Faculty of Electrical Technology and Engineering

DEVELOPMENT OF HEAT MONITORING AND PROTECTION SYSTEM ON SINGLE-PHASE AC INDUCTION MOTOR

IZZATUR RAHMAN BIN RAMLI

Bachelor of Electrical Engineering Technology (Industrial Power) with Honours

2023

DEVELOPMENT OF HEAT MONITORING AND PROTECTION SYSTEM ON SINGLE-PHASE AC INDUCTION MOTOR

IZZATUR RAHMAN BIN RAMLI

A project report submitted
in partial fulfillment of the requirements for the degree of
Bachelor of Electrical Engineering Technology (Industrial Power) with Honours

Faculty of Electrical Technology and Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2023

UNIVERSITI TEKNIKAL MALAYSIA MELAKA
FAKULTI TEKNOLOGI DAN KEJUTERAAN ELEKTRIK

BORANG PENGESAHAN STATUS LAPORAN
PROJEK SARJANA MUDA II

Tajuk Projek : Development of Heat Monitoring and Protection System On Single-Phase Ac Induction Motor

Sesi Pengajian : 2023/2024

Saya Izzatur Rahman Bin Ramli mengaku membenarkan laporan Projek Sarjana Muda ini disimpan di Perpustakaan dengan syarat-syarat kegunaan seperti berikut:

1. Laporan adalah hakmilik Universiti Teknikal Malaysia Melaka.
2. Perpustakaan dibenarkan membuat salinan untuk tujuan pengajian sahaja.
3. Perpustakaan dibenarkan membuat salinan laporan ini sebagai bahan pertukaran antara institusi pengajian tinggi.
4. Sila tandakan (✓):

☐	**SULIT***	(Mengandungi maklumat yang berdarjah keselamatan atau kepentingan Malaysia seperti yang termaktub di dalam AKTA RAHSIA RASMI 1972)
☐	**TERHAD***	(Mengandungi maklumat terhad yang telah ditentukan oleh organisasi/badan di mana penyelidikan dijalankan)
✓	**TIDAK TERHAD**	

Disahkan oleh:

(TANDATANGAN PENULIS)

(COP DAN TANDATANGAN PENYELIA)

Alamat Tetap:
N0. 6132, Jalan Bunga Raja, Gita Jaya, 93050 Kuching, Sarawak.

CHE WAN MOHD FAIZAL BIN CHE WAN MOHD ZALANI
Jurutera Pengajar
Jabatan Teknologi Kejuruteraan
Fakulti Teknologi dan Kejuruteraan Elektrik
Universiti Teknikal Malaysia Melaka

Tarikh: 14/01/2024

Tarikh: 1/2/2024

*CATATAN: Jika laporan ini SULIT atau TERHAD, sila lampirkan surat daripada pihak berkuasa/organisasi berkenaan dengan menyatakan sekali tempoh laporan ini perlu dikelaskan sebagai SULIT atau TERHAD.

DECLARATION

I declare that this project report entitled “DEVELOPMENT OF HEAT MONITORING AND PROTECTION SYSTEM ON SINGLE-PHASE AC INDUCTION MOTOR” is the result of my own research except as cited in the references. The project report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature :

Student Name : IZZATUR RAHMAN BIN RAMLI

Date : 14/01/2024

APPROVAL

I hereby declare that I have checked this project report and in my opinion, this project report is adequate in terms of scope and quality for the award of the degree of Bachelor of Electrical Engineering Technology with Honours.

Signature	:	
Supervisor Name	:	CHE WAN MOHD FAIZAL BIN CHE WAN MOHD ZALANI
Date	:	1/2/2024
Signature	:	
Co-Supervisor Name	:	TS. RAMLAN BIN LATIP
Date	:	1/2/2024

DEDICATION

To my cherished parents, your unwavering support, both emotionally and financially, has been the cornerstone of my journey throughout this project. Your encouragement and belief in my abilities have been instrumental in guiding me from the beginning of my academic endeavors to the successful completion of this research. I am profoundly grateful for your sacrifices, motivation, and relentless faith in my aspirations. This accomplishment stands as a testament to the love, dedication, and values you have instilled in me, propelling me forward with unwavering determination. With heartfelt appreciation, I dedicate this work to both of you, as a token of my deepest gratitude and love.

ABSTRACT

This research focuses on the development of a heat monitoring and protection system for single-phase AC induction motors. The objectives include investigating the system's reliability, efficiency, and safety, developing an accurate heat monitoring system, and evaluating a protection system that prevents motor overheating. The approach involves strategically placing temperature sensors on the motor to detect temperature levels. A control circuit continuously checks the measurements, and if the temperature exceeds a certain threshold, safety measures like warnings or motor shutdown are activated. Extensive testing ensures the system's accuracy and reliability. Optimization is performed by fine-tuning temperature thresholds and adjusting protective measures as needed. The developed system enhances motor performance and safety by preventing overheating and potential damage. It provides real-time monitoring and takes proactive measures to avoid hazards. The research contributes to the efficient management and prolonged lifespan of single-phase AC induction motors in various industrial applications. The expected result is when the temperature exceeds a certain threshold, the relay will shut down the AC motor. Additionally, an indicator will turn on to indicate that the motor has stopped. The LCD continuously shows the temperature, and the microprocessor controls the relay accordingly. Finally, The development of a heat monitoring and protection system for single-phase AC induction motors is very important. Through the system and safe measurement, it will effectively prevent motor overheating and potential damage. Extensive testing and optimization ensure the system's accuracy and reliability. This research provides a valuable tool for industrial applications, enhancing motor performance and prolonging their lifespan.

ABSTRAK

Kajian ini memberi tumpuan kepada pembuatan sistem pemantauan dan perlindungan haba untuk AC motor induksi satu fasa. Objektifnya termasuk menyiasat kemampuan, kecekapan, dan keselamatan sistem, mencipta sistem pemantauan haba yang tepat serta menilai sistem perlindungan yang mengelakkan pemanasan berlebihan pada motor. Pendekatan ini melibatkan penempatan strategik sensor suhu pada motor untuk mengesan tahap suhu. Litar kawalan sentiasa memeriksa pengukuran tersebut, dan jika suhu melebihi ketetapan tertentu, langkah-langkah keselamatan seperti amaran atau motor akan dimatikan. Penambahbaikan dilakukan melalui permerhatian tahap suhu dan penyesuaian langkah perlindungan mengikut keperluan. Sistem yang dibangunkan meningkatkan prestasi dan keselamatan motor dengan mengelakkan pemanasan berlebihan dan kerosakan yang berpotensi. Ia menyediakan pemantauan masa nyata dan mengambil langkah proaktif untuk mengelakkan bahaya. Kajian ini menyumbang kepada pengurusan yang cekap bagi AC motor induksi satu fasa dalam pelbagai aplikasi industri. Keputusan awal adalah apabila suhu melebihi had tertentu, geganti akan mematikan AC motor. Selain itu, indikator akan menyala untuk menunjukkan bahawa motor telah berhenti. LCD secara berterusan menunjukkan suhu, dan pemproses mikro mengawal geganti mengikut keadaan Akhirnya, penciptaan sistem pemantauan dan perlindungan haba untuk AC motor induksi satu fasa adalah penting bagi memastikan kemampuan, kecekapan, dan keselamatan motor tersebut. Melalui sistem tersebut, ia berjaya mengelakkan pemanasan berlebihan dan kerosakan potensi pada motor. Ujian yang meluas dan penambahbaikan memastikan ketepatan dan kebolehpercayaan sistem ini. Kajian ini menyediakan alat yang berharga dalam aplikasi industri, meningkatkan prestasi motor dan memanjangkan jangka hayatnya.

ACKNOWLEDGEMENTS

First and foremost, I extend my sincere gratitude to my supervisor, Mr. Che Wan Mohd Faizal Bin Che Wan Mohd Zalani, and co-supervisor, Ts. Ramlan Bin Latip, for their invaluable guidance and patience throughout this project. Their expertise has been pivotal in shaping the research's direction and fostering a conducive learning environment.

I am appreciative of Universiti Teknikal Malaysia Melaka (UTeM) for providing financial support, enabling the realization of this project. The institution's commitment to academic excellence has been instrumental in achieving the desired outcomes.

Special thanks to my colleagues for their collaborative efforts and insights, enriching the project's scope and depth. Their contributions have facilitated a dynamic exchange of knowledge and innovative ideas.

My heartfelt appreciation goes to my family, especially my parents, for their unwavering support, encouragement, and prayers. Their belief in my capabilities has been a constant source of motivation and strength throughout this academic journey.

I acknowledge my mother's significant influence, her motivation, understanding, and wisdom have been instrumental in navigating challenges and fostering resilience.

Additionally, I thank the staff at UTeM, fellow students, and faculty members for their co-operation and support. Their collective efforts have contributed to a nurturing academic environment conducive to growth and innovation.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Background

Motors were commonly used for industrial purposes nowadays. In the modern environment, a lot of motors are being used for various things, from domestic appliances to industrial facilities' machine tools. In many sectors today, the electric motor is a crucial and essential source of power. This motor must perform a variety of tasks. Industrial automation has greatly advanced thanks to the development of AC induction motors, which have better overall performance characteristics than DC motors. An electric motor that uses electromagnetic induction to derive the electric current needed to generate torque inside the rotor from the magnetic field of the stator winding is known as an induction motor [1].

An electric motor that uses AC power is known as an AC (alternating current) motor. One of the most popular types of motors, it can be used in a variety of settings, including home appliances and industrial equipment. Due to their durability, stability, and minimal maintenance needs, AC motors are widely used [1]. The basic principle of operation of an AC motor is electromagnetic induction. A rotating magnetic field is produced when an AC passes through a wire wound around a magnetic core. A rotor then rotates as a result of this magnetic field's interaction with the rotor's magnetic field. Typically, the rotor is made up of several conducting bars that are short-circuited by metal rings at both ends. Currents are induced in the bars as the spinning magnetic field passes over the rotor, which produces a torque that makes the rotor spin [3].

There are two main types of AC motors which are synchronous and induction. Synchronous motors have a fixed speed and need an external power source to generate the rotating magnetic field. On the other hand, induction motors have a variable speed and rely on an AC power source to generate a spinning magnetic field. Because they are easier to use and less expensive, induction motors are more commonly used [4].

Induction motors can be further divided into single-phase and three-phase categories. Smaller applications, such as home appliances and other tiny machines, frequently use single-phase induction motors. They are suitable for low-power applications and have a simpler design at lower costs. Larger applications, such as those involving heavy machinery, need the application of three-phase induction motors. They are suitable for high-power applications but have a more complicated design and higher price [4].

Further, induction motors have a stator, which consists of a series of wire coils wound around a laminated iron core, and a rotor, which is either wound with conductive bars or consists of a squirrel-cage rotor made of conductive bars connected by short-circuiting rings. When an AC flows through the coils of the stator, the rotating magnetic field it creates induces currents in the rotor. The rotor rotates as a result of an interaction between these currents and the stator's magnetic field. Induction motors are advantageous to other types of motors in several ways. It is very easy to use, dependable, and low maintenance. They have a long operational life and no brushes or commutators, which lowers stress and pressure. Depending on the type and size of the motor, they are also quite efficient, with levels ranging from 70% to 95% [3].

However, induction motors have some restrictions. It normally run at a fixed speed determined by the frequency of the power source and have limited speed control capabilities. Induction motor speeds can be adjusted using variable frequency drives (VFDs), although the system may become more complex and expensive as a result. They are physically larger for the same power output because they have a smaller volume of power compared to other types of motors [3].

Induction motors offer several advantages over other types of electric motors, making them a popular choice in a wide range of applications. Here are some of the main advantages of induction motors which have a simple design. Induction motors require minimal maintenance and have a long operating life, making them cost-effective over their lifetime. Also, induction motors have high efficiency, very reliable due to their simple design and lack of moving parts [1].

Low cost is the best part of it they are typically less expensive than other types of electric motors, making them a cost-effective choice for many applications. Additionally, it is also robust, for example, induction motors can handle high starting torque, making them suitable for a wide range of industrial applications.

To sum up, the fundamental AC motor works based on electromagnetic induction, where a rotating magnetic field induces currents in a rotor to produce motion. Induction motors, which are simpler and less expensive than synchronous motors, are the most widely used form of AC motor. Depending on the application and power requirements, induction motors can be further classified as single-phase and three-phase.

For single-phase AC induction motors, the development of a heat monitoring and protection system is a significant effort. Domestic appliances and industrial machines both regularly use AC induction motors for a variety of purposes. The continuous operation of these motors can result in heat production that could harm the motor and its surroundings.

The primary focus of this project is to develop and put into use a system that can track the motor's temperature and prevent overheating. The system will be built to use sensors to measure the motor's temperature and take the necessary precautions to avoid damage. These actions might involve turning off the engine or sounding an alarm to warn the user.

For single-phase AC induction motors to operate safely and effectively, this system must be developed. It can lengthen the total lifespan of the motor and lessen the need for expensive maintenance and downtime. By avoiding any potential fire threats, it can also improve the security of the system and the user.

The project's significance lies in its potential to improve the reliability, safety, and efficiency of electrical systems that rely on AC induction motors. It can have a positive impact on a broad range of industries and applications where these motors are widely used. The project's success can lead to the development of more advanced protection systems that can prevent other motor failures and provide better protection against electrical hazards. Overall, the development of a heat monitoring and protection system for single-phase AC induction motors is a significant project that addresses an important problem in the field of industries [3].

1.2 Problem Statement

The possible damage and safety risks brought on by single-phase AC induction motor overheating are the issue that the project "Development of heat monitoring and protection system on single phase AC induction motor" attempts to solve. Single-phase AC induction motors have the disadvantage of being capable of overheating, which can result in damage or motor failure. These motors are frequently employed in a variety of applications, and their constant use can result in a large amount of heat that could harm both the motor and its surroundings. Additionally, overheating might present safety problems like fire threats, which could be harmful to users and the environment. The minimal protection devices now set up for these motors may occasionally fail to identify overheating in time to spare damage or safety risks. This may lead to expensive equipment repairs or replacements, as well as significant safety risks in industries. Furthermore, single phasing lowers the motor's speed, causing its rpm variation. The motor will vibrate and make unusual noises. This is the outcome of the remaining two phases' uneven torque [4]. The majority of the ship's motor systems use a standby setup. If the motor is set on standby, there is a single phasing issue [5]. It won't start, which will result in the connected system failing. If the issue is not fixed and the motor is operated as usual, the windings will melt from overheating, which may result in short-circuiting or earthing [4]. When this occurs, an electrical shock that may potentially be fatal will be received by any person who comes into contact with the motor. A negative sequence current is what causes winding overheating most of the time. It may result in overloading of the auxiliary engine's alternator and power-producing equipment. Therefore, there is a need for a more advanced system that can accurately monitor the motor's temperature and take appropriate measures to prevent overheating and associated hazards. The development of a heat monitoring and protection system for single-phase AC induction motors aims to address this problem and provide an effective solution to ensure the safe and efficient operation of these motors. This development is necessary and very important to prevent damage and ensure safe operation. The system must be affordable, reliable, and easy to install to be feasible for widespread adoption in various industries [5].

1.3 Project Objective

a) To investigate the reliability, efficiency, and safety of the designed heat monitoring and protection system on a single-phase AC induction motor,

b) To develop a heat monitoring system that accurately detects the temperature of the single-phase AC induction motor and provides real-time monitoring to prevent overheating.

c) To evaluate and test a protection system that takes appropriate safety measures to avoid the motor overheating, such as turning the motor off or triggering an alarm to alert the user.

