Supervisory Control and Monitoring System for Induction Motor using PLC

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Abstract

The supervisor control and monitoring system for an induction motor using a PLC with variable voltage and variable frequency drive is a modern solution for efficient motor control. In the present era, industrialization has been revolutionized itself to a certain extent. Now a days, because of immense remarkable results of automation process like its better quality, increased production, and affordable cost, it is most desirable and trending process. This gradual shift to advanced PLC from typical relay logic control stimulated highly impressive outcomes. In automation system, PLC based variable voltage and variable frequency drive is considered most compelling and controlling system for AC motor. In industries, AC induction motors are widely used for various operations. Smaller size, lighter weight, cheaper cost, less maintenance and mainly their high technological efficiency lead the extensive use of these motors. In addition, these motors have different torque rating and are more capable to run at different speed. Data acquisition and regulation of speed in accordance with concerned load is very crucial thing and that is core objective of our work.

Therefore, SCADA system using PLC for continuous monitoring, controlling of induction motor will be designed. The supervisory control system involves the use of programmable logic controller (PLC) which enables real-time monitoring and control of the motor's speed, current, and voltage. The system architecture involves the use of sensors to measure the motor parameters such as current, voltage, speed. These parameters are then fed into the PLC system, which uses its algorithm to calculate the required control signals for the VVVFD drive. This drive then adjusts the motor voltage and frequency to maintain optimal motor performance. The system has several benefits, including enhanced energy efficiency, improved motor performance, reduced maintenance costs, and increased equipment lifespan. Moreover, the system provides accurate and timely data on motor performance, which is essential for maintenance scheduling and predicting equipment failures.The energy efficiency and performance improvements offered by the system make it a promising solution for industrial applications. The whole designed system will induce most precise, accurate and proficient results. Further, researchers could proceed and use this designed in a beneficial and worthwhile manner.

KEYWORDS: GUI; SCADA; PLC controller; VVVFD

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List of Abbreviations

IM	Induction motor
VVVFD	Variable voltage variable frequency drive
SCMS	Supervisory control and monitoring system
SCADA	Supervisory control and data acquisition
PLC	Programable logic controller
GUI	Graphical user interface
VVD	Variable voltage drive
VFD	Variable frequency drive
VSD	Variable speed drive
PWM	Pulse width modulation
MOSFET	Metal oxide semiconductor field effect transistor
RPM	Revolution per minutes
GUI	Grphical user interface
TRIAC	Triode for Alternating Current

Chapter 1

Introduction

1.1 Background

Induction motors (IMs) have long been recognized for their simplicity, robustness and cost-effectiveness, making them widely used in various industries[1]. Induction motor is shown in Figure 1.1. Their sturdy construction, characterized by the absence of brushes and commutators, not only minimizes maintenance demands but also mitigates friction losses, resulting in enhanced reliability [2]. One key distinction of DC motors is utilizing of commutators and brushes, which introduce mechanical complexity and limitations that reduce their overall convenience. In terms of efficiency, induction motors outperform DC motors. This efficiency advantage becomes more pronounced at higher power ratings, making induction motors more suitable for industrial applications where large amounts of power are required. Additionally, induction motors outperform DC motors in terms of cost-effectiveness, as their manufacturing process is simpler and their components are generally less expensive [3]. Another technical advantage of induction motors is their superior torque characteristics. They provide high starting torque, making them well-suited for applications that demand high initial torque, such as in industrial machinery and equipment. In contrast, DC motors typically require additional components, such as gearboxes or variable speed drives, to achieve comparable torque characteristics. Therefore, induction motors stand as a superior choice, combining technical advantages, reliability, and cost savings over DC motors. An induction motor's laborious speed regulation is its biggest drawback [4]. Supervisory control and monitoring system (SCMS) is a control system for an induction motor using programmable logic controller (PLC) that gives real-time control and monitoring of an industrial electric motor.

Figure 1.1: Induction motor

1.2 Introduction

Supervisory control and monitoring system (SCMS) is used to control and monitor the operation of the motor. This system uses various sensors (voltage transformer, current transformer, IR beam) and input devices to monitor motor parameters such as voltage, current, and speed. The information is then processed by the PLC, which adjusts motor speed, torque, and other parameters to maintain the desired operating conditions. The SCMS for induction motors using PLC provides many benefits, including improved motor performance, increased efficiency, reduced downtime, and improved safety. The SCMS for induction motors using PLC is flexible and adaptable. PLC can be programmed to perform a range of functions such as monitoring the motor parameters, detecting faults, and providing alerts or alarms if any issues are detected. The PLC can also be used to control the system manually if required, allowing for quick adjustments to be made to the motor parameters [5].

One important component of the SCMS for induction motors is the variable voltage variable frequency (VVVF) drive. A VVVF drive is a type of adjustable speed drive that is used to control the speed of an induction motor by varying the frequency and voltage of the AC power supplied to the motor. This type of drive is often used in industrial applications where precise control of motor speed is required [6]. VVVF drive consists of four main components: the bidirectional phase controller, the rectifier, the DC bus, and the inverter. Bidirectional phase controller is used to convert fix AC voltage into variable voltage. The rectifier is used to convert the AC power from the utility into DC power. The DC bus acts as a buffer, storing energy for later use. The inverter then converts the DC power back into AC power that is supplied to the motor. The inverter is controlled by the PLC, which adjusts the frequency and voltage of the AC power to control the motor speed .

The VVVF drive provides several benefits over other types of drives. First, the drive can operate at high speed, making it well-suited for real-time control and monitoring applications. Second, the it provides precise control over motor speed, allowing for optimal motor performance and efficiency. Third, it can reduce wear and tear on the motor, extending the motor's lifespan. Fourth, the VVVF drive can reduce energy consumption, providing cost savings and improving overall system efficiency [6]. There are several factors to consider when designing a SCMS for induction motors using PLC and VVVF drives. First, the size of the motor and the load it will be driving must be considered to ensure that the drive is appropriately sized for the application. Second, the type of motor must be considered, as different types of motors require different types of drives. Third, the operating conditions of the motor must be considered, such as the environment and the duty cycle, to ensure that the system is designed to handle the required conditions [7].

In conclusion, the SCMS for induction motors using PLC and VVVF drives is an effective control system that offers precise control and monitoring of motor operations. The system provides improved motor performance, increased efficiency, reduced downtime, and improved safety, making it an essential component of any modern industrial setting that uses induction motors. The use of a VVVF drive provides several benefits, including precise control over motor speed, reduced wear and tear on the motor, reduced energy consumption, and improved system efficiency. The SCMS for induction motors using PLC and VVVF drives is flexible and adaptable, allowing modifications to be made to meet changing needs and requirements [8]. The use of a VVVF drive and SCMS for induction motors are important advancement in motor control technology and are expected to continue to play a critical role in industrial settings in the future. As the demand for energy-efficient and reliable industrial processes continues to rise, the utilization of SCMS for induction motors using PLCs and VVVF drives is expected to continue to grow [5]. In summary PLCs are the core of the SCMS, providing the necessary processing power and connectivity to other components of the system. VVVF drives, on the other hand, allow for precise control of motor speed and torque, enabling optimal motor performance and energy efficiency. Design project model is shown in Figure 1.4

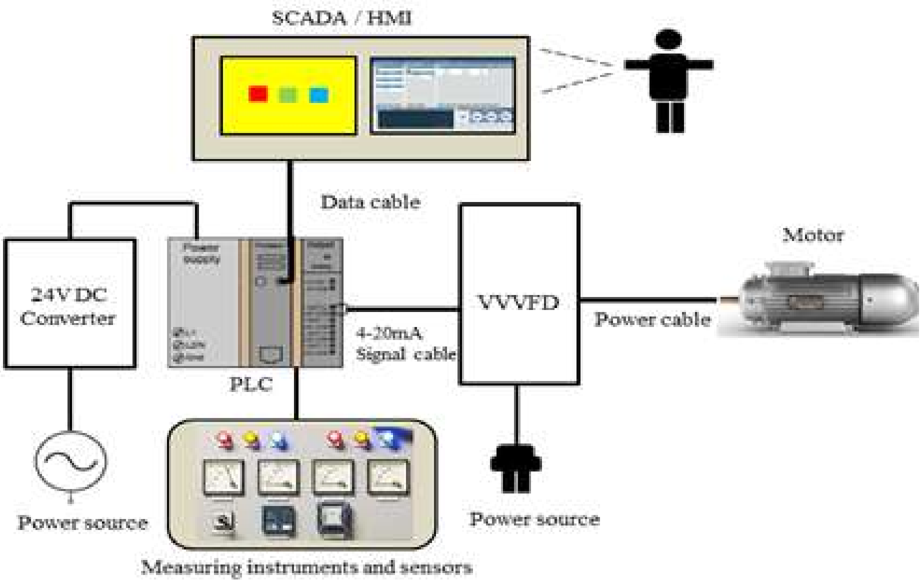


Figure 1.2: Model of design project

1.2.1 VVVFD control operation

The speed of an induction Motor (IM) is directly influenced by two factors: the number of poles and the frequency of the power source. Since the number of poles is fixed for a given motor, the speed can be adjusted by controlling the supply frequency. This is possible because the relationship between speed and frequency is linear in an IM. By increasing or decreasing the supply frequency, the speed of the motor can be effectively changed. However, it is important to note that the torque generated by an induction motor depends on the ratio of applied voltage to supply frequency. To maintain a constant torque throughout the entire speed range, it is necessary to vary both the voltage and frequency while keeping the voltage-to-frequency (v/f) ratio constant. This approach, known as v/f control, aims to regulate the torque-speed characteristics of the induction motor. Additionally, the torque generated by the motor depends on the voltage-to-frequency ratio, which can be controlled through v/f control to maintain a constant torque throughout the speed range [8].

