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Title

Implementing an IoT Smart Device for Monitoring and Controlling Diverse Electromechanical Systems

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We are deeply grateful to the esteemed members of the jury for their participation in the evaluation of this work, an honor that we deeply cherish.

Dedication

To those who granted me life and hope...

To the heartbeat of my soul and the light of my eyes...

To my dearest parents,

I dedicate this humble work to you, in appreciation and love for your invaluable efforts and sacrifices. You have always been my source of support and inspiration, and without you, I would not have reached this stage. Every moment of your hard work and every sincere prayer from you was a reason for this achievement.

I hope I have made you as proud of me as I am proud to be your child.

To the one who has been my steadfast support...

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To my companions and lifelong friends...

To those who have been my support, my laughter, and my comforting hand...

To my dear friends,

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I hope I have succeeded in achieving what you wished for me, and that we can all take pride in this accomplishment just as I take pride in our friendship.

Abstract

This work is a master’s project aimed at designing a control, monitoring, and protection panel for electric motors using Internet of Things (IoT) technology. We observed several deficiencies in the protection and control of electric motors, which led us to choose this project specifically. Among the identified issues are the high operating costs associated with traveling long distances for motor activation or shutdown. Additionally, there are costs related to travel time and the need for rapid motor protection against unexpected faults.

Our project aims to save time by leveraging IoT to enable early detection of motor failures and prompt repairs. This approach minimizes downtime, avoids the inconvenience and expense of long-distance travel, and provides users with peace of mind regarding their motor operations. The system’s real-time motor protection is a fundamental feature of our solution.

Our project is divided into two main parts: hardware and software. In the hardware phase, we studied current and voltage sensors, designed and manufactured a PCB (Printed Circuit Board) using drilling, printing, and Acidification techniques. We assembled electronic components and tested various faults until we achieved accurate results, verified through an oscilloscope device. Additionally, we explored actuator relays, control devices, and motor protection equipment. Moving on to the software aspect, we set up a server for sending and receiving data to an Android application. The Android app displays information on the phone and alerts the user in case of any motor-related issues, particularly regarding motor protection.

Finally, we tested the entire system with a water pump, obtaining good and efficient results. The Android app provided real-time current and voltage values for each phase, allowing us to control the pump remotely. These outcomes align with our project goals.

Keywords: Electric motor control, AC current and voltage monitoring, Internet of Things (IoT), Electric motor protection

Résumé:

Ce travail est un projet de maîtrise qui vise à concevoir un panneau de contrôle, de surveillance et de protection pour moteurs électriques utilisant la technologie Internet des objets (IoT). Nous avons constaté plusieurs lacunes dans la protection et la surveillance des moteurs électriques, ce qui nous a amené à choisir ce projet en particulier. Parmi les problèmes identifiés figurent les coûts d’exploitation élevés, qui nécessitent de parcourir de longues distances pour démarrer ou arrêter les moteurs. Aux coûts de transport s'ajoutent le temps nécessaire au transport et la nécessité d'une protection rapide du moteur contre les pannes inattendues.

Notre projet vise à gagner du temps en tirant parti de l’Internet des objets pour permettre une détection précoce des pannes moteur et une maintenance rapide. Cette technologie réduit les temps d'arrêt, évite les tracas et les dépenses liés aux déplacements longue distance et offre aux utilisateurs une tranquillité d'esprit quant à l'état de leurs moteurs. La protection du moteur en temps réel est une caractéristique clé du système.

Notre projet est divisé en deux parties principales : le matériel et le logiciel. Dans la phase matérielle, nous avons étudié des capteurs de courant et de tension, puis conçu et fabriqué un PCB (circuit imprimé) en utilisant des techniques de gravure, d'impression et d'Acidification. Nous avons assemblé les composants électroniques et testé divers défauts jusqu'à obtenir des résultats précis, qui ont été vérifiés à l'oscilloscope. De plus, nous avons étudié les relais moteurs, les commandes et les équipements de protection moteur. Passant au côté logiciel, nous avons mis en place un serveur pour envoyer et recevoir des données vers l'application Android. L'application Android affiche des informations sur le téléphone et alerte l'utilisateur en cas de problème lié au moteur, notamment en matière de protection du moteur.

Enfin, nous avons testé l'ensemble du système sur une pompe à eau, avec des résultats bons et efficaces. L'application Android nous a montré les valeurs de courant et de tension en temps réel pour chaque phase, en l'allumant et en l'éteignant depuis le téléphone, nous permettant ainsi de contrôler la pompe à distance. Ces résultats sont cohérents avec les objectifs de notre projet.

Mots de clé: Contrôle des moteurs électriques , Surveillance du courant et de la tension AC , Internet des objets , Protection des moteurs électriques.

ملخص:

هذا العمل هو مشروع ماستر يهدف إلى تصميم لوحة تحكم ومراقبة وحماية للمحركات الكهربائية باستخدام تقنية إنترنت الأشياء .(IoT) وقد لاحظنا عدة أوجه قصور في حماية ومراقبة المحركات الكهربائية، مما دفعنا إلى اختيار هذا المشروع بالتحديد. ومن بين المشكلات التي تم تحديدها ارتفاع تكاليف التشغيل, مما يتطلب التنقل لمسافات بعيدة من أجل التشغيل او الايقاف المحركات. بالإضافة إلى تكاليف التنقل وايضا و استهلاك الوقت في التنقل والحاجة إلى الحماية السريعة للمحرك ضد الأعطال غير المتوقعة.

يهدف مشروعنا إلى توفير الوقت من خلال الاستفادة من إنترنت الأشياء لتمكين الكشف المبكر عن أعطال المحركات والصيانة السريعة. تقلل هذه التقنية من وقت التوقف عن العمل، ويتجنب العناء و تكلفة التنقل لمسافات طويلة، ويوفر للمستخدمين راحة البال فيما يتعلق بحالة محركاتهم. وتعد حماية المحرك في الوقت الفعلي سمة أساسية للنظام.

ينقسم مشروعنا إلى قسمين رئيسيين: الأجهزة والبرمجيات. في مرحلة الأجهزة، قمنا بدراسة أجهزة استشعار التيار والجهد، وقمنا بتصميم وتصنيع PCB (لوحة الدوائر المطبوعة) باستخدام تقنيات الحفر والطباعة والتحميض. قمنا بتجميع المكونات الإلكترونية واختبار العيوب المختلفة حتى حصلنا على نتائج دقيقة، تم التحقق منها من خلال جهاز راسم الذبذبات. بالإضافة إلى ذلك، قمنا بدراسة مرحلات المحرك، وأجهزة التحكم، ومعدات حماية المحركات. بالانتقال إلى الجانب البرمجي، قمنا بإعداد خادم لإرسال واستقبال البيانات إلى تطبيق اندروايد. يعرض تطبيق اندروايد معلومات على الهاتف وينبه المستخدم في حالة وجود أي مشاكل متعلقة بالمحرك، خاصة فيما يتعلق بحماية المحرك.

وأخيرًا، قمنا باختبار النظام بأكمله على مضخة مياه، وحصلنا على نتائج جيدة وفعالة. حيث عرض لنا تطبيق اندروايد قيمًا للتيار والجهد في الوقت الفعلي لكل طور، مما يسمح لنا بالتحكم في المضخة عن بُعد. وتتوافق هذه النتائج مع أهداف مشروعنا.

الكلمات المفتاحية: التحكم في المحركات الكهربائية، مراقبة التيار و الجهد AC ، إنترنت الاشياء، حماية المحركات الكهربائية.

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Notation

- V_1: is the voltage across both ends of the resistor R1.
- V_2: It is a voltage across both ends of the resistor R2.
- *I:* is the current passing through the circuit.
- R_1: is the value of the first resistance.
- R_2: is the value of the second resistance.
- Vs: is the input voltage.
- V_{c1}: is the voltage across both ends of the capacitor C1
- V_{c2}: is the voltage across both ends of the capacitor C2
- C_1: is the first capacitor value
- C_2: is the value of the second capacitor
- Vin: is the input voltage
- V_d:Drift speed
- *B:* Magnetic field strength
- E_H: Hall field strength
- q: the charge carrier of the current
- f_e: electric force
- f_m: magnetic force
- n_q: Charge density
- *A*: Cross-sectional area of the slice
- *t*: Slice thickness
- *d:* Slide show
- I: current
- E_p: primary voltage
- N_p: number of turns in the primary winding
- E_s: secondary voltage
- N_s: number of turns in the secondary winding
- π: Constant ratio (pi), approximately 3.14159
- f: Electrical frequency in cycles per second (Hz)
- φ_m: maximum magnetic flux
- I_p: is the primary current
- I_s: is the secondary current.

General Introduction

General Introduction

The rapid advancement of technology has paved the way for significant innovations in the field of electromechanical systems. One such transformative innovation is the integration of Internet of Things (IoT) technology, which offers unprecedented opportunities for monitoring and controlling various electromechanical systems with enhanced efficiency and precision[1]. This graduation project, titled “Implementing an IoT Smart Device for Monitoring and Controlling Diverse Electromechanical Systems” aims to integrate Internet of Things technology, voltage and current sensors , and PCB printed circuits to improve the functions of monitoring protecting and controlling electromechanical systems remotely.

First chapter delves into the critical aspect of protection methods in electromechanical systems and the faults that affect them. It also focuses on understanding the role of protection and control devices in electromechanical systems. These systems which are integral to numerous industrial applications, require robust protection mechanisms to prevent damage and ensure operational reliability[2]. Effective protection strategies are essential for safeguarding against faults such as overloads, short circuits, and other electrical risks.

The second chapter, it focused on studying Internet of Things systems, especially the technology of voltage and current sensors for both DC and AC applications. Which is the main axis of the Internet of Things, the technology of the Internet of Things works to facilitate access to real-time data and remote monitoring, which greatly enhances the management of electromechanical systems and control over them[3]. The use of advanced sensors allows for accurate measurement and analysis of electrical parameters, which is extremely important for the effective operation and maintenance of these systems.

The third chapter focuses on the design and development of custom Printed Circuit Boards (PCBs) for monitoring, controlling, and protecting motors. PCB design is a crucial component that brings together various elements of a smart Internet of Things device, ensuring seamless integration and smooth performance[4]. This chapter discusses design considerations, challenges, and solutions in creating a PCB that supports the requirements for monitoring and controlling electric motors, providing robust protection mechanisms, and integrating them with the Internet of Things for remote control.

Chapter I:

Protection Methods in Electromechanical Systems

I.1 Introduction:

Electromechanical systems are considered one of the fundamental pillars in many modern industries, as they combine electrical and mechanical engineering to provide advanced and effective solutions in multiple fields such as manufacturing, transportation, and energy. These systems require a high degree of protection and control to ensure their efficient and safe operation[5].

The importance of protection and control in electromechanical systems is manifested in their crucial role in preventing failures, reducing downtime, and protecting individuals and equipment from potential risks. By adopting effective protection technologies, the optimal performance continuity of the systems can be achieved and material and human losses can be reduced[6].

Electromechanical systems are used in various applications including industrial robots, motor control systems, and heavy equipment, making them susceptible to a wide range of risks that require advanced protection solutions.

Protection methods for electromechanical systems include various strategies aimed at minimizing failures as much as possible, mitigating their impact, and quick recovery. Among these methods, reliance on advanced sensing and monitoring technologies, and the application of preventive maintenance standards[7].

As for the devices dedicated to protecting electromechanical systems, they include a wide range of equipment such as electrical circuit protection devices, motor control systems, and leakage detection devices. These devices contribute to improving the safety and efficiency of the systems, ensuring the continuity of industrial operations and achieving the required performance.

In this context, a deep understanding and correct application of protection and control methods in electromechanical systems are necessary to achieve safety and efficiency in operation.

I.2 Importance of Protection and Control:

The significance of protecting and controlling electromechanical systems stems from their pervasive and critical role in modern infrastructure[8]. Failures in these systems can lead to cascading effects, disrupting entire networks and causing substantial economic and operational losses.

Effective protection strategies are thus essential to mitigate risks associated with component failures, environmental stresses, and operational anomalies.

Furthermore, the control of electromechanical systems is integral to their optimal performance and longevity. Advanced control mechanisms enable precise management of system dynamics, enhancing efficiency[8]. This not only extends the operational life of the systems but also ensures their reliability under varying conditions.

The control of electromechanical systems is of paramount importance for several reasons:

- **Reliability**: Proper control methods can enhance the reliability of electromechanical systems by preventing faults and minimizing downtime[9].
- **Safety:** Electromechanical systems often operate in environments where safety is critical. Effective control methods can prevent accidents and injuries [9].
- **Efficiency:** Control mechanisms can improve the efficiency of electromechanical systems by optimizing their operation and reducing energy waste [9].

There are several control methods used in electromechanical systems, including:

- **Dynamic State Estimation:** This method accurately tracks the dynamics of a power system and provides the evolution of the system state in real-time[9].
- **Adaptive Control Methodology:** This method uses the functionalities present or potentially present in modern control equipment[9].

The protection and control of electromechanical systems are critical for maintaining the integrity and efficiency of essential technological infrastructures. As these systems become increasingly integrated and complex, developing robust strategies for their protection and control is imperative to ensure continuous and safe operation.

This multi-faceted challenge requires a comprehensive understanding of the risks facing electromechanical systems and identification of the various devices used to control and protect these systems, including users.

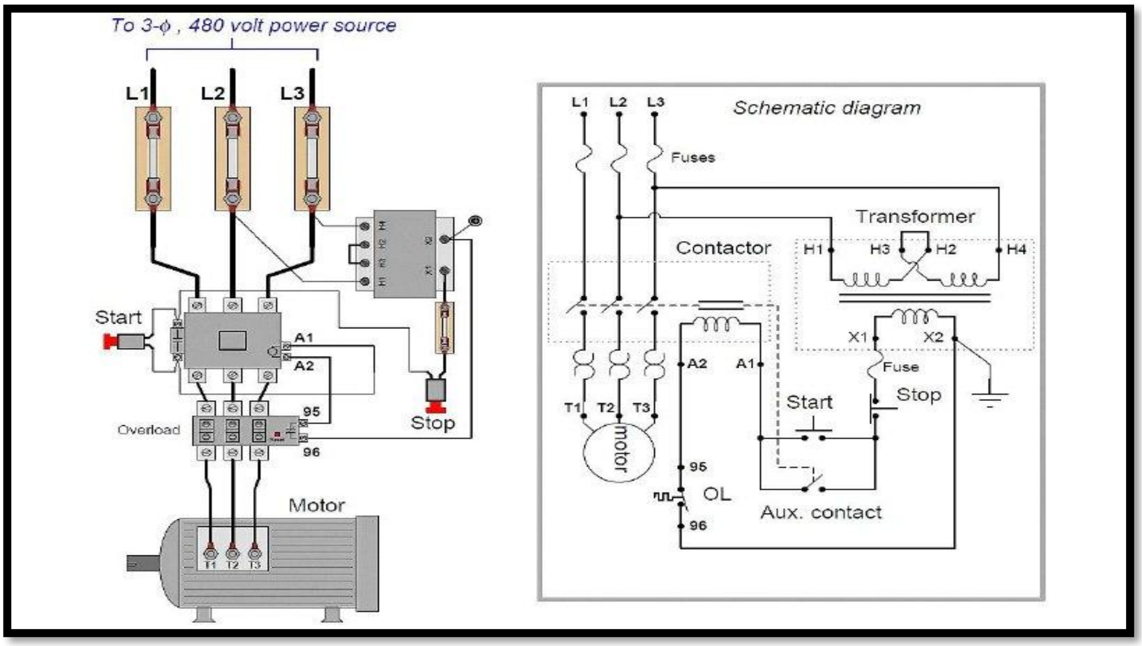


Figure I.1: A simple motor control circuit.

I.3 Applications of Electromechanical Systems:

Electromechanical systems, which involve the interaction of electrical and mechanical processes, are integral to a wide range of applications [10]. These systems require robust control methods to ensure their reliable and safe operation, Electromechanical systems find applications in various fields such as:

I.3.1 Industrial Machinery:

Industrial machinery encompasses all mechanical devices used across various sectors, including mining, manufacturing, energy, construction. This extensive category comprises a diverse array of machines, actuators that collaborate within an industrial setting, for example the construction industry utilizes heavy machinery like excavators, skid steers, and mining trucks. Meanwhile the manufacturing sector employs a variety of machinery, from woodworking to steel and aluminum fabrication machines and CNC machine [7].

Contemporary industrial machinery increasingly integrates automation technologies, including Programmable Logic Controllers (PLCs), Artificial Intelligence (AI), Machine Learning, and Industrial Internet of Things (IoT) devices. These advancements aid in enhancing the efficiency, accuracy, and safety of industrial processes[11] [12].

