault conditions, while providing user feedback (LCD, and push buttons) for diagnostics and control. This framework ensures comprehensive protection by combining electrical and thermal monitoring, persistence logic to reduce false trips, and a low-cost design suitable for Nigerian industries.

In summary, the literature establishes the need for a protection system that is affordable, adaptable, and comprehensive. This project addresses the identified gaps by leveraging the capabilities of the PIC16F877A to deliver a practical solution that enhances motor reliability, reduces downtime, and improves safety in industrial environments.

CHAPTER 3: DESIGN METHODOLOGY

3.1 INTRODUCTION

This chapter presents the methodology adopted in the design and implementation of a micro-controller-based protection system for a three-phase induction motor. The approach combines both hardware and software development to achieve real-time monitoring of current, voltage, and temperature using sensors such as the ACS712, ZMPT101B modules, and DS18B20. The PIC16F877A micro-controller serves as the central control unit, executing programmed algorithms to detect abnormal conditions and initiate protective actions through relays and contractors. The methodology is structured to cover the system design approach, hardware configuration, software development, and testing procedures. By following this systematic process, the project ensures that the final prototype is reliable, cost-effective, and adaptable to industrial applications, particularly within the Nigerian context where power quality issues are prevalent.

- 16 × 2 LCD display
- Crystal oscillator (16 MHz)
- Crystal load capacitors (2 pcs)
- Step-down transformer / SMPS (for low-voltage supply)
- 7805 voltage regulator
- Electrolytic capacitor (filtering)
- Current transformers (1pcs, ACS712)
- Potential transformers (ZMPT101B, 3pc, for phase voltage sensing)
- Temperature sensor (DS18B20)
- Relay or contractor (& ULN2003)
- Flyback diode (e.g., 1N4007)
- Switch (KCD1 Boat Switch)
- PCB / protoboard
- Bulb
- Motor
- PIC16F877A microcontroller

3.2 POWER SUPPLY UNIT(CONVERSION FROM 220V AC TO 5V DC)

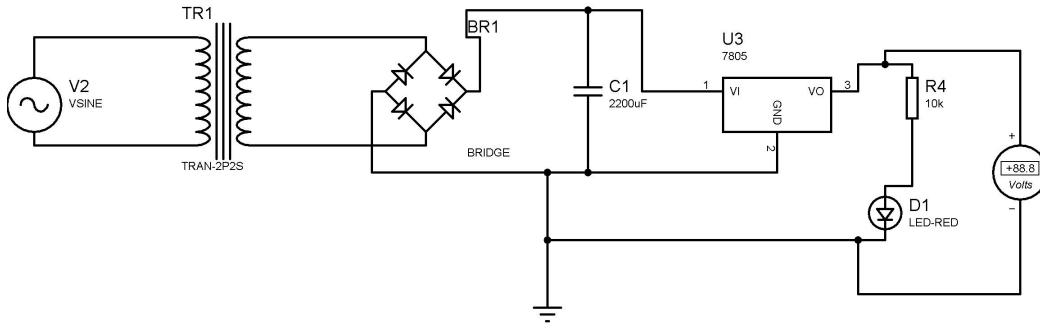


Figure 3.1 : Power Supply Unit (Conversion From 220v Ac To 5v Dc)

Figure 3.1 shows the power supply unit conversion system from 220V to 5V consisting the transformers, diodes, bridge rectifiers and voltage regulators. The steps include:

3.2.1 STEP 1: TRANSFORMER (AC STEP DOWN)

A transformer is employed to reduce the 220 V AC mains supply to a safer low-voltage level suitable for rectification and regulation. In this design, a 12 V AC secondary winding is selected. The transformer operates on the principle of electromagnetic induction, where a varying current in the primary coil produces a magnetic flux that induces a voltage in the secondary coil (Fitzgerald, Kingsley & Umans, 2003). This ensures electrical isolation between the high-voltage mains and the low-voltage control circuit, thereby improving safety.

o Calculation of Secondary Peak Voltage:

500 mA – 1 A (depending on the system).

$$V_{peak} = V_{rms} \times 2 \dots \dots \dots (3.1)$$

Equation 3.1 is used to find the secondary peak voltage of the secondary part of the transformer

$$V_{peak} = 12 \times 1.414 \approx 16.97V$$

Thus, the secondary provides approximately 17 V peak before rectification.

Rationale for 12 V Selection:

Although the final requirement is 5 V DC, a 12 V AC secondary ensures that after rectification, filtering, and diode voltage drops, there is still sufficient headroom for the 7805 regulator to maintain a stable 5 V output (Sedra & Smith, 2015).

Key Notes:

- o Provides isolation from the high- voltage mains.
 - o Supplies adequate voltage for rectification and regulation.
- Must be rated to handle the expected load current

3.2.2 STEP 2: DIODES AND BRIDGE RECTIFIER

A diode is a semiconductor device that permits current flow in only one direction, thereby converting alternating current (AC) into direct current (DC). In this design, four 1N4007 diodes are arranged in a full-wave bridge rectifier configuration. This arrangement ensures that both the positive and negative half-cycles of the AC waveform are rectified, producing a pulsating DC output (Boylestad & Nashelsky, 2013).

Operation Principle:

- During the positive half-cycle of the AC input, two diodes conduct, allowing current to pass through the load.
- During the negative half-cycle, the other two diodes conduct, again directing current through the load in the same direction.
- This results in a continuous pulsating DC waveform at twice the mains frequency (100 Hz for a 50 Hz supply).

Voltage Drop Across Diodes:

Each conduction path includes two diodes, each with a forward voltage drop of approximately 0.7 V.

$$V_{drop} \approx 2 \times 0.7 = 1.4V$$

Equation 3.2 calculates the voltage drop across the diodes

Output Voltage After Rectification:

From Step 1, the transformer secondary provides a peak voltage of $\approx 16.97 V$.

After subtracting the diode drops:

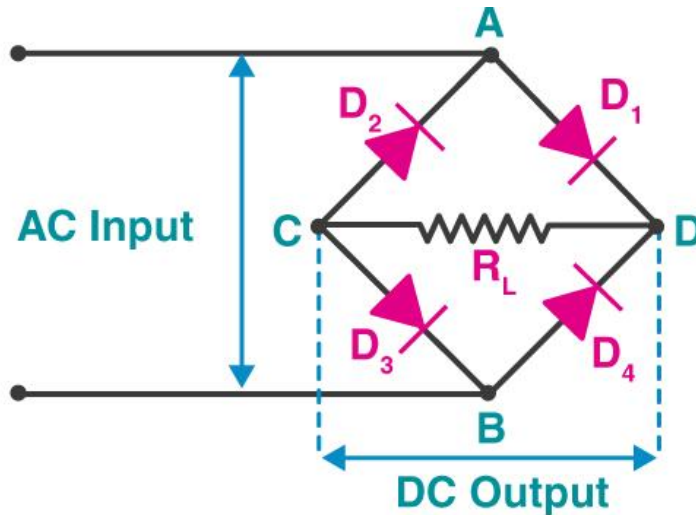
$$V_{DC} = V_{peak} - V_{drop} \dots \dots \dots (3.2)$$