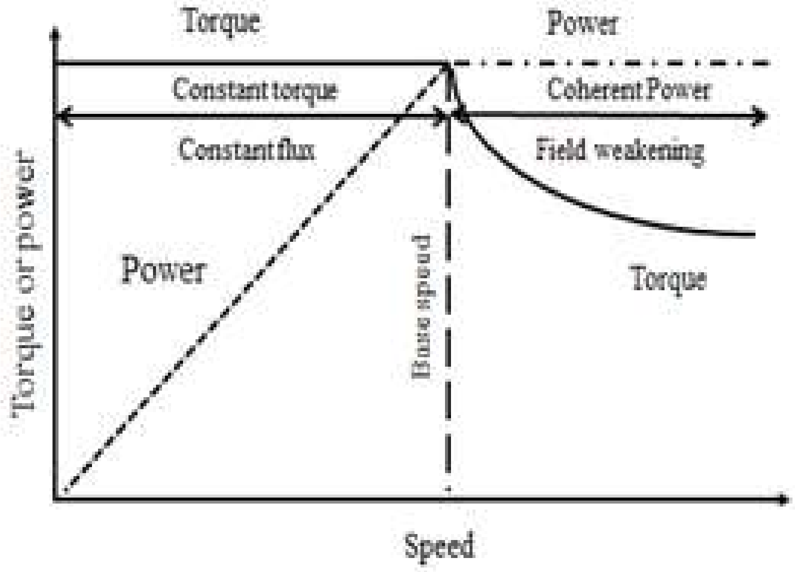


Figure 1.3: Torque speed characteristic of IM by v/f control

Figure 1.3 visually depicts the torque-speed characteristics achieved using v/f control, a vital technique for regulating the motor's performance. This graphical representation showcases the relationship between torque and speed, illustrating the ability to control torque at varying speeds. The implementation of v/f control is essential in effectively managing induction motors, enabling precise torque-speed control through variable voltage variable frequency drive (VVVFD) systems. By utilizing v/f control with VVVFD, operators can optimize the motor's performance, ensuring reliable torque control and efficient operation throughout the motor's speed range.

1.2.2 Motivation

The "supervisory control and monitoring system of induction motor using PLC" is driven by the need for advanced control, monitoring, and optimization of induction motors in industrial applications. One primary technical motivation is the utilization of SCADA (supervisory control and data acquisition) in conjunction with PLC (programmable logic controller) systems. It provides a centralized and comprehensive platform for real-time data acquisition, visualization, and control of industrial processes. By integrating SCADA with PLC, operators can monitor and manage multiple aspects of the motor's performance, including voltage, current and speed. The incorporation of the VVVFD technique further enhances the project's objectives. It allows for precise control over motor speed and torque by adjusting the voltage and frequency supplied to the motor. By combining VVVFD with SCADA through PLC, operators can optimize motor performance, improve energy efficiency, and achieve better control accuracy across varying load conditions. Energy efficiency is a significant driving factor in this project [9,10]. SCADA and VVVFD, operators can control and monitor real-time data, and implement energy-saving strategies. By optimizing voltage and frequency through VVVFD, the motor's energy usage can be fine-tuned, resulting in reduced operating costs and environmental impact. The project also aims to enhance motor reliability and minimize downtime. The SCADA system allows for continuous monitoring of motor parameters, such as current , voltage and speed. The project contributes to the advancement of industrial automation and control systems.

By developing a supervisory control and monitoring system using SCADA through PLC with VVVFD technique, valuable insights can be gained into the integration of these technologies [3].

Figure 1.4: PLC based monitoring and control system

1.3 Scope

1. **Motor Control:** Ensure precise speed control of the induction motor to enhance its efficiency and reliability during operation.

2. **Real-time Monitoring:** Continuously monitor essential motor parameters, such as current, voltage, and speed, in real-time to provide operators with accurate and up-to-date information regarding motor performance.

3. **Energy Optimization:** Implement energy-efficient control strategies that dynamically adjust the motor's speed based on the actual load requirements, thereby optimizing energy consumption.

4. **Integration with SCADA System:** Seamlessly integrate the supervisory control and monitoring system with SCADA system, allowing for centralized monitoring and control of induction motors within an industrial environment.

1.4 Problem statement

1. Induction motors are influenced by factors such as inrush current and over voltage which have impact on motor's performance and shorten its lifespan.

2. Induction motors are difficult to control, and desired torque can't be achieved using conventional relay logic controller.

3. Speed and torque control techniques used in industry for induction motor are costly.

1.5 Objectives

The objectives of our projects are as follows:

1. Design of voltage and frequency control scheme for single phase squirrel cage induction motor.

2. The utilization of a PLC-based single phase squirrel cage induction motor's control system by using VVVFD.

3. Design GUI for controlling and monitoring of induction motor.

1.6 Benefit to the society

Some benefits are:

1. **Extended machine life:**
   The supervisory control and monitoring system can contribute to extending the machine life of induction motors by implementing soft start techniques and operate at required load that reduce mechanical stress during motor startup and operation. This helps prevent premature wear and tear, leading to an extended lifespan for the motors.

2. **Conservation of energy:**
   Through load optimization, energy demand management, and power factor correction, the system minimizes energy wastage, ensuring efficient energy usage and reducing the strain on induction motors, which can contribute to their prolonged lifespan.

3. **Increasing production rate:**
   By implementing load-dependent motor control strategies and optimizing motor performance, the system enables efficient and reliable motor operation, resulting in improved production rates and throughput.

4. **Provides smooth motion for applications such as elevators and escalators:**
   The supervisory control system ensures precise motor control, accurate speed regulation, and coordinated motion, ensuring smooth and reliable operation of applications such as elevators and escalators, enhancing user experience and reducing mechanical stress on the motor

1.7 Applications

SCMS for induction motors using PLC has a wide range of applications in various industries, providing real-time monitoring and control over the motor's performance, ensuring that the processes are efficient, safe, and reliable. Applications are given bellow:

1. **Water treatment plants:** In water treatment plants, induction motors are used in various applications such as pumps, mixers, and blowers. The SCMS can monitor and control the motor's operation, ensuring that the water treatment process is efficient and effective.

2. **Oil and gas industry:** Induction motors are used in various applications in the oil and gas industry, such as drilling rigs, pumps, compressors, and generators. The SCMS can monitor and control the motor's performance, ensuring safe and reliable operation in harsh environments.

3. **Chemical processing industry:** Induction motors are used in chemical processing applications such as mixers, agitators, and pumps. The SCMS can monitor and control the motor's operation, ensuring that the chemical processes are efficient and safe.

4. **Material handling systems:** Induction motors are used in material handling systems such as conveyors, cranes, and lifts. The SCMS can monitor and control the motor's performance, ensuring that the material handling processes are efficient and safe.

5. **Food and beverage industry:** Induction motors are used in various applications in the food and beverage industry, such as mixers, pumps, and conveyor systems. The SCMS can monitor and control the motor's operation, ensuring that the food production process is efficient and hygienic.

1.8 Research questions

1. Sensors and actuator selection for interfacing?
2. In which mode will the PLC operate and why?
3. How does the supervisory control and monitoring system using PLC improve the efficiency of induction motors?
4. What are the key parameters to monitor in the supervisory control system for single phase squirrel cage induction motor using PLC?
5. What are the most effective control strategies to implement in the supervisory control and monitoring system for single phase squirrel cage induction motor using PLC?

1.9 Timeline

The project timeline was carefully structured to ensure systematic progress and timely completion. It began with a literature review and data collection for a strong theoretical foundation. The development phase focused on designing and implementing a supervisory control system, including a PLC with a variable voltage and frequency drive. Rigorous testing verified system functionality. Data analysis and interpretation led to meaningful conclusions. The project adhered to the timeline, ensuring efficient execution and successful completion.

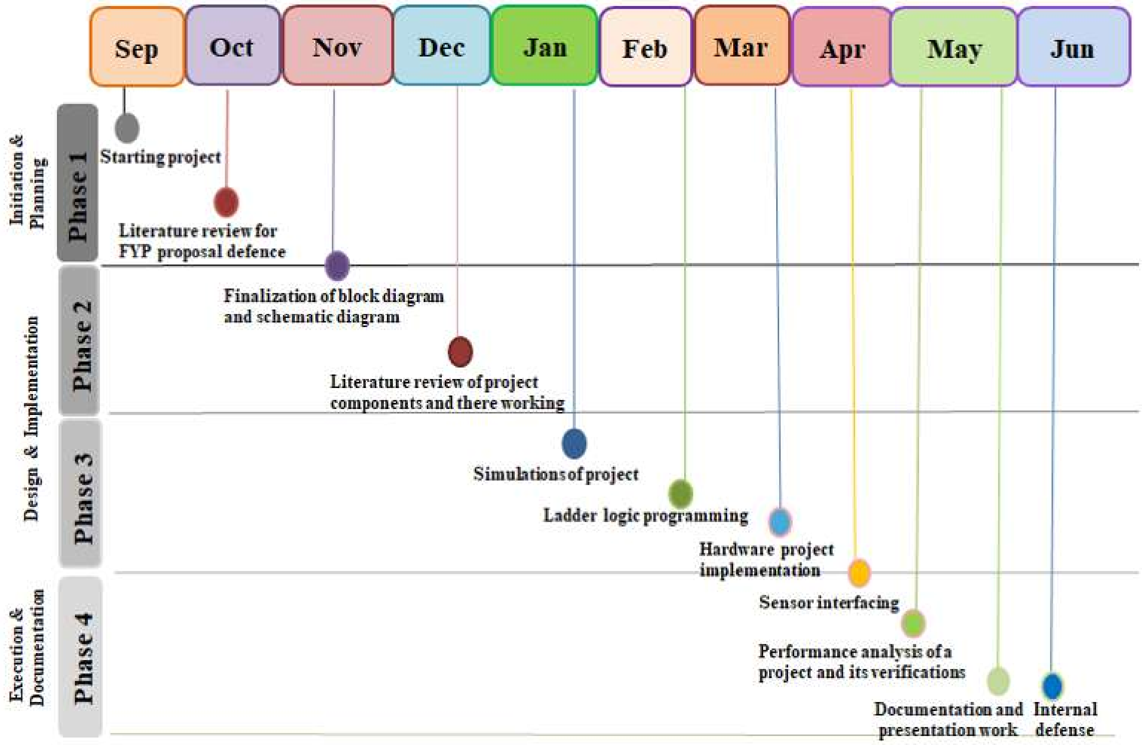


Figure 1.5: Charting the Path to Success: A Timeline of the FYP Project

1.10 UN's sustainable goals

- **Goal 08:**

  The project aligns with goal 8, decent work and economic growth, by improving working conditions and economic productivity through the implementation of the supervisory control and monitoring system for induction motors using PLC. By enhancing motor performance and reducing downtime, the project enables a more efficient and reliable industrial process, leading to increased productivity, job stability, and better employment opportunities. The implementation of the supervisory system ensures a safe working environment by enabling real-time monitoring and proactive maintenance, thereby promoting decent work practices.

- **Goal 09:**

  The project directly relates to goal 9, industry, innovation, and infrastructure, by leveraging advanced technologies such as PLCs and control algorithms to optimize motor performance. The implementation of the supervisory control and monitoring system enhances industrial innovation by enabling precise monitoring, control, and optimization of induction motors. By utilizing PLCs and advanced control algorithms, the project improves energy efficiency, reduces maintenance costs, and enhances overall industrial productivity. Additionally, the project contributes to infrastructure development by ensuring resilient and efficient motor operations, which leads to reliable and sustainable industrial processes. This aligns with the goal of fostering innovation and developing robust infrastructure within the industrial sector capacities throughout all nations.