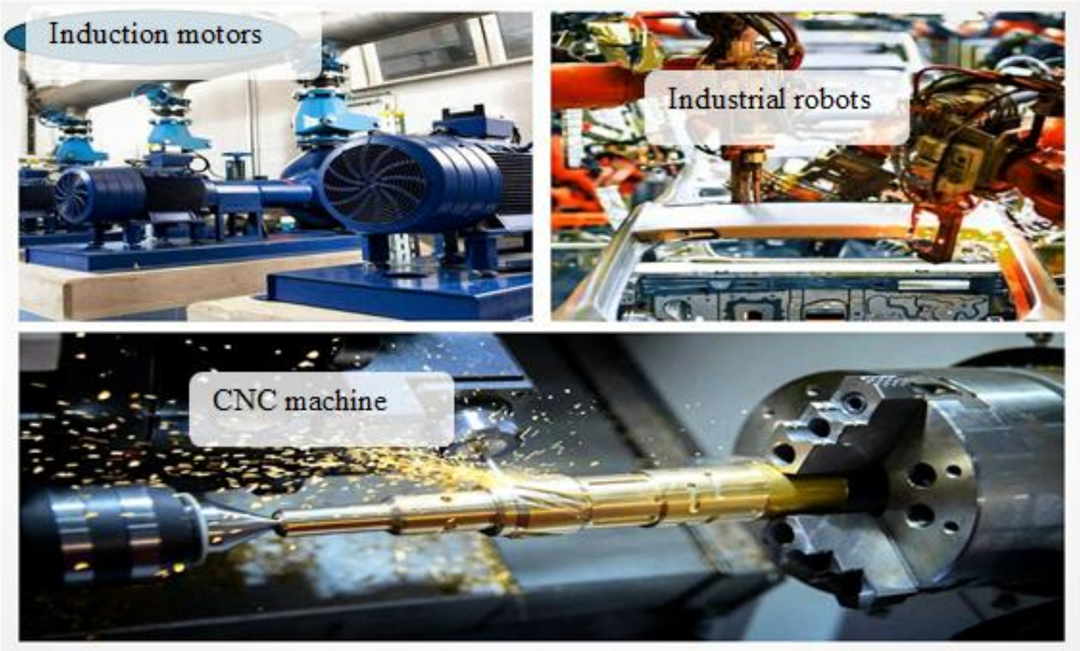


Figure I.2:A collection of predominant industrial machinery.

I.3.2 Precision Device Engineering:

Precision Device Engineering is a specialized field concentrating on the design, development, and production of devices with high accuracy and consistency. It employs cutting-edge technologies and methods to maintain strict tolerances and control over dimensions during manufacturing[13].

The significance of this discipline is paramount in sectors where minor discrepancies can result in major issues or expenses, for example in the semiconductor industrydevices with features just a few nanometers across are produced. Precision engineering is vital in these instances to ensure the features are produced accurately and uniformly[14].

Additionally, Precision Device Engineering is essential in creating Micro-electromechanical Systems (MEMS), which are minuscule mechanical devices powered by electricity, these devices varying from a few micrometers to one millimeter in size, necessitate meticulous engineering for proper operation[13].

I.3.3 Micro-Electromechanical systems (MEMS):

These devices, smaller than 1 mm but larger than 1 µm, are inherently multiphysics and belong to the wider category of electromechanical systems. MEMS are produced using micro fabrication techniques akin to those used for integrated circuits, involving processes like molding, plating, wet etching, and dry etching[10].

MEMS play an essential role in sensing, timing, signal processing, and biomedical diagnostics. They are prevalent in wireless communications, automotive, aerospace, medical devices, and consumer products, becoming an indispensable element of the modern automated world, with their significance ever-increasing as technology progresses.

I.3.4 Power Systems:

They play a crucial role in the generation, transmission, and distribution of power [15]. Generation is the first step where electrical power is produced from various energy sources, the generation plants produce electrical energy at a low voltage level.

The subsequent phase is transmission, where the generated power is sent over long distances. The transmission system transports the power from generation centers to load centers, utilizing high voltage to minimize energy losses and infrastructure costs across vast distances.

Distribution represents the final phase, where the transmitted power is allocated to the end-users. The distribution system delivers power to local homes and industries[16].

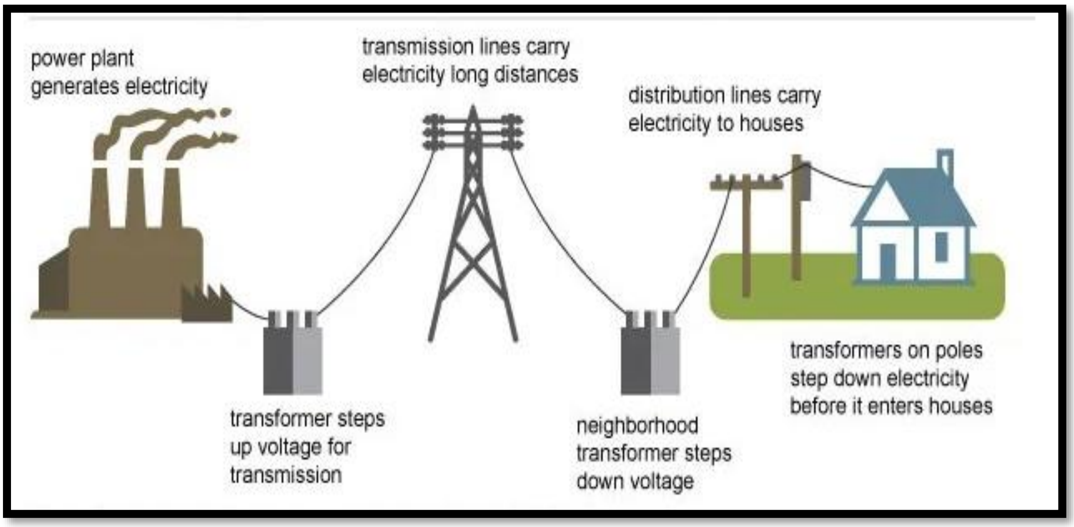


Figure I.3: Schematic diagram of a grid power system.

I.3.5 Medical Engineering:

Electromechanical systems have transformed medical engineering significantly.

- **Precision Surgery:** These systems have facilitated the creation of precise surgical instruments capable of conducting intricate operations with great precision[17].

- **Therapeutic Systems:** In therapeutic devices like insulin pumps and implantable medication delivery systems, electromechanical systems provide accurate medication dosages, enhancing the effectiveness of treatments[18].

I.4 Overview of Protections:

Protection methods in electrical systems are a crucial aspect of power engineering, designed to safeguard electrical power systems from faults and failures. These methods are intended to quickly identify a fault and isolate it, allowing the rest of the system to continue operating under normal conditions [18].

The field of protection engineering encompasses various aspects, including the principal faults on electrical power systems and system components, the main criteria for detecting faults, and the use of instrument transformers for protection purposes [19] [20].

I.4.1 Over current:

Overcurrent is a situation in power systems where the current exceeds the rated value of the equipment or the system. It is one of the most common types of electrical faults and can lead to serious damage to the system components if not properly managed[21].

Overcurrent protection differs from overload protection, overload protection pertains to the ability of equipment including cables and wires, to endure heating due to current flow in its normal path during an overload. Overcurrent protection is mainly for fault clearance, where current deviates from its normal path. In an AC system a fault typically means a short circuit between phases or between a phase and the ground.

Fuses serve as both sensing and isolating devices in overcurrent protection, protective relays detect overcurrent and send signals to the appropriate circuit breakers to isolate the faulty circuit or equipment. The purpose of such protective equipment is to prevent or limit damage from faults and to reduce their impact on the system, this is done by segmenting the power system into distinct protection zones, allowing any defective part to be disconnected while keeping the rest of the system operational.

Overcurrent can be caused by several factors including short circuits, overloads, or equipment failures. Short circuits occur when the insulation between conductors fails, causing a large amount of current to flow[21].

Selecting the right protective devices is crucial for overcurrent protection. This includes adequate short-circuit interrupting capacity, routine disconnect, and on-off circuit switching.

A switching device should:

- Be able to close safely under any load or short-circuit current.
- Be able to interrupt load or short-circuit currents.

The two devices commonly used for the first requirement are circuit breakers rated for switching duty and switches. To interrupt excessive current, the common devices are circuit breakers and fuses [22].

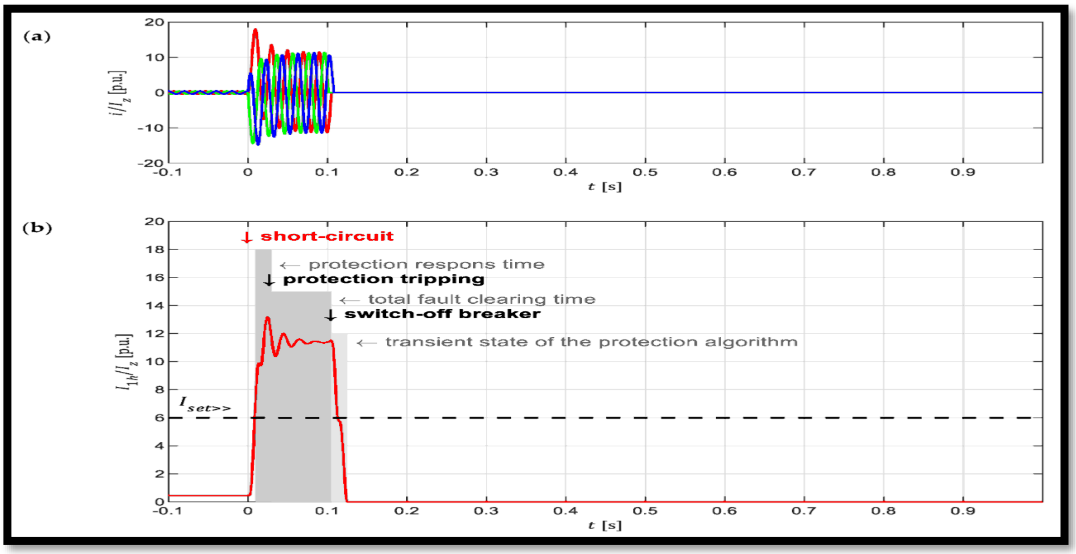


Figure I.4: Illustration of MV line short-circuit overcurrent protection expected operation during a three-phase short-circuit in the line.

The ANSI (American National Standards Institute) codes for overcurrent protection are as follows:

- Instantaneous Overcurrent (ANSI/IEEE Code 50): This protection triggers a breaker trip when the current exceeds a preset "pickup" value, regardless of the duration.
- Time Overcurrent (ANSI/IEEE Code 51): This protection triggers a breaker trip based on a combination of the current's magnitude and duration, with faster tripping for higher currents.

These codes are integral to the ANSI standards, which help identify the roles of protective devices in electrical power systems. It's important to note that these are just two among the numerous ANSI codes for various protection types in electrical systems[23].

I.4.2 Overload:

An overload happens when a motor or another electromechanical system pulls more current than its rated capacity for an extended time. This can cause the temperature of the motor windings or other parts to increase, which may lead to damage[24].

Overloads may be triggered by several factors, such as high demand, mechanical defects, or electrical issues or when the system or a component is subjected to a load greater than it is designed to handle[21]. The consequences of an overload can vary from diminished efficiency and performance to significant damage or even complete failure of the system.

Extension cords can also contribute to circuit overload. This is because the current rating of cords often falls far below the loads necessary to activate breakers and fuses. If too many devices are plugged into an extension cord, it can easily lead to an overload condition.

To prevent circuit overload, overload protection measures are often implemented. These can include the use of circuit breakers or fuses in the circuit design. These devices are designed to automatically shut off electrical flow in a circuit when excessive electrical current is detected [25]. The ANSI code for overload protection is ANSI 49.

I.4.3 Thermal Protection:

Thermal protection an essential aspect of ensuring safe and reliable operation in electrical systems, particularly in applications involving electric motors. Bimetallic switches, which rely on the differential expansion of two bonded metals, play a critical role in preventing overheating of electric motors, transformers, and other electrical components during operation[26].

Excessive heat can lead to insulation breakdown, winding damage, and reduced equipment lifespan. Bimetallic switches offer an effective solution to prevent overheating by responding to temperature changes. Overload protection responds to excessive current, while thermal protection responds to excessive heat.

I.4.4 Min/Max Voltage:

Electromechanical systems, which encompass a wide range of devices from power converters to electrical motors, require robust protection mechanisms to ensure their safe and reliable operation. One such mechanism is the Min/Max voltage protection, a critical aspect of power system operation and control.

Overvoltage refers to a condition where the voltage in an electrical circuit or system exceeds the normal or rated level. This can occur due to various reasons, such as sudden changes in the load, lightning strikes, faults in the power distribution system, or switching operations. Overvoltage can be transient (short-duration spikes) or sustained (lasting for a longer period). Overvoltage is defined as an increase in RMS value [27] [28].

As shown in Figure I.5

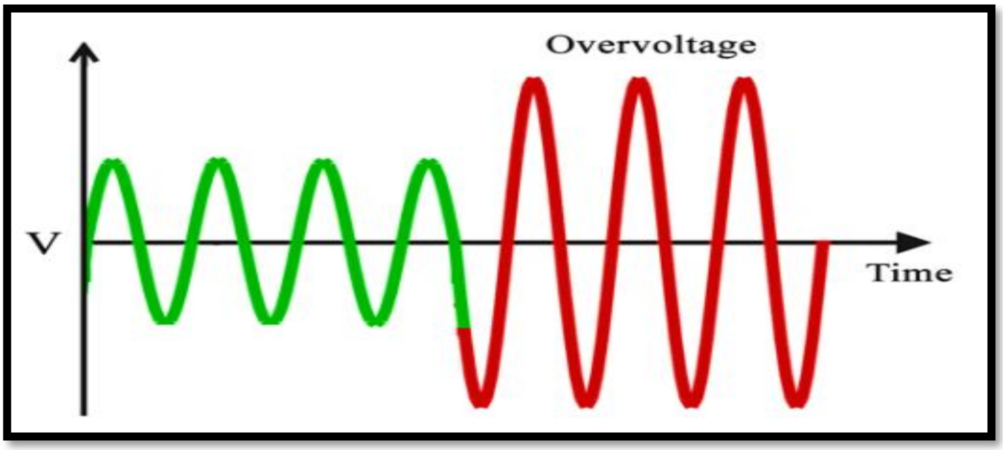


Figure I.5: A graphical representation for overvoltage.

The ANSI code for overvoltage protection is ANSI 59.

Electronic devices and other sensitive devices are also prone to malfunction [27], and there many multiple factors lead to overvoltage:

- Lightning Strikes: Lightning can induce high voltages in power lines and equipment.
- Switching Surges: Quick switching of electrical circuits, such as circuit breakers and capacitors, can create transient overvoltage.

Under-voltage can cause motors to draw excessive current, leading to overheating and potential damage. Under-voltage protection can be provided by overload devices or temperature-sensitive devices. Some control circuits can keep the contactors in a holding position for momentary dips in voltage.

Consistent monitoring and control of the operating voltage in electromechanical systems enable prompt intervention when the voltage surpasses the established minimum or maximum thresholds.

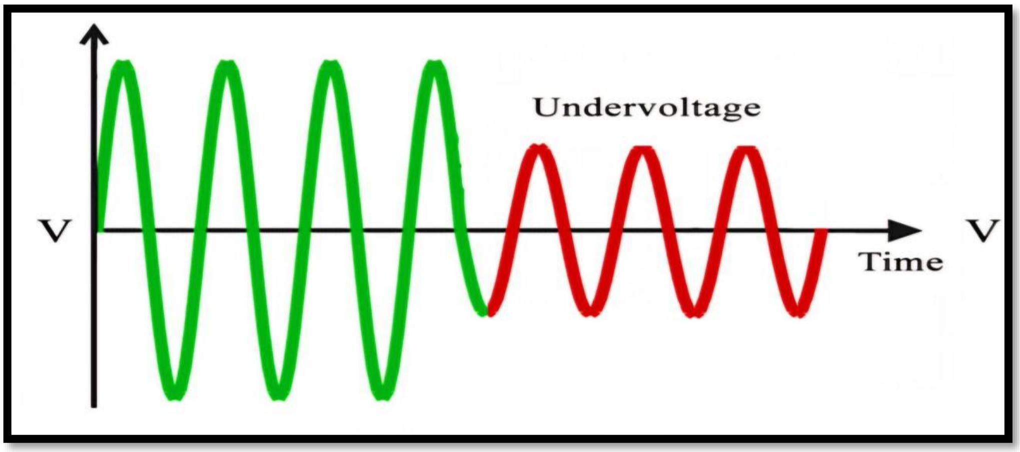


Figure I.6: A graphical representation for under voltage**.**

By implementing these strategies, electric motors can be effectively protected from potential damage caused by operating outside the Min/Max voltage range.

I.4.5 Phase Failure Protection:

Phase Failure Relays play a crucial role in motor protection by continuously monitoring the three-phase supply to the motor.

Phase failure, also referred to as single-phasing, occurs when one phase of a three-phase motor becomes open-circuited during operation. This may happen due to a blown fuse, a loose connection, or a partial breakdown of switchgear.

Phase failure can result in unbalanced voltages in the motor, leading to overheating and potential failure. Such events can cause considerable operational disruptions and financial losses. Consequently, employing Phase Failure Relays is essential to prevent these situations.

These devices are designed to detect any loss of one or more phases, a condition known as phase failure or single-phasing.

The Phase Failure Relay operates by continuously monitoring the three-phase voltages in the system. If it detects a loss of one or more phases, it immediately trips the circuit, disconnecting the motor from the supply. This swift action prevents the motor from operating under unbalanced voltage conditions, thereby protecting it from potential damage[29] [30].

Phase failure protection is an essential element of power system management and control. It is vital for preserving system stability, avoiding damage to equipment, and guaranteeing dependable operation.