1.4 Scope of Project

The scope of the "Development of heat monitoring and protection system on single phase AC induction motor" project can include the following:

a) Designing a user-friendly bay or interface for the system, including visual indicators and alerts, to enable operators to monitor and manage the motor's temperature.

b) Developing a customized heat monitoring and protection system that integrates temperature sensors, control circuitry, and alarms to detect and prevent overheating of the motor.

c) Identifying the key components and parameters that affect the temperature of the motor, such as the operating environment and load.

d) Verifying its ability to prevent motor damage and the hazards that go into it.

e) Providing technical support and assistance to users to ensure proper implementation and utilization of the heat monitoring and protection system.

f) Conducting a thorough analysis of the existing heat monitoring and protection systems used for single-phase AC induction motors.

g) Testing and validating the performance of the developed system using simulation models and experimental data.

h) Developing documentation and materials for the installation, operation, and maintenance of the system.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In this modern age, motors are very important equipment that is used in industrial or home appliances. To prevent the motors from breaking or burning out, a variety of procedures can be used. The development of heat monitoring and protection systems for these motors has attracted a lot of attention in recent years. Household appliances, power tools, and small-scale manufacturing all frequently use AC induction motors. However, the high heat generation that results in motor failure, shortened lifespan, and other safety risks can have a significant impact on their effectiveness and performance. The development of heat monitoring and protection systems specifically created for single-phase AC induction motors is the main topic of this literature study. The main goal is to evaluate the existing research, pinpoint the difficulties encountered, and investigate the creative alternatives put up to improve motor performance and prevent thermal damage.

2.2 Developing New Thermal Protection Method for AC Electric Motor

In 2021, Igor V. Bichkaren developed a device incorporating the proposed thermal protection technique, accompanied by a detailed structural block diagram. Comprehensive experimental research was carried out using a compact electronic thermometer equipped with an external digital temperature sensor. This sensor was connected to a computer via USB and functioned as the temperature monitoring system for the ongoing experiment.

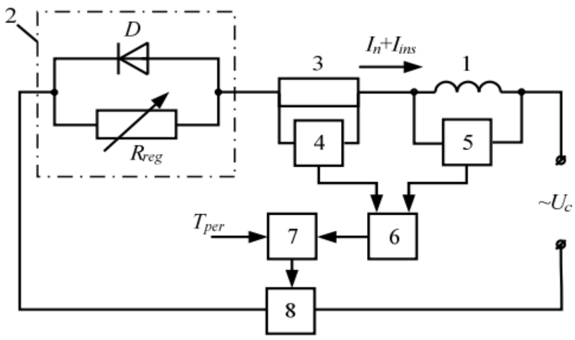


Figure 2.1 Structural block diagram of a thermal protection device [6]

Figure 2.1 depicts a block diagram illustrating a thermal protection device that produces an instrumental current from the AC operation. In this diagram, 1 represents the thermal sensor, 2 signifies the DC input section, 3 is designated for shunt measurement, and 4 is allocated for gauging the instrumental DC value. Additionally, 5 is employed to measure the voltage drop across the temperature sensor induced by the current. The diagram also includes a computing module labeled as 6. Furthermore, it features a threshold switch identified as 7 and an executive component labeled as 8.

The system that is used in this study is by using a thermometer and several electronic parts and the circuit is connected to the computer to get the reading of the heat level. Monitoring the thermal condition of electrical motor windings is necessary for protecting against unacceptably high temperatures. The methods involve regulating the stator winding's active current resistance, which is based only on temperature. The most basic kind of thermal protection relies on temperature sensors that are integrated within the motor's windings to sense the temperature directly. Each of them is typically positioned in the stator winding's extended end coils.

The method is based on the observation that a change in winding impedance due to temperature has the same impact on the angle between the phase voltage and current vectors. Controlling the variation in this angle enables thermal protection [6].

2.2.1 Single-Phase Induction Motor with 4 Windings Design

Through Zuriman Anthony (2023), a review of the literature on single-phase induction motors, two windings are required for the motor to work. It is more complex than the poly-phase induction motor winding design. It is a proven fact that in conditions of variable load, the current density flowing through each motor winding is not the same. It is only required the usage of 4 stator windings and controlled current in an auxiliary winding. The induction motor with capacitor-start capacitor-run was the main emphasis of this design. The design has four windings, the main winding is one and the auxiliary windings are the other three [7].

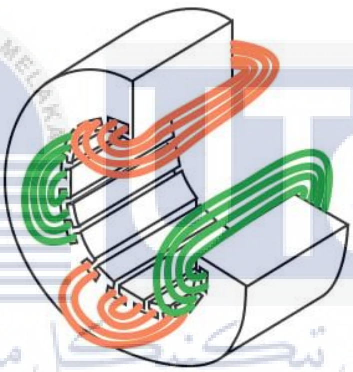


Figure 2.2 Schematic Diagram of 4 winding induction motor [18]

Figure 2.3 Diagram of Single Phase Induction Motor [8]

2.3 Thermal Monitoring of Electric Motors

Oliver Wallscheid (2021) organizes the literature and provides a high-level overview of the three most important estimation classes and one of them is direct methods, which track temperature-sensitive electrical motor parameters by using sensors to monitor the temperature. The method is by placing the sensor inside the motor. For this system, in every motor production, there is a protection system that build-in inside the motor. For the small use of appliances, this technology is very expensive. According to this author, temperature detection in electric motors is crucial for maximizing power and torque potential while ensuring component protection from excessive heat. Essential motor temperatures must be known in real-time to optimize the responsive limits of a motor during continuous operation. Considering temperature measurements have been related to costs and integration efforts, model-based estimating approaches have become increasingly important. Many potential contributions to this issue have been developed in recent years, leading to an extensive collection of literature. [9].

2.3.1 Sensor-Based Temperature Tracking

Temperature sensors are an obvious choice for monitoring the thermal status of a motor. A large range of contact-based, electrical sensors, thermistors or thermocouples, are available as commercial off-the-shelf devices, particularly for sensing stator temperatures (in the winding). In this discussion, it is preferable to avoid sensor-based temperature monitoring in both the stator and the rotor as much as possible. As a result, estimating approaches based on mathematical models have grown in popularity in both business and academics. As previously stated, real-time temperature monitoring is necessary for difficult applications with varying loads and environmental operating conditions.

Otherwise, the motor control unit cannot avoid thermal overload scenarios unless significant safety margins are included in the motor design. As a result, the focus of this work is on computational lightweight model-based monitoring approaches that are appropriate for application on current or prospective (low-cost) embedded control hardware. Standard motor control includes all temperature monitoring approaches based on electrical parameter tracking. It normally run at the same task frequency as the motor control software, which is in the micro- to millisecond range. In this situation, traditional field-oriented techniques or model-predictive control are commonly applied. The field is relatively numerous, and none of the approaches are universally applicable. There is frequently a focus on functioning at either low or fast speeds. Furthermore, the measurement setup and control software integration affect the application benefits and drawbacks of the various methodologies. Because there is no universal solution, responsible engineers should carefully examine if and which approach is best suited for their needs based on the system requirements [9].

2.4 Protection of Single-Phase Motor and Monitoring

In this project, Aditya Narayan Sharma (2018) provides a unique concept of industrial automation and error monitoring. The method is by using the Arduino-Based as a core to process all of the input and output including sensors and monitors. Many industries rely on induction motors. As a result, industrial automation is necessary for precise and accurate functioning. The project Arduino-based parameter monitoring system for induction motor presents an induction motor control and monitoring system based on the Arduino communication protocol for safe and cost-effective data exchange in industrial areas. The induction motor's current, voltage, and temperature are critical factors for its control system. These essential parameters have a direct impact on the performance of an induction motor.

However, controlling the devices during continuous operation is tough. The Arduino system is used to gather and store data as well as to produce control signals that start and stop the induction machine [2].

2.4.1 Automatic Temperature Control System Using Arduino

The temperature is managed through a microcontroller system based on the Arduino Uno. Given its increasing use, the Arduino Uno finds diverse applications across various fields. Utilizing the LM35 temperature sensor alongside the Arduino Uno, the system interfaces with the computer to maintain room temperature. An LCD displays the temperature, facilitated by the A1 hardware pin working in tandem with an analog pin and pulse width modulation (PWM). This innovative temperature regulation system represents a unique approach that has not been previously implemented in this specific manner [10].

The Arduino Uno serves as a microcontroller platform primarily built around the ATmega328P chip. This board features 14 digital I/O pins, with 6 designated for PWM functionality. Additionally, it offers 6 analog input ports, operates at a frequency of sixteen MHz via a quartz crystal, and comes equipped with essential components such as a USB port, a power interface, an ICSP connector, and a reset mechanism. To initiate its operation, one can either connect it to a computer using a USB cable or power it using an AC-to-DC adapter or a suitable battery source [2].

Microcontroller	ATmega328P
Operating Voltage	5V
Input Voltage (recommended)	7-12V
Input Voltage (limit)	6-20V
Digital I/O Pins	14 (of which 6 provide PWM output)
PWM Digital I/O Pins	6
Analog Input Pins	6
DC Current per I/O Pin	20 mA
DC Current for 3.3V Pin	50 mA
Flash Memory	32 kb
SRAM	2KB
EEPROM	1KB
Clock Speed	16 MHz
LED_BUILTIN	13
Length	68.6 mm
Width	53.4 mm
Weight	25 g

Figure 2.4 Technical specification of Arduino [2]

2.5 AC Motor Thermal Protection Using Overload Relay

According to Danielle Collins (2020), the temperature plays a crucial role in determining the performance and longevity of motors. A primary cause of motor overheating is the electric current that courses through its windings. Given that excessive heat can jeopardize a motor's functionality, safeguarding against thermal overload becomes imperative. In their research, an overload relay was employed to prevent an AC motor from reaching temperatures that could lead to its failure. Overheating can be triggered by increased resistance or excessive current flow. Typically, thermal overload relays are integrated into motor starters, encompassing not just the relay but also contact components. Importantly, these relays are designed specifically to shield the motor from overheating; they won't activate in the event of a short circuit.

Therefore, additional protective measures like fuses or circuit breakers are essential for overall circuit protection. These relays are positioned in series with the motor, ensuring that the current destined for the motor also travels through the relay. Once the current exceeds a predetermined threshold for a set duration, the relay activates, causing specific contacts to open and thereby halting the current supply to the motor.

Thermal overload relays come with trip classes that determine the duration an overload can persist before the relay activates or trips. Commonly employed trip classes include intervals of 5, 10, 20, and 30 seconds. For AC induction motors, it's crucial to account for both time and current because these motors can draw significantly more than their rated current, often exceeding 600 percent during startup. If the relay were to trip instantly upon surpassing the overload current, it would hinder the motor's ability to initiate properly [12].

2.5.1 Bimetallic thermal overload relays

Bimetallic thermal relays are constructed from two different metals. Typically, the two metals are nickel and iron or steel, however, other materials can be used depending on the purpose.

Figure 2.5 Bimetallic Thermal Overload Relay [12]

When electricity passes through the relay and subsequently the motor, it warms up a bimetallic strip made of two different metals that expand unequally. This unequal expansion causes the strip to curve toward the metal with the lesser thermal expansion rate. This curving action triggers a normally closed contact, leading it to disconnect and interrupt the current to the motor. After the bimetallic component cools down and the metal strips revert to their initial shape, the system resets automatically, allowing the motor to operate again [12].

2.5.2 Eutectic thermal overload relays

Eutectic thermal overload relays utilize a specific alloy that both melts and solidifies at a predetermined temperature. This alloy is housed within a tube and connected to a heating coil. As the motor's operating current passes through the coil, it heats the alloy. Once this alloy attains a certain temperature threshold, it rapidly transitions into a liquid state [12].

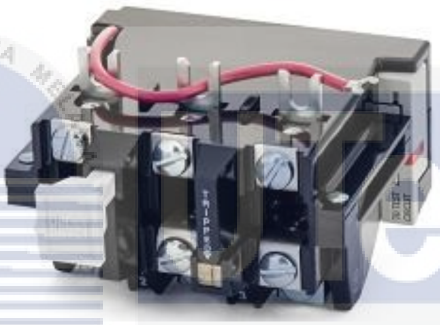


Figure 2.6 Eutectic thermal overload relays [13]

The alloy serves to hold a mechanical component, such as a spring or ratchet, in place when it's in its solid state. Yet, once the alloy reaches its melting point, the mechanical system loosens, enabling the overload contacts to disengage. A thermal overload relay, designed with a eutectic composition similar to bimetallic structures, remains non-resettable until the alloy cools down and returns to its solid form [13].

2.5.3 Electronic thermal overload relays

Electronic thermal overload relays operate without depending on heat to sense current, making them unaffected by changes in surrounding temperatures. Moreover, they have a reduced tendency for unintended or "nuisance" trips. These electronic relays offer valuable data, including metrics like the percentage of thermal capacity used (%TCU), the percentage of full-load current (%FLA), time-to-trip, current RMS, and ground fault current. Such information aids operators in diagnostic tasks and helps anticipate potential relay trips [12].

Figure 2.7 Electronic thermal overload relay [14]

Electrical configurations can also shield motors from phase loss, commonly known as phase failure. This situation arises when one current phase reaches zero amperes, frequently resulting from a short circuit or a blown fuse. Such occurrences compel the motor to consume an overabundance of current across the remaining two phases, resulting in considerable motor overheating [14].

2.6 Heat pipe-based cooling strategy for permanent magnet synchronous motors

In 2020, Yalong Sun said that the current work proposes an innovative heat pipe-based thermal management technique to solve the severe heat dissipation problem of permanent magnet synchronous motors (PMSM). 3-dimensional heat pipes are installed in the space between the winding and the casing, and potting silicon gelatin is used to secure the heat pipes while simultaneously increasing the contact surface.

The winding temperature rise is measured under a variety of cooling and operating settings to assess the cooling effect of this heat pipe-based cooling approach. The tests also include the original motor and the motor solely with heat pipes as a comparison. The results reveal that this unique strategy retains the lowest temperatures with a maximum drop of 22.9 °C compared to the original motor, whilst the motor solely with heat pipes has a 10 °C decrease. Furthermore, the stable running time of the PMSM with this unique cooling technique has improved by roughly 50.6 s under peak-load conditions, whereas the equivalent with simply heat pipes has essentially no improvement.

Furthermore, a numerical model is constructed and has the potential to coincide well with the experimental results, opening the door for the suggested heat pipe-based thermal management method to be enhanced. Air-cooling and liquid cooling are two popular cooling methods nowadays. The convection concept is used in the air-cooling process. The fins on the casing's outside surface can significantly increase convection area and cooling efficiency. The heat pipe, as an efficient phase change heat transfer technology, has ultrahigh thermal conductivity, is lightweight, and cheap cost, which has been widely employed and acquired outstanding cooling benefits in the battery and CPU cooling fields, in contrast to ceramic materials [15].

2.7 Asynchronous motors

In the work by Cavagnino Andrea (2022), the focus revolves around asynchronous or induction motors, which operate based on fundamental principles of electromagnetism. These motors function in accordance with Faraday's law of electromagnetic induction, indicating that a change in magnetic flux induces an electromotive force in a coil. Additionally, Lenz's principle is instrumental, suggesting that any induced current opposes the change causing it. In practical terms, when considering cylindrical electromagnetic setups, if the rotor is short-circuited and the stator produces a rotating magnetic field, it induces currents in the rotor. These induced currents generate a torque that aims to align the rotor with the stator's magnetic field, ensuring stability in the system. Essentially, the rotor acts in tandem with the stator's magnetic field [16].

Importantly, asynchronous motors can produce torque across a range of speeds, excluding a specific speed known as the "synchronous speed." This refers to the speed at which there's perfect alignment between the rotor and the magnetic field in the air gap, resulting in no relative motion or change in magnetic flux. For effective operation in ac electrical machines, it's crucial that both stator and rotor magnetic fields possess an equal number of poles and rotate at consistent speeds relative to the stator's frame of reference [16].