$$V_{DC} \approx 16.97 - 1.4 = 15.6V \text{ (unfiltered peak)}$$

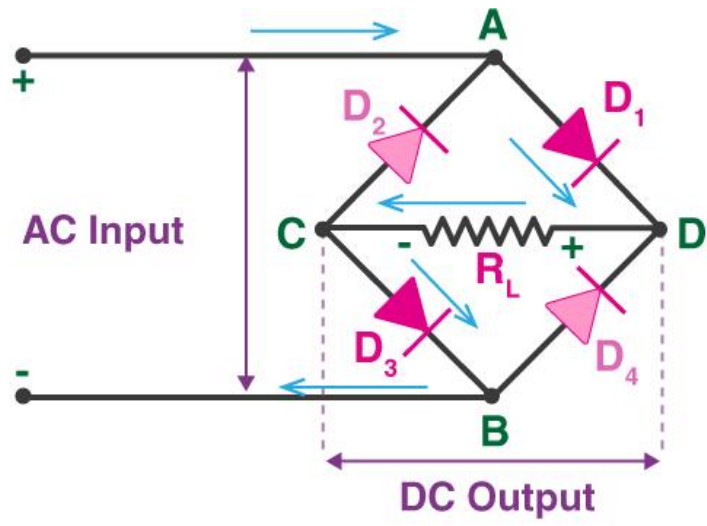
Equation 3.2 calculates the output voltage after rectification.

Key Notes:

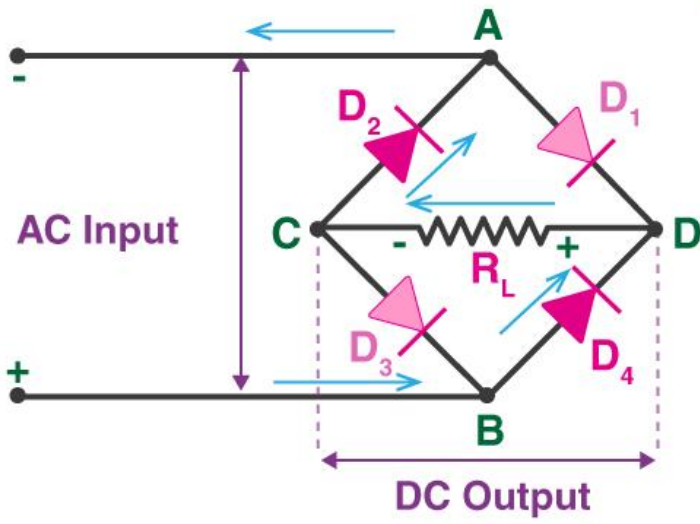
- The bridge rectifier doubles the ripple frequency, making filtering more efficient.
- The 1N4007 diodes are chosen for their high reverse voltage rating (1000 V) and current handling capacity (1 A), ensuring durability and safety in this application.
- The rectifier output is still pulsating DC and requires further smoothing with a filter capacitor.



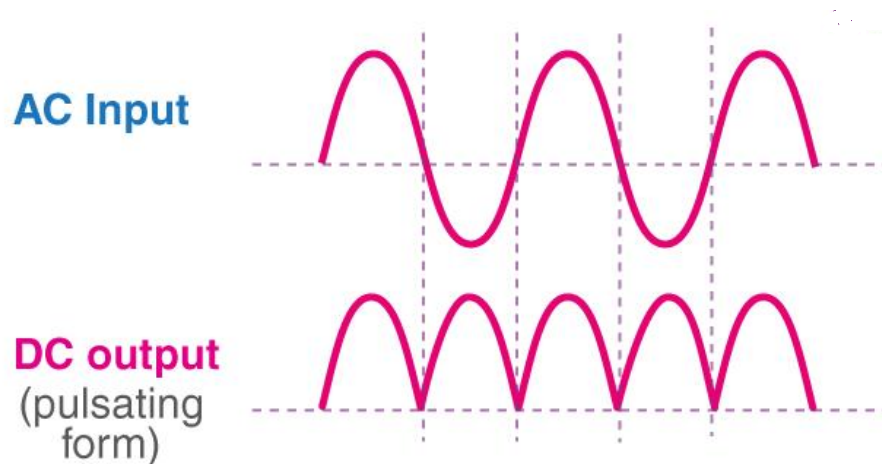
(a)



(b)



(c)



(d)

Figure 3.2 Rectifier Circuit

(Byju's 2025, Bridge Rectifier, Byju's Viewed 25 November 2025,

<<https://Byjus.Com/Physics/Bridge-Rectifier/>>)

Figure 3.2 shows the diagram of a rectifier circuit which consist of 4 diodes and how it functions.

A diode is a semiconductor device with two terminals, typically allowing the flow of current in one direction only. It means current can't go on the reverse direction.

Components: Four diodes (e.g., 1N4007) arranged in a bridge configuration.

On that image the - and +. Electron flows from cathode (-) to anode (+). If you used the diode on reverse direction, the bulb wouldn't glow. This happens because the diode does not let current flow on the other direction. So, there no big difference between the open and the reversed diode circuit. In figure 3.2d I showed the basic wave form of alternating current. AC current changes it's direction based on it's frequency. In conclusion, AC is an electric current that reverses its direction many times a second

On the positive half cycle of the AC, the diode is forward biased. That means the LED will glow. (LED stands for Light Emitting Diode. That means LED is also a diode.)

But during the negative, the diode is not forward biased. So, it will end up being an open circuit. That means the LED won't glow. Again when positive half cycle the AC, the diodes is forward biased. And this happens over and over again. The LED will blink in every 0.02second provided the source the frequency is 50Hz. Although it blinks pretty fast but it's still noticeable.

A full-wave bridge rectifier using four 1N4007 diodes converts the AC voltage into pulsating DC.

Each conduction path has two diodes in series.

Voltage drop: $0.7V$ per diode $\rightarrow 1.4V$ total

DC output after rectification:

$$V_{DC} \approx 16.97 - 1.4 = 15.6V \text{ (unfiltered)}$$

3.2.3 STEP 3: FILTER CAPACITOR

After rectification, the output is a pulsating DC waveform that still contains significant ripple. To smooth this voltage and provide a more stable DC supply, a filter capacitor is connected across the rectifier output. The capacitor charges during

the peak of the waveform and discharges when the input voltage falls, thereby reducing the ripple amplitude (Sedra & Smith, 2015).

Design Calculation:

$$C = \frac{I}{2f\Delta V} \dots\dots\dots(3.3)$$

Equation 3.3 is used in determining the capacitance of the capacitor used for the power supply unit

The required capacitance can be estimated using:

where:

- (I) = load current (assume 0.5 A for micro-controller, LCD, sensors, and relay coil),
- (f) = ripple frequency = 2 × mains frequency = 100 Hz (for 50 Hz mains),
- (Delta V) = allowable ripple voltage (assume 1 V).

Substituting values:

$$C = \frac{0.5}{2 \times 50 \times 1}$$

Practical Selection:

While the theoretical value is 5000 μF, in practice, standard capacitor values such as 2200 μF to 4700 μF are commonly used. For this project, a 2200 μF electrolytic capacitor is sufficient for moderate loads.

Key Notes:

- The capacitor must have a voltage rating at least 25 V, to safely withstand the rectified DC (~15.6 V).
- Larger capacitance reduces ripple but increases size and cost.
- Electrolytic capacitors are typically used due to their high capacitance-to- volume ratio.