Figure 1.6: UN's sustainable goals

1.11 Thesis breakdown

To provide a comprehensive understanding of SCMS of induction motor, the project will be structured into several main chapters, each focusing on different aspects are explained as follows;

- **Chapter 1**

  This chapter focuses on the design and implementation of a PLC-based control and monitoring system for industrial machines (IM). Project objectives align with the united nations' sustainable development goals, aiming to create a sustainable future and provide societal benefits. The problem statement addresses the requirement for an efficient, reliable, and automated system to control and monitor IMs.

- **Chapter 2**

  This chapter provides an analysis of the literature on various research techniques used in past to achieve monitoring and control of IM. Conduct a comprehensive review and comparison of these technique in order to identify the most effective methods for achieving most optimal control and monitoring of IM .By analyzing the strength and weakness of each techniques, we aim to provide a rigorous method with lake of weakness and better accuracy.

- **Chapter 3**

  This chapter presents the methodology used to develop a detailed functional description of our proposed project, which include block diagram, mathematical models, flowcharts, schematics diagram, wiring diagram and component selection .Included complete comprehension of these components, detailing the technical specification and design consideration that informed our selection of specific component and design choice.

- **Chapter 4**

  This chapter entails the implementations of proposed method including a detailed account of the conducted tests, the acquisition of results throughout the project, and an explanation of all simulations, hardware architecture, and the project's outcome.

- **Chapter 5**

  In this chapter, conclude the project and establish its future trajectory outline the future directions for enhancing the project's cost-effeteness and efficiency through the utilization of alternative condition. Additionally, provide references and appendix for our proposed project.

Chapter 2

Literature review

2.1 Literature review

Through our discussion, we delved into the evaluation of motors based on their cost-effectiveness, working accuracy, ease of maintenance and installation, as well as their efficiency in meeting the specific demands of industrial sectors. Here the question arises after detailed analysis why the control of motor is important for industries and which methods are being used for controlling and monitoring the speed as well as torque of motor is also discussed. Challenges, motivation as well as any other crucial parameters for controlling of motor such as voltage, frequency and UN sustainable goals are all part of the research. Analyze all the ways taken to attain the best potential results according to requirements and the UN's development goals in this literature review. The chapter will begin with an overview, followed by a comparison of the best ways, and finally, conclusions. Induction motors (IM) are extensively employed in industries due to their robust design and low maintenance requirements, making them a popular choice. They are particularly well-suited for applications that demand high-performance variable speeds [4].

However, controlling induction motors poses a significant challenge in industrial settings with demanding dynamic performance requirements, mainly due to their inherent nonlinearity and parameter fluctuations, notably rotor resistance [21]. This presents a complex problem for precise control and operation. While star-delta starters are commonly used for starting and running induction motors, variable frequency drives offer better control over speed due to their ability to vary the frequency of the power supplied. This makes them ideal for applications that require consistent speed control. Programmable logic controllers (PLCs) are the preferred choice for monitoring and controlling induction motors in industrial environments, ensuring efficient and reliable operation [4]. The combination of minimal maintenance needs, durability, and the availability of precise control options positions induction motors as a versatile and essential component in various industries [3]. Supervisory control and data acquisition (SCADA) system is used in industries to collect data from numerous sensors [18]. Primary purpose of SCADA system, collect the necessary data from distant places and show it on control room's main computer monitor, store data on hard drive of master computer, and enable remote or local field device control from the con- trol room. Induction motor operation analysis is made possible by monitoring systems in both on load and off load, safeguarding the system from fault and error situations [23].

2.2 Induction motor

The IM is most prevalent kind of electric motor because of its simple and sturdy construction, low cost, beneficial operating characteristics, absence of a commutator, and effective speed regulation [23]. IMs supply almost 80utilized by industries. In an IM, induction moves power from stator to rotor winding. Since IM operates at speed other than synchronous speed, it is also referred to as asynchronous motor [25]. The mathematical expression for rotor speed is given by way of equation 2.1 [2].

$$n = \frac{120f(1-s)}{P} \tag{2.1}$$

Here, n is used for speed, p shows number of poles, f denotes frequency and s for slip. Electric motive force (EMF) of IM is proportional to magnetic flux, frequency and rotor speed mathematically shown in equation 2.2.

$$E = \sqrt{2}\pi\phi_m fn \tag{2.2}$$

Here,ϕ_m shows maximum flux, f denotes frequency and n use for rotor speed in RPM.

2.2.1 Construction

Like every other type of electrical motor, three-phase IM comprises two main parts: the rotor and stator.

- Rotor: An IM's rotor is a rotating part. Through shaft, rotor is connecting to the mechanical load.
- Stator: An IM's stator is a stationary part, as its name suggests. IM's stator is equipped with armature winding, and three-phase supply is applied [7].

Following categories for 3- phase IM exist depending on the rotor construction.

- Slip ring induction motor , wound induction motor, or phase wound IM.
- Squirrel cage IM.

2.3 Wound rotor IM

Numerous slots make the rotor, and rotor winding is inserted into these spaces. The three end terminals are connected to form star connection. As implied by name, three phase slip ring is made up of slip rings coupled to the rotor on the same shaft. The three ends of the three-phase windings are inexorably connected to these slip rings. By only connecting external resistance through brushes and slip rings, 3-phase IM's starting torque may be raised and speed can be adjusted. The brushes carry current from rotor winding. Additionally, three phase star connected resistances are connected to these brushes [3,17]. Figure 2.1 showes construction of wound rotor IM.

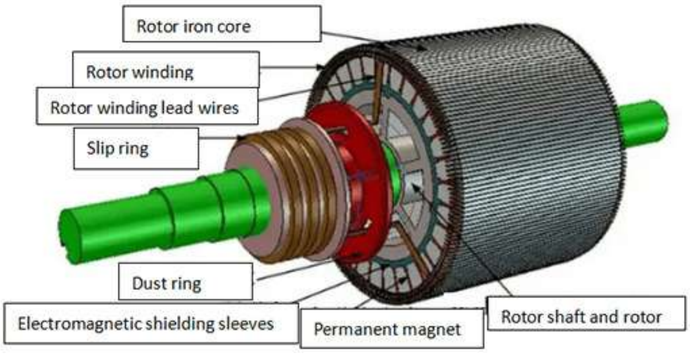


Figure 2.1: Construction of wound rotor

2.3.1 Limitation of wound rotor IM

- Construction is complicated because presence of slip rings and brushes that makes motor more costly.
- This motor is rarely used only 10 % industry uses slip ring induction motor.
- Rotor copper losses are high and hence less efficiency.
- Frequent maintenance is required due to presence of brushes.

2.4 Squirrel cage IM

Copper or aluminum bars are used to make rotor conductors of squirrel cage induction motors. As construction of squirrel cage IM shown in Figure 2.2. On the other hand, slip ring induction motor makes use of 3-phase winding on the rotor that is comparable to the stator winding. They also require slip rings and brushes. As a result, the squirrel cage induction motor's overall construction is simple and robust [5].

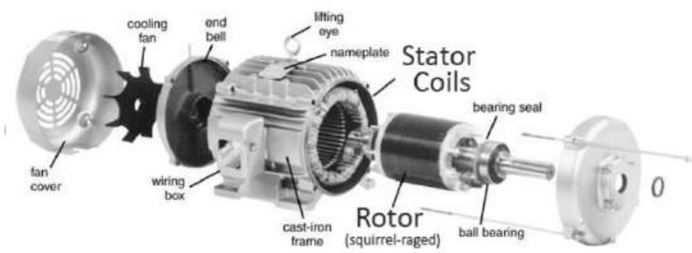


Figure 2.2: Construction of squirrel cage

2.4.1 Advantages of squirrel cage IM

- Highly efficient motor due to less rotor copper losses.
- In comparison to a slip ring IM, it is less expensive.

- Squirrel cage IM is widely used due to its straightforward construction and low cost.
- Less maintenance is required due to absent of slip ring and brushes

From above discussion, as squirrel cage IM is extensively used in various industrial process so that's why we will use squirrel cage IM for speed control due to its high efficiency and several advantages over other motors.

2.5 Induction motor's load characteristics

In real life, variety of loads with varied speed torque curves is available when needed load torque is equal to develop motor's torque. The electrical time constant of motor is typically negligible as compared to mechanical time constant in drives therefore, motor can assume to be in electrically balanced state during transient operation, indicating this kind of action likewise follows the steady state torque speed curve. Figure 3.1 illustrating the operation mode of the variable speed drive in four quadrants. Due to the fact that both speed and torque are positive in Quadrant 1, forward motoring quadrant is so named. Similar to quadrant 3, Reverse Motoring is when both speed and torque are in the opposite direction. Similar in quadrants 2 and 4, both speed and torque are in opposition to one another, producing a braking effect. As a result, the quadrants 2 and 4 were both designated as reverse and forward braking [12].

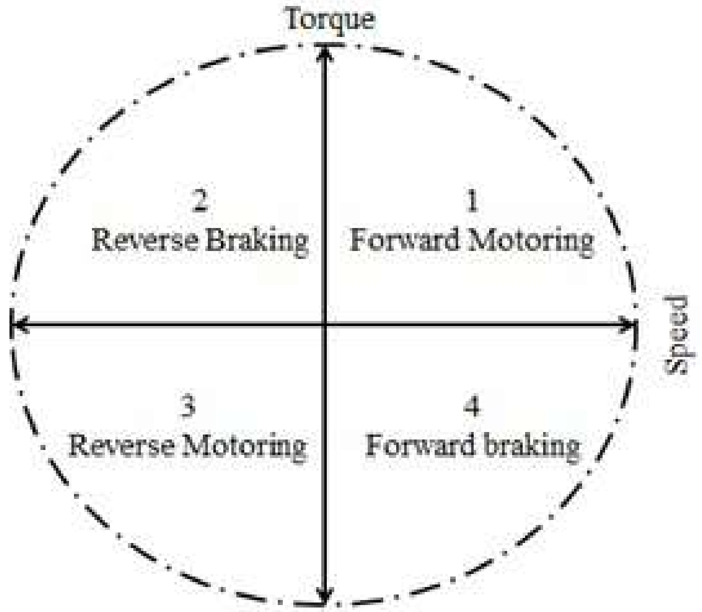


Figure 2.3: Four quadrant operation

Table 2.1: State of the art of all approaches

Reference No #	Title	Approach	Results
[1]	Experimental results of VFD for 3-phase IM using microcontroller. (Choksi, H. R., & Joshi, H. I. (2015)).	Various parameter estimate methods and dynamic modeling of induction motors have been reviewed in this paper.	The basis for modeling and managing 3-phase IM parameters is provided by straightforward and efficient method is presented in this paper.
[2]	A review of speed control methods of induction motor. (Mr.Ankit Agrawal, Dr. Pragya Nema).	Speed control method of induction motor.	This paper compares various IM drive speed control techniques that have been examined by various writers nd examine how they approach issues with induction motors such speed variances, current and voltage ripple, or harmonics.
[3]	On advantages of multi-phase machines, annual conference proceeding IEEE (L. Parsa, November 2005)	Comparison of multiple phase machines.	This paper concludes that IM is compatible and widely use due to its efficient working with less maintains.
[4]	Design and development of PLC and SCADA based control panel for continuous monitoring of 3-phase induction motor. (Mrs.Jignesha Ahir)	Development of PLC and SCADA base control panel, enables the monitoring of three phase IM.	Mentioned paper proves the versatility and effectiveness of PLC as a controlling tool for industrial electric drive applications and creates a monitoring and control system for an IM that is powered by a VFD and managed by a PLC.
[5]	PLC based induction motor starting and protection. (ChetanBorse)	The intention for the study is to discuss induction motor's protection, speed management, and starting.	IM speed control as well as protection is demonstrated in this study. The operation is incredibly reliable and appropriately efficient. PLC-based systems require less hardware to change a programme without altering any hardware connections.