2.8 Thermal Sensor

In this article, Prashant Gupta (2020) said that thermal sensors track temperature changes. Temperature sensors are used in various process sectors to detect gas, liquid, and solid thermal characteristics and are designed for both general and specialized applications. Bimetallic streams, thermocouples, thermometers, and thermistors are among the most common thermal stimulation detection technologies. Low-level heat sources can also be classified using infrared cameras. Temperature sensors may sense or detect any physical change creating analog or numerical output at this temperature and measure heat energy and even coldness released by an item or device. The principal temperature sensors utilized are thermocouples, real-time digital simulators (RTDs), thermistors, and semiconductor integrated currents (ICs). Thermocouples are affordable to test, have a wide temperature range, and are stable. Sensors, detectors, and transducers are electronic equipment that can detect thermal characteristics as well as regulate and display signal input. A temperature sensor generally uses an RTD or thermistor to measure and convert temperature into an output voltage. Maximum and lowest observable temperatures are formed by sensors and detectors, and diameter and length measurements are the main characteristics [17].

2.8.1 Measuring temperature differences and changes

Temperature sensors with great precision are costly, due to the necessary calibration and trimming operations. Furthermore, the accuracy should be tested regularly, and care should be given during application, for example, during thermal cycling or a strong mechanical strain, to ensure that the appropriate precision is maintained. In many industrial applications, stability and excellent resolution over a certain time frame are more significant than standard accuracy [17].

2.8.2 Temperature changes over time

Consider that temperature sensors are employed to track the thermal consequences of living or physical activities, such as characterizing materials or monitoring chemical and physical processes. In such circumstances, the temperature variations over time must be tracked with appropriate resolution across a specific time span. Absolute temperature is less important and is sometimes just monitored to compensate for the impacts of temperature coefficients. As a result, for such applications, the primary criteria for temperature sensors may be resolution and stability, with exact precision being minor [17].

2.8.3 Temperature differences

A thermal sensor may be used to measure the intensity of IR radiation. A heat-absorbing membrane converts radiation into heat in such a sensor. This heat travels into the sensor's bulk through a well-characterized thermal conductor. The temperature differential between the two ends of the thermal conductor represents absorbed heat. Because of a characteristic that allows temperature variations to be sensed offset-free, See-beck sensors are ideal for measuring temperature differences.

The output voltage of these sensors is proportional to the temperature difference between the two junctions, with some variability. In this case, it seems sensible to measure the temperature of one of the junctions, for example, to account for the impacts of temperature dependency on heat conductance and the See-beck coefficient. The precision required for a temperature sensor is often substantially lower than that necessary for a temperature-difference sensor [17].

2.9 Comparison of previous related Heat Monitoring and Protection System

In every field of study or industry, comparing and analyzing comparable works is an essential stage in understanding the development, patterns, and breakthroughs in that specific field. This comparison assists investigators, individuals, and participants in gaining useful insights, identifying gaps, and collect on current information to drive innovation and improve outcomes. Below are table 2.1 shows a comparison of the literature review of the Development of protection and monitoring systems of AC induction motors. The comparison will include the methods used, equipment, and the objectives of the previous researcher.

Table 2.1 Comparison of previous literature

Author	System/Method	Equipment	Objectives	Comment
Igor V.Bichkarev [6]	Using computer software and electronic devices.	a. Thermal sensor b. DC input supply c. Computer d. USB cable e. Electronic Device (measuring device for input voltage)	Monitoring the thermal condition.	Very efficient but too complex.
Oliver Wallscheid [9]	The direct method to measure temperature is by placing the sensor inside the winding motor.	a. A large-scale range of contact-based. b. Electrical sensor c. Thermistors d. Thermocouple	To monitor the temperature inside the winding motor.	Expensive and complex.
Aditya Narayan Sharma [2]	Errors monitoring using Arduino-Based.	a. Arduino Uno b. Sensor LM35 c. LCD d. Power supply adapter (for powering the Arduino)	To detect any errors that can cause high temperatures and monitoring temperature levels.	Simple and cheap.

Danielle Collins [11]	Using overload relays to detect overcurrent and overly resistance.	a. Bimetallic thermal overload relays b. Contactor relay	To protect the motor from overheating.	Simple and cheap but doesn’t have a monitoring system.
Yalong Sun[15]	Heat pipe-based cooling system where the heat is transferred from the machine using a pipe that consists of coolant/water.	a. Ceramic material b. Copper pipe c. Coolant liquid d. Heat Sink	To reduce heat from the motor.	Suitable for industrial use. Car radiator using the same system.
Prashant Gupta [17]	Using a Thermal sensor to track temperature changes.	a. Thermocouples b. Thermistor c. Real-time digital simulators (RDTs) d. Semiconductor integrated current (ICs)	Measuring the temperature changes.	Very expensive equipment to do the heat measurement testing.

2.10 Summary

Finally, the literature study highlights the importance of a heat monitoring and protection system for single-phase AC induction motors. Temperature monitoring and preventative maintenance have helped researchers identify and prevent overheating. Examining a variety of research data reveals that motor overheating is a common cause of motor failures, and handling this issue is important. By implementing advanced temperature monitoring techniques and incorporating protective measures such as thermal sensors, cooling mechanisms, and automatic shutdown systems, researchers have made significant progress in mitigating the risks associated with motor overheating. However, further research is required to improve accuracy and efficiency in this field.

CHAPTER 3

METHODOLOGY

3.1 Introduction

In general, the effectiveness in implementing the Development of a Heat Monitoring and Protection System on Single Phase AC Induction Motor application is very effective. This method successfully monitors and protects the motor from overheating, which is a major problem in single-phase AC induction motors. It minimizes possible damage and improves the motor's lifespan by continually monitoring the temperature of the motor and implementing preventative measures such as automated shutdown. The system's efficiency makes it an invaluable tool for ensuring the reliable operation of single-phase AC induction motors while minimizing the risk of overheating-related failures.

3.2 Methodology

Several processes are included in the "Development of Heat Monitoring and Protection System on Single Phase AC Induction Motor" approach. First, detect temperature levels from the motor using sensors strategically positioned on the motor. Then, a control circuit that constantly checks the temperature measurements. If the temperature rises over a 90°C, the system takes safety steps such as activating a warning (indicator) or shutting down the motor. Extensive testing should be carried out to ensure the accuracy and reliability of the system. Finally, optimize the system's performance by fine-tuning the temperature thresholds and adjusting the protective measures as needed. Figure 3.1, shows the flowchart on how the system works.

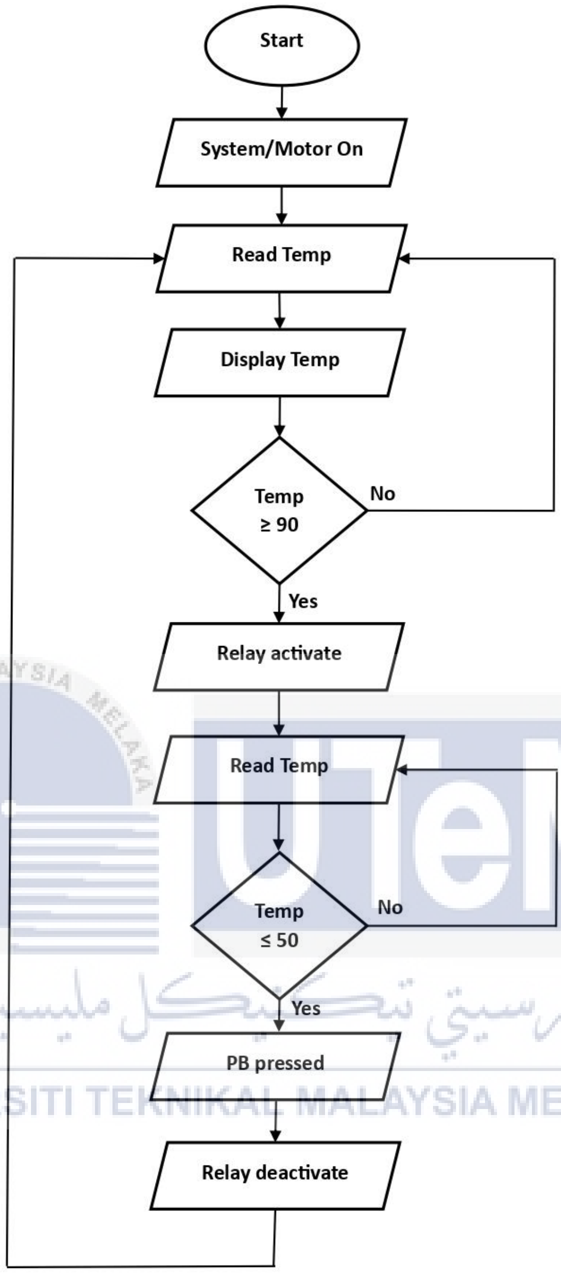


Figure 3.1 Flowchart of process

3.2.1 Experiment setup

The setup consists of a single-phase AC induction motor connected to a power source, a heat sensor for temperature measurement, the Arduino a microcontroller for data processing, and a relay module for motor protection. The heat sensor is attached to the motor's body to monitor its temperature, and the data is fed to the Arduino for real-time analysis. The Arduino is programmed to trigger the relay module when the temperature exceeds a certain threshold, then it will disconnect the motor from the power source and preventing overheating. Figure 3.2 show the constructed circuit of the schematic diagram.

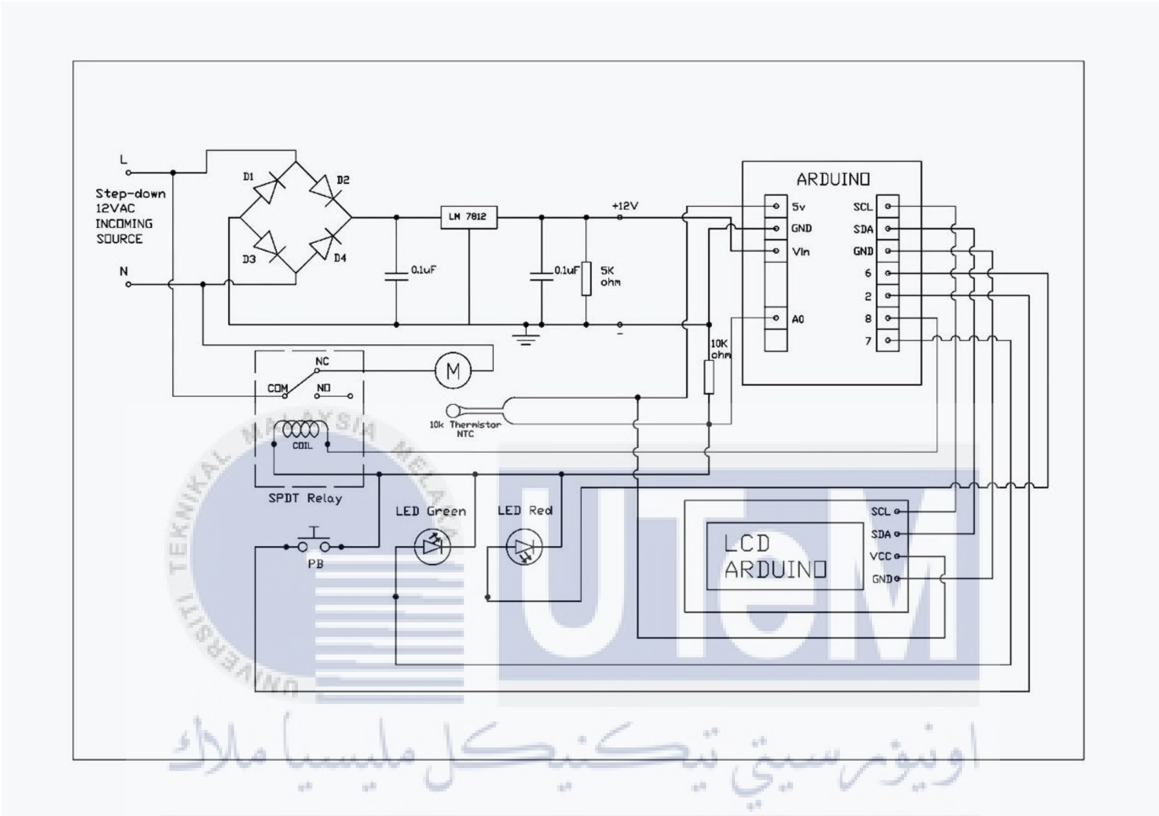


Figure 3.2 Schematic diagram

3.2.2 Parameters

Experimental parameters is a motor load conditions. The experiment will include different load conditions on the single-phase AC induction motor to evaluate the performance of the heat monitoring and protection system. This can involve putting the mechanical load on the motor or using different resistive loads. Next is temperature threshold. A predefined temperature threshold should be set to trigger the relay module and disconnect the motor from the power source. This threshold value can be determined based on the motor's specifications and the desired level of protection.

3.2.3 Equipment

Several components are utilized to ensure that the hardware is capable of carrying out its intended function effectively. Firstly, diodes, capacitors, and voltage regulators are employed to create a circuit that converts AC to DC, providing the necessary power supply to the Arduino microcontroller. Additionally, a heat sensor is utilized to detect the temperature of the motor, enabling efficient monitoring. LCD is to display the temperature of the motor. The Arduino serves as the processor to receive input data from the various sensors. Finally, a Single-Pole Double-Throw (SPDT) relay is incorporated into the system, receiving data from the Arduino and facilitating the disconnection of the motor from the power supply when required.

3.2.3.1 Diode

Figure 3.3 Diode [19]

Figure 3.4 is a diode. An electronic component with two terminals that allows current to flow in one direction while blocking it in the opposite direction. It acts as a one-way valve for electric current. The primary function of a diode in the context of the described setup is to rectify alternating current (AC) to direct current (DC).

3.2.3.2 Capacitor

Figure 3.4 Ceramic capacitor [20]

Figure 3.5 is a ceramic capacitor. It is used for filtering. Ceramic capacitors are often used for filtering noise and stabilizing voltage levels in power supply circuits. They can help remove high-frequency noise and prevent voltage spikes.

3.2.3.3 Voltage regulator

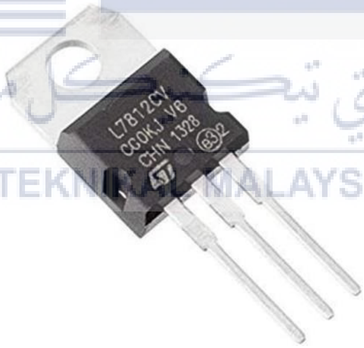


Figure 3.5 Voltage regulator [21]

Figure 3.6 is a voltage regulator. Its main function is to regulate and control the voltage supplied to a specific device or circuitry within a specified range. Voltage regulators are commonly used to protect sensitive components from overvoltage.

3.2.3.4 Relay

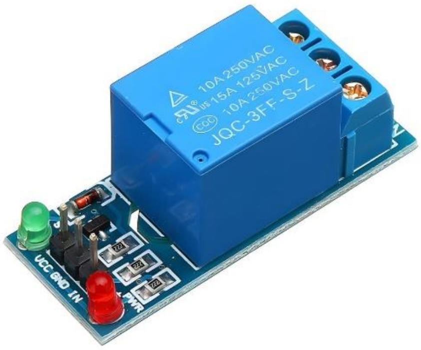


Figure 3.6 SPDT relay [22]

Figure 3.7 is a Single-Pole Double-Throw (SPDT) relay. It’s an electromechanical device commonly used in electrical circuits. It consists of a coil, a movable contact, and two stationary contacts. The primary function of an SPDT relay is to control the switching of a circuit between two different output paths.

3.2.3.5 Heat sensor (Thermistor NTC)

Figure 3.7 Thermistor NTC 10Kohm [23]

Figure 3.8 is an NTC (Negative Temperature Coefficient) thermistor. It’s an electronic component whose electrical resistance decreases as the temperature increases. The term NTC refers to the fact that the resistance decreases with rising temperature.