3.2.4 STEP 4: VOLTAGE REGULATOR (LM7805)

After rectification and filtering, the DC voltage available is approximately 15.6 V. However, this is too high and unstable for powering logic circuits such as the PIC16F877A micro-controller, LCD, and sensors. To obtain a constant and reliable. 5 V DC, a linear voltage regulator (LM7805) is employed.

The LM7805 is a three- terminal regulator that provides a fixed 5 V output regardless of variations in input voltage or load current, provided the input remains above its dropout requirement (Horowitz & Hill, 2015).

Input Voltage Requirement:

The LM7805 requires a minimum input of about 7 V to regulate properly. With ≈15.6V available after filtering, the regulator has sufficient headroom.

Output Voltage:

$$V_{out} = 5V$$

Power Dissipation:

The regulator dissipates excess voltage as heat.

$$P = (V_{in} - V_{out}) \times I_{load} \dots\dots\dots(3.5)$$

Equation 3.5 is used in determining the power dissipation

Assuming $V_{in} = 15.6V$, $V_{out} = 5V$ and $I_{load} = 0.5A$

$$P = (15.6 - 5) \times 0.5 = 1 / 0.6 \times 0.5 = 5.3W$$

Key Notes:

- Provides a stable 5 V supply for all digital components.
- Protects sensitive IC from voltage fluctuations.
- Simple to use, with only input and output capacitors required for stability.

3.3 16 X 2 LIQUID CRYSTAL DISPLAY (LCD)

3.3.1 FUNCTIONS OF THE 16×2 LCD IN THE PROJECT

The LCD provides real-time monitoring by displaying phase voltages, motor temperature, and ON/OFF status. It indicates faults such as under-voltage, phase loss, or overheating with clear messages, shows system initialization and running status, and offers a simple, user-friendly interface that removes the need for external meters.



Figure 3.3 16x2 Liquid Crystal Display Screen

Figure 3.3 is a diagram of a 16 by 2 LCD Screen

3.4 CRYSTAL OSCILLATOR

A 16 MHz crystal oscillator provides the clock signal that drives the micro-controller's timing and operations.

In your project, the 16 MHz crystal oscillator is connected to the PIC16F877A to ensure precise and stable timing for instruction execution. It generates a consistent clock pulse that synchronizes all internal processes of the micro-controller, including reading sensor inputs, processing data, and controlling outputs like the relay and LCD. Without it, the micro-controller would not have a reliable time base, and system performance could become inaccurate or unstable.

In short: the 16 MHz crystal oscillator acts as the “heartbeat” of the micro-controller, ensuring accurate timing, stable operation, and reliable coordination of all protection functions in your motor protection system.



Figure3.4 16 MHZ Crystal Oscillator

Figure3.4 is a diagram of a 16Mhz crystal oscillator

3.5 STEP-DOWN TRANSFORMER / SMPS (FOR LOW-VOLTAGE SUPPLY)

The transformer has:

Input (Primary): 220V AC (red, black, yellow wires).

Output (Secondary): 12V–0–12V AC (blue, white, blue wires).

Its job is to step down the dangerous high-voltage AC (220V) to a safer low-voltage AC (12V).

The center tap (0V) allows you to use either 12V AC (one side + center) or 24V AC (both sides together).

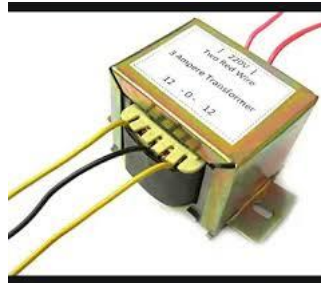


Figure 3.5 Step Down Transformer

Figure 3.5 shows the diagram of transformer that converts 220V AC to 12V DC

3.6 LM7805 VOLTAGE REGULATOR

The 7805 voltage regulator provides a fixed, stable 5V DC output from a higher DC input. It is mainly used to power electronic circuits that require a constant 5V supply

3.6.1 FUNCTIONS OF 7805

- **Voltage Regulation:** Maintains a constant 5V output regardless of input fluctuations (within limits).
- **Power Supply Stabilization:** Smooths out ripples from rectified DC after a transformer and rectifier stage.
- **Overload Protection:** Shuts down or limits current if the load draws too much.
- **Thermal Protection:** Automatically turns off if it overheats.
- **Short-Circuit Protection:** Prevents damage if the output is accidentally shorted.



Figure 3.6 LM7805 Voltage Regulator

Figure 3.6 shows the diagram of a voltage regulator LM7805 that gives an outputs of 5V

3.7 ACS712 Current Sensor

3.7.1 Functions of ACS712

- **Current Measurement:** Measures both AC and DC current using the Hall effect.
- **Electrical Isolation:** Safely separates the high-current load from the low-voltage control circuit.
- **Analog Output:** Provides a voltage proportional to the current, readable by microcontrollers (e.g., Arduino, PIC, ESP32).
- **Bidirectional Sensing:** Can detect current flow in both directions (positive and negative).
- **Applications:** Power monitoring, motor control, over-current protection, battery management, and energy meters.



Figure 3.7 ACS712 Current Sensor

Figure 3.7 shows the diagram of a current sensor ACS712 that measures the temperature of the circuit

3.8 POTENTIAL TRANSFORMERS(ZMPT101B, 3PC, FOR PHASE VOLTAGE SENSING)

The ZMPT101B is a small single-phase potential transformer module used for accurate AC voltage sensing. In your project, its function is to safely step down and measure mains phase voltage (e.g., 220V AC) so that a microcontroller can monitor it.

3.8.1 FUNCTIONS OF ZMPT101B

- **Voltage Sensing:** Measures AC mains voltage (up to about $\pm 250V$ AC) and outputs a scaled-down signal.
- **Isolation:** Provides galvanic isolation between the high-voltage mains and the low-voltage control circuit, ensuring safety.
- **Signal Conditioning:** The module includes an op-amp and potentiometer to adjust sensitivity and scale the output for ADC input.
- **Phase Monitoring:** When using multiple modules (e.g., 3 pcs), each can be connected to a different phase in a 3-phase system for phase voltage sensing.
- **Applications:** Energy meters, power monitoring, voltage protection circuits, and smart grid projects.

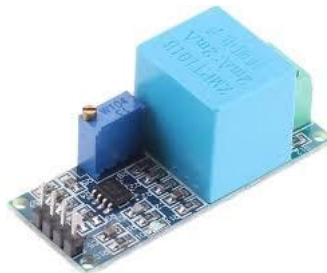


Figure 3.8 ZMPT101B Potential Transformer

Figure 3.8 shows the diagram of ZMPT101B voltage/potential transformer.

3.9 DS18B20 TEMPERATURE SENSOR

3.9.1 Functions of DS18B20 in This Project

1. **Motor Temperature Monitoring** Continuously measures the surface or housing temperature of the induction motor.
2. **Overheating Protection** Sends real-time temperature data to the PIC16F877A, which compares it against preset thresholds (trip and reset at $65^{\circ}C$).
3. **Digital Accuracy** Provides precise digital readings over the 1-Wire protocol, reducing errors compared to analog sensors.
4. **Fault Detection** Helps detect abnormal heating caused by overload, poor ventilation, or electrical faults.