There isn't a single dedicated ANSI code for phase failure protection, However a couple of ANSI codes can be used to achieve this functionality depending on the specific type of phase failure you want to protect against:

ANSI 50/27 Accidental Energization: This code combination offers protection against a situation where a circuit becomes energized with an incomplete phase sequence. This could happen due to a single-phase open fault or a missing phase connection.

ANSI 47 Phase-Sequence Voltage Relay: This code identifies abnormal phase voltage sequences, it can be set to trip the circuit breaker in case of a missing phase or an incorrect phase sequence.

I.5 Devices for Motor Protection:

Electric motors are the workhorses of industry, driving countless applications across various sectors. Their reliable operation is paramount for maintaining efficient production processes and ensuring safety. However, motors are susceptible to various electrical faults that can lead to damage, downtime, and even fire hazards. To safeguard motors against these potential threats, a comprehensive protection scheme is crucial.

I.5.1 Overload Relays:

Overload relays are a critical component in the protection of electric motors. They are designed to protect motors during an overload event, which occurs when a motor draws more current than it is designed to handle for an extended period.

This could be due to a mechanical overload, where the motor is required to drive a load that is too heavy, or an electrical overload, where the supply voltage is higher than the motor’s rated voltage[21].

Overload relays function by tracking the electric current passing through a motor. Should the current surpass a predetermined threshold for a specified duration, the relay activates and cuts off the motor's power supply. This mechanism serves to avert possible motor damage arising from excessive heat.

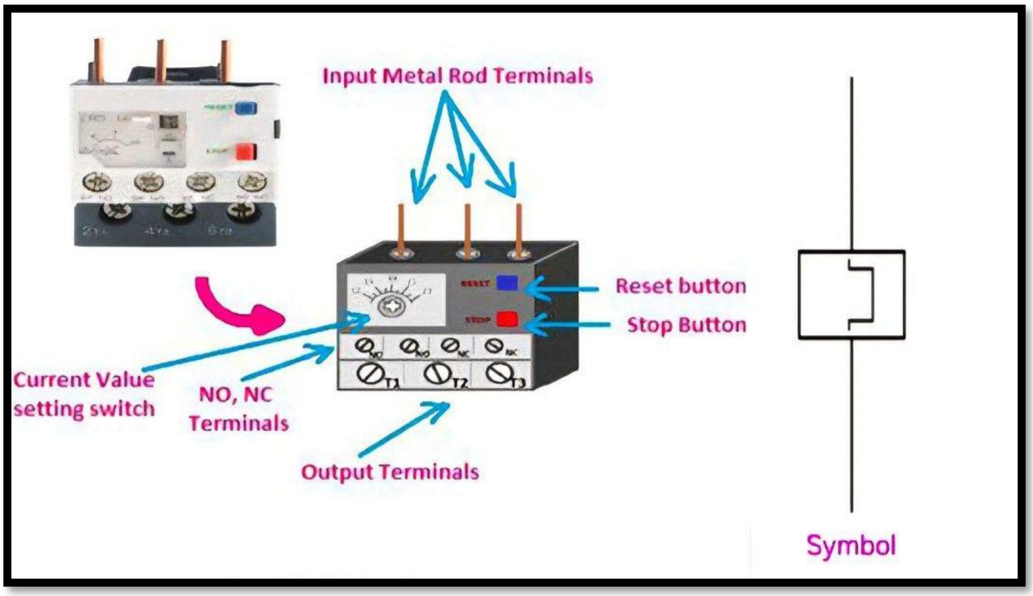


Figure I.7: Three Phase Over Load Relay(OLR) and terminals.

- There are various types of overload relays, such as thermal and magnetic overload relays:

Thermal overload relays utilize a bimetallic strip or a solder pot element to sense the rise in temperature due to an overload, triggering the relay when a specific temperature threshold is reached. Conversely, magnetic overload relays employ an electromagnetic device to detect an increase in electrical current.

Thermal overload protectors function by monitoring the heat produced by the current passing through a motor. If the temperature surpass a predetermined threshold for a specific duration, the protector activates and cuts off the power supply to the motor, thereby preventing possible damage from overheating. [31].

I.5.2 Circuit Breakers:

Circuit breakers are switching devices that interrupt the abnormal or fault current, it is a mechanical device that disturbs the flow of high magnitude (fault) current and, in addition, performs the function of a switch. The circuit breaker is mainly designed for closing or opening of an electrical circuit, thus protecting the electrical system from damage. Circuit Breakers represent one of the most critical power apparatus in the power system [32].

The primary role of a circuit breaker is to stop the flow of current upon the detection of a fault, the resulting arc from the interruption is typically directed into a series of arc chutes, which consist of insulated parallel metal plates that segment and dissipate the arc's heat. The arc is extinguished once the current reaches zero.

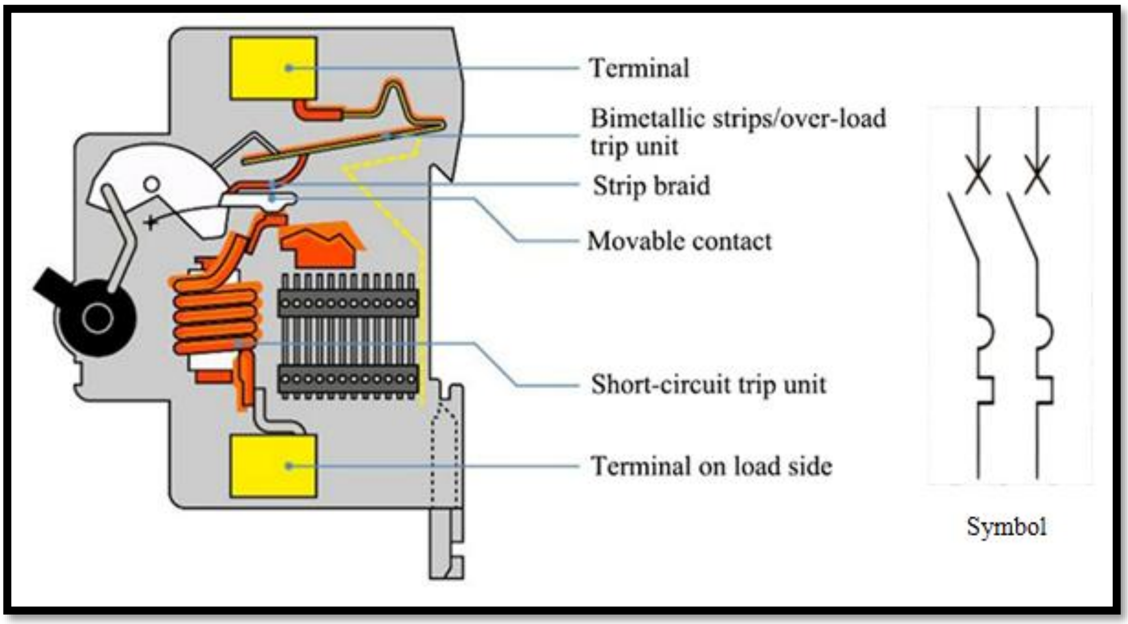


Figure I.8: working principle of circuit breaker.

I.5.3 Fuses:

Fuses serve as protective devices that safeguard circuits against excessive current. They house a thin wire that melts when the current surpasses a specific threshold, thus interrupting the circuit and averting additional harm. As crucial elements of motor protection, fuses contribute to the secure and dependable functioning of motors.

The basic function of a fuse is to interrupt current flow after a fault is detected. It houses a metal wire or strip that melts when excessive current passes through, thus halting the current. After a fuse has been triggered, it becomes an open circuit and stays that way until replaced with a new fuse[33].

Fuses can be composed of elements such as zinc, copper, silver, and aluminum. They function similarly to circuit breakers, interrupting the circuit in the event of a sudden fault. Fuses serve not only as protectors but also as safety measures to shield humans from electrical hazards.

There are several types of fuses, each designed for specific applications. These include:

- **Fast-Acting Fuses:**

These fuses open rapidly when the rated current is exceeded and are used to protect sensitive electronic equipment from overcurrent damage.

- **Slow-Blow or Time-Delay Fuses:**

These fuses can endure temporary surge currents without opening, making them ideal for protecting motors and other inductive loads that draw high currents upon startup.

- **Semiconductor Fuses:**

These fuses are specifically designed to protect power semiconductors, including diodes, thyristors, and transistors.

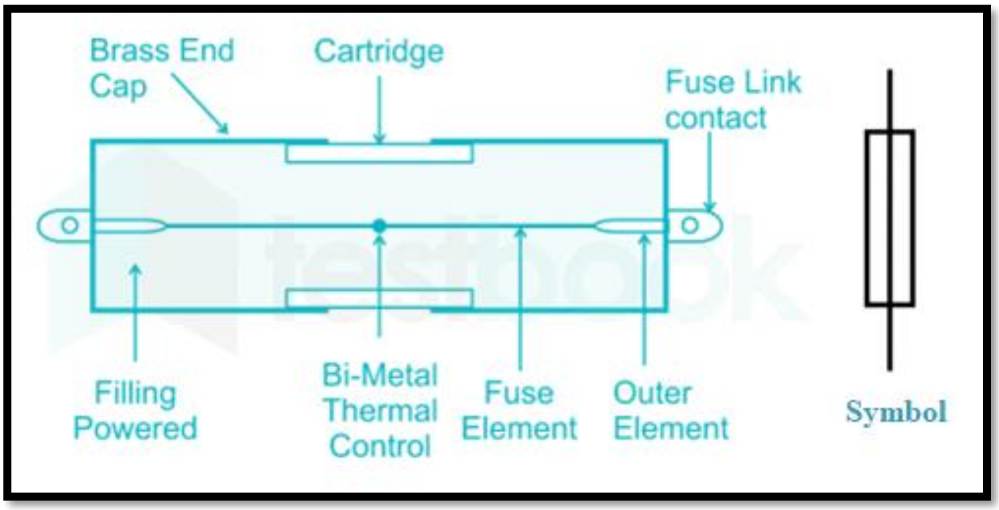


Figure I.9: Structure of a Fuse.

I.5.4 Phase Failure Relays:

Phase Failure Relays are protective devices developed over a century ago to provide the “last line” of defense for electrical systems. They are designed to detect a phase failure, a situation where any of the three phases in a power system fails. This could result from a fuse blowing up or an interruption in the power line[34].

Phase failure could be caused by several factors as like Unbalanced voltage or Single phase or phase loss or Overload and Overvoltage, Undervoltage.

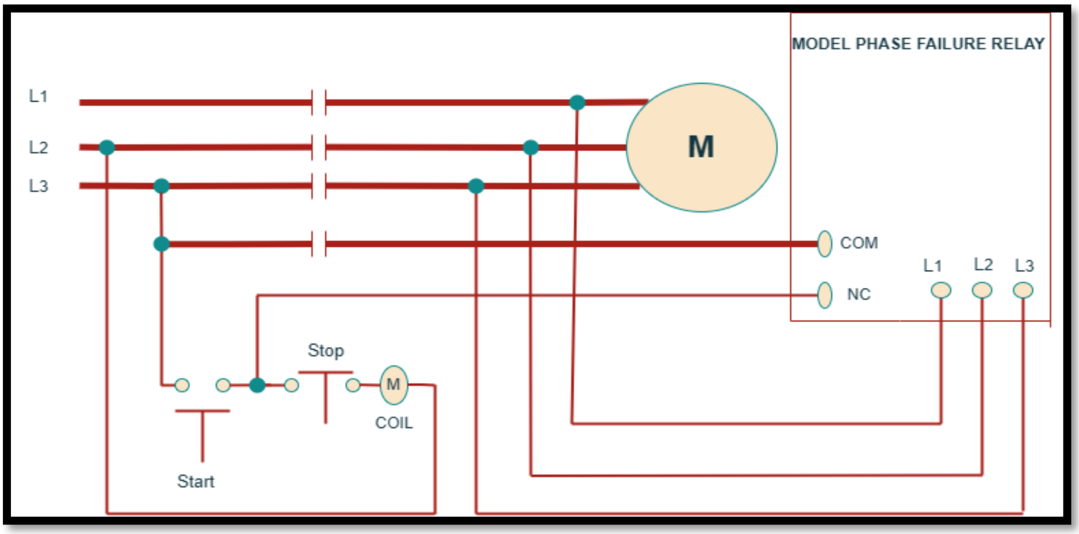


Figure I.10: phase failure relay wring diagram.

Protecting consumer equipment and appliances from damage or complete destruction due to phase failures is critically important. Phase failure detectors are essential for enhancing the quality of service provided by power utility companies and for safeguarding the lives and property of electricity consumers.

I.5.5 Phase Sequence Relays:

Phase Sequence Relays serve as protective devices within power systems, responding to the phase sequence rotation of the utility supply. Their sensitivity to phase sequence is vital for safeguarding power equipment[35].

The primary function of Phase Sequence Relays is to monitor the sequence of supply phases and to disconnect the load if the sequence is incorrect[36]. This is particularly important in three-phase systems, where the phase sequence can affect the operation of certain types of equipment.

Phase-sequence relays are widely used in a variety of applications, including:

- **Motor Protection:** Motors are vulnerable to damage from incorrect phase sequence, which can cause reverse operation or excessive heat. Phase-sequence relays are utilized to maintain the correct phase sequence and protect motors from such damage[37].
- **Pump Control:** Phase-sequence relays in pumping systems safeguard against reverse pump operation caused by incorrect phase sequence, loss of efficiency.

- **Generator Synchronization:** In power plants, phase-sequence relays are critical for ensuring generators are synchronized with the correct phase sequence, avoiding equipment damage due to out-of-phase paralleling.
- **Elevator Control:** Elevators use phase-sequence relays to prevent incorrect phase sequence, ensuring safe and correct directional operation and speed control.

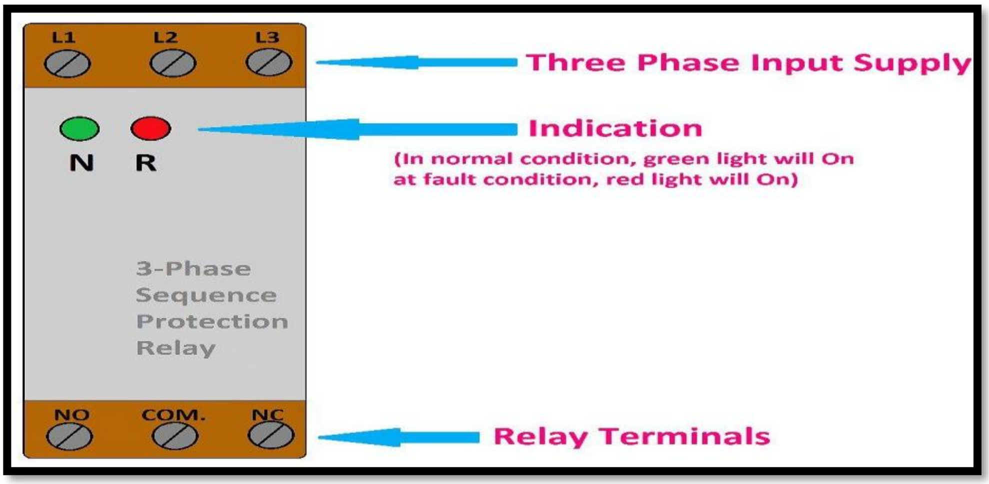


Figure I.11: phase sequence relay terminals.

I.5.6 Under Voltage and Over Voltage Relays:

Under-voltage relays are protective devices utilized in power systems, designed to safeguard electrical systems from potential damage caused by under-voltage conditions. Such conditions may lead to brownouts, distortion, or even permanent damage.

Under Voltage Relays monitor the voltage level in an electrical system and disconnect the load when the voltage drops below a preset level. This helps prevent damage to the equipment and ensures the safety of the system[18].Under Voltage Relays are widely used in a variety of applications, including:

Motor Protection: Motors are sensitive to under voltage conditions, which can cause them to generate excessive heat, leading to damage. Under Voltage Relays are employed to ensure that motors operate within the correct voltage range, protecting them from potential damage.

Power Supply Monitoring: In power supply systems, Under Voltage Relays monitor the voltage level and disconnect the power supply if the voltage drops below a certain level, preventing damage to the power supply and connected equipment.

Over Voltage Relays are crucial in electrical power systems, serving to shield electrical equipment from harmful voltage levels. They are usually linked to a potential transformer and set to activate at or above a predetermined voltage level.

The working principle of an Over Voltage Relay is quite straightforward. It monitors the voltage of the electricity flow in case the voltage goes above or below a preset standard. If the voltage fluctuates too much, the relay trips, shutting off the system and preventing equipment damage and safety issues[38].

In the context of motor protection, overvoltage relays are crucial for safeguarding electric motors. Overvoltage relays work by monitoring voltage levels and acting quickly to isolate the motor during overvoltage conditions, preventing potential damage [18].

Modern motor protection systems have advanced to function near their thermal limits, requiring sophisticated and intelligent protection relays. in this context, Over Voltage Relays offer essential protection against overvoltage conditions that could lead to significant rotor overheating. These relays have the capability to monitor and diagnose potential long-term failures.