3.2.3.6 Arduino Uno

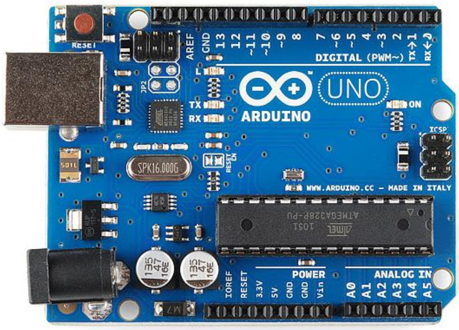


Figure 3.8 Arduino Uno [24]

Figure 3.9 is an Arduino Uno. It serves as the brain of the system, executing program instructions and coordinating the operation of other components. The Arduino Uno features a versatile input/output interface, allowing it to interface with a variety of sensors and actuators. Its programmable nature enables users to write and upload custom code to control and automate processes based on sensor inputs and desired output actions.

3.2.3.7 LCD

Figure 3.9 Liquid-crystal display (LCD) [25]

Figure 3.9 The LCD (Liquid Crystal Display) serves as an output component in the heat monitoring and protection system. It provides visual feedback and information to the user or operator. The LCDs critical data such as motor temperature.

3.2.3.8 Red LED

Figure 3.10 Light emitting diode (Red LED) [26]

Figure 3.10 is a LED. The function is indicated in the motor system, LED will instantaneously recognize when the motor has stopped, enabling it to take necessary actions or address any potential concerns promptly.

3.2.3.9 Green LED

Figure 3.11 Light emitting diode (Green LED) [26]

Figure 3.11 illustrates a Light Emitting Diode (Green LED). When this green LED is illuminated, it serves as an essential indicator signifying that the system is safe for operation. Additionally, the glowing green light signifies that the system is powered on and functioning correctly. This LED plays a crucial role in providing users or operators with a visual cue, ensuring they are aware of the system's status. By emitting a green light, it assures users that all necessary parameters are met, allowing them to proceed with their tasks confidently.

3.3 Limitation of the proposed methodology

The methodology used in the development of the heat monitoring and protection system for single-phase AC induction motors has a few limitations. Firstly, the experiment may not surround all possible load conditions and scenarios that the motor could encounter in real-world applications. This may limit the generalizability of the findings to specific operating conditions. Another factor is the accuracy and precision of the temperature measurements obtained from the heat sensor and the overall reliability of the system could be influenced by factors such as sensor calibration, noise interference, and environmental conditions.

3.4 Preliminary results

The expected result of simulating the monitoring temperature on AC motor using Arduino with a relay to shut down the AC motor and a red LED as an indicator is to effectively monitor the temperature and trigger the relay when it exceeds a certain threshold in this simulation (50 Celsius) depending type of the motor, and LCD is to display value of temperature. The simulation will involve the following steps:

a) The LCD will continuously monitor the temperature using a temperature sensor connected to the Arduino.
b) As the temperature rises, the Arduino will compare it to a predefined threshold value.
c) If the temperature exceeds the threshold, the Arduino will activate the relay, which will interrupt the power supply to the AC motor, effectively shutting it down.
d) Simultaneously, the Arduino will turn on the red LED to provide a visual indicator that the motor has been shut down due to overheating.

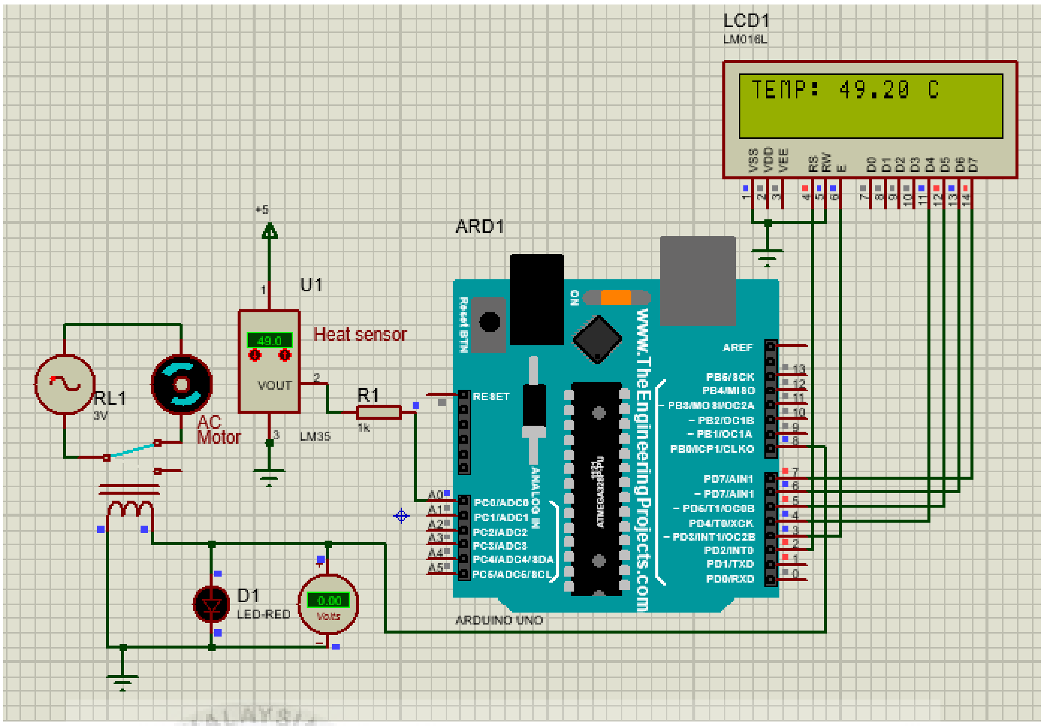


Figure 3.12 Simulation temperature below 50C

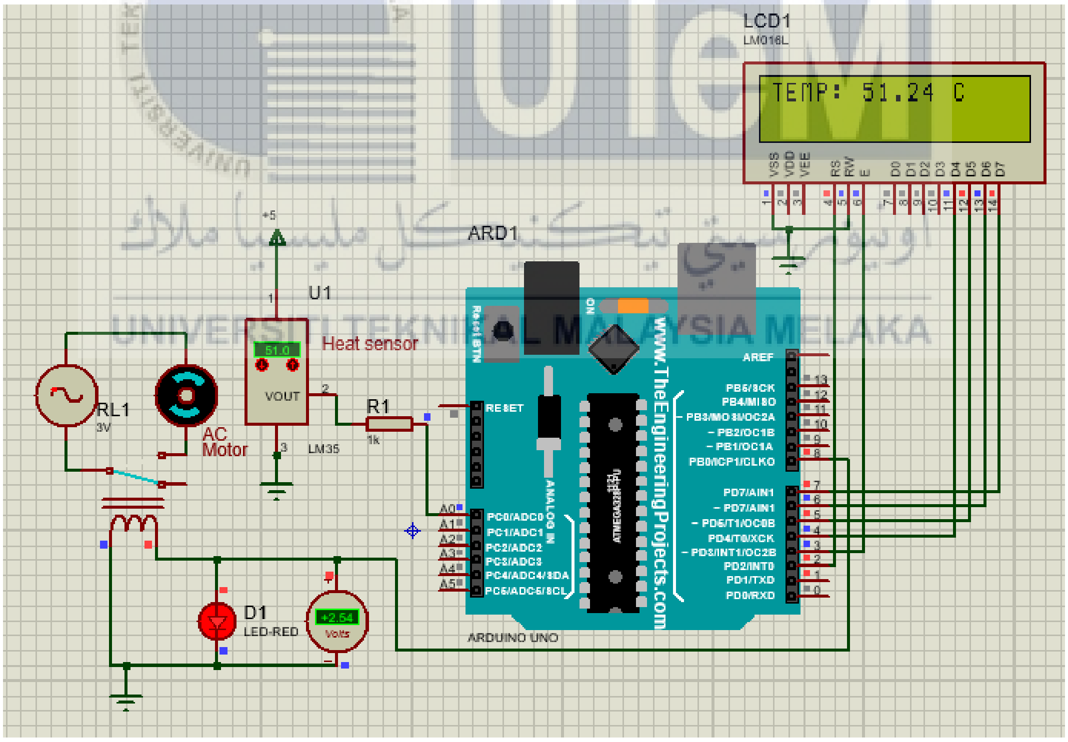


Figure 3.13 Simulation temperature above 50C

By implementing this simulation, the expected outcome is a reliable monitoring and protection system that actively detects and responds to overheating conditions in the AC motor. The relay acts as a safety measure to prevent further damage or hazards by shutting down the motor, and the red LED serves as a visible indication of the motor's status. This simulation enables effective monitoring and protection against motor overheating, ensuring the motor's reliability, efficiency, and safety.

3.5 Summary

The summary of the project "Development of protection and monitoring system of AC induction motor" involves a step-by-step methodology to ensure the reliability, efficiency, and safety of a single-phase AC induction motor. The primary objectives of the project is the investigation of the designed heat monitoring and protection system on a single-phase AC induction motor to evaluate its reliability, efficiency, and safety. Then, the development of an accurate heat monitoring system capable of detecting the temperature of the single-phase AC induction motor in real-time, aiming to prevent overheating. Evaluation and testing of a protection system that implements appropriate safety measures to prevent motor overheating, which may include shutting down the motor or triggering an alarm to alert the user. To achieve these objectives, a thorough literature review was conducted, and a systematic approach was adopted. The initial steps involved gathering the necessary components and equipment, with specific focus on acquiring an Arduino microcontroller. Subsequently, the motor's parameters were identified and analyzed to determine the specific requirements for protection and monitoring. Finally, suitable sensors were selected and connected to the Arduino, enabling the measurement of crucial variables such as temperature. Through this comprehensive methodology, the project aims to create a robust protection and monitoring system that effectively safeguards the AC induction motor while providing real-time insights into its temperature, thereby ensuring optimal performance, preventing overheating-related issues, and enhancing overall safety.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Introduction

In the chapter, a comprehensive analysis and interpretation of the data related to the single-phase AC induction motor's temperature behavior is presented. Specifically, data points capturing the temperature fluctuations are recorded at five-minute intervals over a duration of 30 minutes. This data collection have three distinct operational conditions. Firstly, when the single-phase AC induction motor operates without any external load. Secondly, when subjected to a load of approximately 320 grams and lastly, when subjected to a load of around 420 grams. Furthermore, to understand the correlation between temperature variations and current flow, a detailed examination is conducted by plotting temperature against current values. To facilitate this temperature monitoring process, an NTC thermistor is employed as a crucial parameter. Through the utilization of this thermistor, accurate and consistent temperature readings are ensured, providing invaluable insights into the motor's performance under varying load conditions.

4.2 Results and Analysis

This part presents real-time monitoring data of the single-phase AC induction motor. The temperature is measured using an NTC thermistor, processed through an Arduino system, and displayed on a LCD monitor. Concurrently, the current readings are obtained using a Sanwa DCM 400AD clamp meter.

Figure 4.1 Final product

Figure 4.1 is presented as the overview of the project on the Development of a Heat Monitoring and Protection System for a Single-Phase AC Induction Motor. Within this figure, the key components and their interactions are depicted in detail. The attachment between the NTC thermistor and the Single-Phase AC motor is clearly illustrated.

4.2.1 Project demonstration

Figure 4.2 The system ON

Figure 4.2 illustrates the initial stage of the system's operation. At the outset, the temperature stands at 29.9 degrees Celsius, which represents the ambient temperature. Simultaneously, the clamp meter shows a current reading of 0.13 amperes.

Figure 4.3 Temperature exceed 90 degrees celsius

Figure 4.3, the temperature surpasses 90 degrees Celsius, with the monitor indicating a specific reading of 92.54 Celsius. Consequently, the red LED indicator illuminates, signaling a critical temperature threshold has been exceeded. Concurrently, the clamp meter shows a reading of 0.00A, indicating the absence of current flow in the single-phase AC motor.

Figure 4.4 Temperature below 50 degrees celsius

Figure 4.4, the temperature reading registers at 46.71 degrees Celsius, comfortably below the specified limit of 50 degrees Celsius. As a result, the red LED indicator is deactivated, indicating a safe operational temperature range. Concurrently, the green LED illuminates, signaling that conditions are within the prescribed safety parameters for both the motor and the user. Additionally, the clamp meter records a current flow of 0.13A, confirming the active functioning of the single-phase AC motor.

4.2.2 Data Acquisition Overview

Data acquisition overview provides a concise summary of the methods and processes used to gather information or measurements present by table and graph. Essentially, it offers a structured insight into how data is systematically collected, ensuring clarity and consistency in the information obtained for analysis.

4.2.2.1 No load condition

a) Time vs Temperature

Table 4.1 Data for Time vs Temperature (no load)

Time (mins)	0	5	10	15	20	25	30
Temp (°C)	28.16	31.00	35.35	42.61	46.71	49.49	51.60

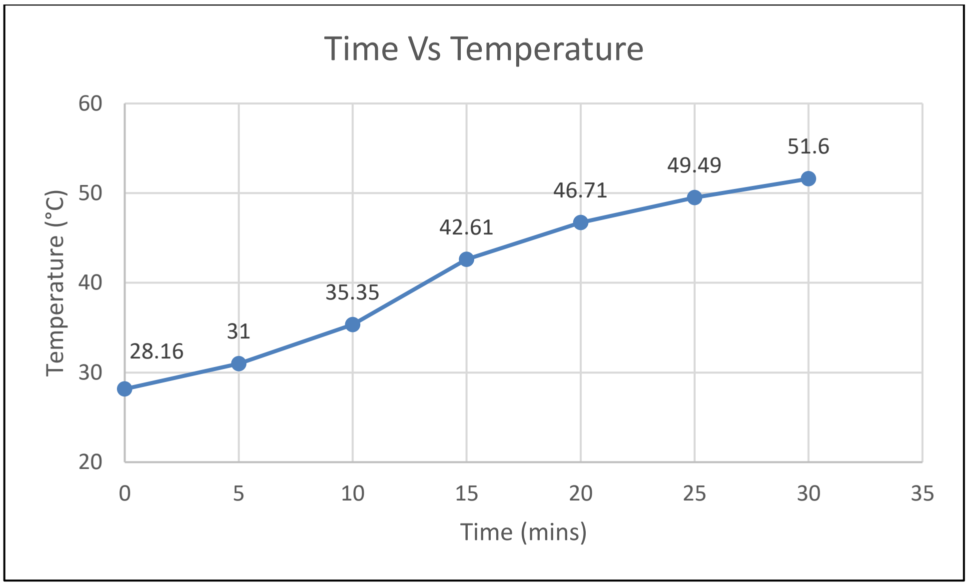


Figure 4.5 Graph Time Vs Temperature (no load)

In Figure 4.5, the graph displays how temperature changes over time in a scenario described as "no load." From the initial moment at 0 minutes, where the temperature starts at 28.16°C (ambient temepratture), there's a noticeable upward trend. As time progresses in 5-minute intervals, the temperature consistently rises by the 30-minute mark, it reaches 51.60°C.