[6]	Speed control of induction motor using fuzzy logic controller. (Ayushi)	Controlling IM speed with a fuzzy logic controller.	Design strategies for hybrid control architectures combine traditional control methods with fuzzy logic and neural networks are presented in this paper.
[7]	Design and implementation of PLC based monitoring control system for induction motor. (Maria G. Ioannides, *Senior Member, IEEE*)	Monitoring and control system for IM using PLC.	This study describes IM's control and monitoring system that is controlled by a PLC and powered by inverter and shows how well the system regulates speed when load is varied while running at a constant speed.
[8]	Industrial automation using PLC, HMI and its protocols based on real time data for analysis (mhetraskar s. s)	Data analyzing using industrial components like PLC, HMI, and VFD.	Data is evaluated in this study using a variety of industrial components, including PLCs, HMIs, VFDs, and energy meters.
[9]	PLC and fuzzy logic control of a variable frequency drive (Rinchen Geongmit Dorjee)	Control of VFD with PLC.	This research article's focus is on controlling a variable frequency drive that serves as a link between a three-phase IM and programmable logic controller (PLC).
[10]	Research to study VFD and its energy savings (Tamal Aditya)	VFD's principle	This paper explains how VFD works and described its performance.
[11]	Detection of various abnormal condition in 3-phase IM based on principal component analysis (D.B.Palamkar)	Analysis for detection of abnormal conditions in 3-phase IM	This paper discusses the topics of voltage imbalance, single phasing, overvoltage, under voltage, and healthy induction motor monitoring circumstances. The classification of abnormal conditions based on an experimental finding is also provided.
[12]	Reach to study VFD and its energy savings. (Mr.Vinayak Gaikwad)	Analysis of VFD	This paper reviewed complete analysis and operation of VFD and describes its energy savings.

[13]	FPGA based implementation of variable-voltage variable-frequency controller for a 3-phase IM (Krishna Chandran Vinay)	FPGA is used to implement the open loop control strategy of 3-phase inverter.	It describes implementation and design of SPWM -based VVVF controller for a 3-phase IM by utilizing FPGA.
[14]	VVVF electric drive. (Thomas H. Onnieyer).	Detailed reviewed on state performance of VVVFD system.	VVVFD's steady state performance base for gas turbine prime mover is detail described in this work.
[15]	VSD of single phase IM using frequency control method. (Mr. Aung Zaw Latt)	Developing VSD for IM using method of frequency control.	It shows how proposed VSD used in combination with frequency control technique to makes it simple for modifying the motor's speed. Also shows how single-phase IM may be driven efficiently from changing frequency.
[16]	Inverter faults in VVVF IM drive. (Gamal Mahmoud, SMIEEE)	This paper describes the performance of a VVVFD under inverter failure scenarios.	This study presents simulation and real-world findings of problem that frequently affects voltage supply inverters.
[17]	The study of PLC control technology application in motor VVVF System. (Jiangcai liu)	This paper examines use of PLC control technology for motor's VVVF systems.	The paper describes application features for PLC control technology in motor VVVF system by examining the fundamental operating principles and features of the PLC coupled with VVVF technology of AC and DC motor
[18]	Monitoring and control of a VFD using PLC and SCADA. (Rinchen Geongmit Dorjee)	SCADA system using PLC for monitoring and control of IM.	The goal of current task was to create a plan for using PLC to control and monitor VFD.

[19]	VVVF drive feature, commissioning procedure and challenges. (M Ramana Rao)	Detailed operation of VVVFD.	This article discusses the fundamentals of VVVFD, its benefits, and a few case examples that list the challenges and solutions.
[20]	Critical survey on IoT based monitoring and control of IM. (Sudharani Potturi).	IoT base monitoring and control system for IM.	Analysis of the literature on use of IoT to monitoring and control of induction motor in variety of applications is provided in this paper .This review also includes block diagrams of different authors' proposals for IT-based monitoring and motor control systems.
[21]	High efficiency, unity power factor VVVF drives system of an IM. (Masayuki Morimoto)	VVVF drive scheme with a high power factor and unity efficiency for IM is described.	This research suggested a new control technique for a high efficiency converter system. The outcomes of experiment demonstrate the development of featuring an IM's high-performance, unity power factor VVVF drive system.
[22]	PLC VVVF elevator control system. (Yujian Tang Tianyu Gui)	This paper introduces the PLC VVVF elevator and its control system.	This paper present complete introduction of elevator control system by using PLC, VVVFD.
[23]	Speed control of induction motor using PLC and SCADA system. (Ayman Seksak Elsaid)	Speed control of IM.	This project's motivation is to use PLC for motor's speed control.
[24]	Speed control of induction motor using vector control technique (Hanumant Sarde)	Speed control of IM using vector control technique.	The main driving force of project is by utilizing vector control technique to manage motor speed.

[25]	Speed control of induction motor three Phase by using scalar control techniques (Hassan Siralkhatim Hassan Altayeb)	Speed control of IM using scalar control techniques	The project's motivation is to use scalar control techniques for controlling the motor's speed.

2.6 Motor control methods

Various techniques for speed control of IM are extensively used are shown in Figure 2.4:

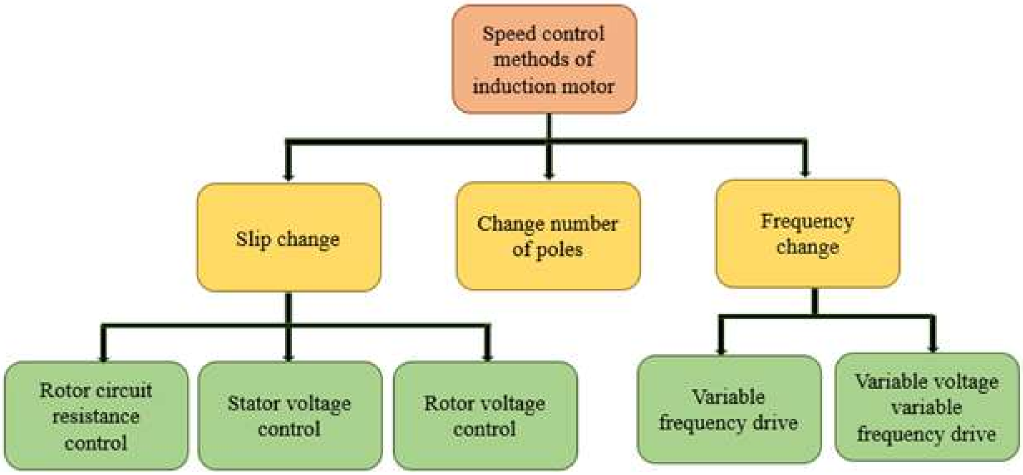


Figure 2.4: Speed control methods

2.6.1 Speed control techniques of induction motor

In the industrial sphere, number of terminologies are used to manage the motor's speed. While the acronyms are frequently used interchangeably, the terminologies are meant to have different meanings [3,12].

2.6.2 Variable speed drive (VSD)

With this type of drive, the motor's itself regulates the speed of driven equipment. Basically, hydrostatic, electrical, and mechanical speed drives all use this kind of mechanism. Variable speed drives (VSD) are electronic devices that allow for the control of the speed of an electric motor. This control allows for improved energy efficiency, process control, and equipment performance. VSDs are widely used in industrial and commercial applications to regulate the speed of pumps, fans, and other equipment. However, there are some drawbacks to using VSDs. The initial cost of purchasing and installing a VSD can be higher than other control methods. VSDs can also be susceptible to electrical noise and voltage spikes, potentially causing damage to the motor or other equipment in the electrical system. Additionally, the harmonic distortion generated by VSDs can impact the power quality of the electrical system and other equipment connected to it [12,15].

2.6.3 Variable frequency drive (VFD)

This device mostly comprises of power electronics equipment designed to change the system's supply frequency, which is used to regulate the motor's speed [9,5]. The system is divided into two parts: the power circuit and control circuit. These comprise the complete system. Single phase PWM inverter, single-phase bridge rectifier, DC filter, and make the power circuit. The gate drivers, opto couplers, and micro controller make comprise the control circuit in contrast. To produce DC output voltages that are passed across a DC filter, a single-phase diode bridge rectifier receives an input AC voltage from the single-phase PWM inverter. The PWM inverter is operated by a control circuit that produces a single phase PWM signal. The PWM inverter will then convert the DC input voltage to AC output voltage. Frequency and magnitude of AC output voltage can be adjusted by (v/f constant). Control of frequency and voltage is required because it enables the user to adjust the IM's speed at various angles [6, 7].

2.6.4 Adjustable speed drive (ASD)

The usage of mechanical and electrical applications for speed-controlling devices is referred by this broader name. Adjustable speed drives (ASDs) are electronic devices used to control the speed and torque of electric motors. They are commonly used in various applications, including HVAC systems, conveyors, and robotics, to achieve energy efficiency and precise control over motor speed. ASDs work by converting the incoming AC or DC power into a variable frequency and voltage output that matches the requirements of the motor. This enables the regulation of the motor's speed and torque by adjusting the frequency and voltage supplied to it [12].
Despite the many benefits of ASDs, they have a few drawbacks. High-frequency switching used in ASDs can generate electrical noise and harmonic distortion, potentially affecting other equipment in the electrical system. The switching can also cause voltage spikes that may damage the motor or other components. Additionally, ASDs require proper maintenance and protection from environmental factors, such as moisture and heat, to ensure their reliable operation. The initial cost of purchasing and installing an ASD can also be higher than other control methods [10].