5. **System Control** When overheating is detected, the micro-controller DE-energizes the relay/contractor to disconnect the motor, preventing damage.
6. **User Feedback** The measured temperature is displayed on the 16×2 LCD, giving operators clear visibility of motor thermal conditions.

3.9.2 Specifications of DS18B20

- **Operating Voltage:** 3.0 V – 5.5 V (compatible with your 5 V system).
- **Temperature Range:** –55 °C to +125 °C.
- **Accuracy:** ±0.5 °C (from –10 °C to +85 °C).
- **Resolution:** Programmable from 9-bit to 12-bit (0.5 °C down to 0.0625 °C steps).
- **Interface:** 1-Wire digital communication (single data pin).
- **Conversion Time:** Up to 750 ms for 12-bit resolution.
- **Unique 64-bit Serial Code:** Allows multiple sensors to be connected on the same bus.
- **Package:** Available in TO-92 (transistor-like), waterproof probe, or SMD forms.



Figure 3.9 DS18B20 Temperature Sensor

Figure 3.9 shows the diagram DS18B20 temperature sensor used in the system to check for overheating.

3.10 RELAY/CONTRACTOR WITH ULN2003 DRIVER

3.10.1 FUNCTIONS OF RELAY/CONTRACTOR (WITH ULN2003)

1. **Motor Isolation and Protection** The relay/contractor acts as the switching device that physically connects or disconnects the induction motor from the three-phase supply when a fault is detected.
2. **Fault Response Execution** When the PIC16F877A detects abnormal conditions (overheating, under-voltage, phase loss), it sends a low-power control signal to the ULN2003 driver, which in turn energizes or DE-energizes the relay coil.
3. **Signal Amplification and Protection** The ULN2003 serves as an interface between the micro-controller and the relay. Since the PIC16F877A cannot directly drive the higher current required by the relay coil, the ULN2003 amplifies the signal and provides safe switching.
4. **System Reliability** Ensures that the motor is disconnected quickly during faults, preventing winding damage, insulation breakdown, or fire hazards.
5. **User Feedback** The relay's switching action corresponds with LCD/LED indications, giving operators confidence that the system is actively protecting the motor.



Figure 3.10 ULN2003 Driver

Figure 3.10 shows a diagram of a ULN2003 driver relay/contractor that breaks down the circuit when there is a fault.

3.11 PIC16F877A MICRO-CONTROLLER

3.11.1 FUNCTIONS OF PIC16F877A MICRO-CONTROLLER IN THIS PROJECT

1. **Central Control Unit** Acts as the “brain” of the system, coordinating all inputs (sensors) and outputs (relay, LCD).
2. **Signal Processing** Reads analog signals from the ACS712 current sensor and ZMPT101B voltage sensors via its built-in ADC channels.
3. **Temperature Monitoring** Communicates digitally with the DS18B20 sensor over the 1-Wire protocol to obtain accurate temperature readings.
4. **Decision Making** Compares measured values against preset thresholds (over-current, under-voltage, overheating) and decides whether to keep the motor running or disconnect it.
5. **Output Control** Sends control signals to the ULN2003 driver, which energizes or de-energizes the relay/contractor to isolate the motor.
6. **User Interface Management** Drives the 16×2 LCD to display real-time system status, voltages, temperature, and fault messages

3.11.2 SPECIFICATIONS OF PIC16F877A

- **Architecture:** 8-bit RISC microcontroller.
- **Program Memory:** 14 KB Flash (8K × 14 words).
- **RAM:** 368 bytes.
- **EEPROM:** 256 bytes (for storing calibration or threshold values).
- **Operating Voltage:** 4.0 V – 5.5 V (typically 5 V).
- **Clock Speed:** Up to 20 MHz (using external crystal; in your project, 16 MHz).
- **I/O Pins:** 33 programmable I/O pins.
- **ADC:** 10-bit resolution, up to 8 analog input channels.
- **Timers:** 3 timers (Timer0, Timer1, Timer2).
- **Communication Interfaces:**
 - USART (serial communication)
 - I²C and SPI (for peripheral interfacing)
- **Instruction Set:** 35 simple instructions (RISC).
- **Package Types:** 40-pin DIP, 44-pin PLCC, or QFP.
- **Operating Temperature:** –40 °C to +85 °C (industrial grade).

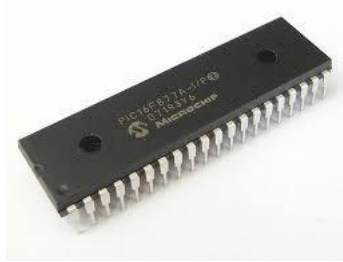


Figure 3.11 PIC16F877A Micro-controller

Figure 3.11 is the diagram of pic16f877a micro-controller that is the brain of the circuit.

3.12 CODE

The PIC micro-controller was programmed using C/C+ programming language and PIC kit

```
// 3-Phase protection for induction motor
// PIC16F877A, MikroC PRO for PIC
// ZMPT101B sensors on AN0, AN1, AN2
// DS18B20 on RC2 (1-Wire)
// Relays via ULN2003 on RB0, RB1, RB2
// LCD on PORTD (RD0=RS, RD1=EN, RD2..RD5 = D4..D7)
sbit RELAY_A at RB0_bit;
sbit RELAY_B at RB1_bit;
sbit RELAY_C at RB2_bit;
// LCD pins (change wiring if needed)
sbit LCD_RS at RD0_bit;
sbit LCD_EN at RD1_bit;
sbit LCD_D4 at RD2_bit;
sbit LCD_D5 at RD3_bit;
sbit LCD_D6 at RD4_bit;
sbit LCD_D7 at RD5_bit;
sbit LCD_RS_Direction at TRISD0_bit;
sbit LCD_EN_Direction at TRISD1_bit;
sbit LCD_D4_Direction at TRISD2_bit;
sbit LCD_D5_Direction at TRISD3_bit;
sbit LCD_D6_Direction at TRISD4_bit;
sbit LCD_D7_Direction at TRISD5_bit;
// DS18B20 pin
#define ONEWIRE_PIN PORTC.B2
#define ONEWIRE_DIR TRISC.B2
// Configuration constants (tune these)
#define SAMPLES_PER_MEASURE 200 // number of ADC samples used for
peak detection
#define SAMPLE_DELAY_US 100 // delay between ADC samples in
microseconds
// IMPORTANT: calibrate VOLTAGE_SCALE to map measured sensor Vrms ->
actual mains Vrms
// Example: if measured_vrms_sensor = 1.2V corresponds to 230VAC,
VOLTAGE_SCALE = 230.0 / 1.2
float VOLTAGE_SCALE = 190.0; // <<-- default, YOU MUST CALIBRATE
```

```

float PHASE_PRESENT_THRESHOLD_V = 180.0; // if measured mains Vrms <
this -> consider phase absent (adjustable)
// Temperature thresholds (surface/housing). Conservative defaults (change if motor
datasheet says otherwise)
#define TRIP_TEMP_C 80 // trip (cut motor) when surface temp >= this (°C)
#define RESET_TEMP_C 60 // reconnect when temp <= this (°C)
// Debounce / counters
#define PHASE_CONFIRM_COUNT 3 // number of consecutive checks to declare
phase absent/present
#define TEMP_CONFIRM_COUNT 2 // consecutive reads to declare overheating
// delay between main loop checks (ms)
#define LOOP_DELAY_MS 1000
// function prototypes
unsigned int measure_peak_adc(unsigned char channel);
float adc_vpp_to_sensor_vrms(unsigned int vpp_counts);
float measure_phase_vrms(unsigned char channel);
unsigned char is_phase_present(unsigned char channel);
bit onewire_reset();
void onewire_write_bit(unsigned char b);
unsigned char onewire_read_bit();
void onewire_write_byte(unsigned char b);
unsigned char onewire_read_byte();
int ds18b20_get_temp_c(); // returns temperature in degC (rounded)
void motor_cut_off();
void motor_reconnect();
void update_lcd(float va, float vb, float vc, int tempC, bit motor_on);
bit MOTOR_ON = 0;
unsigned char phase_absent_count[3];
unsigned char phase_present_count[3];
unsigned char temp_trip_count = 0;
void main() {
    unsigned int a_counts, b_counts, c_counts;
    float va, vb, vc;
    int tempC;
    // Port configuration
    TRISB = 0x00; // B output for relays (RB0..RB2)
    PORTB = 0x00;
    RELAY_A = 0;
    RELAY_B = 0;
    RELAY_C = 0;
    // ADC config
    ADCON1 = 0x80; // Vref = Vdd, configure later with ADC_Init if needed
    ADC_Init();
    // Configure AN0..AN2 as analog in ADON via ADCON0? ADC_Read will handle
channel select
    // Note: In mikroC, ADC_Read(channel) is available
    Lcd_Init();
    Lcd_Cmd(_LCD_CLEAR);
    Delay_ms(100);
    Lcd_Out(1,1,"3-Phase Motor Prot");