This consistent increase suggests that without any external load or influence, the system or environment being observed tends to heat up steadily over time. Such observations could be crucial for understanding how systems behave or for making informed decisions related to temperature-dependent processes.

b) Temperature vs Current

Table 4.2 Data for Temperature vs Current (no load)

Temp (°C)	28.16	31.00	35.35	42.61	46.71	49.49	51.60
Current (A)	0.13	0.12	0.12	0.12	0.12	0.11	0.11

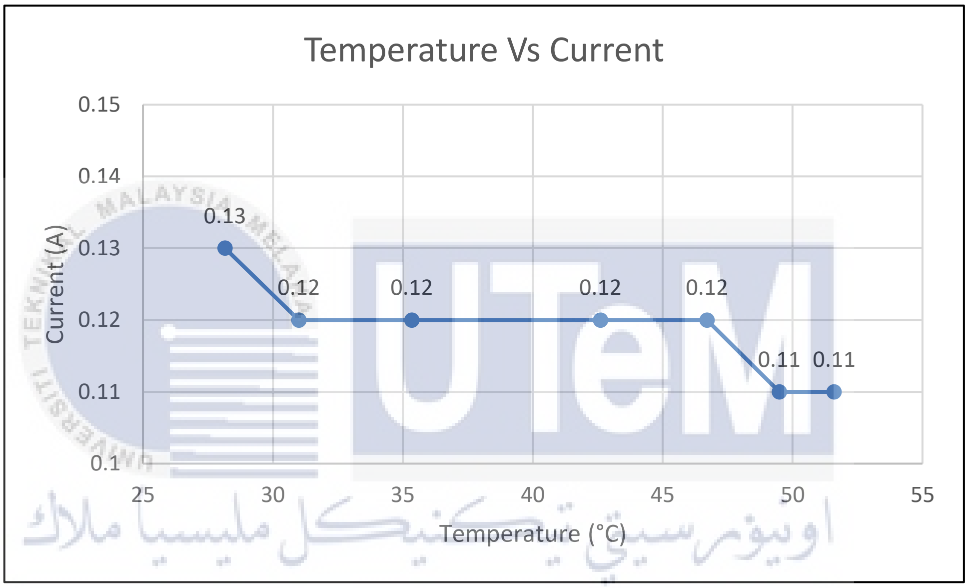


Figure 4.6 Graph Temperature vs Current (no load)

Figure 4.6 illustrates the relationship between the temperature and current of a single-phase AC motor operating under no load conditions. As the temperature of the motor rises from 28.16°C to 51.60°C over a period, there is a subtle decrease in the current, dropping from 0.13A to 0.11A. This inverse relationship suggests that as the motor's temperature escalates, the current required to maintain its operation slightly decreases.

c) Time vs Temperature vs Current

Table 4.3 Data for Time vs Temperature vs Current (no load)

Time (mins)	0	5	10	15	20	25	30
Temp (°C)	28.16	31.00	35.35	42.61	46.71	49.49	51.60
Current (A)	0.13	0.12	0.12	0.12	0.12	0.11	0.11

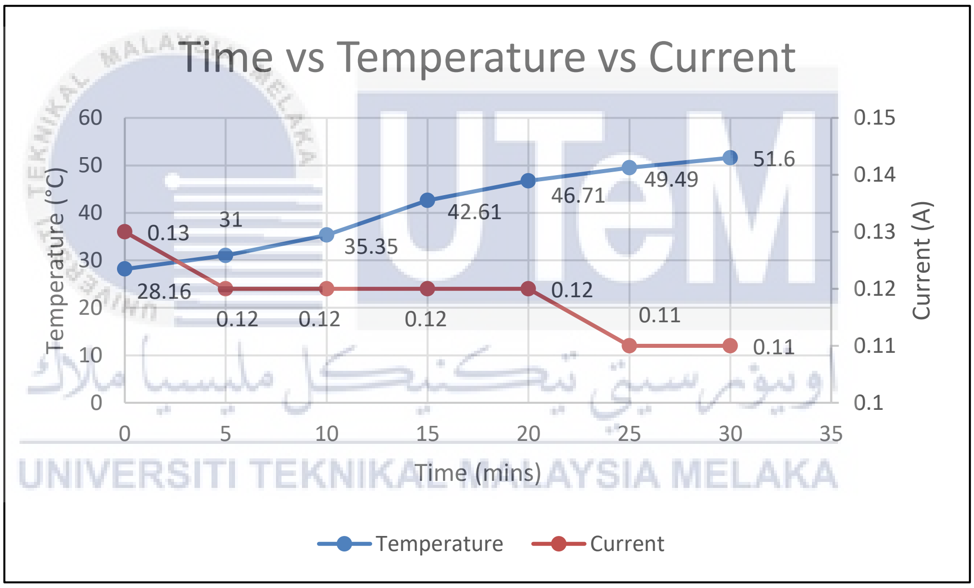


Figure 4.7 Graph Time vs Temperature vs Current (no load)

Figure 4.7 illustrates the relationship between time, temperature, and current for a single-phase AC motor operating under no load conditions over a span of 30 minutes. As depicted in the graph, as time progresses from 0 to 30 minutes, there is a increase in temperature. At the outset, the temperature starts at 28.16°C, and concurrently, the current is recorded at 0.13A. As the minutes tick by, the temperature steadily rises, reaching its peak at 51.60°C by the 30-minute mark. While, the current exhibits a slight decline, moving from 0.13A initially to 0.11A by the end of the observation period.

4.2.2.2 Load ≈ 320 grams

a) Time vs Temperature

Table 4.4 Data for Time vs Temperature (320g)

Time (mins)	0	5	10	15	20	25	30
Temp (°C)	28.52	32.43	38.50	43.86	47.33	50.02	51.77

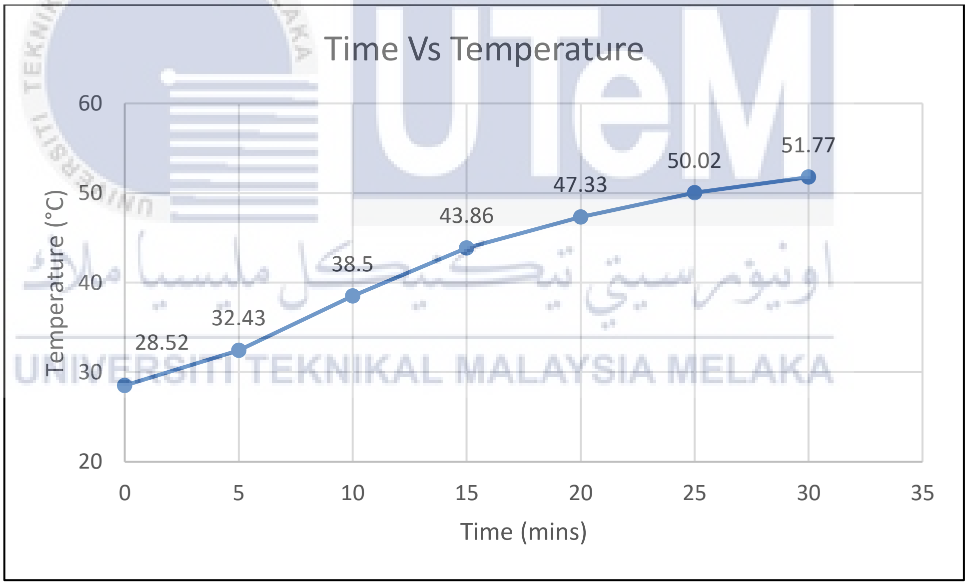


Figure 4.8 Graph Time Vs Temperature (320g)

Figure 4.8, the graph illustrates the relationship between time, measured in minutes, and temperature in degrees Celsius for a single-phase AC induction motor carrying a load of 320 grams. When compared to a scenario with no load, the temperatures observed are consistently higher throughout the 30-minute interval. Specifically, the temperature values, ranging from 28.52°C (ambient temperature) at the start to

51.77°C at the 30-minute mark, indicate that the motor's temperature rises more rapidly when carry a 320-gram load. Overall, the data underscores that the motor's thermal response is notably influenced by the load, with a noticeable acceleration in temperature when bearing the 320-gram load.

b) Temperature vs Current

Table 4.5 Data for Temperature vs Current (320g)

Temp (°C)	28.52	32.43	38.50	43.86	47.33	50.02	51.77
Current (A)	0.14	0.13	0.13	0.12	0.12	0.12	0.11

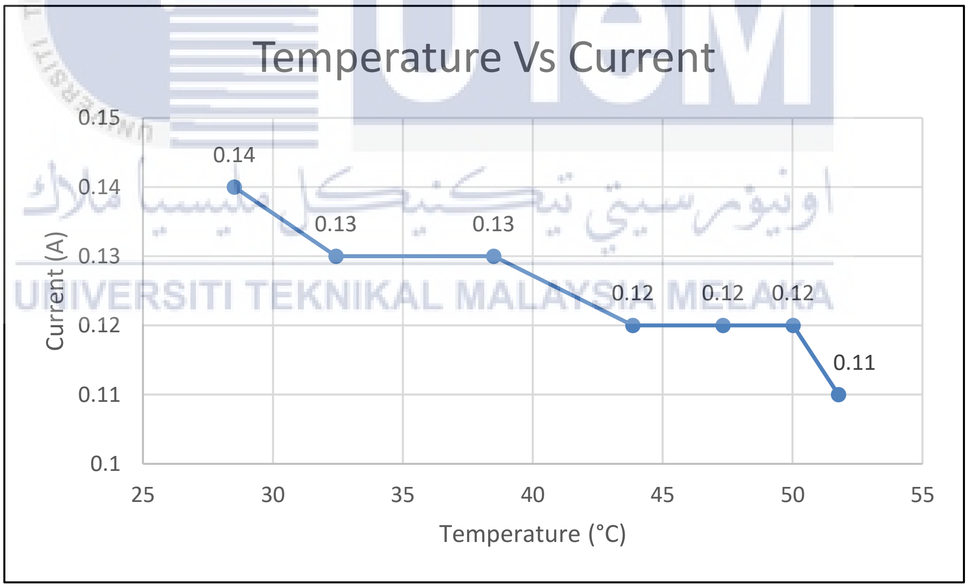


Figure 4.9 Graph Temperature vs Current (320g)

In Figure 4.9, a graph depicts the relationship between temperature and current for a single-phase AC induction motor carrying a load of 320 grams. As the load is applied, the initial temperature registers at 28.52°C, corresponding to a current of 0.14A.

Subsequently, with the load sustained, the temperature progressively rises to 51.77°C, while the current exhibits a declining trend from 0.14A to 0.11A.

c) Time vs Temperature vs Current

Table 4.6 Data for Time vs Temperature vs Current (320g)

Time (mins)	0	5	10	15	20	25	30
Temp (°C)	28.52	32.43	38.50	43.86	47.33	50.02	51.77
Current (A)	0.14	0.13	0.13	0.12	0.12	0.12	0.11

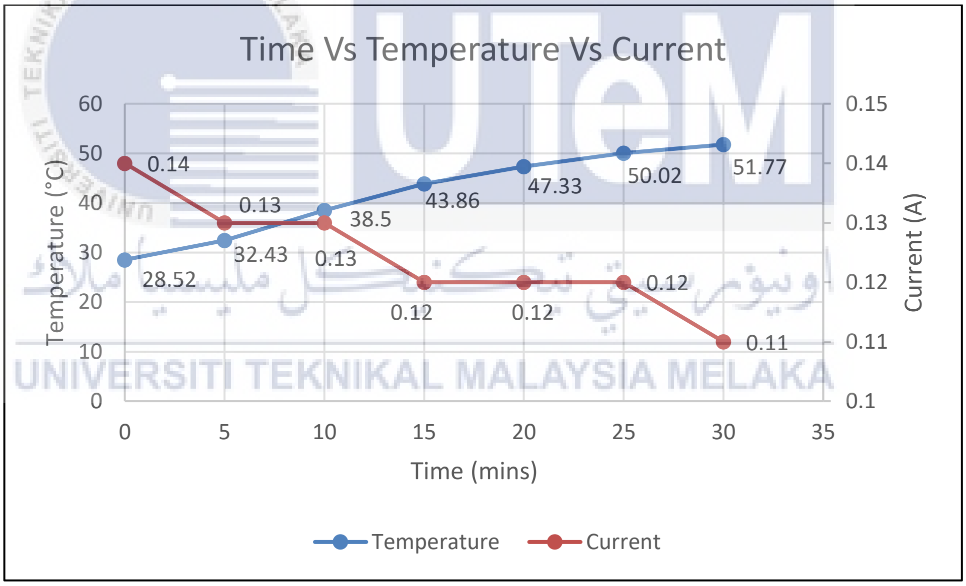


Figure 4.10 Time Vs Temperature Vs Current (320g)

In Figure 4.10, there are three distinct parameters monitored time in minutes, temperature in degrees Celsius, and current in amperes. As time progresses from 0 to 30 minutes, there's a noticeable rise in both temperature and current. Specifically, the temperature begins at 28.52°C and end at 51.77°C, showing a consistent upward trend. Similarly, the current, starting at 0.14A, experiences a gradual decline to 0.11A by the end of the 30-minute period. This data implies that as the AC induction motor carries the 320-gram load, it undergoes increasing thermal stress, leading to elevated temperatures, while the current decrease slightly over time.

4.2.2.3 Load ≈ 420 grams

a) Time vs Temperature

Table 4.7 Data for Time vs Temperature (420g)

Time (mins)	0	5	10	15	20	25	30
Temp (°C)	28.79	36.85	44.33	47.95	49.56	54.12	58.84

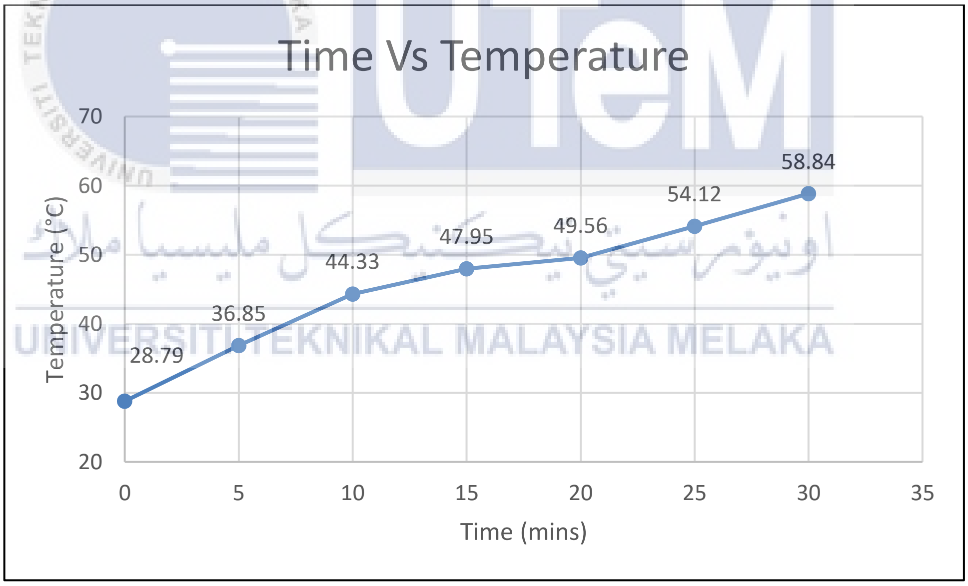


Figure 4.11 Graph Time Vs Temperature (420g)

Figure 4.11 illustrates the temperature variations of a single-phase AC induction motor carrying a load of 420 grams over a duration of 30 minutes. As depicted, the temperature exhibited a drastic rise over the observed period. Beginning at 28.79°C at the onset, the temperature surged significantly, culminating at 58.84°C by the end of the 30 minutes.

b) Temperature vs Current

Table 4.8 Data for Temperature vs Current (420g)

Temp (°C)	28.79	36.85	44.33	47.95	49.56	54.12	58.84
Current (A)	0.17	0.14	0.13	0.13	0.13	0.12	0.12