2.6.5 Mechanical VSD method

VSDs, especially DC drivers used to be complicated, expensive as well as restricted to the most crucial and challenging applications. The mechanical drives were created to fit between the shaft of driven machine and an electric drive motor with fixed speed. Because of their simplicity and low price, mechanical variable speed drives continue to be preferred by many engineers (especially mechanical engineers) for specific applications [10].

2.6.6 Hydrostatic variable speed drive method

The most typical application for this kind of hydraulic VSD is in mobile machinery like earthmoving, mining equipment and transportation. Fundamentally, prime mover is in charge of set speed hydraulic pump and hydraulic fluid is being transferred to hydraulic motor .This fluid can circulate in a close circuit from pump to the motor and back. Since pump and hydraulic motor are typically housed in the same casing. The displacement motor and fluid flow rate are both directly related to hydraulic motor's speed. The regulation of fluid flow, pump control is therefore necessary for the VSD. Technically speaking, these drives are ideal for mining and earthmoving equipment since they have step-less variable range that goes from zero to full synchronous speed. Main advantages of hydraulic variable speed drives are listed below.

1. Even no damage is done when the drive unit stalls at full speed.
2. Hydrostatics VSDs typically operate in both directions.
3. High power to weight ratio.
4. High torque at low speed is possible [10].

2.6.7 Electrical VSD method

Electrical VSDs regulate the speed of electric motor directly rather than through intermediary device, in contrast to hydraulic and mechanical speed drives. Variable speed drives, that regulate the speed of AC motors, referred to as AC variable speed drives or just AC drives, whereas those regulate the speed of DC motors are known as DC variable speed drives or just DC drives. The majority of electrical VSDs are built to operate using a typical three-phase AC power supply system [15].

2.7 Limitations of VFD

In essence, the VSD is made to regulate the motor's speed rather than its voltage level. Disadvantages were discussed below.

2.7.1 Harmonics

The harmonics are primarily produced by variable frequency drive at rate of 30% or higher than the fundamental frequency. However, the pollution between the drives and the motor remains same when harmonic filtering device is installed in the front.

2.7.2 Internal losses

VFD has Internal losses are around 4% - 8% that reduce efficiency of electrical device. Variable frequency drives (VFDs) experience internal losses, including conduction losses due to semiconductor resistance, switching losses due to pulse-width modulation techniques, core losses due to magnetic core inefficiencies, and cooling losses due to heat dissipation. These losses impact VFD performance.

2.7.3 Motor life expectancy

There are basically 3 categories of parameters for estimating the life of motors.

1. Mechanical stress.
2. Operating temperature.
3. Voltage stress.

The RMS voltage is constantly decreased while using variable frequency drive; reduction of voltage undergoes more stress.If harmonic production took place in variable frequency drive, temperature inside the motor may increase by 80 to 100 degrees celsius. According to the Arrhenius law, the efficacy of insulation is reduced by 50% for every 100°C increase. It indicates that the lifespan motor efficiency is decreased by current VFD installation.

2.7.4 Cost

Variable frequency drive essentially needs extra filters to reduce harmonic pollution, which encourages cost growth. There are numerous more filtration solution types that can be used, each of which can provide a different amount of filtration. As a result, the price goes up [12].

2.8 PWM technique

Different power electronics switches with different switching patterns were used in VSD circuits to drive and regulate the speed of single-phase IM. There are many PWM techniques that can be utilized for most industries and other applications, including sinusoidal PWM and space vector pulse width modulation, main purposes of which are to control output voltage and minimize harmonics [1]. Steady torque at low speeds and full speed control from zero to the motor's rated speed are two advantages of using sine wave-weighted pulse width modulation (PWM) switching when running an AC induction motor [6].

Pulse width modulation drives are used to adjust a motor's speed because they supply the output voltage and frequency required. The needed waveform is created by combining pulses of different widths produced by pulse width modulation (PWM) inverter. To reduce harmonics, Diode bridge is use by some converters. Unwanted heating is decreased by PWM because it creates current waveforms that are more similar to those of line sources. At all speeds, power factor of PWM drives is virtually close to unity and constant. Several motors can be operated from single drive using PWM technique.

The speed at which power device switch turns ON and OFF determines the carrier frequency. Switch frequency is another name for it. As a result, PWM contain more resolution higher the carrier frequency. The average carrier frequency is between 3 and 4 KHz, or 3000 and 4000 times per second, as opposed to the previous SCR-based carrier frequency, that is between 250 and 500 times per second. Hence, it's cleared that output waveform's resolution will increase with increasing carrier frequency. Additionally, it should be remembered that the carrier frequency reduces drive efficiency by raising the drive circuit's temperature [10]. Figure 2.5 illustrates the output result of PWM technique.

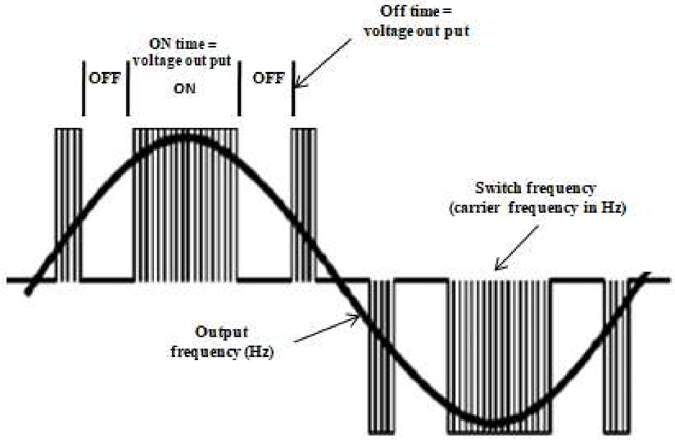


Figure 2.5: Drive output waveform components

2.9 Vector control technique

Scalar control and vector control make up the two categories of induction motor control techniques. When compared to vector control, scalar control is rather simple approach. In order to control the magnitude of selected quantities, a scalar control method is used. Scalar control cannot be used to govern systems with dynamic behavior, making vector control a more difficult technique. Scalar control's progression was inevitable. Vector control approach uses vector quantities and space phases to control the desired values. Because identifying the motor's field flux is necessary for implementation, it also goes by the name field-oriented control. The industrial VSD system with vector control technology thus uses IM. For speed control, this system needs a speed sensor. But in other circumstances, such as motor drives in high-speed drives and hostile environments, speed sensors cannot be placed [24].

2.9.1 Problem identification

1. It also grows pricey and cumbersome. Although the performance is satisfactory at high speed, it is poor at extremely low speed. The issue is that terminal voltage has a limit that, if it is exceeded, will have severe impact on insulation and motor operation.

2. The primary disadvantage of the rotor resistance approach is its low efficiency, which results from additional losses brought on by resistance [24].

2.10 Stator control technique

This approach is ineffective because rotor losses are proportional to slip . Additionally; it is ineffectual in most motors due to limited range of controllable slip. For broad variety the only workable approach is speed control; changing the supply frequency. To generate adjustable-frequency, adjustable-magnitude, and three-phase voltage for IM drives, power electronic inverters are most frequently used. Inverters are dc to ac converters, so in order to supply the inverter with dc power, the standard 60 Hz (or 50 Hz in some countries) ac voltage must first be rectified [25]. Closed loop diagram of this technique is given in Figur 2.6.

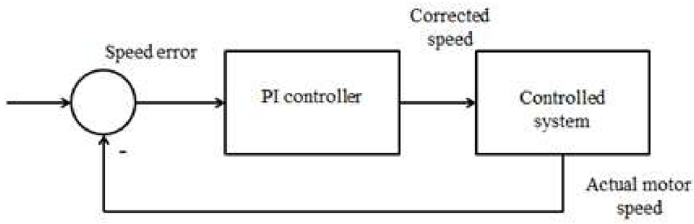


Figure 2.6: Closed loop of scalar control method

2.10.1 Problem identification

The main drawbacks of stator voltage control are that it results in lower power efficiency as the voltage reduction is not directly proportional to the speed reduction. The reduction in voltage causes increased current, leading to increased losses and reduced efficiency. This can result in higher operating costs and reduced equipment lifespan. Additionally, stator voltage control can cause issues with motor starting and acceleration, as well as increased mechanical stress on the motor due to the increased current flow. It can also lead to increased electrical noise and harmonic distortion in the electrical system, which can affect other equipment [24].

2.11 Controller

The controller's is used to increase the motor's efficiency operation, power output over the necessary speed range, and dynamic performance. Over time, control engineering has been changed. In the past, the primary method for regulating a system was through humans. Earlier, electrical control relied on relays.That relays make it possible for turn on off power without using a mechanical switch. Relays are frequently used to implement straightforward logical control choices [23].

PLCs are used in automation processes in many industries to lower production costs and improve quality and dependability. PLC's control action is given in Figure 2.7. compared to the conventional relay logic, FPGA (field programmable gate arrays) PID (proportional-integral-derivative), DSP (digital signal processor) techniques were used but PLC offers more accuracy as well as a safe and visible environment. The most recent revolution, programmable logic controller, was brought about by the introduction of low-cost computers (PLC). The advantages of PLC include flexible, rapid, and easy use for controlling other systems, as well as economical operation of complex systems. Due to computer power, more sophisticated control is feasible. Programming is made simpler, and downtime is decreased by troubleshooting tool .These are likely to work for years before due to their reliable components [13].

PLC is a control system with a microprocessor that was developed for industrial automation processes. It uses programmable memory to store user-oriented instructions for carrying out activities like arithmetic, counting, logic, sequencing, and timing inside. PLC has number of I/O that allows integration of electrical signals because it may be configured to sensors, activate, and control industrial equipment. PLCs connected to power converters, computers, and other electrical devices are required to produce accurate industrial electric drive systems [4,9].