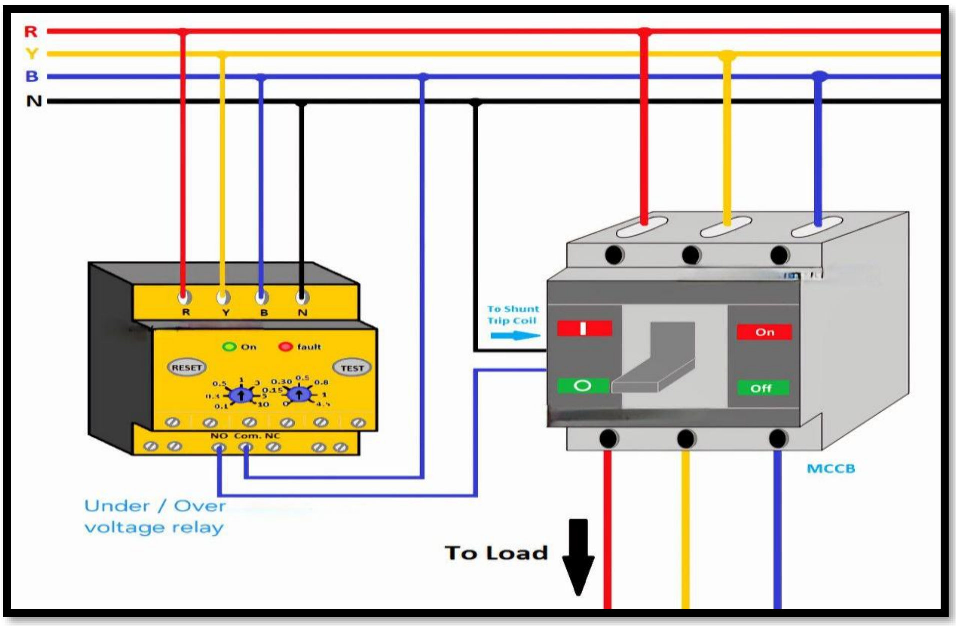


Figure I.12: Under and Over voltage relay connection diagram with load control circuit.

I.5.7 Earth Fault Relays:

Earth Fault Relays are vital for the safety of electrical power systems, serving to shield electrical equipment from harmful earth fault conditions. They are typically connected to a current transformer and calibrated to operate when a fault current to earth exceeds a specific level.

The operation of an Earth Fault Relay is relatively simple. It continuously monitors the fault current to earth and activates if the current exceeds a predetermined threshold. Should the fault current vary excessively, the relay sends a signal to shut off the system, thereby preventing equipment damage and ensuring safety [39].

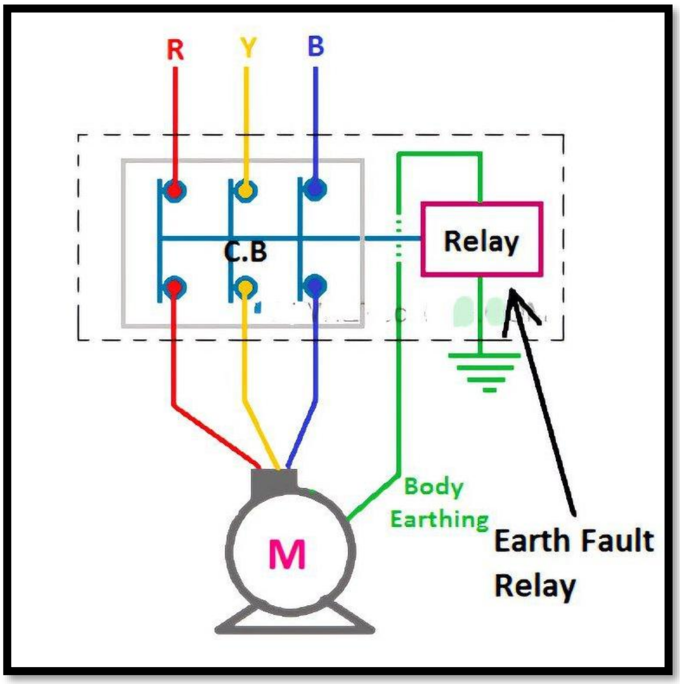


Figure I.13: Earth fault relay protection for a motor.

Earth Fault Relays are crucial. As vital elements of industrial and commercial power systems, motors are vulnerable to earth fault conditions. Earth Fault Relays protect these motors by monitoring the fault current to earth and quickly isolating the motor toprevent potential damage during such conditions.

I.6 Conclusion:

Protection systems of electromechanical system and control devices are crucial for ensuring operational reliability and safety. These systems prevent damage caused by overcurrent, thermal issues, overvoltage, and phase failure.

Electromechanical systems find applications in various industries, including manufacturing and agriculture. Essential motor protection devices include overload relays, thermal protectors, circuit breakers, fuses, phase failure relays, and ground fault relays, each playing a vital role in maintaining motor safety and efficiency.

In the next chapter, we will explore the integration of Internet of Things (IoT) technologies in protecting electromechanical systems, which will undoubtedly lead to more effective strategies for safeguarding these systems.

Chapter II:

IoT System and Voltage / Current Sensors For DC and AC

II.1 Introduction:

Internet of Things (IoT) technology and related devices represent an exciting emerging field in computer science, which is growing rapidly globally. The increasing demand for automation and efficiency has been a key factor in driving progress in this field in the recent period. The proliferation of IoT devices coincides with advances in wired and wireless networking technologies, especially driven by enhanced connectivity to the Internet. Nowadays, most everyday objects can be connected to the network, which reflects the growing demand for automation and efficiency [40] [41].

Voltage and current sensing for both direct current (DC) and alternating current (AC) applications with Internet of Things (IoT) systems is revolutionizing many industries. Hence, this chapter aims to delve deeper into the importance of these sensors and their applications in IoT settings, with a particular focus on Electric motor protection designs[41].

II.2 IOT Applications:

Smart homes are among the uses of Internet of Things, enabling remote control appliances like air conditioning and lighting. used in smart farms to monitor soil and water conditions, improving agriculture. IoT is used by smart cities to enhance infrastructure, including energy efficiency and traffic control. In order to improve security and logistics, location sensing technologies are also employed to precisely locate persons and items. Here's the next Scheme:

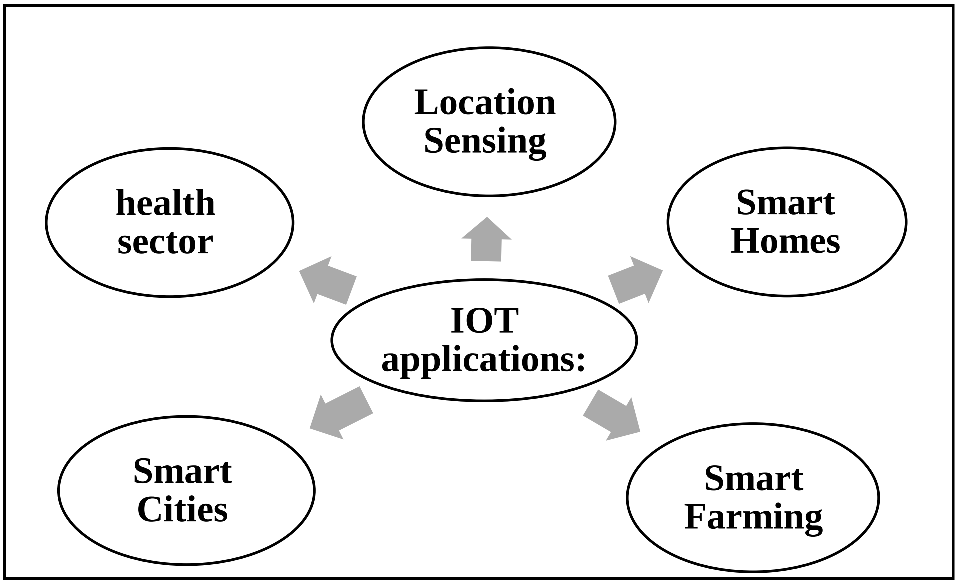


Figure II.1: A diagram of some Internet of Things applications

II.2.1 Location Sensing:

Internet of Things (IoT) utilizes Global Positioning System (GPS) devices for various applications, including:

II.2.1.1 Supply Chain Management and Asset Tracking:

The Internet of Things makes it possible to track assets in real time as they travel around the globe. The efficiency of supply chain management increases with the addition of tracking capabilities.

For instance, businesses can track the whereabouts of vehicles, cargo containers, or expensive equipment as they travel[42].

Figure II.2: Livestock Tracking System.

II.2.1.2 Traffic Management:

IoT can be used in conjunction with location-based systems to collect and analyze information for drivers, helping them choose the best and fastest routes while avoiding roads with accidents, maintenance, or congestion [43].

II.2.1.3 Anti-Theft Protection:

This technology is commonly used in the automotive industry.Through this technology, it’s possible to track the location of a vehicle and locate it if it’s stolen.

Figure II.3: The picture shows detecting the car's location from the phone.

II.2.2 Smart Homes :

Smart homes allow us to remotely control various devices within the house. Examples include turning lights on and off, adjusting curtains, and directly contacting emergency services in case of incidents like gas leaks or fires. Additionally, smart climate control systems can adjust heating or cooling based on weather conditions.

Figure II.4: The picture represents connecting many home devices to the Internet of Things.

II.2.3 Smart Farming:

IoT is used in smart farms to facilitate work and increase productivity. For instance, it enables remote operation of pumps and helps detect malfunctions.

Figure II.5: Using the Internet of Things to spray pesticides.

II.2.4 Smart Cities:

In cities, IoT is used for smart lighting to save electricity. These lights automatically turn on at dusk and off at dawn. Additionally, The Internet of Things helps facilitate the work of police, civil protection, and emergency services, [44]and inform them of the accident site.

Figure II.6: The image represents the use of the Internet of Things in smart cities.

II.2.5 Internet of Things applications in the medical field:

In healthcare, the Internet of Things offers a multitude of uses that help patients, families, doctors, and organizations. The most important of these technologies are the following:

II.2.5.1 Internet of Things for Doctors:

Physicians can better monitor their patients' health by using wearables and other Internet of Things (IoT)-enabled home monitoring technology. They are able to monitor patients' compliance with treatment regimens and any urgent medical needs.

Healthcare providers can interact with patients more proactively and with more vigilance thanks to IoT. Find the most effective way to treat patients while achieving the desired outcomes[45].

II.2.5.2 Follow-up treatment for the elderly:

People's lives have been transformed by the Internet of Things, particularly those of elderly patients, as technology has made it possible to continuously track health status. The families and individuals who live alone are greatly impacted by this.

The warning mechanism notifies the affected family members and health care providers if a person's regular activities are disrupted or altered.

Internet of Things applications have also been used to connect limb mobilization devices, which use electrical or motor sensors to read data.

II.2.5.3 Basic health care:

Patients can receive individualized care with wearable technology like fitness bands and other wirelessly connected equipment like glucometers, heart rate monitors, and blood pressure monitoring cuffs.

You can program these devices to remind you of various things, such as blood pressure changes, appointments, activity checks, and calorie counts.

Figure II.7: The figure represents linking the health sector to the Internet of Things.

II.3 Importonce of sensors in IOT:

The Internet of Things has brought about a major transformation in various fields, as sensors played a crucial role in this revolution, as this technology includes collecting information and measurements, processing them, and translating them into usable information. This is done through sensors, and then we connect them to a communications network and send them to the user who can read and control them through a program connected to the Internet[46]. It becomes clear to us here that the sensors are like the five senses of this technology, as they are responsible for the initial measurements and basic information. Accordingly, we are taking measures. There is no IoT without sensors.

Figure (II.8) illustrates the configuration of an IoT network with sensors. Sensors are usually referred to as the endpoint in the IoT network because they are at the outermost edge from the cloud servers' perspective. Note the cloud servers on the right side of Figure(II.8). Even though these sensors are small and do not seem as important as the cloud servers, they can play a critical role in system design.

Sensors need to connect and communicate with the gateways and cloud servers to operate in the IoT network. Nowadays, wireless technologies such as Bluetooth, NFC, RF, Wi-Fi, LoRaWAN, NB-IoT (cell) are commonly used. Depending on how the network is set up, more and more gateway products are used to perform edge computing (data analytics) before sending data to the cloud servers.

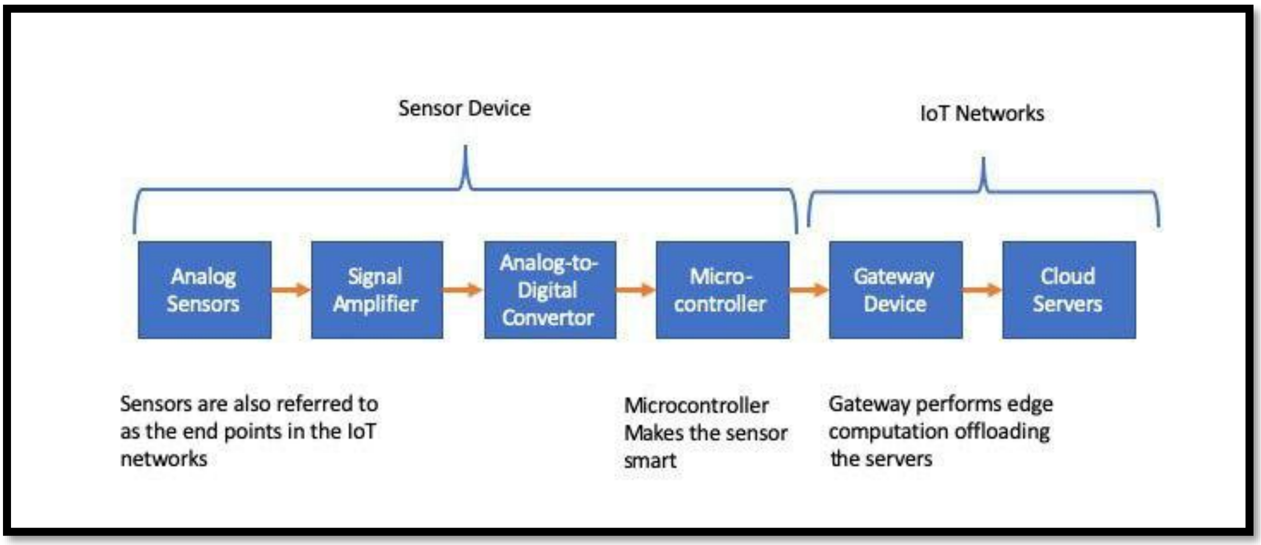


Figure II.8: The sensor network block diagram shows the relationship between the sensor device and the IoT network.

The Industrial Internet of Things or IOT solution has been gaining global attention in recent years and this is when it comes to technological advancement and connectivity. With only human interaction, intelligent IoT connectivity allows sensors to send real-time data via virtual dashboards. Industries in almost all fields are using sensors, however, the communication aspects offered by IoT using sensors have evolved with the enhancement of some promising features that can solve any traditional problem of industries and here we will mention some of them.

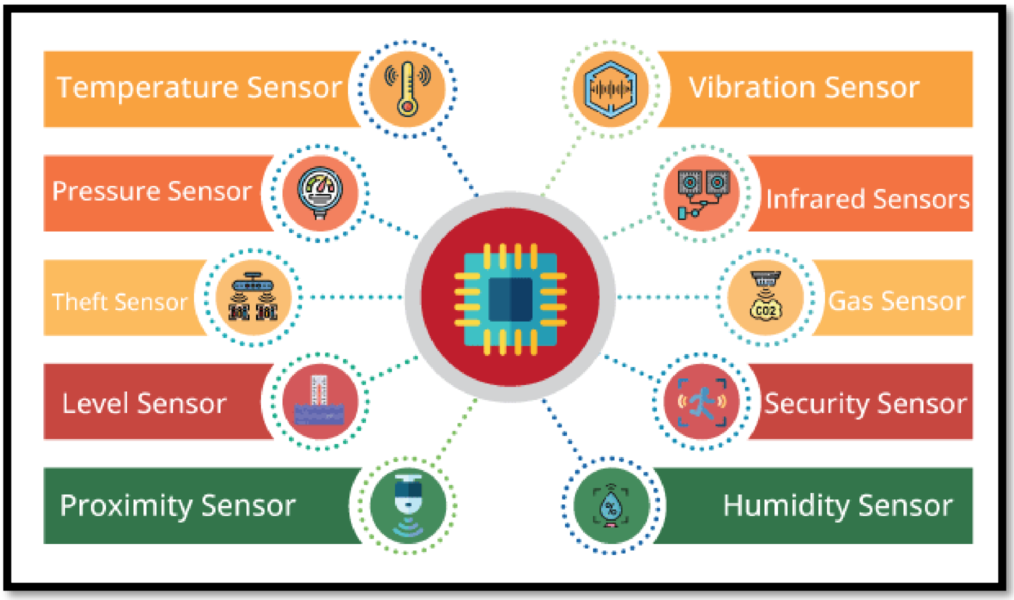


Figure II.9: Top 10 sensors for IOTsolutions.

II.4 Sensors for Motor protection:

In today's industrial world, motor protection is crucial in industrial environments to prevent equipment damage and ensure continuous operation. Different sensors are used to protect electric motors, and several types of devices are relied upon to monitor the condition of the motor and detect any potential problems.

These devices include sensors for temperature, vibration, current, voltage, pressure and humidity. By monitoring these parameters, sensors can identify abnormal changes and predict malfunctions before they occur, helping to reduce unplanned downtime and improve operating efficiency. There are three important sensors in protecting motors: temperature, current and voltage sensors.