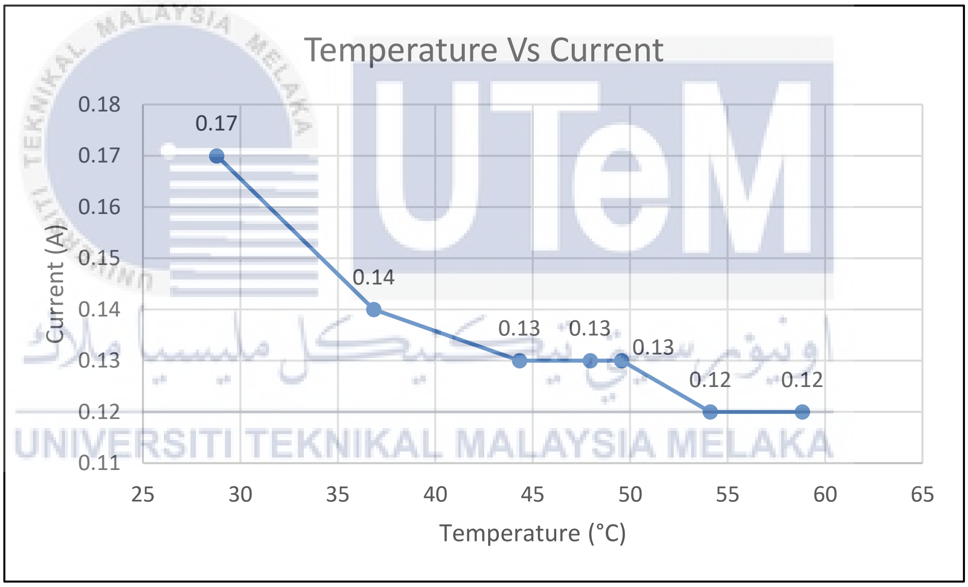


Figure 4.12 Graph Temperature vs Current (420g)

Figure 4.12 displays the relationship between temperature and current. As depicted, when the current starts at a higher value of 0.17A due to the 420g load, a subsequent decrease in current to 0.12A leads to a considerable rise in temperature from an initial 28.79°C to a peak of 58.84°C.

c) Time vs Temperature vs Current

Table 4.9 Data for Time vs Temperature vs Current (420g)

Time (mins)	0	5	10	15	20	25	30
Temp (°C)	28.79	36.85	44.33	47.95	49.56	54.12	58.84
Current (A)	0.17	0.14	0.13	0.13	0.13	0.12	0.12

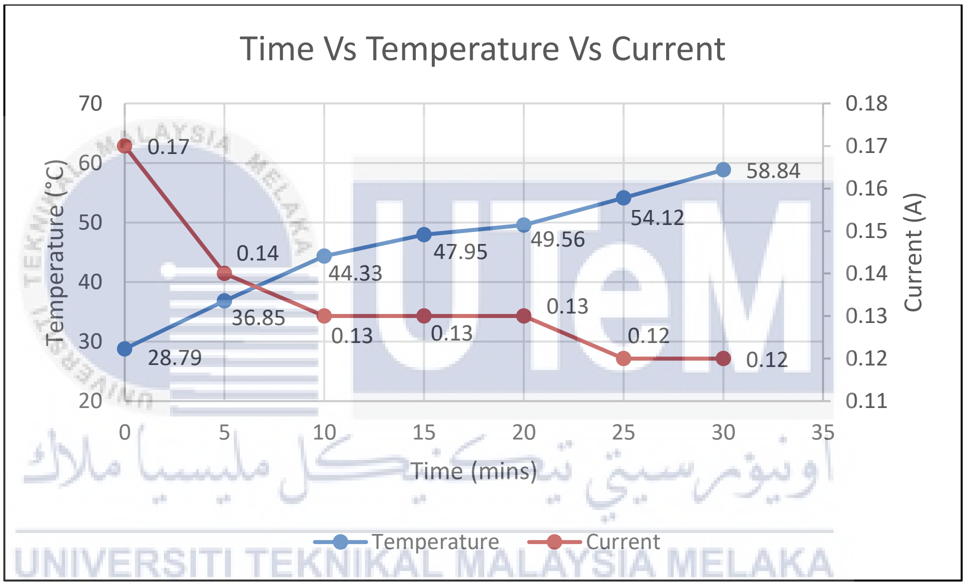


Figure 4.13 Time Vs Temperature Vs Current (420g)

Figure 4.13 illustrates the relationship between time, temperature, and current for a single-phase AC induction motor carrying a load of 420 grams. The graph clearly displays how these parameters evolve over a 30-minute duration. Beginning with an initial reading, the temperature starts at 28.79°C and steadily rises to 58.84°C. Meanwhile, the current demonstrates a slight decline, moving from an initial value of 0.17A to 0.12A by the end of the 30-minute period.

4.2.2.4 Comparative Analysis of Three Data Variables

a) Time Vs Temperature

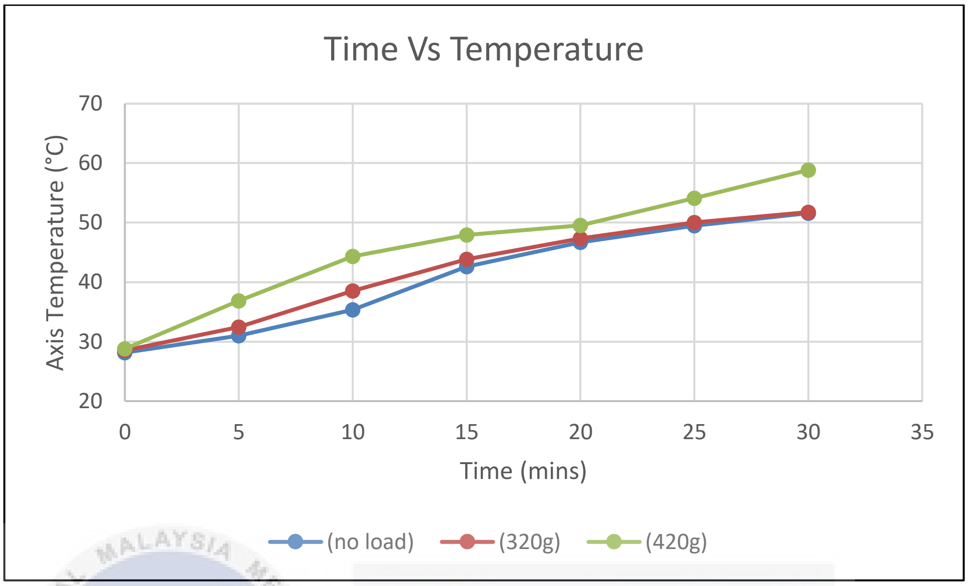


Figure 4.14 Time Vs Temperature of Three Data Variables

In Figure 4.14, the data reveals a temperature rise over time when there is no load present. As the analysis progresses, it becomes evident that with the introduction of a 320g load, there is a significant increase in temperature. Subsequently, when comparing this to the 420g load, it's observed that the 420g load experiences a higher temperature increase. This sequence suggests that, beginning with the no-load scenario and progressing through the 320g and 420g loads, there is a pattern of escalating temperatures, highlighting the influence of load weight on temperature fluctuations.

b) Load Vs Current

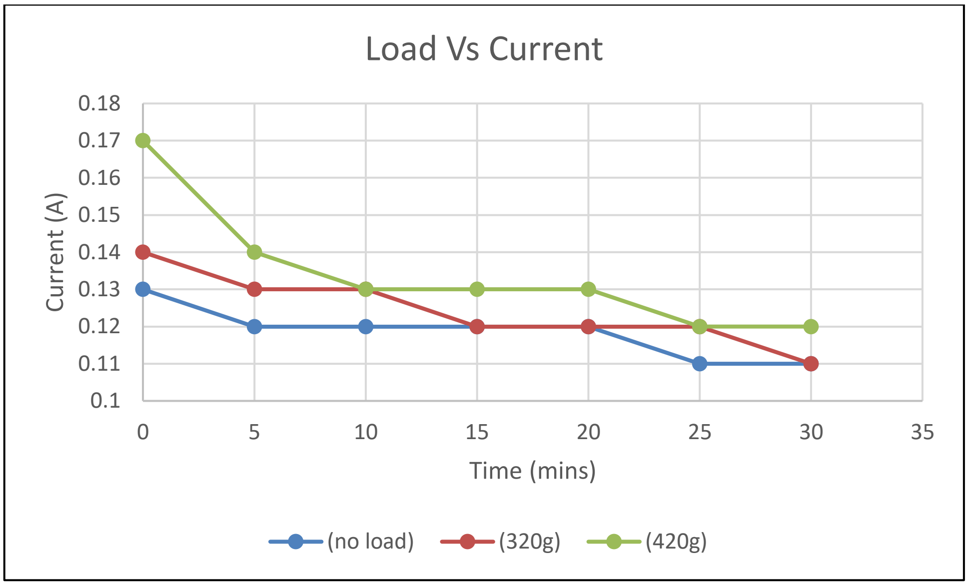


Figure 4.15 Load Vs Current of Three Data Variables

In Figure 4.15, the relationship between load and current per time is highlighted. It is observed that as the load weight is increased, an increase in starting current levels is recorded. Specifically, a starting current of 0.13A is measured in the absence of a load, which rises to 0.14A with a 320g load, and further elevates to 0.17A when a 420g load is applied. This indicates that when a heavier load is introduced, a more significant effect on the initiation and progression of current flow is experienced. It can be inferred that a heavier load results in a higher initial current being drawn. This finding highlights the direct association between the weight of the load and the magnitude of the electrical current generated.

4.2.3 Increment in percentage

The increment in percentage is observed every 5 minutes, providing a clear indication of the temperature increase during the analysis. This systematic observation allows for a comprehensive understanding of the temperature's trend over the specified intervals.

4.2.3.1 Analysis of Temperature Increase Characteristics (no load)

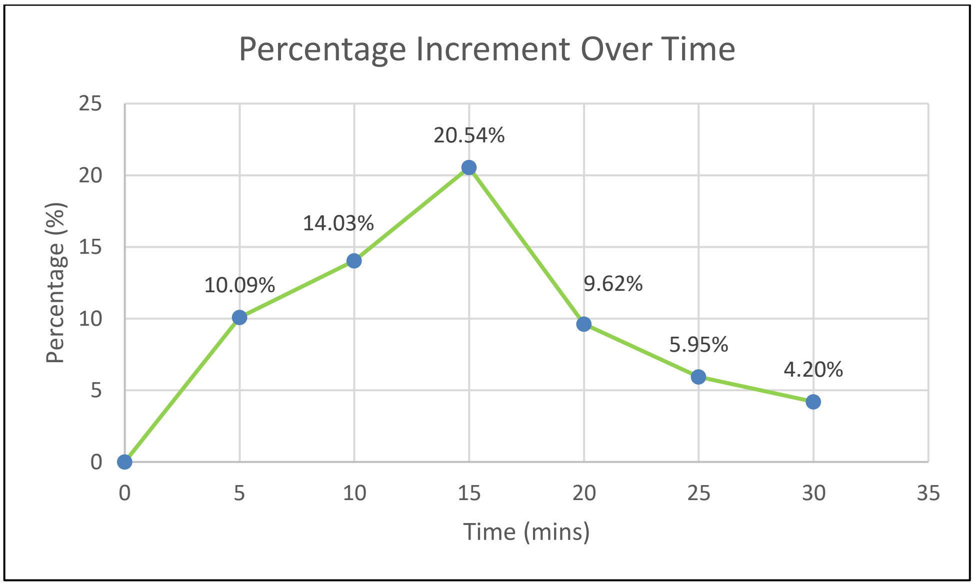


Figure 4.16 Characteristic Temperature Increase (no load)

In Figure 4.16, the data reveals a distinct pattern in the incremental temperature changes observed over consecutive 5-minute intervals. Beginning with a moderate rise of 10.09% in the initial 5 minutes, there's a noticeable acceleration as the subsequent time frame witnesses a surge of 14.03%. The momentum intensifies further in the subsequent interval, peaking at a significant 20.54% increment between the 10 to 15-minute mark. However, this upward trajectory encounters a decline as the temperature rise decelerates to 9.62% between 15 and 20 minutes. This deceleration continues with deceleration increments of 5.95% and 4.20% in the 20-25 minute and 25-30 minute intervals, respectively.

4.2.3.2 Analysis of Temperature Increase Characteristics (320g)

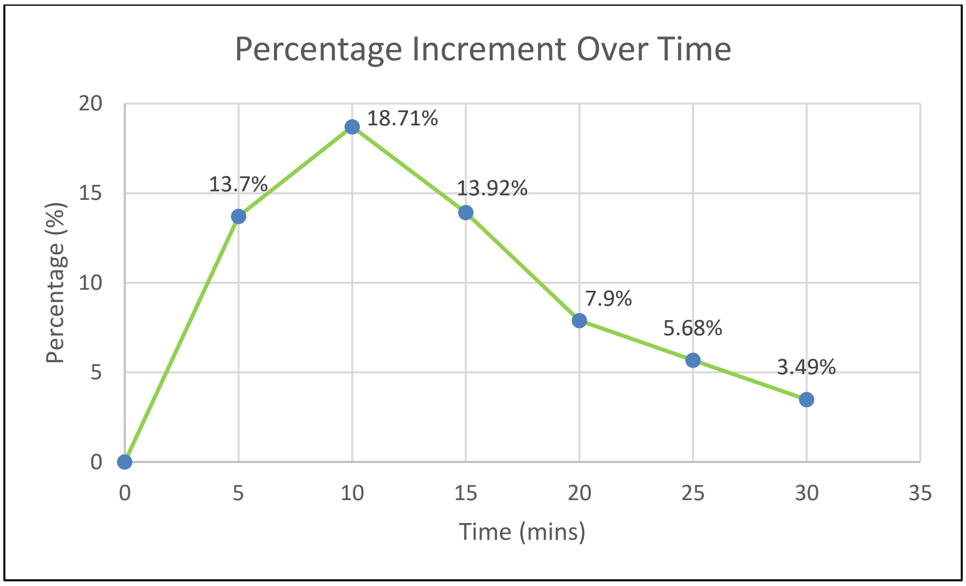


Figure 4.17 Characteristic Temperature Increase (320g)

In Figure 4.17, the data presented illustrates the incremental changes in temperature percentages over successive 5-minute intervals. Beginning from the initial 0-5 minute period with a rise of 13.70%, the increments demonstrate a varied pattern. Notably, the highest increment occurs between the 5-10 minute interval at 18.71%, followed by a slight dip to 13.92% between 10-15 minutes. Subsequent intervals show a diminishing trend, with percentages reducing to 7.9%, 5.68%, and 3.49% for the 15-20, 20-25, and 25-30 minute segments, respectively. This progression suggests a declining rate of temperature increase over time, potentially influenced by external factors or system limitations.

4.2.3.3 Analysis of Temperature Increase Characteristics (420g)

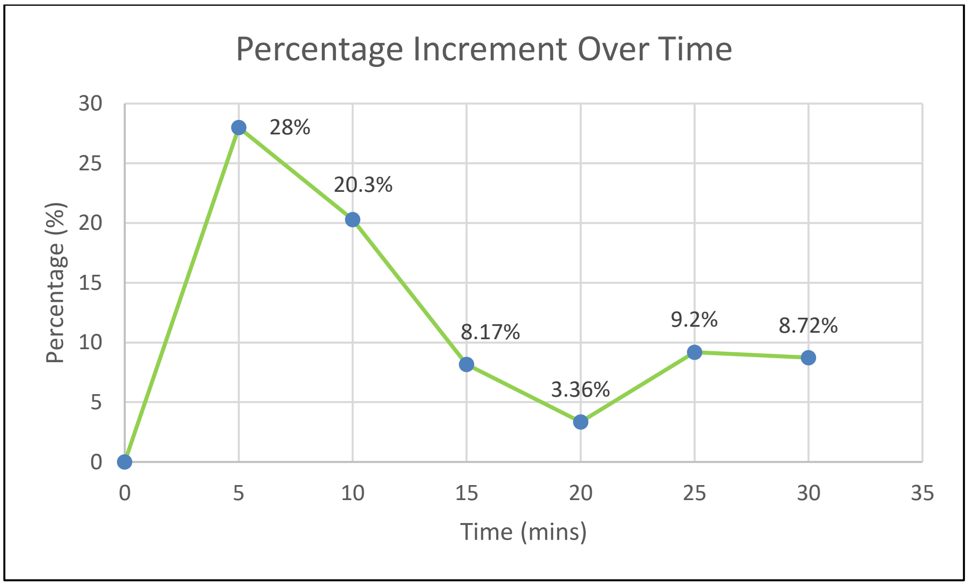


Figure 4.18 Characteristic Temperature Increase (420g)

In Figure 4.18, the provided data shows fluctuations in temperature percentages across successive 5-minute intervals, with a noticeable pattern of rise, decline, and subsequent rise again. When analyzing such patterns in the context of a single-phase AC motor, several factors come into play. Initially, the sharp rise from 0-5 minutes to 28% could be attributed to the start-up phase, where the motor consumes a higher current to overcome initial inertia. The subsequent decline to 8.17% between 10-15 minutes might signify a stabilization phase as the motor reaches its optimal operating condition, thus reducing the rate of temperature increase. However, between 15-20 minutes, the modest increase of 3.36% suggests potential external factors or operational nuances that might momentarily suppress the temperature rise. The subsequent rise between 20-25 minutes and 25-30 minutes, peaking at 9.2% and 8.72%, respectively, could indicate varying load demands or cyclic operational patterns inherent to single-phase AC motors.