```

```

Lcd_Out(2,1,"Init...");
Delay_ms(800);
Lcd_Cmd( LCD_CLEAR);
MOTOR_ON = 1; // assume starting state: motor connected. You can set initial
state differently.
motor_reconnect();
// init counters
phase_absent_count[0]=phase_absent_count[1]=phase_absent_count[2]=0;
phase_present_count[0]=phase_present_count[1]=phase_present_count[2]=0;
while(1) {
    // measure phases (Vrms estimated)
    va = measure_phase_vrms(0); // AN0
    vb = measure_phase_vrms(1); // AN1
    vc = measure_phase_vrms(2); // AN2
    // read temp
    tempC = ds18b20_get_temp_c();
    // check each phase presence with debounce
    float vmeas[3];
    vmeas[0] = va; vmeas[1] = vb; vmeas[2] = vc;
    bit any_phase_absent = 0;
    for (unsigned char i=0;i<3;i++) {
        if (vmeas[i] < PHASE_PRESENT_THRESHOLD_V) {
            // count absent
            if (phase_absent_count[i] < 255) phase_absent_count[i]++;
            phase_present_count[i] = 0;
        } else {
            // present
            if (phase_present_count[i] < 255) phase_present_count[i]++;
            phase_absent_count[i] = 0;
        }
        if (phase_absent_count[i] >= PHASE_CONFIRM_COUNT) {
            any_phase_absent = 1;
        }
    }
    // temperature trip debounce
    if (tempC >= TRIP_TEMP_C) {
        if (temp_trip_count < 255) temp_trip_count++;
    } else {
        if (temp_trip_count > 0) temp_trip_count--;
    }
    // Decide motor control:
    if (any_phase_absent || (temp_trip_count >= TEMP_CONFIRM_COUNT)) {
        if (MOTOR_ON) {
            motor_cut_off();
            MOTOR_ON = 0;
        }
    } else {
        // only reconnect when ALL phases present AND temp <= RESET_TEMP_C
        bit all_present = 1;
        for (unsigned char i=0;i<3;i++) {

```

```

    if (phase_present_count[i] < PHASE_CONFIRM_COUNT) { all_present = 0;
break; }
    }
    if (all_present && (tempC <= RESET_TEMP_C)) {
        if (!MOTOR_ON) {
            motor_reconnect();
            MOTOR_ON = 1;
        }
    }
}

// update LCD
update_lcd(va,vb,vc,tempC,MOTOR_ON);
Delay_ms(LOOP_DELAY_MS);
}
}
// Measure Vpp counts (max-min) across SAMPLES_PER_MEASURE using
ADC_Read()
unsigned int measure_peak_adc(unsigned char channel) {
    unsigned int maxv = 0;
    unsigned int minv = 1023;
    unsigned int val;
    unsigned int i;
    for (i=0;i<SAMPLES_PER_MEASURE;i++) {
        Delay_us(SAMPLE_DELAY_US);
        val = ADC_Read(channel); // returns 0..1023
        if (val > maxv) maxv = val;
        if (val < minv) minv = val;
    }
    if (maxv < minv) return 0;
    return (maxv - minv);
}
// Convert ADC Vpp counts to sensor Vrms (voltage at sensor output, in volts)
float adc_vpp_to_sensor_vrms(unsigned int vpp_counts) {
    // ADC reference assumed Vref = 5.0V, ADC 10-bit (0..1023)
    float vpp_volts = ((float)vpp_counts * 5.0) / 1023.0;
    // For sine wave Vrms = Vpp / (2*sqrt(2)) = Vpp * 0.353553
    float vrms = vpp_volts * 0.353553;
    return vrms;
}
// Measure phase Vrms (estimated mains Vrms after scaling)
float measure_phase_vrms(unsigned char channel) {
    unsigned int vpp_counts = measure_peak_adc(channel);
    float sensor_vrms = adc_vpp_to_sensor_vrms(vpp_counts);
    float mains_vrms = sensor_vrms * VOLTAGE_SCALE; // scale factor -> calibrate
this
    return mains_vrms;
}
// Motor control helper functions
void motor_cut_off() {

```

```

// deactivate relays (assume HIGH drives relay via ULN, set low -> off)
RELAY_A = 0;
RELAY_B = 0;
RELAY_C = 0;
// small feedback on LCD will be done by main loop
}
void motor_reconnect() {
  RELAY_A = 1;
  RELAY_B = 1;
  RELAY_C = 1;
}
// Simple 1-Wire routines for DS18B20 (approx timing)
bit onewire_reset() {
  unsigned char r;
  ONEWIRE_DIR = 0; // output
  ONEWIRE_PIN = 0;
  Delay_us(480);
  ONEWIRE_DIR = 1; // input release
  Delay_us(70);
  r = ONEWIRE_PIN;
  Delay_us(410);
  return (r == 0); // presence = 0
}
void onewire_write_bit(unsigned char b) {
  ONEWIRE_DIR = 0;
  ONEWIRE_PIN = 0;
  if (b) { // write 1
    Delay_us(6);
    ONEWIRE_DIR = 1; // release
    Delay_us(64);
  } else { // write 0
    Delay_us(60);
    ONEWIRE_DIR = 1;
    Delay_us(10);
  }
}
unsigned char onewire_read_bit() {
  unsigned char b;
  ONEWIRE_DIR = 0;
  ONEWIRE_PIN = 0;
  Delay_us(6);
  ONEWIRE_DIR = 1;
  Delay_us(9);
  b = ONEWIRE_PIN;
  Delay_us(55);
  return b;
}
void onewire_write_byte(unsigned char b) {
  for (unsigned char i=0;i<8;i++) {
    onewire_write_bit(b & 0x01);
  }
}