II.4.1 Temperature sensors:

Its function is to keep an eye on the motor's temperature and, should it increase above the allowable limit, to transmit signals and commands to halt the motor.

II.4.1.1 Types of temperature sensors:

There are a variety of temperature sensors available.We mention the most common ones as follows:

a) **Resistive sensors:** These sensors' resistance varies with temperature, which affects the voltage that is measured.

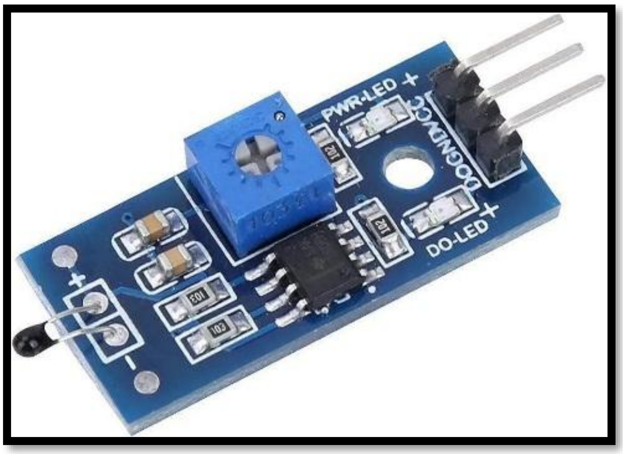


Figure II.10: Resistive sensors.

b) **Thermocouple sensors (PTCs):** When a specific temperature is attained, they quickly alter their resistance, which is used to control motor protection circuits.

Figure II.11: Thermocouple sensors

II.4.2 Current sensors:

Its function is to monitor the motor's current and, should an excessive current be detected that could harm the motor, to send signals and commands to turn it off right away.

II.4.2.1 Types of current sensors:

There are a variety of current sensors available. We mention the most common ones as follows:

a) **Current transformers**: transform the motor current into a quantifiable, lesser current.

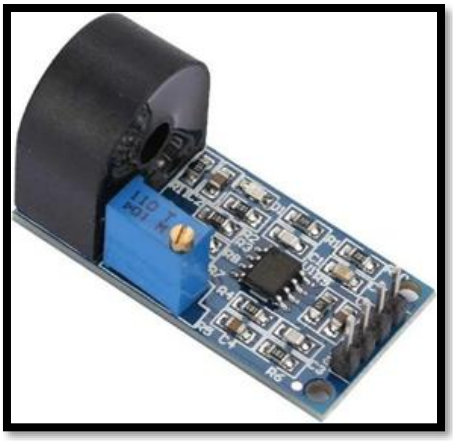


Figure II.12: Current transformers.

b) Hall sensors: utilized for measuring current without coming into contact with the current conductor directly.

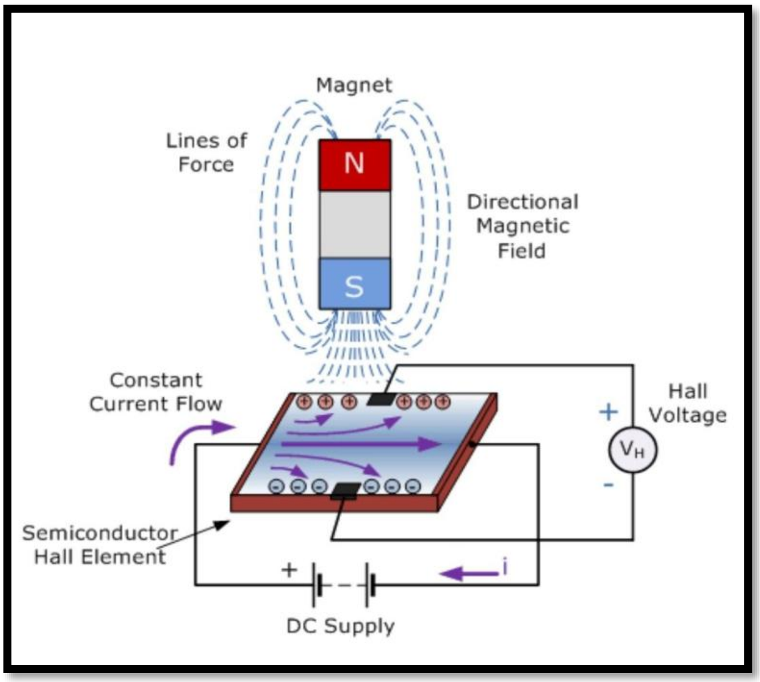


Figure II.13: Hall effect sensors.

II.4.3 Voltage sensors:

Its function is to monitor the motor's voltage and, should the voltage drop or rise beyond the allowable limit, to transmit signals and commands to stop the motor.

❖ **Types of voltage sensors:**

There are a variety of voltage sensors available. We mention the most common ones as follows:

- **Voltage Dividers:** It divides the motor voltage into smaller, measurable voltages.

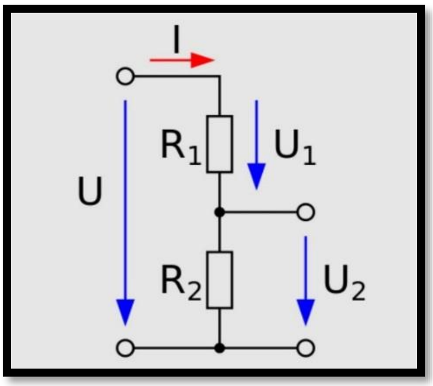


Figure II.14: Resistive Voltage divider

II.5 Sensor Technologies for AC and DC:

Sensing methods for direct current (DC) and alternating current (AC) are essential in many different applications. The precise and efficient measurement of electrical current and voltage is the goal of these methods. Typical methods include the following:

II.5.1 Isolated amplifiers for sensor :

Because of their isolation barrier, isolated amplifiers are different from their non-isolated counterparts. They are made to separate signals from input and output, guaranteeing precise data transfer and safeguarding delicate equipment. In high-voltage applications, this isolation barrier guards against the risk of electrical shock and isolates individual circuits or sections of circuits from one another by obstructing return current interference.

Isolation barriers are highly resistant to electromagnetic interference (EMI), which results from external sources. Ignoring EMI can lead to decreased signal chain performance or data errors.

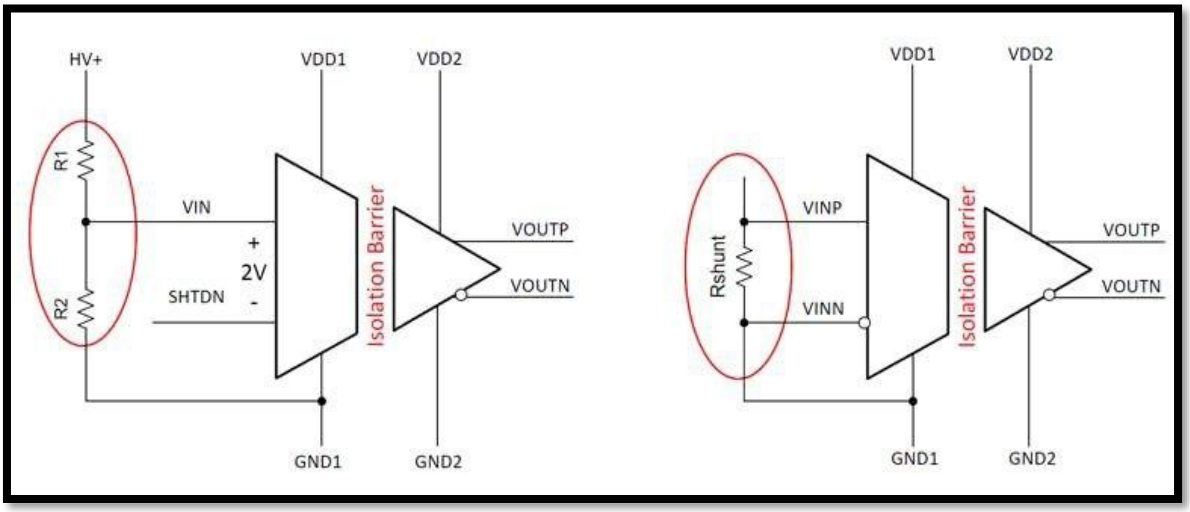


Figure II.15: The figure represents an isolated Amplifiers.

II.5.1.1 Working principle of isolated amplifiers:

There are many isolated amplifiers. We suggest the AMC1200 and explain its working principle.

First, Input Signal Reception: The AMC1200 receives an input voltage signal (VIN+ and VIN-) from an external source.This input signal can represent various parameters, such as current or voltage, depending on the use.[47] [48] [49].

Second, Optical Isolation: The magic happens here! The AMC1200 utilizes a silicon dioxide (SiO2) barrier to achieve optical isolation. This barrier ensures there is no direct electrical connection between the input and output sides. Think of it as a protective wall that prevents undesirable electrical currents from crossing [47] [48] [49].

Third, Signal Conversion and Amplification: Inside the AMC1200, a delta-sigma (ΔΣ) modulator processes the input signal. The modulator converts the analog input into a digital stream, which is then amplified. The final stage generates two differential output voltages: VOUT+ and VOUT- [47] [48] [49].

Fourth, Differential Output: VOUT+ and VOUT- represent the amplified and isolated version of the input signal. These outputs are referenced to an isolated ground, ensuring safety and preventing ground loops. These differential outputs can be used for precise measurements or control purposes [47] [48] [49].

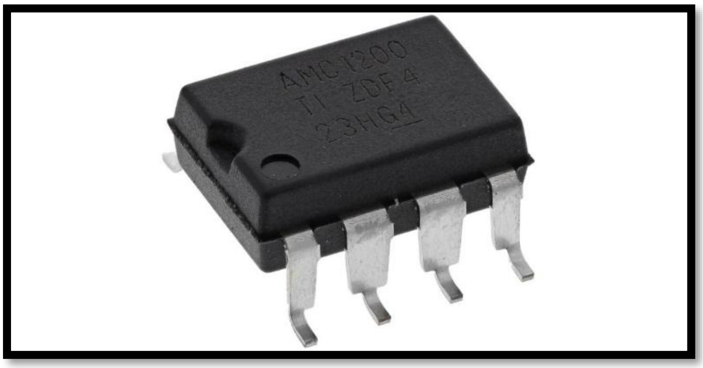


Figure II.16: AMC 1200 electronic element form.

II.5.1.2 Types of Isolation Amplifiers:

There are various varieties of isolation amplifiers available. The most typical ones are:

a) Optical Isolation Amplifiers:

These devices use light waves to convey electrical signals via an optocoupler. Although they provide a high level of isolation, they may experience fluctuations in performance due to temperature.

b) Transformer Isolation Amplifiers:

These transfer signals via a transformer. Transformer isolation amplifiers often have high degrees of isolation and are sturdy. They might not be the best choice for high-frequency applications.

c) Capacitive Isolation Amplifiers:

These amplifiers are resistant to magnetic fields because they transport signals over a capacitive barrier. However, strong electric fields may have an effect on them.

II.5.1.3 Applications isolated amplifiers:

- ✓ Isolated amplifiers are typically used for two purposes: voltage and current sensing. Figure (II.15)shows an illustration of one such implementation. While current sensing is often accomplished with an in-line shunt resistor and an isolated modulator, voltage sensing is typically accomplished using a resistor-divider circuit with an isolated amplifier.
- ✓ Since there can be significant ground potential differences between the high- and low-voltage grounds, isolated amplifiers are frequently used in industrial and automotive applications as parts of voltage- and current-sensing systems to isolate two different voltage potentials from one another. Large currents will flow from a direct connection between these two ground potentials, damaging equipment.
- ✓ Large noise currents are injected into the ground returns during operation by equipment, including electric motors, which might mix with the ground returns of the signal-path measurement findings. By breaking the ground returns with the isolation barrier, isolated amplifiers stop "noisy" and "clean" ground returns from coupling together.

II.5.2 Sensor for measuring Voltage AC and DC:

The voltage level in things is measured via voltage sensors. These gadgets are utilized in several applications and incorporate a range of technologies. Among these methods are the following:

II.5.2.1 Resistive Voltage Divider:

It is an electrical circuit used to divide into two voltages, and it consists of two resistors connected in series. The principle of voltage division is based on the fact that the voltage across the resistance in the circuit is directly proportional to the value of the resistance. The same current flows in the two resistances. Using Ohm and Kirchhoff's second law, we find[50]:

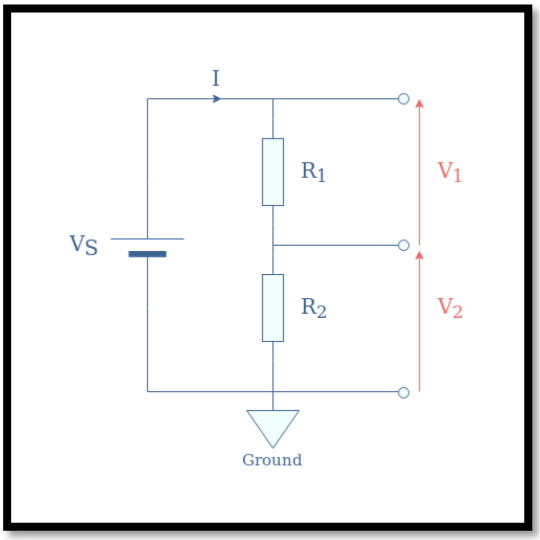


Figure II.17: The picture explains Resistive Voltage divider

we've got

$$V_1 = I.R_1 \quad \text{II.1}$$

$$V_2 = I.R_2 \quad \text{II.2}$$

Also

$$Vs = V_2 + V_1 = I.R_1 + I.R_2 \quad \text{II.3}$$

$$\text{Req} = R_1 + R_2 \quad \text{II.4}$$

$$Vs = Req.I \quad \text{II.5}$$

$$I = \frac{Vs}{Req} \quad \text{II.6}$$

$$I = \frac{Vs}{Req} \quad \text{II.7}$$

$$I = \frac{Vs}{R_1 + R_2} \quad \text{II.8}$$

Substituting in V_1 or V_2 we find:

$$V_1 = \frac{Vs.R_1}{R_1 + R_2} \quad \text{II.9}$$

$$V_2 = \frac{Vs.R_2}{R_1 + R_2} \quad \text{II.10}$$

By exploiting these two expressions, the input voltage can be determined through the resistors or vice versa

Where:

- V_1: is the voltage across both ends of the resistor R1.
- V_2: It is a voltage across both ends of the resistor R2.
- *I:* is the current passing through the circuit.
- R_1: is the value of the first resistance.
- R_2: is the value of the second resistance.
- *Vs*: is the input voltage.

II.5.2.2 Capacitive Voltage Divider:

The working principle of a voltage divider with capacitors is the same way as a voltage divider with resistors, but we put capacitors in place of the two resistors we find[51].

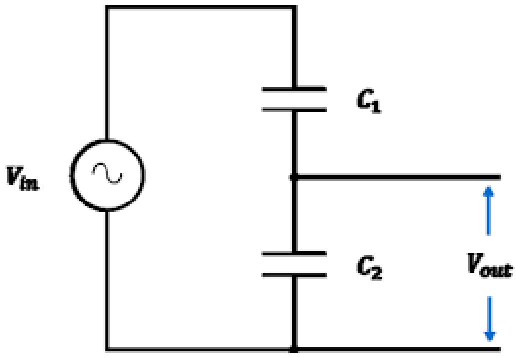


Figure II.18: The picture explains Capacitive Voltage Divider

$$V_{c1} = \frac{Vin.Ceq}{C_1} \quad \text{II.11}$$

$$V_{c2} = \frac{Vin.Ceq}{C_2} \quad \text{II.13}$$

$$Ceq = \frac{C_1.C_2}{C_1 + C_2} \quad \text{II.15}$$

$$V_{c1} = \frac{Vin\,.C_2}{C_1 + C_2} \quad \text{II.17}$$

$$V_{c2} = \frac{Vin\,.C_1}{C_1 + C_2} \quad \text{II.19}$$

Where :

- V_{c1}: is the voltage across both ends of the capacitor C1.
- V_{c2}: is the voltage across both ends of the capacitor C2.

- I: is the current passing through the circuit.
- C_1: is the first capacitor value.
- C_2: is the value of the second capacitor.
- Vin: is the input voltage.

II.5.3 Effet hall:

When an electric current is passed through a metal strip made of conductive or semi-conducting material that is positioned in a vertical magnetic field as a negative charge carrier, as shown in Figure (II.19), a magnetic force is created on the current-carrying charges in the strip that pushes the charges in the force's direction[52].

The right-hand rule for force direction states that if the charge carrying the current is negative, the magnetic force will be upward. This pushes some negative charges upward because the upper side of the strip acquires a negative charge and, in the event of electrical neutrality, a local deficit develops on the lower side of the material, making it charged. When a chip has a positive charge, this indicates that there is a potential difference at its two edges. This potential difference, known as the Hall potential difference, can be detected with an extremely sensitive voltmeter[52].

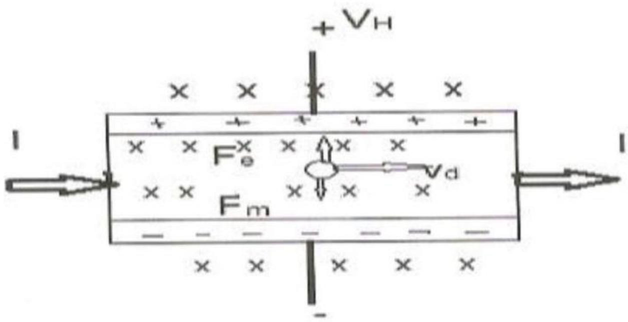


Figure II.19: explains the hall effect at the electron level[52].