4.2.4 Temperature Dynamics: Divergence between Motor's Body and Heat Sink in Thermal Regulation

Temperature data is gathered from a motor system in which a strategically positioned heat sink serves as an intermediary between the sensor and the motor. The temperature-measuring sensor is affixed to the heat sink, while the motor is situated on the opposite side of the heat sink. The incorporation of the heat sink in this configuration aims to optimize the dissipation of heat naturally produced by the motor during its operation. Over time, temperature differences are observed and analyzed. The heat sink, functioning as a thermal conductor, effectively draws heat away from the motor, facilitating its dispersion into the heat sensor. This part allows for the passive monitoring and assessment of temperature variations, contributing valuable insights into the dynamic thermal behavior of the motor system.

4.2.4.1 Time-Driven Temperature Differences: Monitoring Motor's Body and Heat Sink Dynamics Over Time

a) No load

Table 4.10 Temperature Trends: Motor Body vs. Heat Sink Over Time (no load)

Time (mins)	0	5	10	15	20	25	30
Motor's body Temp (°C)	28.14	31.09	35.77	43.80	47.96	50.28	52.06
Heat sink Temp (°C)	28.16	31.00	35.35	42.61	46.71	49.49	51.60

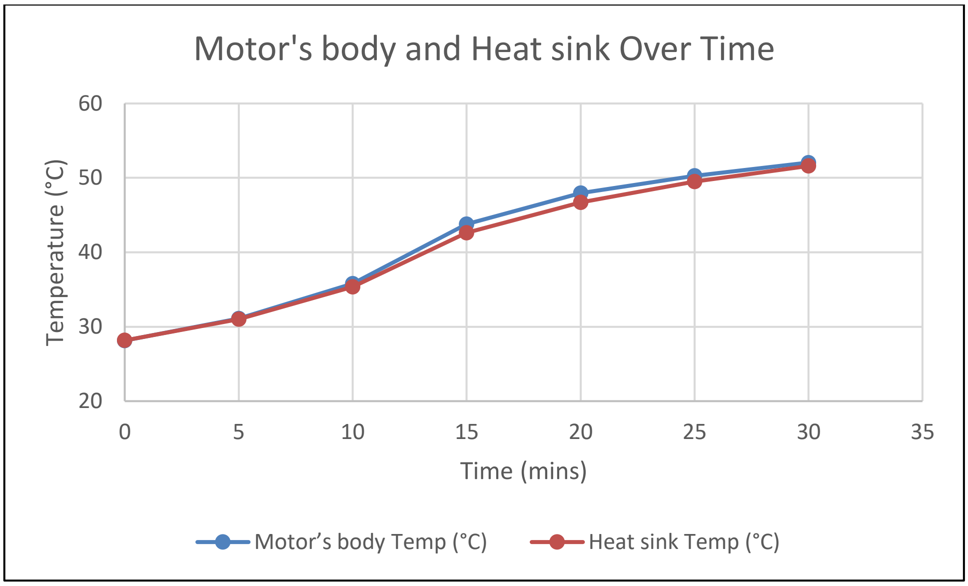


Figure 4.19 Motor's body and Heat sink Over Time (no load)

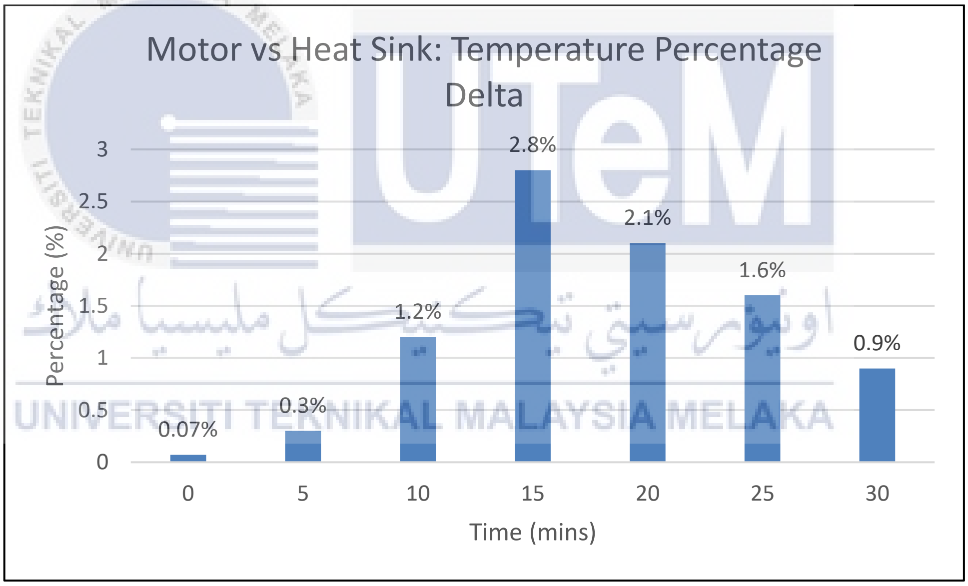


Figure 4.20 Temperature Difference in Percentage (no load)

Initial temperatures showed negligible difference (0.07%) but were slightly affected by ambient temperature variations. As temperatures increased, heat transfer rates rise, causing variations. Over time, temperatures elevated, and the heat sink demonstrated enhanced efficiency, reducing percentage differences from a peak of 2.8% to 0.9% over 30 minutes.

b) 320g

Table 4.11 Temperature Trends: Motor Body vs. Heat Sink Over Time (320g)

Time (mins)	0	5	10	15	20	25	30
Motor's body Temp (°C)	28.56	32.54	39.19	45.07	48.37	50.92	52.29
Heat sink Temp (°C)	28.52	32.43	38.50	43.86	47.33	50.02	51.77

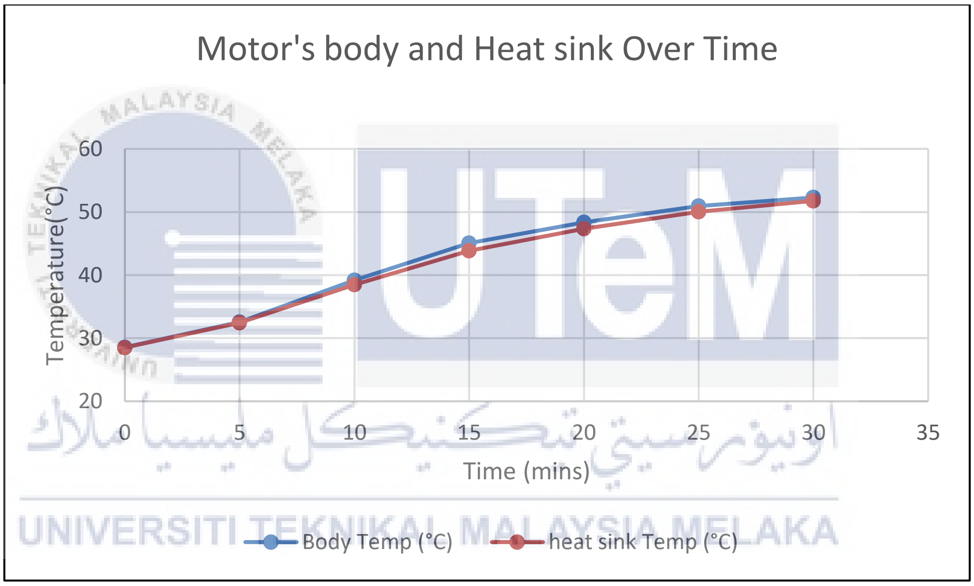


Figure 4.21 Motor's body and Heat sink Over Time (320g)

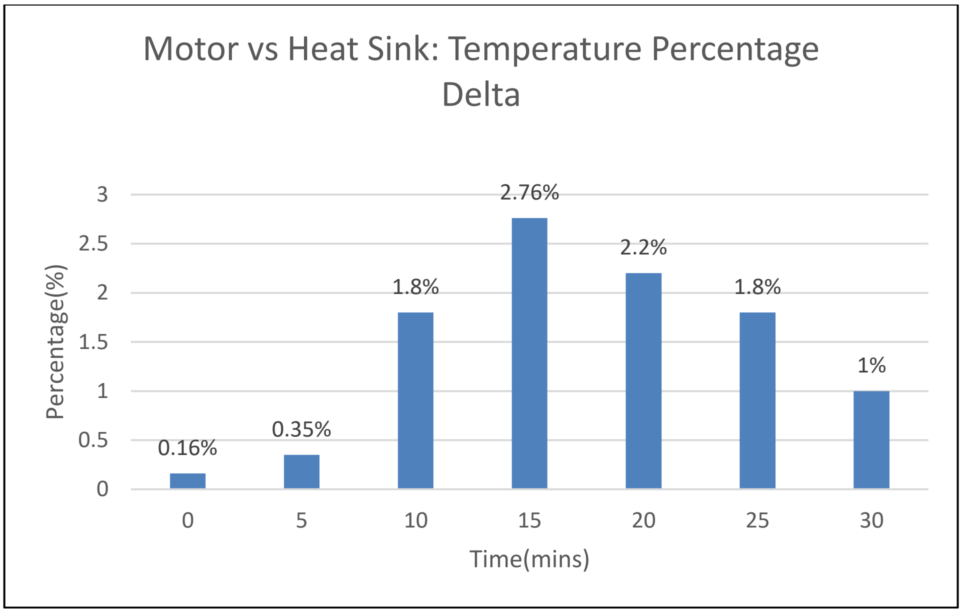


Figure 4.22 Temperature Difference in Percentage (320g)

Initially, temperature readings should have exhibited zero percentage difference, but a slight variance in ambient temperature during data collection resulted in a minor temperature distinction, reflected in the small percentage differences. As temperatures increased, the accelerated heat transfer rate contributed to varying temperature differences. However, due to the presence of a load, the temperature increase became more pronounced, causing the percentage to initially escalate. Subsequently, the percentage differences gradually diminished in the middle of the observation period until the end of the 30 minutes, reaching a final value of 1%.

c) 420g

Table 4.12 Temperature Trends: Motor Body vs. Heat Sink Over Time (420g)

Time (mins)	0	5	10	15	20	25	30
Motor's body Temp (°C)	28.78	37.01	45.16	48.74	50.16	55.02	59.91
Heat sink Temp (°C)	28.79	36.85	44.33	47.95	49.56	54.12	58.84

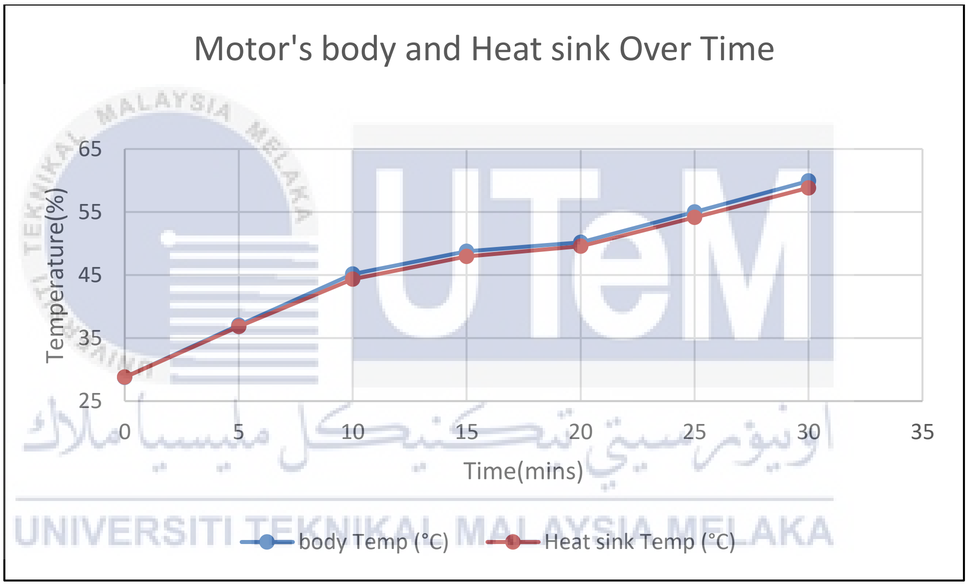


Figure 4.23 Motor's body and Heat sink Over Time (320g)

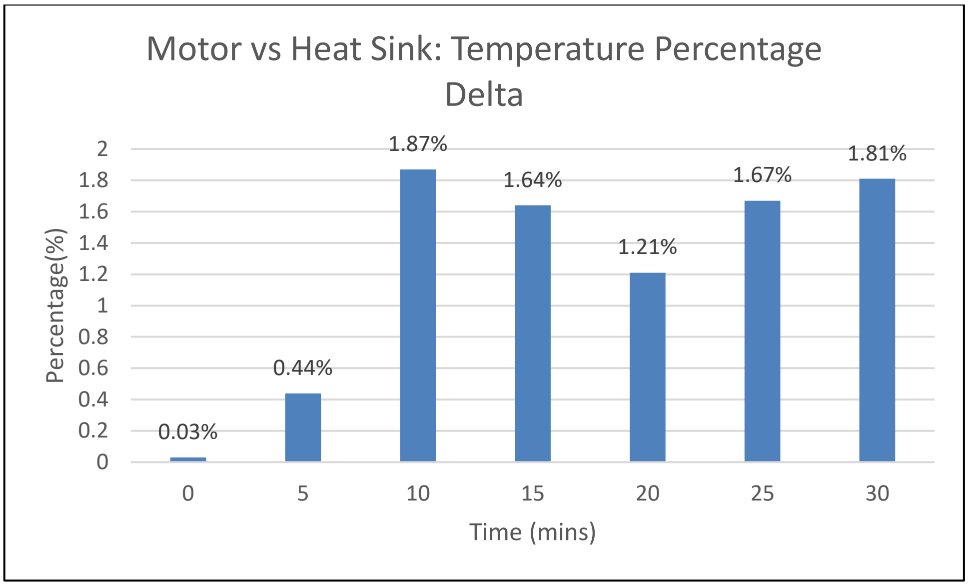


Figure 4.24 Temperature Difference in Percentage (420g)

Initially, temperature readings were anticipated to exhibit zero percentage difference, yet a slight variance in ambient temperature during data collection introduced a minor distinction in temperature, resulting in small percentage differences. With increasing temperatures, the augmented heat transfer rate led to variations in temperature differences. However, due to the presence of a load, the temperature increase became more significant, surpassing the temperature rise observed with a 320g load, consequently yielding larger percentage differences. Despite a gradual reduction in percentage differences in the middle of the observation period until the end of the 30 minutes, the final percentage remained larger than that observed with the 320g load.