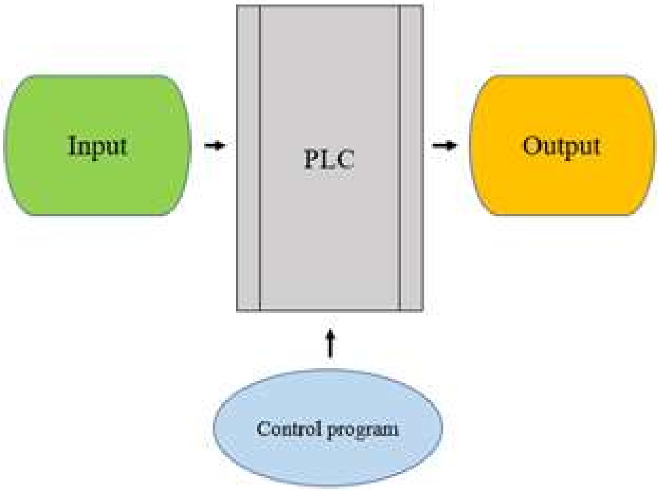


Figure 2.7: Control action of PLC

2.12 Design VVVFD

However, proposed design is a single SCADA system that controls speed of induction motor using PLC, in which data is acquire for monitoring and controlling through GUI screen according to load variations. The main concern of the project is to control torque and speed of IM by VVVFD. This proposed system will provide speed control technique for induction motor. Earlier, changing frequency led to semi control of induction motor. Irrespective to it, design the fully controlled loop system by varying frequency as well as voltage with higher accuracy to get better results.

Supervisory control and monitoring system for an induction motor using PLC (Programmable Logic Controller) and VVVF drive might include:

1. PLC: The PLC is the main controller of the system and is responsible for monitoring and controlling the motor's operation. It receives signals from various sensors, such as voltage and RPM sensors, and uses this information to adjust the motor's speed and torque.

2. VVVF Drive: The VVVF drive is used to control the frequency and voltage of the power supplied to the motor, which allows for precise control of the motor's speed and torque. The PLC communicates with the VVVF drive to adjust the frequency and voltage as needed.

3. Graphical user interface (GUI): The GUI is the interface between the user and the system. It allows the user to monitor the motor's operation, adjust the settings, and receive alerts and alarms if there are any issues.

4. Sensors: Various sensors are used to monitor the motor's operation, including voltage and RPM sensors. These sensors provide feedback to the PLC, which uses this information to adjust the motor's operation.

5. Motor: The induction motor is the device being controlled and monitored by the system. The motor is connected to the VVVF drive, which controls its speed and performance based on the input from the PLC

Overall, a supervisory control and monitoring system for an induction motor using PLC and VVVF drive is designed to provide precise control of the motor's speed and torque, while also monitoring its operation to ensure that it is operating safely and efficiently. A supervisory control and monitoring system for induction motors using PLCs and VVVF drives consists of sensors to monitor the motor, a PLC to control and manage the system, a VVVF drive to adjust the motor's speed and torque, an HMI for user interaction, a communication network to connect the different parts of the system, and the motor itself.

Chapter 3

Methodology

3.1 Overview

The overview of proposed system is shown in Figure 3.1. The diagram shows the working of a system in which The supervisory control and monitoring system for induction motor using programmable logic controller (PLC) with variable voltage and variable frequency (VVVF) drive and GUI-based RPM control is designed which is an advanced solution to regulate and monitor the operation of an induction motor.

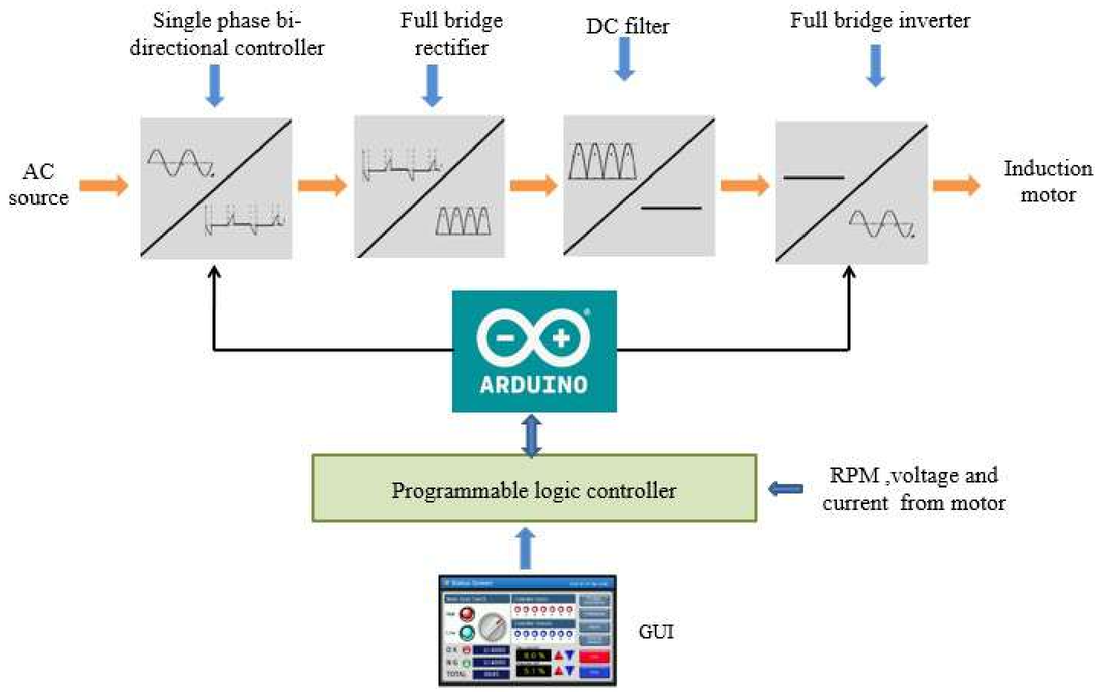


Figure 3.1: Diagram for SCMS of IM

The designed supervisor control and monitoring System for an induction motor aims to provide efficient control and monitoring capabilities using a programmable logic controller (PLC). The system diagram, as shown in Figure 3.1, depicts the complete working of the system. The system begins with an input AC power source, which is subjected to conversion into variable AC through a suitable conversion mechanism [11]. This variable AC is further transformed into DC using appropriate power electronics. The DC power is then directed to an inverter, where it undergoes conversion

back into AC. This inversion process is facilitated by an Arduino microcontroller, which assumes the responsibility of controlling the voltage and frequency of the AC output. To achieve precise control over the induction motor's speed, the arduino interprets RPM signals received from a 4A2D PLC module. The desired RPM value for the motor is set through the graphical user interface (GUI) provided by the PLC. The Arduino utilizes this reference RPM value to regulate the voltage and frequency of the output AC, ensuring that the motor operates at the desired speed.
To ensure accurate RPM control and maintain synchronization with the set RPM value, an IR beam sensor is incorporated into the system. This sensor continuously measures the actual speed of the motor and compares it with the required RPM obtained from the GUI. Any deviation between the measured speed and the desired RPM prompts the system to take corrective actions. These actions involve adjusting the voltage and frequency of the output AC through the Arduino, thereby ensuring that the motor's speed aligns with the desired RPM value. The supervisor control and monitoring system for the induction motor provides comprehensive functionality. It encompasses the conversion of input AC to variable AC, followed by conversion to DC and subsequent inversion back to AC using an Arduino-controlled inverter. The RPM signals obtained from the PLC, which are set through the user-friendly GUI, enable precise speed control. The inclusion of an IR beam sensor adds an extra layer of accuracy by continuously monitoring and comparing the actual motor speed with the desired RPM value. The designed system showcases a supervisor control and monitoring system for an induction motor, leveraging the capabilities of a PLC. It employs a series of conversions and control mechanisms, facilitated by an Arduino microcontroller, to regulate the voltage, frequency, and speed of the motor. The integration of an IR beam sensor ensures accurate speed monitoring and enables the system to promptly adjust the motor's parameters to maintain synchronization with the desired RPM value. The PLC module (4A2D) acts as the central control unit of the system, responsible for coordinating and supervising the overall operation. It receives the measured speed from the IR beam sensor and compares it with the desired RPM set via the GUI. If any deviation is detected, the PLC module can make necessary adjustments to the inverter frequency to maintain the motor's speed within the specified range [12].

3.2 System architecture of VVVFD

Table 3.1: Building block of VVVFD

Sr #	Part name	Part description
1	Single phase bi-directional controller.	First section uses TRIACs for converting fix AC source voltage into variable voltage by trigging TRIACs at different duty cycles.
2	Full bridge rectifier/Converter	That section converts variable voltage into DC voltage by diodes.

3	DC filter	This section contributes to make pure DC signal by blocking high frequency signals.
4	Variable frequency controlled full bridge inverter	Last section uses MOSFETs to convert DC signal to AC and controls frequency to required level.

3.2.1 Single phase bi-directional controller

The single-phase AC voltage controller's circuit with a resistive load is shown in Figure 3.2

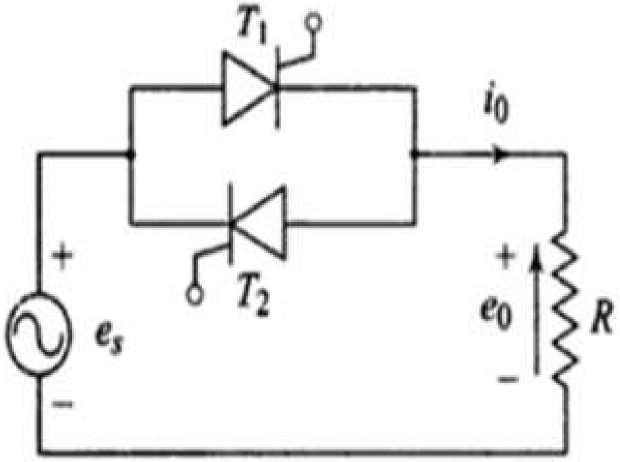


Figure 3.2: Circuit

As demonstrated; two antiparallel-connected thyristors have been used. Figure 3.2(b) displays the waveforms for the source voltage (e_s), gating pulses (i_{g1}, i_{g2}), load current (i_{g1}) load voltage (e_0) voltage across T1 as V_{T1}, and voltage across $T2$ as VT_2.The forward bias of thyristors $T1$ and $T2$ occurs throughout the positive and negative halves of the cycle, respectively. $T1$ is triggered at a firing angle $\alpha$of during the positive half-cycle. $T2$ is triggered at $(\pi + \alpha)$ during the negative half-cycle.$T2$ conducts from $(\pi + \alpha)$ to π. Soon after 2π, $T2$ is turned into reverse bise so that waveform of the load and source currents are identical.$T1$ is forward biased from zero to , so $V_{T1=e_s}$ as illustrated in right side Figure 3.3. $T1$ conducts from to π, therefore V_{T1} is approximately $1V$. Following, $T1$ is reverse biased by the source voltage, causing V_{T1} to from $(\pi + \alpha)$. Figure 3.3 depicts the voltage fluctuation V_{T1} through $T1$. The change of voltage V_{T2} across the thyristor $T2$ can be depicted similarly. To emphasize the length of the reverse bias between thyristors $T1$ and $T2$, the voltage drop across these devices is purposefully shown in Figure 3.3. A closer look at this figure indicates that each thyristor is reverse biased for $\pi\,\omega$ seconds for any value of α.