The top of the chip becomes positively charged and the bottom becomes negatively charged if the current-carrying charges are positive, as they are in some semiconductor types. This means that an upward magnetic force is also acting on the charges. The creation of an electric field inside the chip results in the generation of an electric force on the electric charges when the chip's edges are charged with both positive and negative charges. This force is opposing the magnetic force. A state of equilibrium between the electric and magnetic forces is induced as seen in Figure (II.19), following the saturation of the chip's edges with electric charges[52].

When the electric force f_e is equal to the magnetic force f_m.

$$f_e = f_m \tag{II.21}$$

$$q.E_H = V_d.q.B \tag{II.22}$$

Become

$$E_H = V_d.B \tag{II.23}$$

where

- V_d:Drift speed
- B: Magnetic field strength
- E_H: Hall field strength
- q: the charge carrier of the current
- f_e: electric force
- f_m: magnetic force

And we have the current

$$I = n_q.A.V_d \tag{II.24}$$

Where:

- n_q: Charge density
- A: Cross-sectional area of the slice
- $A = t.d$
- t: Slice thickness
- d: Slide show
- I: current

Become

$$V_d = \frac{I}{n_q.A} \tag{II.25}$$

We substitute it into E_H we find

$$E_H = \frac{I}{n_q.A}.B \tag{II.26}$$

And also equal

$$E_H = \frac{V_h}{d} \qquad \text{II.27}$$

Where:

V_h: voltage hall

equal relations(II.6) and (II.7)

$$\frac{V_h}{d} = \frac{I}{n_q.A}.B \qquad \text{II.28}$$

Hall voltage becomes equal to

$$V_h = \frac{I}{n_q.t}.B \qquad \text{II.29}$$

So that the Hall coefficient is equal to $\frac{1}{n_q}$ and is symbolized by R_H any $R_H = \frac{1}{n_q}$.

$$V_h = \frac{I.B}{t}.R_H \qquad \text{II.30}$$

Using Hall voltage, we can measure current or voltage by placing the Hall effect sensor close to the conductor that transmits the current. A magnetic field is produced proportionate to the current flowing through the conductor. When the Hall effect sensor is exposed to this magnetic field, it produces a Hall voltage that increases with the magnetic field's strength.

After then, an amplifier measures and processes the Hall volta to create an output signal that is proportionate to the input current. This output signal is usually a voltage or current. There are therefore several control, security, and measurement applications that can make use of this output signal. Including voltage and current measurement[53].

II.5.4 Current Transformers (CTs):

A current transformer works by converting a high current into a lower current that can be easily measured by measuring instruments. This is done through the principle of electromagnetic induction, as described by Faraday's law.

He CT consists of a core, a secondary winding, and a primary winding often with a single loop. It is a useful sensor for monitoring strong AC current. This device does not need additional driving circuits. Its ability to monitor very high current while consuming very little electricity is another important feature. However, a very high initial current or a large DC component in the current may cause the ferrite material used in the core to saturate, leading to signal distortion. Another problem is that once the core becomes magnetic, it will suffer hysteresis, which will reduce accuracy unless it becomes magnetic again. Furthermore, they are unable to detect DC currents in standard form because the basic principle is based on detecting a flux change, which is proportional to the change in current[54] [55].

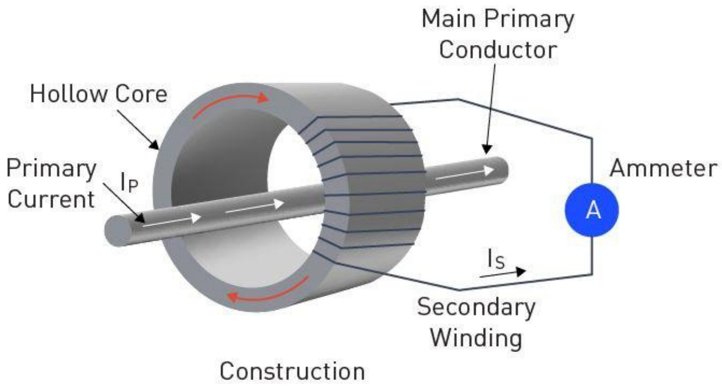


Figure II.20: Represents a current transformer.

This is a simple explanation of Current transformers (CTs), also known as instrument transformers, are used to measure currents in the electrical network. These transformers have a good response to moderate overcurrent and can respond very quickly to short circuit fault currents. They also provide good galvanic isolation between the primary and secondary circuits. Like voltage transformers (VTs) or potential transformers (PTs), CT transformers are transformers with special characteristics that allow primary and secondary circuits to be electrified at the same time without any direct electrical connection between them[56].

II.5.4.1 Types of current transformers:

Figure II.21: The figure shows Types of current transformers.

Some of Faraday's laws used in these sensors:

This equation shows how to calculate the secondary voltage in an electrical transformer based on the frequency, the number of turns in the secondary coil and the maximum magnetic flux.

$$E_p = \sqrt{2}\pi f N_p \varphi_m \qquad \text{II.31}$$

And

$$E_s = \sqrt{2}\pi f N_s \varphi_m \qquad \text{II.33}$$

The transformer current ratio is given by the following relationship:

$$N_s = \frac{I_p}{I_s} \times N_P \qquad \text{II.34}$$

Where:

- E_p: primary voltage.
- N_p: number of turns in the primary winding.
- E_s: secondary voltage.
- N_s: number of turns in the secondary winding.
- π: Constant ratio (pi), approximately 3.14159.
- f: Electrical frequency in cycles per second (Hz).
- φ_m: maximum magnetic flux.
- I_p: is the primary current.
- I_s: is the secondary current.

II.6 Proposed Motor Protection Design with Sensors:

First, we have a power schematic labeled “Ph1-2-3” that connects to a contactor. We control it using a relay through commands from a microcontroller system. When triggered, it opens either A1 or A2.

The microcontroller system can open or close the relay based on readings from voltage and current sensors. By collecting data from these sensors, we can achieve several objectives:

- **Decision Making**: The system can decide whether to activate or deactivate itself.

- **Predictive Analysis:** It can predict different types of overloads by monitoring voltage and current values. For instance, if the voltage exceeds a threshold or the current goes beyond a certain limit, the system can take action to open or close the relay.

While some predictive features work without internet connectivity, there are commands that require internet access. For instance, using cloud services, we can remotely control the relay through a smartphone app. We've chosen Model Sim for data transmission and communication, ensuring real-time updates.

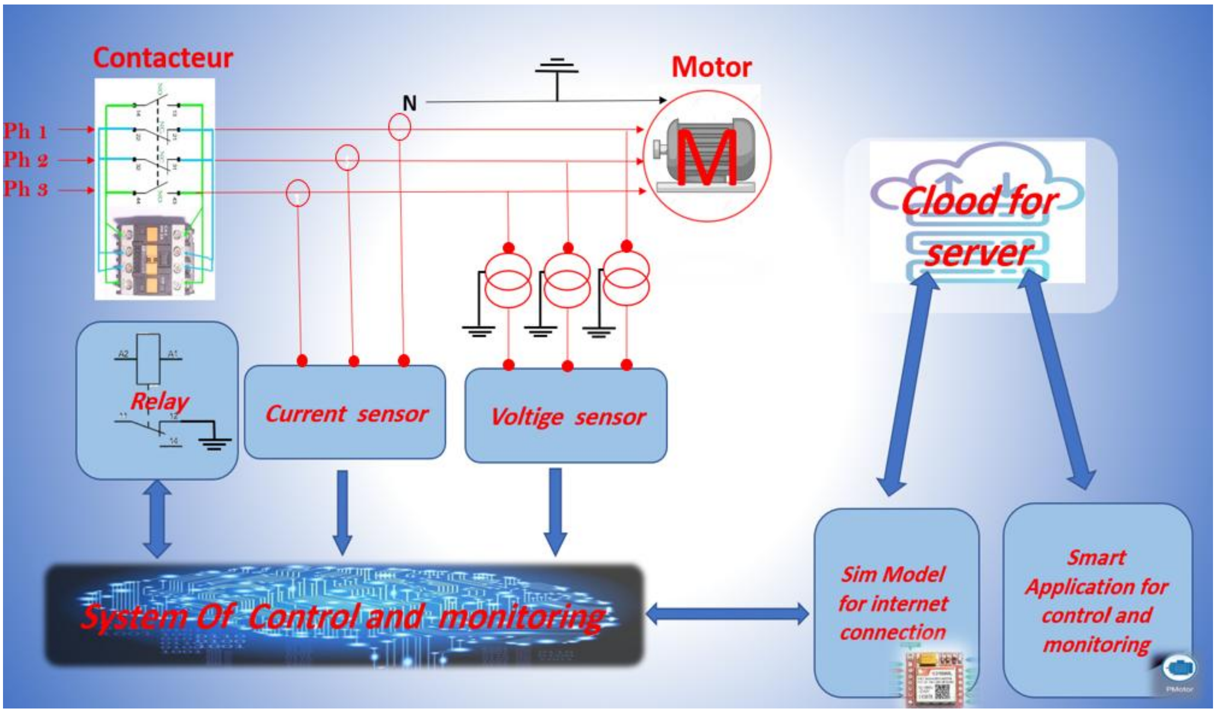


Figure II.22: Proposed scheme for designing motor protection with sensors.

II.7 Conclusion:

The integration of Internet of Things systems with voltage and current sensors offers numerous benefits for the industry, playing a crucial role in enhancing the protection of pumps and industrial equipment. In this chapter, we have explored the applications of the Internet of Things and the significance of sensors In improving production efficiency and minimizing unexpected failures through monitoring equipment conditions and predicting potential issues. We have examined various sensor technologies, such as AC and DC current sensors, voltage sensors, insulation sensors, and isolation amplifiers, as well as Hall effect sensors for voltage and current.

These sensors have demonstrated their role in protecting motors and industrial machinery, showing how sensor technology can help avoid unplanned downtime and reduce operating costs. Investing in this technology is not merely a step towards technological progress but an investment in enhancing overall production and maintenance processes, improving the work environment, and increasing worker safety.

With the completion of this chapter, we now look forward to designing printed circuit boards (PCB) in the next chapter, where we will delve into the details of designing and implementing PCBs that utilize control and protection technologies for motors. We will also learn about the verification of results and measurements.

Chapter III:

PCB Design for Motor Monitoring, Control, and Protection

III.1 Introduction:

The world has transitioned from traditional, challenging lifestyles to easier and faster ways of living in various fields. This is largely due to the widespread use of the Internet of Things (IoT), which connects devices to users via the internet[57]. Despite these advancements, there are still challenges in controlling and protecting electrical motors. In response to this challenge, we have developed a smart control panel for monitoring and protection the power supply to electrical motors, integrated with IoT.

This presentation aims to highlight the stages of development and implementation of this intelligent panel, focusing on the steps involved in coordination, design, and manufacturing. We will review the results achieved through this practical work and assess its effectiveness in improving the management of motor protection operations.

The smart panel is connected to the Internet of Things (IoT) via a SIM card, allowing real-time communication with the user. Consequently, the user can remotely control motor operation and shutdown using their phone.

The project aims to enhance the efficiency of electrical motors, increase their lifespan, and reduce operational costs through several precise stages. These stages include designing and manufacturing a PCB (printed circuit board), installing the necessary electronic components, and developing voltage and current sensors. The controller is programmed to send information and commands via an internet-connected cloud server, and apply this entire system to the pump.

III.2 Sensor Design:

In this title, we will explain how voltage and current sensors work :

III.2.1 Description of voltage sensor:

The sensor we designed consists of an integrated set of electronic components that work together to measure voltage and then generate a signal, which is then processed using a controller such as an Arduino.

Elements:

- Two resistors, each with a capacity of 4.7 MΩ, connected to a voltage of 220 volts.
- A resistance of 4 KΩ is connected to the two resistors in parallel. This resistor is variable, and is adjusted based on the maximum input voltage the AMC1200 can handle, ensuring it does not exceed $250mV$ for $Vmax \times 2$.

- Several capacitors were also used to smooth the signal coming from the resistors, ensuring an accurate and distortion-free signal after passing through the capacitors and arriving at the AMC1200 isolation amplifier.
- The AMC1200 isolates and amplifies the signal, ensuring that the power circuit is isolated from the control circuit, enhancing readability.
- The Arduino module then receives the amplified signal from the AMC1200 and takes it as a standard reference value. If any changes in this value occur due to **errors or** voltage differences, the Arduino takes appropriate action based on the installed software.

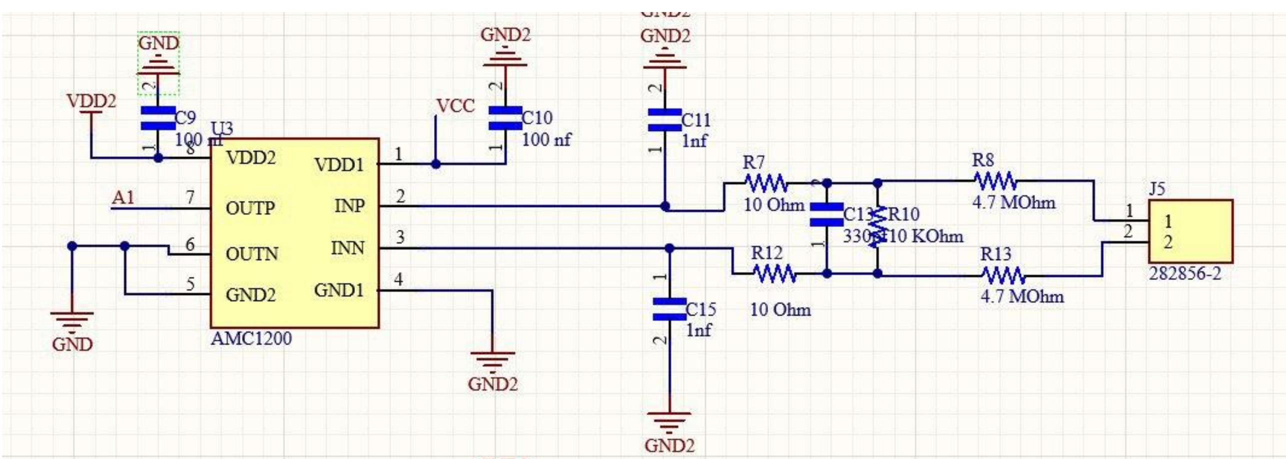


Figure III.1: Voltage sensor design.

- **The working principle of the sensor:**

Firstly, the process of connecting the resistors and capacitors begins in the specified way to obtain a signal related to the tension to be measured. Secondly, the signal smoothing process, where the signal then passes through the capacitors to smooth it out and ensure it is free of distortion. Thirdly, the signal amplification process, where the signal reaches the AMC1200, where it is isolated and amplified. Fourthly, the processing process, where it is sent. The amplified signal is sent to the Arduino module, which takes it as a reference value. When any change in tension occurs, the change is detected by the Arduino, which in turn takes the necessary actions based on the software installed on it.

III.2.2 Current sensor description:

The current sensor we have manufactured consists of several electronic components including resistors, capacitors, the AMC1200, and an Arduino. It is designed to measure the current in a 220 volt circuit. First, a resistor with a capacity of 0.18 Ω or less is installed in series with the electrical current socket, and the resistor's capacity is determined based on the electrical load. To facilitate signal conditioning and filtering, a set of capacitors with various capacities are also used to further smooth the signal. The filtered signal passes through the capacitors and reaches the AMC1200, an analog isolation amplifier, which isolates and amplifies the signal. The amplified signal is then sent to an Arduino controller, which takes it as a normal reference value. When any changes in the current are detected by the sensor, and if there is an increase that could potentially cause faults, this value changes, prompting the Arduino to take necessary actions according to the installed program. However, the sensor experienced a malfunction when more than one sensor was connected together.