```

```

    b >>= 1;
  }
}
unsigned char onewire_read_byte() {
  unsigned char res = 0;
  for (unsigned char i=0;i<8;i++) {
    if (onewire_read_bit()) res |= (1 << i);
  }
  return res;
}
// Read DS18B20 temperature (integer °C, rounded). Returns 0x8000 on error.
int ds18b20_get_temp_c() {
  unsigned char low, high;
  int temp;
  if (!onewire_reset()) return 0x8000; // no device
  onewire_write_byte(0xCC); // SKIP ROM
  onewire_write_byte(0x44); // CONVERT T
  // wait for conversion ~ up to 750ms for 12-bit resolution
  Delay_ms(750);
  if (!onewire_reset()) return 0x8000;
  onewire_write_byte(0xCC); // SKIP ROM
  onewire_write_byte(0xBE); // READ SCRATCHPAD
  low = onewire_read_byte();
  high = onewire_read_byte();
  temp = (high << 8) | low; // signed 16-bit
  // DS18B20 gives temp * 16 for 12-bit (LSB = 0.0625)
  // Convert to °C (rounded)
  int tempC = temp >> 4;
  // handle negative and fraction? For simplicity use integer rounding
  return tempC;
}
// Update LCD with readings
void update_lcd(float va, float vb, float vc, int tempC, bit motor_on) {
  char buf[16];
  Lcd_Cmd(_LCD_CLEAR);
  // line 1: Phase voltages (short)
  // format "A:230 B:229" trimmed to fit 16 chars
  sprintf(buf, "A:%3.0f B:%3.0f", va, vb);
  Lcd_Out(1,1,buf);
  sprintf(buf,"C:%3.0f T:%2d", vc, tempC);
  Lcd_Out(2,1,buf);
  // show Motor state briefly on top-right (blink style)
  Lcd_Out(1,13, motor_on ? "ON " : "OFF");
  // optionally more detailed messages could be toggled with buttons
}

```

3.12 FLOWCHART

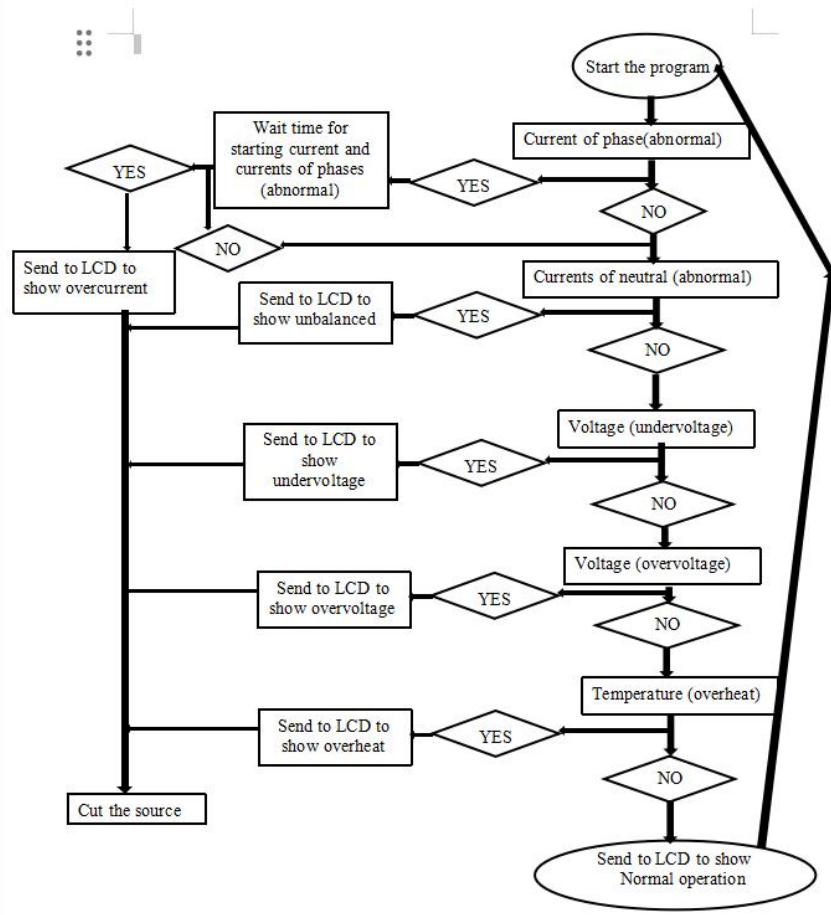


Figure 3.12 Flowchat

Figure 3.12 is the flow chat of the system.

The project operation, as governed by the flowchart, can be explained through these three primary stages:

1. Initialization and Data Acquisition: The system begins by initializing the 16x2 LCD. Once active, the micro-controller enters a continuous sensing loop. It acquires analog signals from the ZMPT101B voltage sensors to monitor the three phases and the DS18B20 digital sensor to measure the motor's temperature. These raw signals are converted into digital values (ADC scaling) so the micro-controller can understand the real-time status of the motor.

2. Fault Detection and Logic Comparison: The core of the flowchart involves comparing the live data against predefined safety thresholds. The system is programmed with specific logic to identify two critical conditions:

Overheating: The micro-controller checks if the temperature has exceeded 60°C.

Phase Failure: It verifies if any of the three phase voltages are absent or significantly irregular.

3. Action and Protection Response

If the data remains within safe limits, the motor continues to run, and the LCD provides real-time updates of current, voltage, and temperature. However, if a fault is confirmed, the flowchart dictates two immediate actions:

Isolation: The micro-controller sends a signal through the ULN2003 driver to the relay, which instantly disconnects the motor from the power supply to prevent winding burnout

Notification: The system triggers a piezoelectric buzzer for an audible alarm and displays the specific fault type (e.g., "OVER TEMP OFF" or "PHASE FAILURE") on the LCD

The system typically remains in this protective state until the fault is cleared and the system is manually reset

3.13 BLOCK DIAGRAM

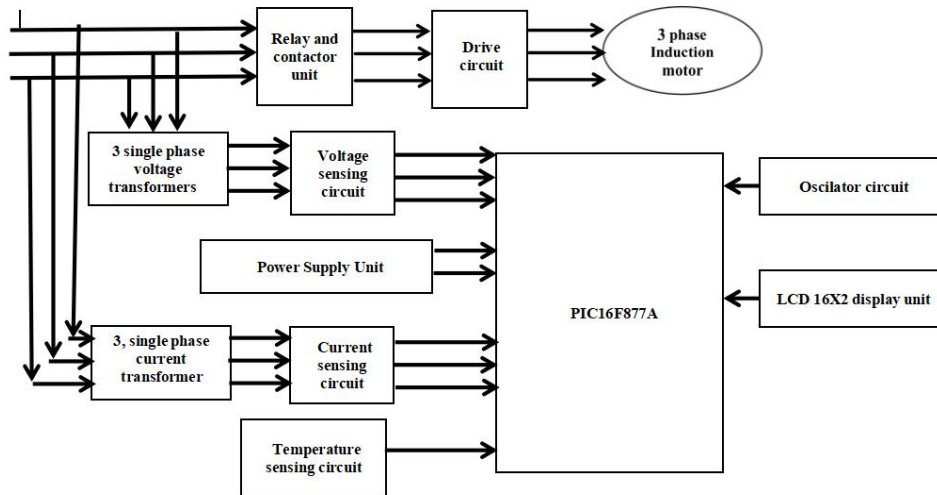


Figure 3.13 Block Diagram

Figure 3.13 above shows the block diagram of the three phase induction motor protection system against phase failure and temperature overheating

3.14 SIMULATION

The Figure 3.14 below shows the Proteus simulation of the three phase induction motor protection system against phase failure and temperature overheating.