4.2.5 Limitations of Single-Phase AC Induction Motors

The motor under inspection carries the serial number 2023L 2311216 and is manufactured by Foshan Xinchuangi Electric Co.Ltd. It is designed for an input power of 40W and an output power of 8W. The insulation class designated is B, suitable for a rated frequency of 50Hz. Operating within a working system denoted as S1 4P, the motor is designed to function effectively at a rated voltage of 220V. For protection against environmental factors, it possesses an IP42 protection level. Additionally, the motor operates at a rated current of 0.3A and maintains a consistent speed of 1300r/min.

When the motor was exposed to varying load conditions, its operational characteristics were assessed. Under no load, efficient functioning was observed. As the load was incrementally raised from approximately 320g to 420g, the performance of the motor consistently adhered to expected standards. Nevertheless, upon increasing the load to about 500g, significant limitations were recognised. A decline in the motor's ability to maintain optimal performance was noted, leading to an unstable operational condition. Despite attempts to support the motor's motion, it eventually faltered under the 500g load. This observed behavior indicates that the motor's rated current of 0.3A might not be sufficiently robust to sustain consistent performance under such elevated load conditions. It should be noted that for load testing, increments of 100g were applied, although initial tests considered increments of 30g. However, the variations in temperature and current were very minimal.

Furthermore, it's essential to address the motor's thermal constraints. While it can tolerate up to 105°C (include ambient temperature), a safety threshold of 90°C is established to prevent potential harm. Before restarting, ensure the motor cools to 50°C or below, as its usual operating temperature is around 30°C. Adherence to these temperature guidelines is paramount for the motor's durability and safe operation.

4.3 Summary

To summarize the data taken from real-time monitoring of an 80W single-phase AC induction motor, several key observations emerge regarding temperature and current dynamics under varying load conditions. At the outset, the motor's temperature exhibits a progressive increase as the load amplifies. Specifically, when no load is applied, the temperature commences at a relatively cooler 28.16°C, gradually climbing to 51.60°C over a 30-minute span. This thermal ascent is more pronounced with increased loads, for instance, at an approximate load of 320g, the starting temperature is slightly elevated at 28.52°C, peaking at 51.77°C by the end of the monitoring period. Similarly, the heaviest load tested, approximately 420g, sees an even more significant temperature surge, initiating at 28.79°C and reaching a notably higher 58.84°C after 30 minutes. Alongside these thermal variations, the current readings mirror this upward trajectory. Notably, the current characteristics display a pattern of escalation that corresponds with the load increments. This increase in current draw aligns with the motor's augmented effort to manage and overcome the additional resistance posed by the weights. Such behavior underscores the fundamental relationship between load, temperature, and current in the motor's operational dynamics. The intensification of both temperature and current with escalating loads can be attributed to the motor's increased effort to manage and overcome the additional resistance posed by the weights. It's imperative to note that efforts to subject the motor to a 500g load culminated in premature failures, underscoring the motor's operational limitations and emphasizing the critical importance of aligning loads with specified motor capacities. In essence, this comprehensive analysis illuminates the intricate interdependencies between load variations, temperature fluctuations, and current behaviour, offering valuable insights into optimizing motor performance while ensuring system longevity and reliability.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The research presented in this thesis has successfully achieved its objectives related to the "Development of Heat Monitoring and Protection System on Single-Phase AC Induction Motor". The reliability, efficiency, and safety of the designed heat monitoring and protection system have been thoroughly investigated and confirmed. A heat monitoring system has been developed, ensuring that temperature variations of the single-phase AC induction motor are accurately detected, thereby facilitating real-time monitoring to prevent overheating. Furthermore, a protection system has been evaluated and tested. Appropriate safety measures, such as motor shutdown and alarm triggering, have been incorporated to prevent motor overheating and potential damage. The development of a customized heat monitoring and protection system was a significant milestone. This system seamlessly integrates temperature sensors, control circuitry, and relay to detect and prevent motor overheating effectively. Key components and parameters affecting motor temperature were identified, ensuring comprehensive understanding and effective system implementation.

Overall, this research has contributed significantly to the advancement of heat monitoring and protection systems for single-phase AC induction motors. The systematic approach, encompassing design, development, testing, and validation, has ensured the system's reliability, efficiency, and safety. Future endeavors may further refine and expand upon these findings, ensuring continued enhancement of motor longevity and operational safety.

5.2 Potential for Commercialization

The potential for commercialization of the developed heat monitoring and protection system for single-phase AC induction motors is substantial, with applications across various industries and manufacturing settings. In industries such as factory setting, the integration of the heat monitoring and protection system can significantly enhance production processes. By preventing motor overheating and associated disruptions, factories can maintain consistent production levels, hold to strict quality standards, and optimize resource utilization. Furthermore, in the construction and infrastructure sectors, where single-phase AC induction motors power essential equipment and machinery, the adoption of this advanced monitoring system can mitigate risks associated with motor failures. Proactively identifying temperature anomalies and initiating protective measures ensures the longevity of equipment and fosters a safer working environment.

Moreover, the transportation sector, encompassing railways, marine, and aerospace industries, can benefit immensely from this technology. The integration of heat monitoring and protection systems in locomotives, ships, and aircraft powered by single-phase AC induction motors ensures reliable performance, adherence to safety protocols, and compliance with regulatory standards.

However, it is important to balance the system's commercial promise with its core features. This ensures organizations benefit from improved operations, longer equipment life, and a safer environment. As safety and efficiency remain paramount across sectors, there's a growing demand for such advanced solutions, highlighting the system's market potential and scalability.

5.3 Future Works

For future enhancements, the precision of the temperature monitoring system can be elevated in the following ways:

i) Enhance Sensor Accuracy: Improve the calibration and accuracy of the NTC 10k thermistor for more precise temperature readings, ensuring optimal motor protection.

ii) Integration of Advanced Cooling Systems: Incorporate innovative cooling mechanisms, such as liquid cooling or enhanced airflow systems, to efficiently regulate motor temperatures and prolong equipment lifespan.

iii) IoT Connectivity: Develop capabilities for remote monitoring and control through Internet of Things (IoT) connectivity, enabling real-time alerts and adjustments based on operational conditions.

iv) User Interface Enhancements: Design a user-friendly interface with intuitive controls, detailed temperature analytics, and predictive maintenance insights to facilitate seamless operation and monitoring.

v) Environmental Adaptability: Enhance the system's adaptability to varying environmental conditions, such as humidity levels, dust, and corrosive elements, ensuring consistent performance and longevity.

vi) Energy Efficiency: Optimize the system's energy consumption by integrating power-saving modes and intelligent control algorithms, reducing operational costs and environmental impact.

vii) Redundancy Measures: Introduce redundancy features within the control circuitry and relay systems to ensure fail-safe operations and mitigate risks of system failures.

REFERENCES

[1] AC motor: What is it? How does it work? Types & uses. (n.d.). Iqsdirectory.com. Retrieved June 20, 2023, from https://www.iqsdirectory.com/articles/electric-motor/ac-motor.html

[2] Aditya Narayan Sharma, Jaikaran Singh, Deepak Kumar, Rahul Rajawat, Vibhor Rastogi J. S. (2018). PROTECTION OF SINGLE-PHASE INDUCTION MOTOR. India.

[3] (N.d.). Electrical4u.com. Retrieved June 20, 2023, from https://www.electrical4u.com/induction-motor-types-of-induction-motor/

[4] Draganov, N. (June (2023)). Regulator of Induction Motor Rotation Frequency. Anatoliy Aleksandrov.

[5] Marine Inside. (2019). Single Phasing in Electrical Motors: Causes, Effects, and Protection Methods. Marine Electrical.

[6] V. Bochkarev, Igor , et al. 1 Mar. (2021). Developing New Thermal Protection Method for AC Electric Motors.

[7] Anthony, Zuriman , et al. Accessed 29 May (2023) "Single Phase Induction Motor with 4 Windings Design and Current Control in Auxiliary Winding." Elicit.org, 2023.

[8] Luyang. "【Small AC Electric Motor】from Luyang Technology | Leader AC Electric Motor Supplier in Taiwan." Www.luyangmotor.com, www.luyangmotor.com/cat-ac-small-motor.html. Accessed 3 June 2023.

[9] Wallscheid, Oliver. 13 Oct. (2021). "Thermal Monitoring of Electric Motors: State-of-The-Art Review and Future Challenges." IEEE Open Journal of Industry Applications, vol. 2, 2021, pp. 204–223.

[10] Alam, Rahimul. Oct. (2022) "(PDF) Automatic Temperature Control System Using Arduino." ResearchGate.

[11] COLLINS, DANIELLE, 21 Oct. (2020), "What Are Thermal Overload Relays and What Components Do They Protect?" Www.motioncontroltips.com.

[12] Overload relays. (n.d.-b). Global Electronic Services. Retrieved June 3, 2023, from https://gesrepair.com/product-category/overload-relays/page/3/

[13] Grupo Comercial Acomee. (n.d.). Busqueda por Clasificacion RELEVADORES DE SOBRECARGA de la marca ALLEN-BRADLEY ?. Com. Mx. Retrieved June 3, 2023 https://www.acomee.com.mx/busqueda-clasificacion-marca.php?marca=ALLEN

[14] (N.d.). Abb.com. Retrieved June 3, 2023, from https://electrification.us.abb.com/products/contactors-starters/thermal-overload-relay

[15] Sun, Yalong, et al, Apr. (2020) "Experimental and Numerical Investigation on a Novel Heat Pipe Based Cooling Strategy for Permanent Magnet Synchronous Motors." Applied Thermal Engineering, vol. 170, p. 114970.

[16] Cavagnino, A. (2022). Asynchronous motors. In Reference Module in Materials Science and Materials Engineering. Elsevier.

[17] Gupta, P. (2022). Polymer-graphene composites as sensing materials. In Polymer Nanocomposites Containing Graphene (pp. 401–424). Elsevier.

[18] (N.d.-b). Allaboutcircuits.com. Retrieved June 3, 2023, from https://www.allaboutcircuits.com/textbook/alternating-current/chpt-13/single-phase-induction-motors/

[19] Robledo, E. (2022, October 25). How to do a Diode and LED Work? Fusion 360 Blog. https://www.autodesk.com/products/fusion-360/blog/diode-led-work/

[20] Agarwal, T. (2013, October 28). Types of capacitors : Working and their applications. ElProCus - Electronic Projects for Engineering Students. https://www.elprocus.com/capacitors-types-applications/

[21] Amazon. In. (n.d.). Amazon. In. Retrieved June 20, 2023, from https://www.amazon.in/LM7812-7812-Positive-Voltage-Regulator/dp/B0839953SK

[22] SPDT relay DPDT relay. (2017, August 9). TheoryCIRCUIT - Do It Yourself Electronics Projects; theoryCIRCUIT. https://theorycircuit.com/spdt-relay-dpdt-relay/

[23] Johnson, A. (2020, November 25). When to use NTC thermistor probes and why it's necessary. Ametherm. https://www.ametherm.com/blog/thermistors/when-to-use-ntc-thermistor-probes-and-why-its-necessary/

[24] Kleveno, C. (2020). What is an Arduino? In Arduino for Absolute Beginners. Apress.

[25] LCD (16×2). (n.d.). Perintang.com. Retrieved June 20, 2023, from https://www.perintang.com/product/lcd-d

[26] What is the function of the indicator light? (n.d.). Led-indicator.com. Retrieved June 2023, from https://led-indicator.com/faqs-what-is-the-function-of-the-indicator.html

APPENDICES

Appendix A_Datasheet of NTC 10k Thermistor

⚠Note Please read rating and ⚠CAUTION (for storage, operating, rating, soldering, mounting and handling) in this PDF catalog to prevent smoking and/or burning, etc.
This catalog has only typical specifications. Therefore, you are requested to approve our product specifications or to transact the approval sheet for product specifications before ordering.

R44E9.pdf 05.4.13

● Part Numbering

NTC Thermistors for Temp. Sensor and Compensation Chip Type

(Part Number) NC P 18 XH 103 J 03 RB
❶ ❷ ❸ ❹ ❺ ❻ ❼ ❽

❶Product ID

Product ID	
NC	NTC Thermistors Chip Type

❷Series

Code	Series
P	Plated Termination Series

❸Dimensions (L×W)

Code	Dimensions (L×W)	EIA
03	0.60×0.30mm	0201
15	1.00×0.50mm	0402
18	1.60×0.80mm	0603
21	2.00×1.25mm	0805

❹Temperature Characteristics

Code	Temperature Characteristics
WB	Nominal B-Constant 4050–4099K
WD	Nominal B-Constant 4150–4199K
WF	Nominal B-Constant 4250–4299K
WL	Nominal B-Constant 4450–4499K
WM	Nominal B-Constant 4500–4549K
XC	Nominal B-Constant 3100–3149K
XF	Nominal B-Constant 3250–3299K
XQ	Nominal B-Constant 3650–3699K
XH	Nominal B-Constant 3350–3399K
XM	Nominal B-Constant 3500–3549K
XV	Nominal B-Constant 3900–3949K
XW	Nominal B-Constant 3950–3999K

❺Resistance

Expressed by three figures. The unit is ohm (Ω). The first and second figures are significant digits, and the third figure expresses the number of zeros which follow the two figures. If there is a decimal point, it is expressed by the capital letter "**R**". In this case, all figures are significant digits.

Ex.)

Code	Resistance
102	1kΩ
103	10kΩ
104	100kΩ

❻Resistance Tolerance

Code	Resistance Tolerance
E	±3%
F	±1%
J	±5%
K	±10%

❼Individual Specifications

Structures and others are expressed by two figures.

Code	Individual Specifications
03	Standard Type

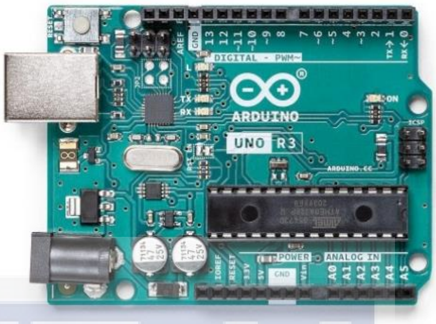
Please contact us for details.

❽Packaging

Code	Packaging
RA	Plastic Taping 4mm Pitch
RB	Paper Taping 4mm Pitch
RC	Paper Taping 2mm Pitch (10000 pcs.)
RL	Paper Taping 2mm Pitch (15000 pcs.)

Appendix B_Datasheet of Arduino Uno

Product Reference Manual
SKU: A000066



Description

The Arduino UNO R3 is the perfect board to get familiar with electronics and coding. This versatile development board is equipped with the well-known ATmega328P and the ATMega 16U2 Processor.
This board will give you a great first experience within the world of Arduino.

Target areas:

Maker, introduction, industries

Features

- **ATMega328P** Processor
  - **Memory**
    - AVR CPU at up to 16 MHz
    - 32KB Flash
    - 2KB SRAM
    - 1KB EEPROM
  - **Security**
    - Power On Reset (POR)
    - Brown Out Detection (BOD)
  - **Peripherals**
    - 2x 8-bit Timer/Counter with a dedicated period register and compare channels
    - 1x 16-bit Timer/Counter with a dedicated period register, input capture and compare channels
    - 1x USART with fractional baud rate generator and start-of-frame detection
    - 1x controller/peripheral Serial Peripheral Interface (SPI)
    - 1x Dual mode controller/peripheral I2C
    - 1x Analog Comparator (AC) with a scalable reference input
    - Watchdog Timer with separate on-chip oscillator
    - Six PWM channels
    - Interrupt and wake-up on pin change
  - **ATMega16U2 Processor**
    - 8-bit AVR® RISC-based microcontroller
  - **Memory**
    - 16 KB ISP Flash
    - 512B EEPROM
    - 512B SRAM
    - debugWIRE interface for on-chip debugging and programming
  - **Power**
    - 2.7-5.5 volts