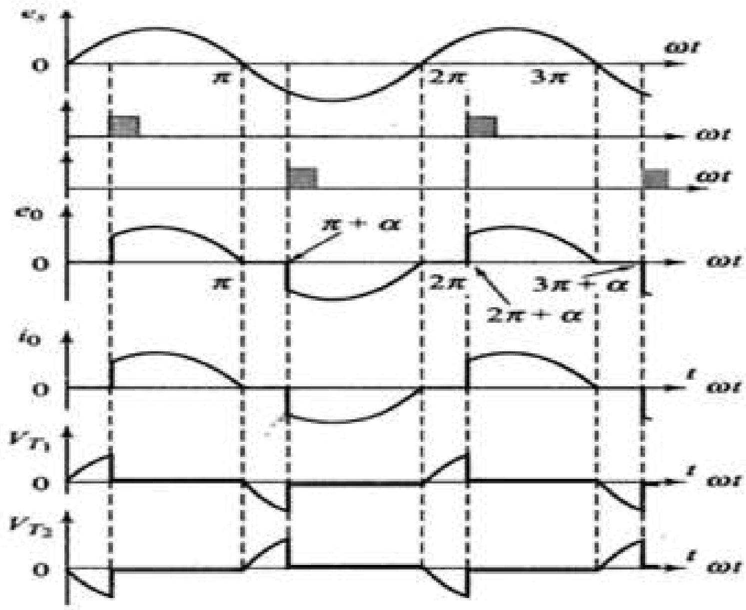


Figure 3.3: Wave form

3.2.2 Full bridge rectifier/Converter

Alternating current (AC) is transformed into direct current (DC) via the rectifier circuit .Half-wave, full-wave, and bridge rectifiers are the three basic types of rectifiers. All of these rectifiers have the same primary purpose.

- **Construction:** Figure 3.4 illustrating, bridge rectifier construction. The four diodes D1, D2, D3, and D4 can be used in this circuit, along with a load resistor (RL). To effectively convert AC (alternating current) to DC (direct current), these diodes can be connected in a closed-loop arrangement.

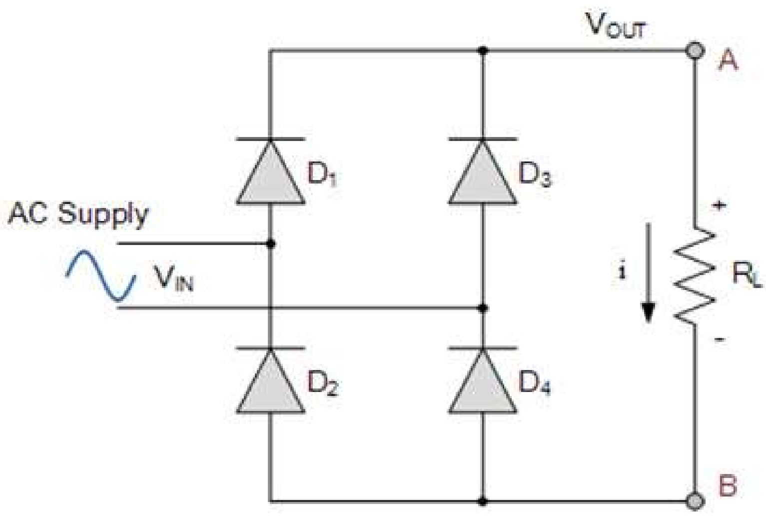


Figure 3.4: Full bridge rectifier's circuit

This design's key advantage is that it does not require a special center-tapped transformer. Therefore, both the size and the price will be reduced. The placement of two diodes can be done in such a way that two diodes will conduct electricity during each half cycle. Electric current will flow via diode pairs like D_1 and D_4 for the duration of the positive half cycle. D_2 and D_3 diodes behave similarly, conducting current during a negative half cycle.

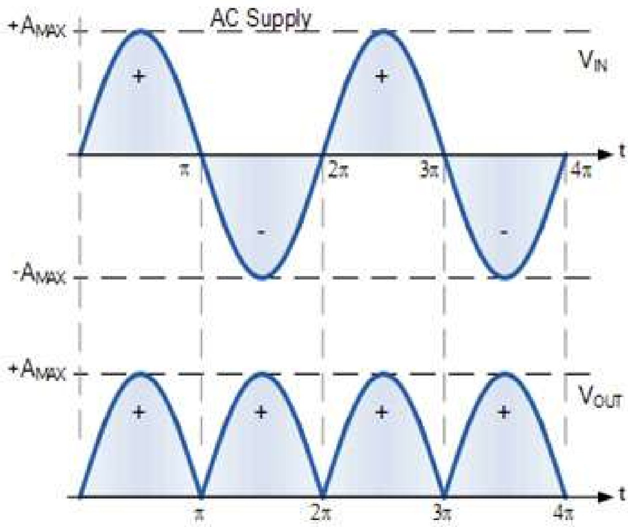


Figure 3.5: Rectified output waveform

3.2.3 DC filter

Filter circuit is a circuit that creates pure dc output across the load by removing the ac component from the rectifier's output. Between the rectifier and the load, the filter circuit should be installed.
The essential components of a filter circuit are inductors (L) and capacitors (C). The DC component cannot travel through a capacitor but the AC component can. An inductor, on the other hand, inhibits ac components while allowing dc components to pass through.

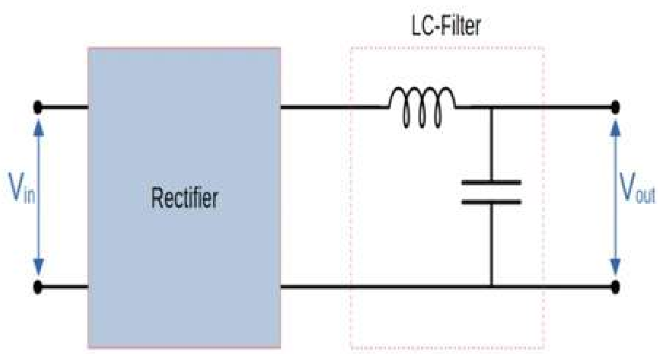


Figure 3.6: DC filter's circuit

First Stage: Inductor

For AC component of the rectifier's output waveform, inductor (L) serves as a 'choke' and works like an inductor filter. The DC component can pass through it without being attenuated by inductive reactance. The inductive reactance (XL), which is proportional to the frequency of the signal and the strength of the inductor, causes impedance in the AC component, which implies that higher frequencies are attenuated more than lower frequencies. Therefore, inductors are very effective at minimizing the effect of higher-order harmonics.

$$X_L = 2\Pi f L \tag{3.1}$$

As outcome of an inductor filter is seen bellow. It generates a sine wave DC signal that oscillates around the rectifier's average output voltage (VDC).We can observe that the inductor strengthens the waveform by limiting the whole DC pulse's enormous voltage fluctuations.
However, adding a capacitor can improve the signal even further.

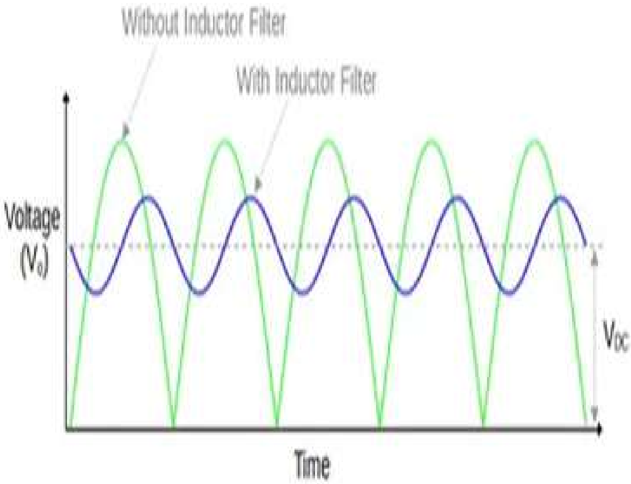


Figure 3.7: Inductor filter's outcome

Second Stage: Capacitor
While blocking the DC current, a smoothing capacitor permits the signal's AC component to flow to ground. Additionally, it stores and releases electrical energy, supplying the load with DC voltage and current when the input waveform would otherwise sharply increase and fall. As a result, it serves as a capacitor filter.
At low frequencies, the capacitive reactance (attenuation) is greatest:

$$X_L = \frac{1}{2\Pi f C} \tag{3.2}$$

In a distinctive way, capacitors improve the waveform. They generate a voltage when the waveform dips below the voltage they produce, storing charge when the voltage is higher than the voltage across the capacitor. During the capacitor's discharge cycle, the output voltage is smoothed.In order to improve clarity, take note that the figure 3.4 depicts the impact of a capacitor filter on a half-wave rectifier (by spacing out the charging and discharging cycles).

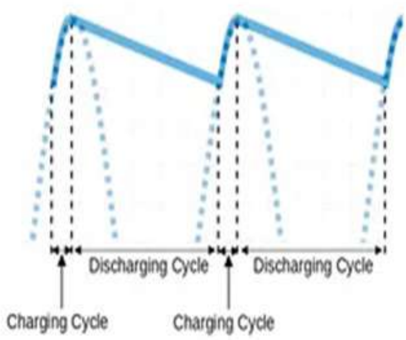


Figure 3.8: Capacitor filter's outcome

LC filter: The output waveform of an LC filter, which is created by combining an inductor filter with a capacitor filter, is essentially that of a two stage filter. The following image graphically displays this output.

1. **Green:** This line displays a full-wave rectifier's output, or stages zero (0).

2. **Dark Blue:** This depicts inductor filter's output, or stage one (1).

3. **Light blue line:** The stage two output of the LC filter is shown by dashed light blue line (2).
   The output is only shown in the following image for clarity's sake. Now it is very evident that the output of either the inductor filter or capacitor filter alone is much improved by the LC filter.

3.2.4 Variable frequency controlled H-bridge inverter

H-bridge inverter, which transforms DC power into AC power. This kind of inverter uses four switches. Peak voltage of a full bridge inverter is equal to the DC supply voltage. Figure 3.9 depicts the full bridge inverter's circuit diagram.