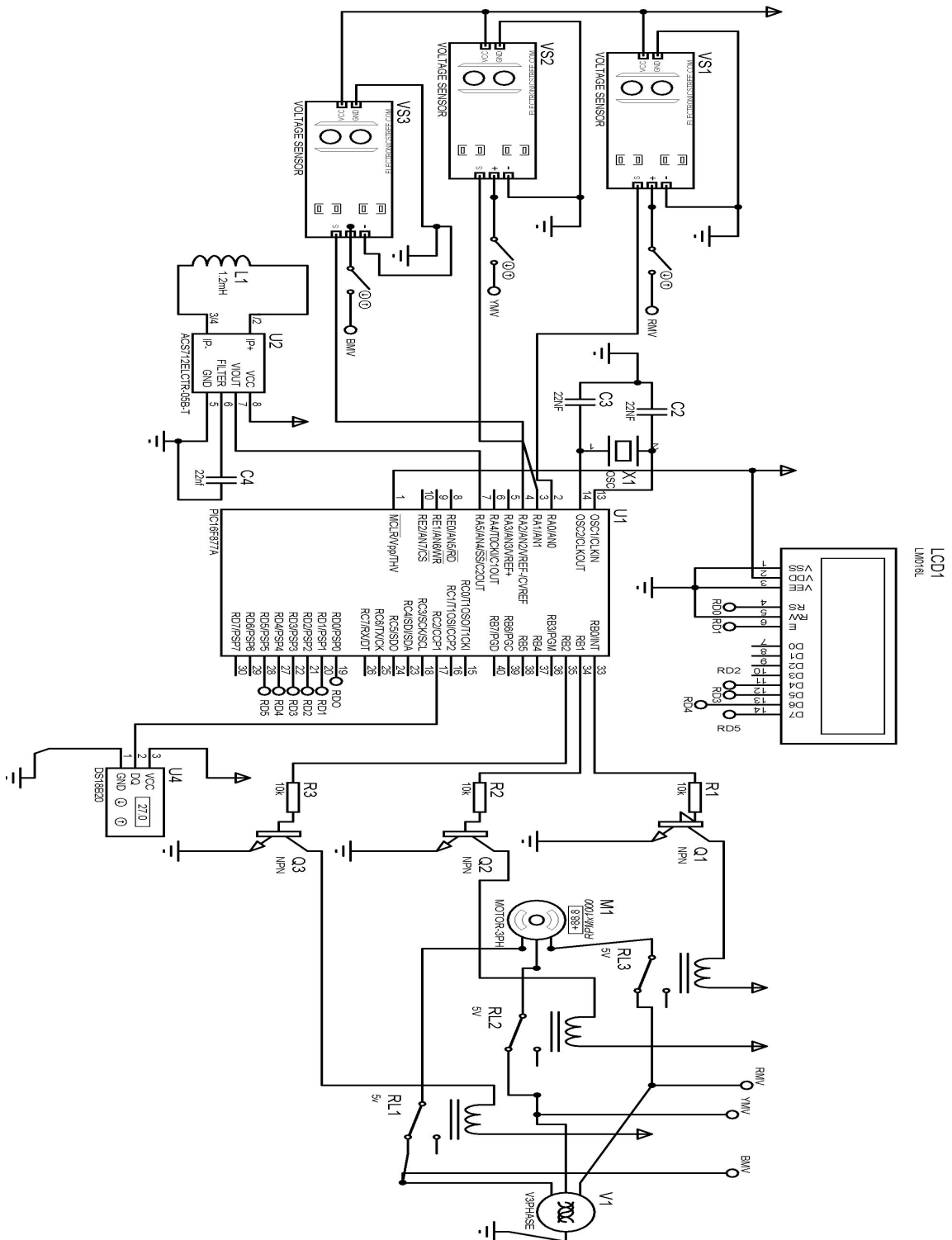


Figure 3.14 Proteus Simulation

3.15 WORKING PRINCIPLE

The conversion from 220V AC to 5V DC begins with a step-down transformer, which utilizes electromagnetic induction to reduce the high-voltage mains electricity to a safer 12V AC level while providing essential electrical isolation for the control

circuitry. This reduced AC voltage is then fed into a full-wave bridge rectifier consisting of four 1N4007 diodes. The rectifier's role is to redirect the alternating current so that both halves of the AC cycle flow in the same direction, resulting in a pulsating DC output. To stabilize this signal, a high-capacity electrolytic filter capacitor acts as a reservoir, charging during the voltage peaks and discharging during the troughs to smooth out the ripples and create a steadier DC voltage. Finally, this filtered DC enters an LM7805 voltage regulator, which maintains a precise and constant 5V output, ensuring the sensitive electronic components are protected from fluctuations in the power grid.

With a stable 5V supply established, the various sections of the protection system function as an integrated unit to safeguard the induction motor. The sensing layer—comprising ZMPT101B voltage sensors and a DS18B20 temperature sensor—continuously monitors the physical state of the motor. Under normal operating conditions, the system reads approximately 220V for each of the R, Y, and B phases, keeps the current within a standard range, and confirms the temperature remains below 60°C. These values are processed by the PIC16F877A micro-controller and displayed on a 16x2 LCD. However, if the system detects an abnormality, it immediately initiates protective measures. If a voltage drop or loss occurs in any phase, the LCD displays "Phase Failure" followed by the specific faulty voltage readings. Similarly, if the motor heat rises, the display shows "Over Temp" for any temperature above 60°C, followed by the exact real-time temperature measurement. In either fault scenario, the micro-controller triggers a relay via the ULN2003 driver to disconnect the motor while an audible buzzer alerts the operator to the specific nature of the failure.

CHAPTER 4 : CONSTRUCTION TESTING AND RESULT

4.1 INTRODUCTION

This chapter presents the construction and testing of the micro-controller-based three-phase induction motor protection system.

It begins with hardware and software outcomes, followed by experimental measurements under normal operating and fault conditions.

The results are analyzed against the project objectives and design thresholds to evaluate accuracy, response time, and reliability.

4.2 HARDWARE ASSEMBLY AND INTEGRATION



Figure 4.1 Bulbs Representing The Three-Phase Induction Motor

Figure 4.1 shows the Three-phase induction motor protection system against phase failure temperature overheating. The bulbs in this case is used to represent each phase of the three-phase induction motor.



Figure 4.2 Internal Layout/Chassis Layout



Figure 4.3 Three-Phase Induction Motor Protection System Prototype

Figure 4.2 and 4.3 shows a closer view into the internal/chassis layout of the protection system. The various components such as the vero board, wires, transformer, PIC16F877A, ZMPT101B voltage sensor, ACS712 current sensor, DS18B20 temperature sensor and the white casing.