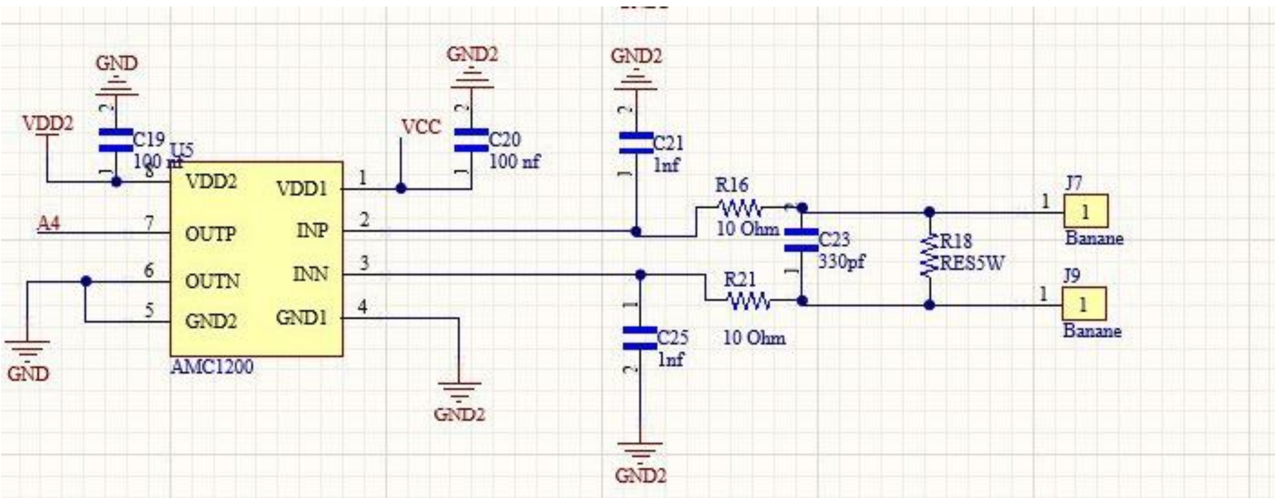


Figure III.2: Current sensor design**.**

III.2.3 Current transformer sensor:

Following the failure of the previous current sensor, we designed and implemented a current sensor using a current transformer (CTS) to measure the current in an electrical circuit operating at a voltage of 380 volts. The design consists of a magnetic ring that is affected by the magnetic field generated by the current passing through the primary wire, which induces a secondary current proportional to the original current. This secondary current is converted into a voltage via a 200 ohm resistor, and the signal then passes through capacitors to filter out noise and distortion. The resulting voltage is sent to the Arduino module which reads the signal and analyzes it to take appropriate actions based on the preset programming. This design features electrical insulation that protects the control circuit from electrical hazards in the event of faults, enhancing the safety and reliability of the system.

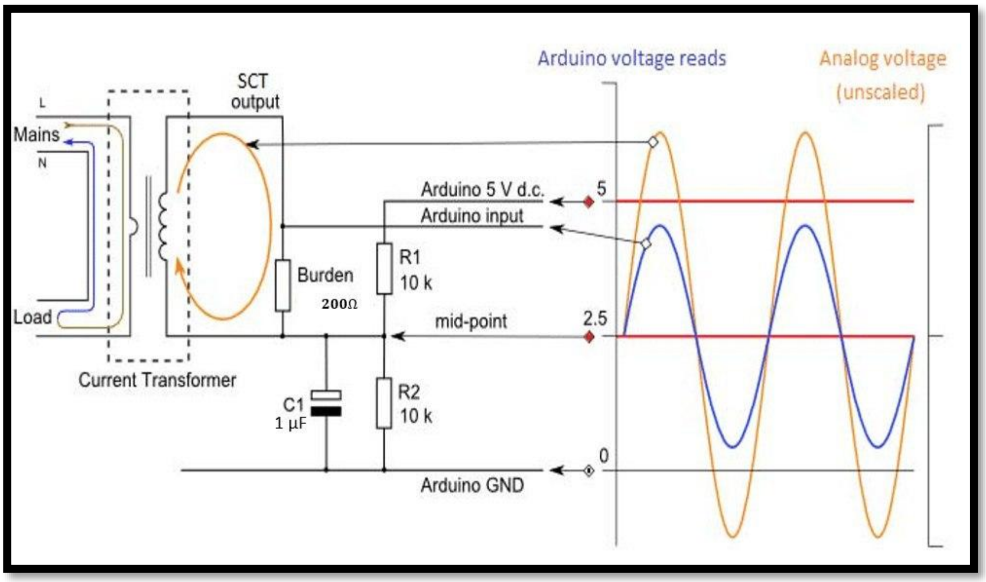
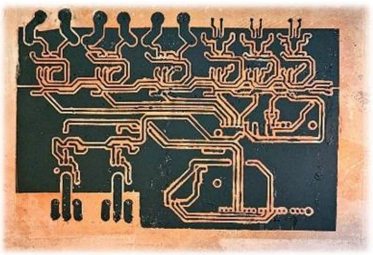
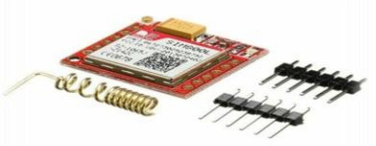


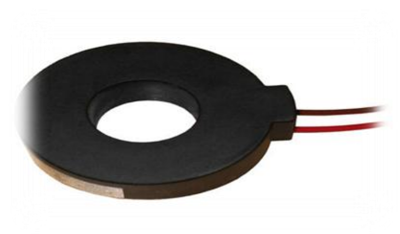
Figure III.3: Current transformer sensor design.[58]

III.3 System Components :

Here we mention the basic components needed to complete the project :

The Number of pieces	Image	The Description	Hardware
1		Its role: It brings all the components together in a compact and organized design. Provides copper tracks to connect components to each other electrically.	PCB board
3		Its role: A high-precision differential amplifier used to isolate analog signals. It can be used to monitor motor current and send precise information to the Arduino controller.	AMC1200

1		Its role: It works as an insulator for the electrical circuit, as the control circuit is isolated from the main sensor circuit to ensure the safety and stability of the system and prevent interference between the circuits	BO505s-1w
		Its role: Smoothing voltages and removing interference from electrical signals. They provide greater circuit stability for better control	Capacitors
		Its role: Controls the flow of electrical current through the circuit. They are used to adjust voltage and current levels to protect sensitive components such as Arduino and SIM module.	Resistors
1		Her role: The mastermind of the department. It receives commands via the mobile network (through the SIM module) and sends control signals to the rest of the components to control the motors.	Arduino Uno
1		Its role: It enables the circuit to connect to the Internet and the user to receive commands from a remote location. This will be done on the Internet.	SIM Module
2		Its role: It acts as an electromagnetic switch to enable high-current control of motors. It is powered by signals from the Arduino.	Relay honko

3		Its role: It monitors the electrical current passing through the motors and transmits this information to the Arduino controller. Which Allows accurate current reading for efficient motor control.	Current Transformers

III.4 PCB Design and Manufacturing Steps:

To manufacture a PCB board, you must go through several steps. These steps constitute a technical PCB manufacturing process to obtain an efficient and high-quality PCB board.

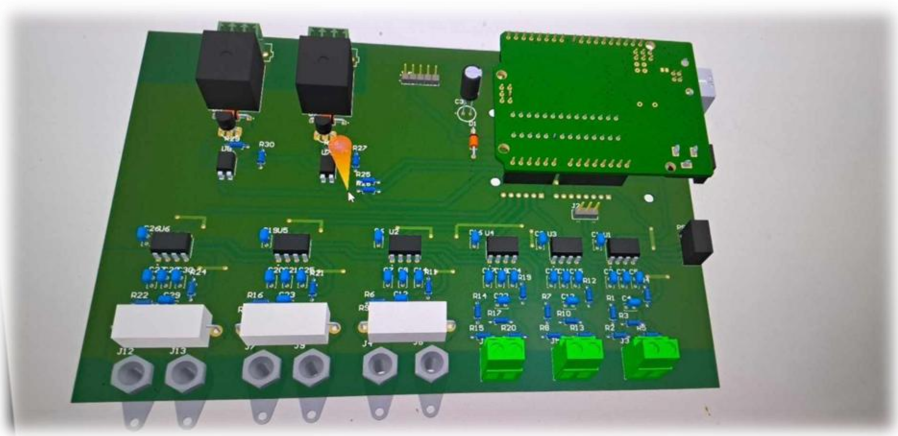


Figure III .4: 3D PCB Design.

- Firstly, before starting the PCB manufacturing process, we design the integrated circuit with all its components in real-world dimensions using a 3D version of the Altium Designer software.

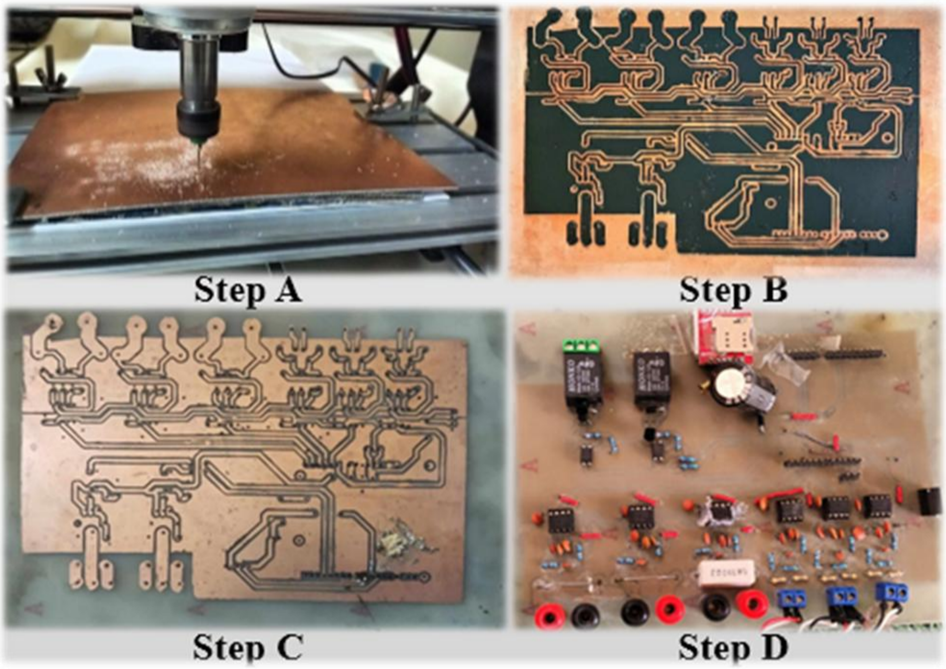


Figure III .5: PCB Design and Manufacturing Steps.

- **Step A (Drilling):** We design holes for mounting electronic components by soldering onto a copper board, lift it to a CNC machine, and give it the command to drill.

- **Step B (Printe):** First, we print the circle design on transparent paper, then paste it on the light source, then paint a piece of silk cloth with light-sensitive ink, then dry the cloth well.

  Then we place the silk coated with ink on the transparent paper located on a light source, wait two minutes, then turn off the light source. This work is done in a dark place. Then clean the silk fabric from excess ink with water until only the circuit design remains.

  Then we transfer the design to the copper plate by sticking the Circuit-printed silk cloth onto the plate tightly and precisely with holes, then coating it with printing ink, then drying it.

- **Step C (Acidification):** We then immerse the copper piece with the printed circuit in the acid bath for 15 minutes while stirring. The non-printed areas are removed using the chemical etching process, leaving only the printed tracks and gaps. Then we make sure that the printed circuit is free of defects using a multimeter.

- **Step D (Solderer):** The electronic components are mounted on the pre-drilled board in their designated locations and soldered precisely.

III.5 IOT Server and wireless control:

The Internet of Things (IoT) service goes through three fundamental stages, devices, cloud server, and Android application :

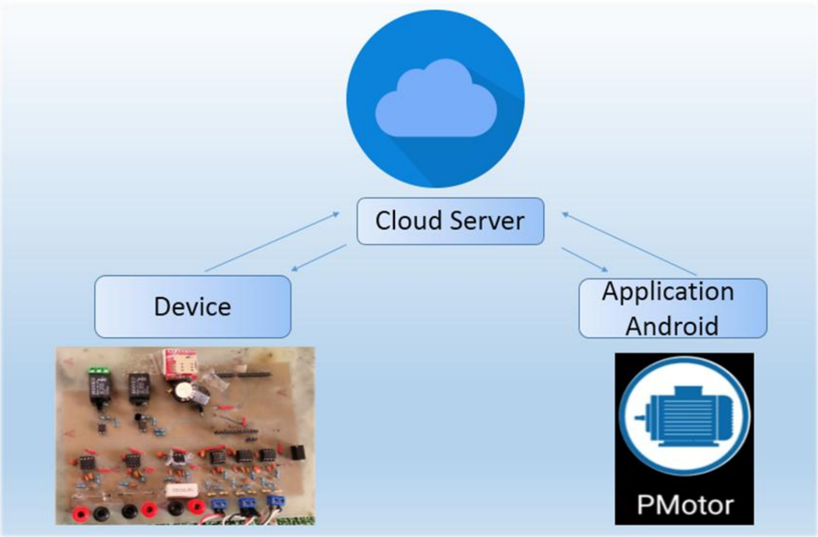


Figure III .6: IOT Server and wireless control and device.

- **Devices:** The device performs data collection during the monitoring process using sensors within the device, such as current and voltage measurements. Then, it sends this data via an internet-connected chip to the cloud server. Additionally, the device receives commands from the cloud server.

- **Cloud Server:** A Cloud server acts as an intermediary between the device and the Android application or user. It is present on the internet, where it receives, stores, analyzes, processes information, and sends commands to both the user and the device[59] .

- **User Interface :** It is an Android application connected to the internet, allowing users to remotely control a device. The application sends and receives commands from a cloud server. The design of this application is customized based on its usage. For example, in our application, the user has an interface to display current and voltage values for each phase separately, along with buttons for turning on and off.

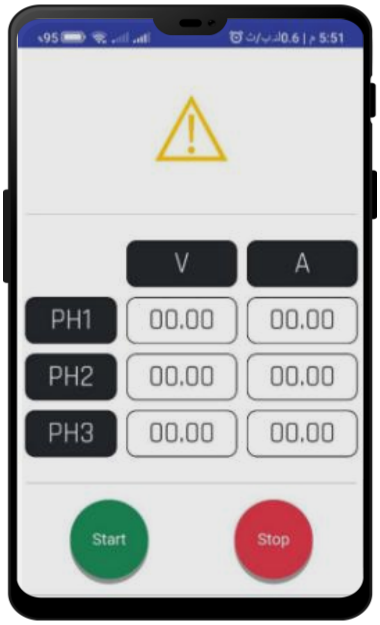


Figure III.7: user interface(Android Application).

III.6 Test Results and Implementations:

After conducting numerous experiments, we obtain the results related to the voltage sensor and current sensor. Initially, we design the first circuit on a BreadBoard before creating the PCB layout. Once we achieve desirable results, we proceed with designing the PCB specifically for the project. The figure (III.8) represents the preliminary experiment before PCB design, where we observe the results of the voltage sensor using an Oscilloscope on the computer screen . The figure (III.9) illustrates the results after PCB design, with the sensors integrated into the circuit. We place the voltage sensor before the contactor and the current sensor after the contactor. We monitoring the results related to the voltage sensors using an Oscilloscope on the computer screen, as shown in the figure (III.10). Additionally, in the figure (III.11), We monitoring the results related to thecurrent sensors using an Oscilloscope on the computer screen, in the figure (III.12) we see the results obtained by monitoring Arduino's analog input.

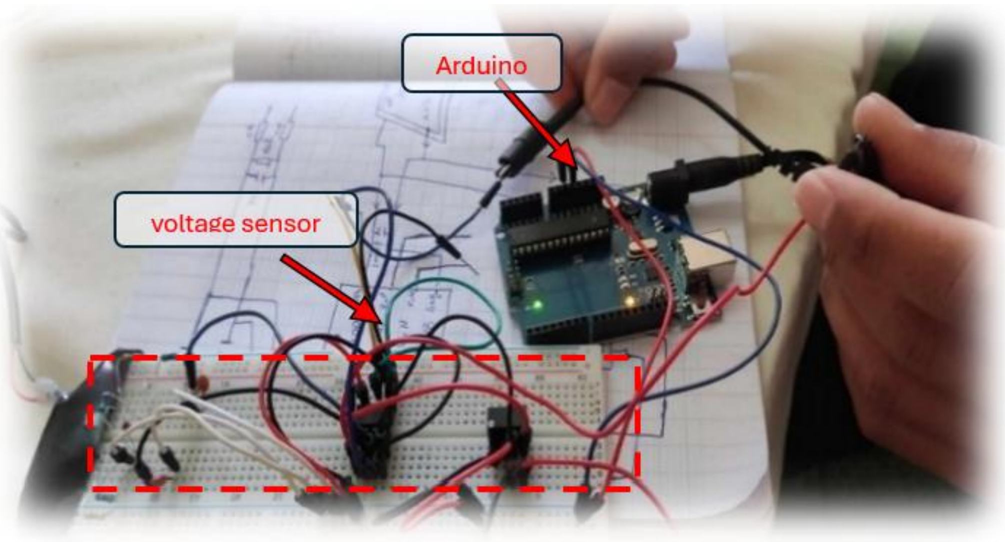


Figure III.8: Design the first circuit on a BreadBoard.