Figure 4.4 Three-Phase Induction Motor Protection System in Normal Operating Condition (Complete System)



Figure 4.5 Three-Phase Induction Motor Protection System in Normal Operating Condition Closer View (Complete System)

Figure 4.4 and 4.5 shows the complete three phase induction motor protection system against phase failure and temperature overheating in normal operating condition. The three bulbs representing the three phases each of a three phase induction motor, so the three bulbs lighting up represents the three phase induction motor working. The three switches i.e the red, black and green representing each phase supply voltage and they are used to represent phase failure for each phase when any of them is switched off. The LCD readings are “R:220 Y:220 B:220, T:29.6C, I:0.06A”. The R represents the red phase, the Y represents the yellow phase, the B represents the blue phase and the values in fronts of each represents their respective voltages. The T represents the temperature, and the value in front represents the temperature in degree Celsius, and I represents the current in Amperes.

So the picture reads
 Red phase – 220V
 Yellow phase – 220V
 Blue phase – 220V
 Temperature -29.6 C
 Current – 0.06A

4.2 STEPS IN TESTING THE PROJECT

4.2.1 POWER SUPPLY CHECK

Step: Connect transformer, rectifier, capacitor, regulator; measure output.
 Outcome: Stable 5 V DC confirmed.

4.2.2 MICROCONTROLLER STARTUP

Step: Power PIC16F877A, observe LCD and oscillator.
 Outcome: LCD shows initialization, clock runs correctly.

4.2.3 SENSOR CALIBRATION

Step: Apply known voltage, current, and heat to sensors.
 Outcome: LCD displays accurate RMS voltage, current, and temperature.



Figure 4.6 Voltages Applied To Each Phase Being Read

In fig 4.6 the LCD reads “ R:0 Y:0 B: 220 T:29.6C I:0.02A” Red phase is 0V, Yellow phase reads 0V, Blue phase reads 220V, Temperature is 29.6C, and current is 0.02A. So the micro controller is able to read the voltages of each phase, the temperature and also the current.

4.2.4 NORMAL OPERATING CONDITION

Step: Run motor on three-phase supply.

Outcome: Motor runs smoothly, LCD shows correct values.



Figure 4.7 Normal operating condition

Fig 4.7 shows the normal operating condition of the three phase induction motor protection system. The LCD reads

Red phase 221V

Yellow phase 221V

Blue phase 221V

Temperature 29.6C

Current 0.13A

The voltages are within 207-253V the nominal voltage for safe motor running. The temperature is 29.6C and its below 60C that is safe for motor running.

4.2.5 PHASE FAILURE/UNDERVOLTAGE

Step: Disconnect or lower one phase.

Outcome: Fault detected, relay trips, motor disconnects; restarts only when stable.



Figure 4.8 Faulty Operating Condition



Figure 4.9 Faulty Operating Condition Due To Under Voltage Of Three Phases



Figure 4.10 Faulty Operating Condition Due To Under-Voltage Of Two Phases



Figure 4.11 Faulty Operating Condition Due To Under-Voltage Of One Phase

Figures 4.8,4.9, 4.10 and 4.11 show different fault conditions, the causes and how it displays on the screen. As seen in figure 4.8 when there's fault in any of the phase it indicates "phase failure" indicating that there is a fault, so the relay trips off. Figure 4.9 shows a three phases having no voltage, Figure 4.10 shows two phases with no voltages and Figure 4.11 shows one phase with no voltage. So the relay kept the circuit open.

4.2.6 OVERHEATING

Step: Raise DS18B20 temperature above threshold.

Outcome: Motor disconnects; reconnects after cooling.



Figure 4.12 Three Phase Induction Motor Protection System At Overheating Condition

Figure 4.12 show the response of the system to overheating i.e. temperature above 60 degrees the relay trips off the system and indicates "over temp – off". So the relay waits till the temperature is restored to normal condition before the circuit is closed again

4.2.7 System Recovery

Step: Restore safe conditions after each fault.

Outcome: Motor operation resumes automatically.



Figure 4.13 Three Phase Induction Motor Protection System Restored To Normal Operating Condition



Figure 4.14 Three Phase Induction Motor Protection System Restored To Normal Operating Condition(Closer View)

Figures 4.13 and 4.14 shows when the system is restored back to normal condition so the relay closes the circuit so the LCD indicates “relay on”.

TABLE 4.1: BILL OF ENGINEERING MEASUREMENTS AND EVALUATION

Table 4.1 shows the bill of engineering measurements and evaluation.

S/N	Description of item	Quantity	Unit of measurement	Rate in naira	Amount
1	Current Sensor module	3	pieces	14,000	42,000
2	4 channel 5V active relay	1	pieces	5,000	5,000
3	20x4 LCD	1	pieces	6,500	6,500
4	Temperature Sensor	1	pieces	1,000	1,000
5	Bulb	1	pieces	1,000	1,000
6	PIC16	1	pieces	4,000	4,000
7	Switches	4	pieces	500	2,000
8	Cables, wires & jumpers	1	2 rolls, yards, pieces	3,000	3,000
9	connectors	5	pieces	500	2,500
10	Terminal block	5	pieces	500	2,500
11	Glue	1	pieces	1,000	1,000
12	Project box	1	pieces	4,000	4,000
13	5V AC to DC converter	1	pieces	3,000	3,000
14	Vero Board	1	pieces	2,000	2,000
15	Resistors	20	pieces	100	2,000
16	Capacitor	15	pieces	100	1,500
17	LEDs and Diodes	10	pieces	50	150
18	Transistor	10	pieces	500	1,000
19	Electric tape	1	pieces	500	500
20	Waybill	1	No	15,000	15,000
21	Component cost	-	-	99,650	96,650
22	Shipping fee and logistics charge for materials				20,000
23	Total Cost				119,650

CHAPTER 5 : CONCLUSION

5.1 CONCLUSION

This project successfully designed and implemented a micro-controller-based protection system for three-phase induction motors using the PIC16F877A micro-controller, ACS712 current sensor, ZMPT101B voltage sensors, DS18B20 temperature sensor, ULN2003 driver, relay/contractor, LM7805 regulator, and a 16×2 LCD. The system reliably detected faults such as phase loss, under-voltage, and overheating, and isolated the motor to prevent damage while providing clear feedback to the user. With features like startup delay, persistence timing, and real-time monitoring, the design proved to be low-cost, adaptable, and effective. Overall, it demonstrates a practical solution for improving motor safety, reducing downtime, and laying a foundation for future enhancements such as remote monitoring and predictive maintenance.

5.2 FINAL THOUGHTS

This project has demonstrated that a simple, low-cost micro-controller-based system can effectively protect three-phase induction motors from common electrical and thermal faults. By integrating key components such as the PIC16F877A, ACS712, ZMPT101B, DS18B20, ULN2003 driver, relay/contractor, and LCD display, the design achieved reliable monitoring, timely fault detection, and automatic motor isolation. While the prototype was developed on a small scale, it provides a strong foundation for future improvements like over-current protection, remote monitoring, and predictive maintenance. Ultimately, the work highlights the importance of combining affordability, adaptability, and safety in industrial motor protection systems.

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