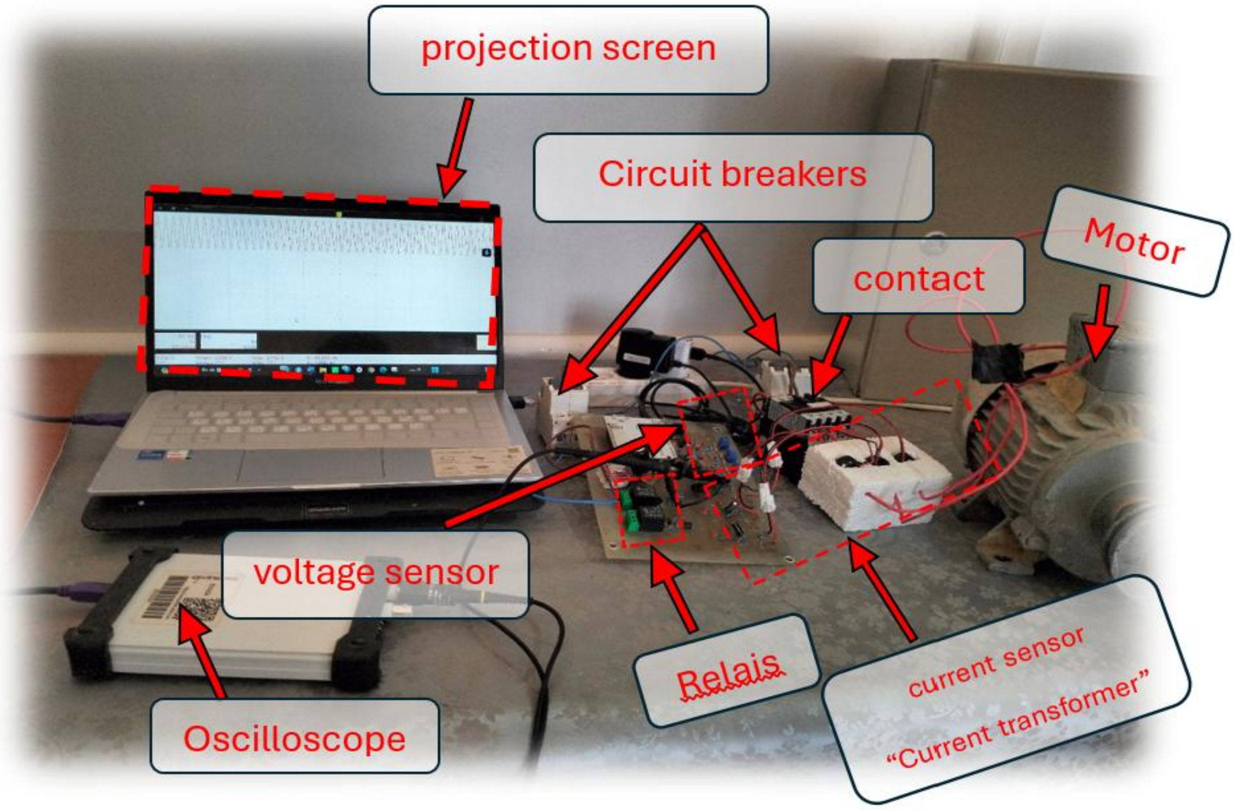


Figure III.9: A picture illustrating the device connected to the circuit with an oscilloscope displaying the results.

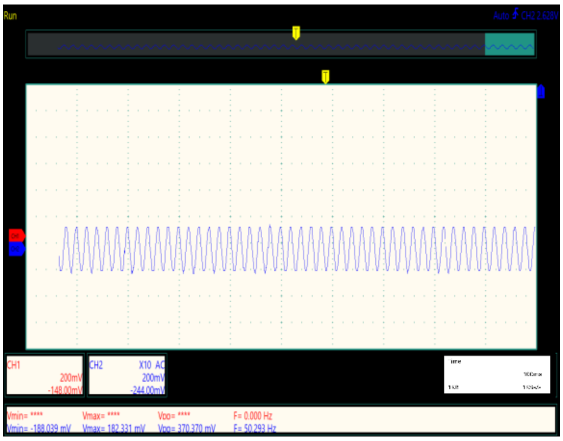
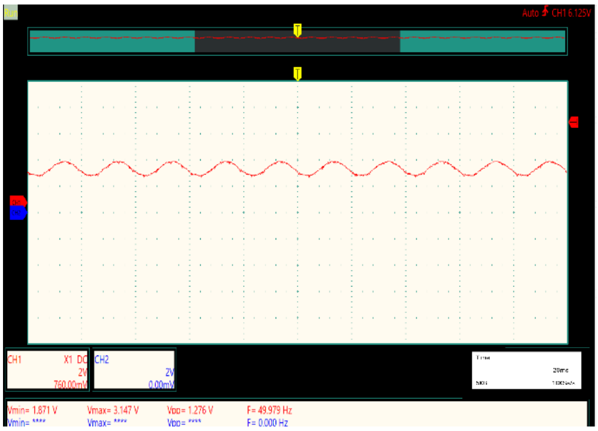
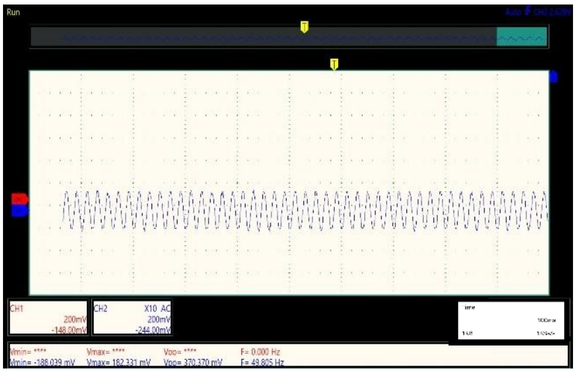
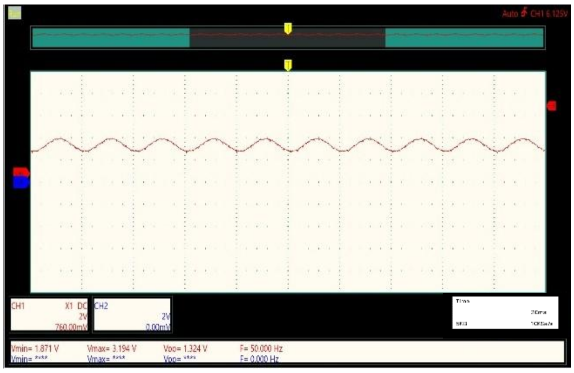
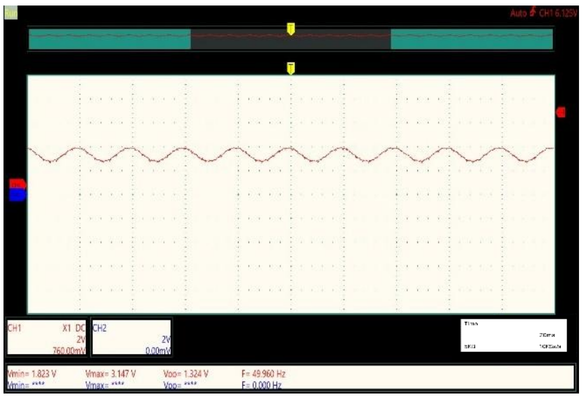
Voltage sensor Before AMC1200	Voltage sensor After AMC1200
	
	
	

Figure III.10: A table illustrating the results from the voltage sensors connected to the circuit using an oscilloscope**.**

<table>
<tr><th>Current sensor

When carrying an electrical load of 2.7A</th><th>Current sensor

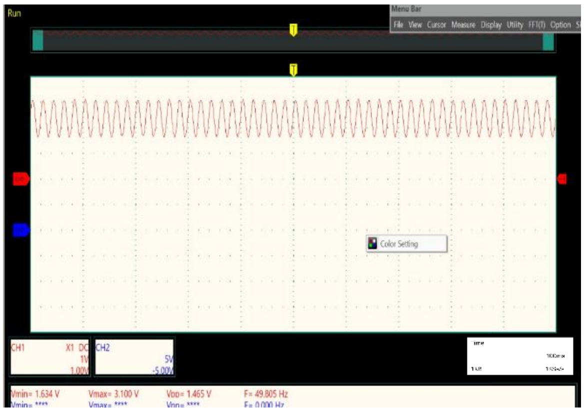
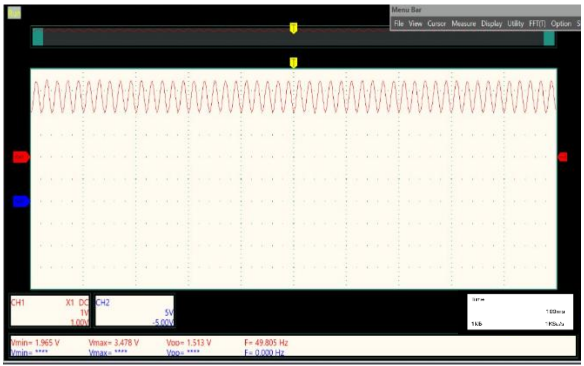
When carrying an electrical load of 5.4 A</th></tr>
<tr><td></td><td></td></tr>
<tr><td></td><td></td></tr>
<tr><td></td><td></td></tr>
</table>

Figure III.11: A table illustrating the results from the Current sensor connected to the circuit using an oscilloscope**.**

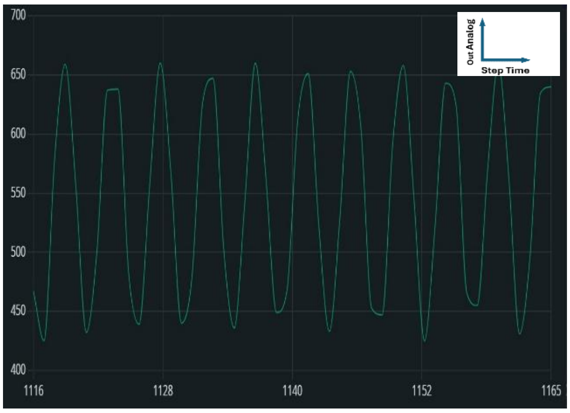
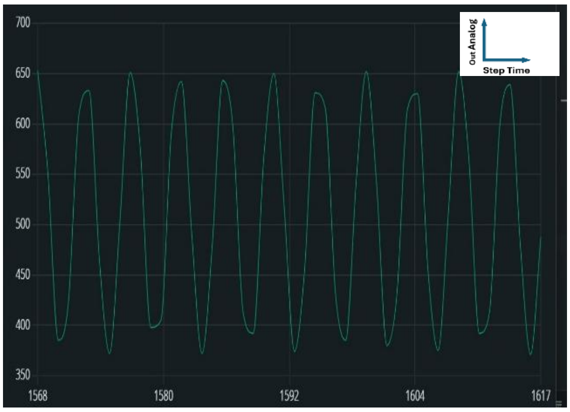
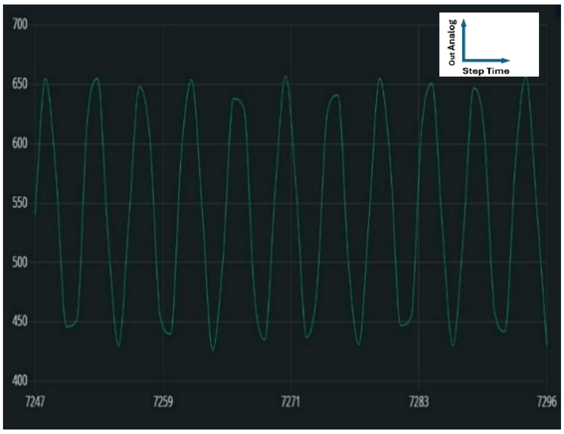
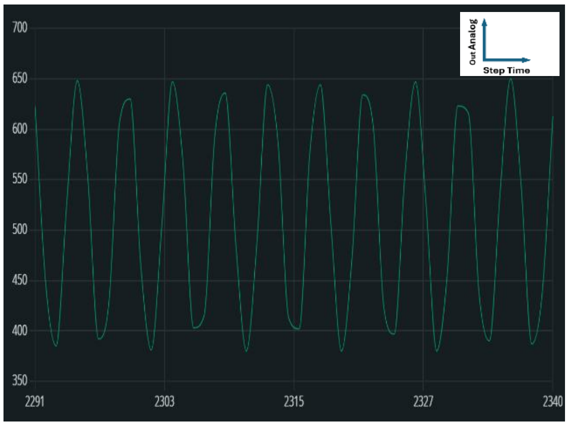
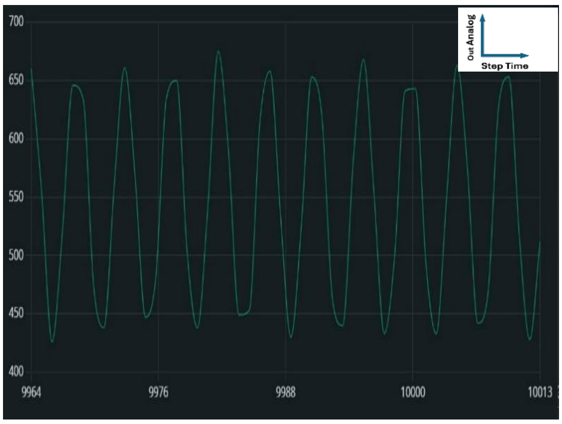
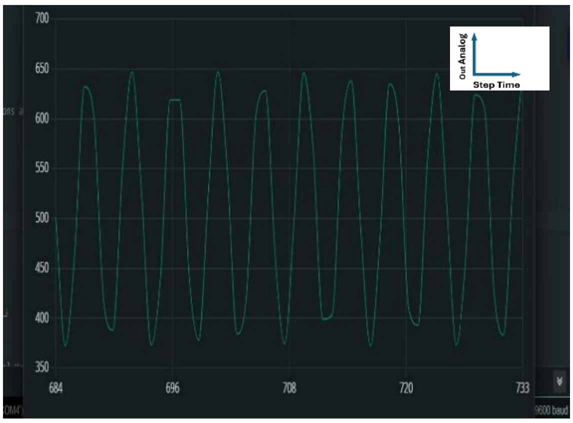
Voltage sensor	Current sensor
 Step Time	
	
	

Figure III.12: A table illustrating the results obtained by monitoring Arduino's analog signals input.

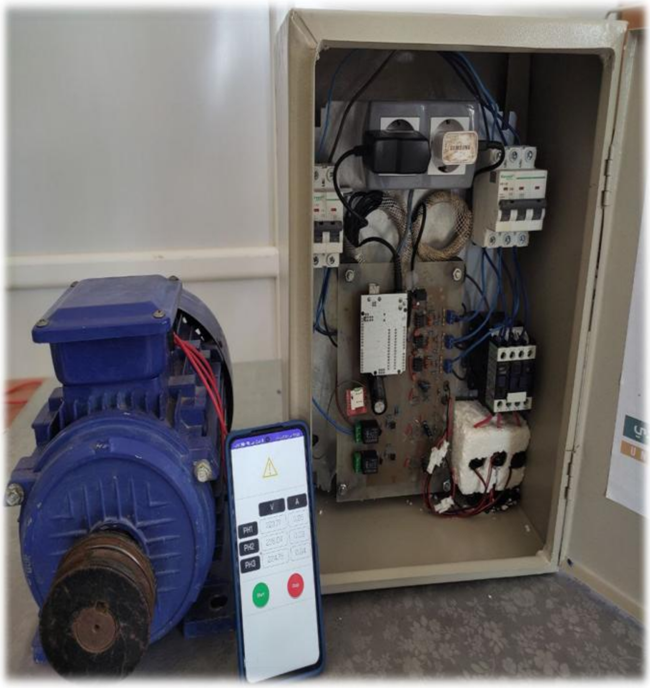


Figure III.13: A picture of the smart cabinet operating through the Internet of Things IoT, a connection to a smartphone application.

After designing the PCB as required, the system is controlled, protected, and monitored using the Internet of Things (IoT). All circuit elements related to protection are assembled along with a motor inside the electrical cabinet. as it shown in the figure III.13 .The smart cabinet operates via IoT, connecting to a smartphone application, and has yielded good and efficient results.

III.7 Conclusion:

In this chapter, we discussed the application and embodiment of a smart board to control, monitor, and protect electric motors remotely, and we explained how to design current and voltage sensors and how they work. They were tested on an experimental board, where they gave acceptable results, using an Arduino and an oscilloscope device. We verified the results in multiple ways. To ensure accuracy, we designed a PCB board explaining the design steps. We also programmed the Android application and the cloud server to complete the process of connecting the device to the user and the Internet. We tested the entire system, including the control panel, monitoring, protection with the Internet of Things, and the pump, and we were able to read the current and voltage from the phone. The results were good, and this is what we were working for.

General conclusion

General conclusion

In this project, we designed and manufactured an intelligent panel for controlling, monitoring, and protecting electric motors. To achieve these results, we went through a series of achievements related to protection, control, monitoring, and IoT. These accomplishments were presented in three stages.

First, In this chapter, we reviewed the importance and methods of protecting electromechanical systems. We studied fundamental concepts related to protection and control, as well as the applications of various electromechanical systems in industry and different sectors. In this chapter, we highlighted the protection methods used in these systems, with a specific focus on devices used for motor protection, such as circuit breakers and thermal relays. The axis concludes by emphasizing the importance of effective implementation of protective measures to ensure the safety and efficiency of electromechanical systems.

Secondly, we conducted a comprehensive study of sensor technologies relevant to electric motor protection. We also explored their significance in the context of the Internet of Things (IoT) and their applications across various fields. and we developed a comprehensive system that integrates sensors with the motor to enhance protection.

Finally, in this chapter, we dealt with the implementation of this board for controlling, monitoring, and protecting the electric motors in IoT, where we explained and detailed the design of the voltage and current sensors, explained the process of manufacturing the PCB board, and investigated its operation accurately and effectively, and we programmed the controller in order to send the data to the cloud. We also programmed the cloud server to receive and send data and connect the user to the device. We also programmed an Android application to receive data. The system was tested with a water pump and it gave good and effective results. But before reaching these good results, we went through challenges, difficulties, and faults that led to damage to several components and electronic elements, causing us to replace some of them with sensors and other circuits in order to achieve accurate results.

This system also has prospects that we seek to develop by adding sensors to monitor the motor temperature and others to know the motor running time, improving the user interface and adding other features by setting a specific time to start the motor and another time to stop the motor.

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