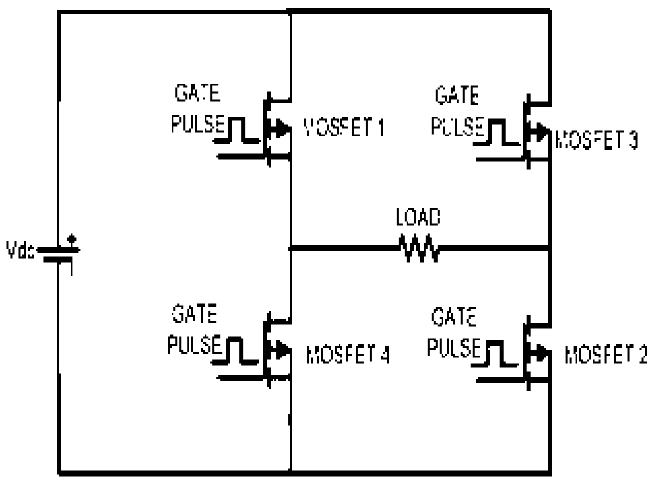


Figure 3.9: Full bridge inverter circuit

Figure 3.10 Both MOSFET 1 and MOSFET 2 have the same gate pulse. The two switches are both active at the same time. Similar to this, MOSFETs 3 and 4 operate simultaneously and have the same gate pulses. MOSFETs 1 and 4 (vertical arm), however, never run simultaneously. A short circuit will result if this occurs, shorting out the DC voltage source. MOSFETs 1 and 2 are triggered for the upper half cycle (0 ¡ t ¡ pi), and current will flow as depicted in the figure. The current is moving in a left to right direction throughout this time.

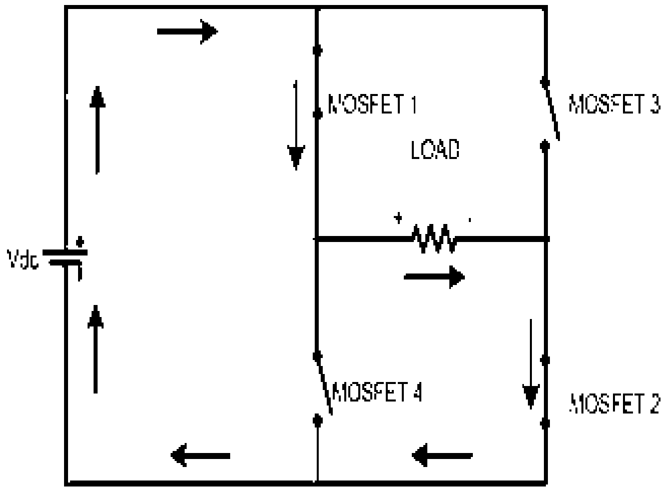
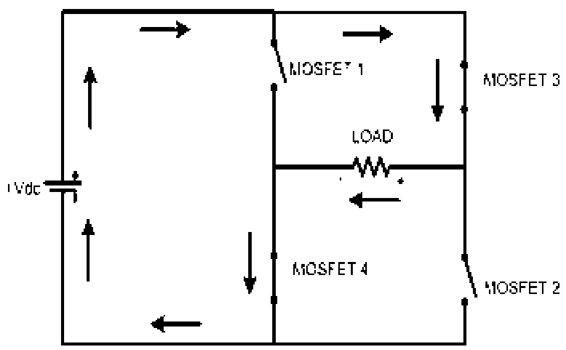
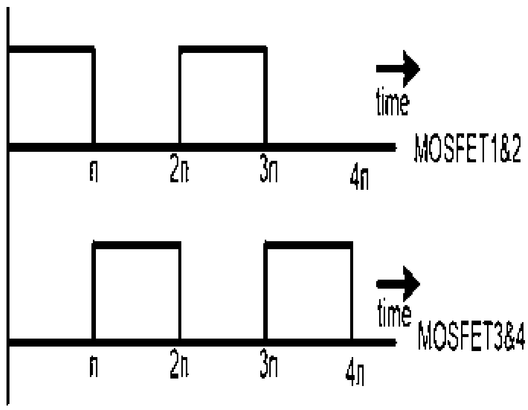


Figure 3.10: Gate pulses of MOSFET 1 and 2

Figure 3.11a shows MOSFETs 3 and 4 are triggered during the lower half cycle (π ¡ t ¡ 2π), causing the current to flow as depicted in the figure. The current is flowing from right to left throughout this time. In all scenarios, the peak load voltage is equal to the DC supply voltage Vdc.



(a) Gate pulses of MOSFET 34



(b) Gate signal for H-bridge inverter

The output of an H-bridge inverter in square wave form consists of alternating high and low voltage levels, resulting in a square-shaped waveform. This type of waveform is commonly used in applications where basic on-off switching is required, providing a simple and efficient method for controlling the output voltage and frequency of the inverter.

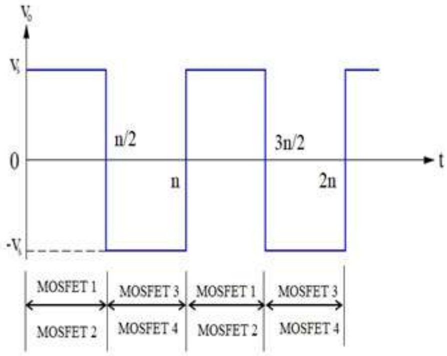


Figure 3.12: Inverter's output waveform

3.3 Block diagram

The block diagram of designed project shown in Figure 3.13 and Figure 3.14.

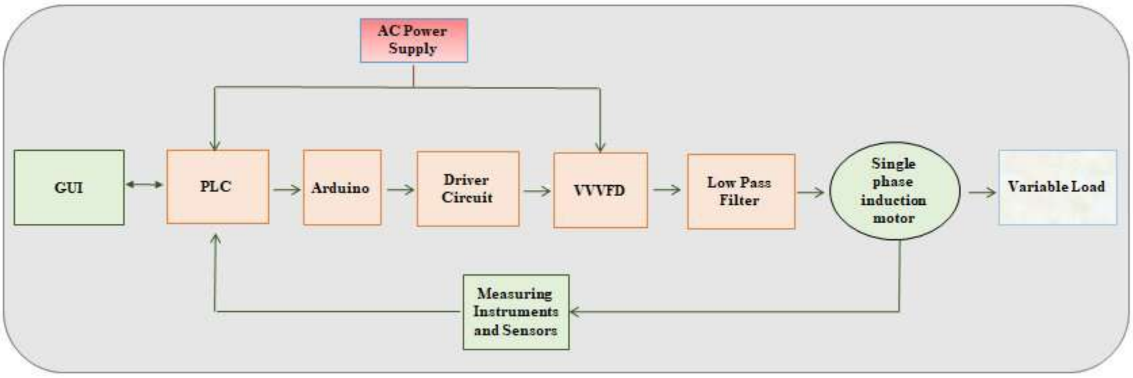


Figure 3.13: Supervisory control and monitoring system for induction motor using PLC

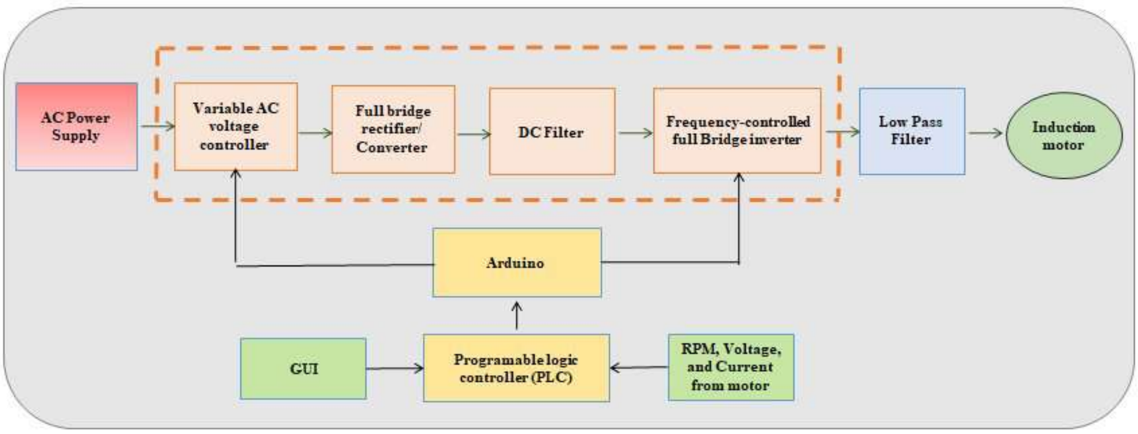


Figure 3.14: Variable voltage variable frequency drive (VVVFD)

3.3.1 Working

The project involves the implementation of a system for controlling and monitoring an induction motor using a variable voltage variable frequency drive (VVVFD).

The supervisor control and monitoring system for the induction motor utilizes a Programmable logic controller (PLC) with a 4A2D module to facilitate control signals. The system allows the user to input the desired RPM value through a graphical user interface (GUI) provided by the PLC. This RPM value serves as the reference for the motor's speed control.The control signal generated by the user's input through the GUI is sent from the PLC to the arduino. The arduino acts as the central control unit and receives the RPM signal from the 4A2D module. It interprets this signal to determine the required voltage and frequency adjustments necessary to maintain the desired RPM.
To achieve voltage and frequency control, the system employs variable voltage variable frequency drive (VVVFD) techniques. The first component in this process is an AC voltage controller. The AC voltage controller receives the control signals from the arduino and regulates the output voltage accordingly. By adjusting the amplitude of the AC voltage, it facilitates control over the motor's speed.The regulated AC voltage is then passed through a rectifier. The rectifier converts the AC voltage into direct current (DC) using diodes, resulting in a unidirectional flow of current. This rectified DC is then directed to a DC filter. The DC filter is responsible for smoothing out the pulsating DC waveform, ensuring a stable and consistent DC voltage supply.The filtered DC voltage is then fed into an H-bridge inverter. The H-bridge inverter is a circuit configuration that utilizes power electronics components such as transistors or IGBTs (insulated gate bipolar transistors) to convert the DC voltage back into AC. It achieves this by switching the polarity of the DC input, generating an AC output waveform.
To monitor and maintain the motor's speed accurately, an IR beam sensor is attached to the motor. The IR beam sensor measures the actual rotational speed (RPM) of the motor and continuously feeds this information back to the PLC. The PLC then compares the measured RPM with the required RPM obtained from the GUI input. If there is a deviation between the measured and desired RPM values, the PLC sends control signals to the arduino to adjust the voltage and frequency output accordingly. The arduino receives these control signals and implements the necessary changes to maintain synchronization between the measured and desired RPM. Additionally, the GUI provided by the PLC allows the user to monitor various parameters such as current and voltage. By displaying these parameters, the GUI provides real-time information on the motor's performance and helps in diagnosing any issues that may arise.

3.4 Schematic diagram

Schematic diagram of project shows the components and design circuitry in below image. That is divided into four sections.

Section 1: Single phase bi-directional controller

Section 2: Full bridge rectifier/Converter

Section 3: DC filter

Section 4: Variable frequency controlled full bridge inverter

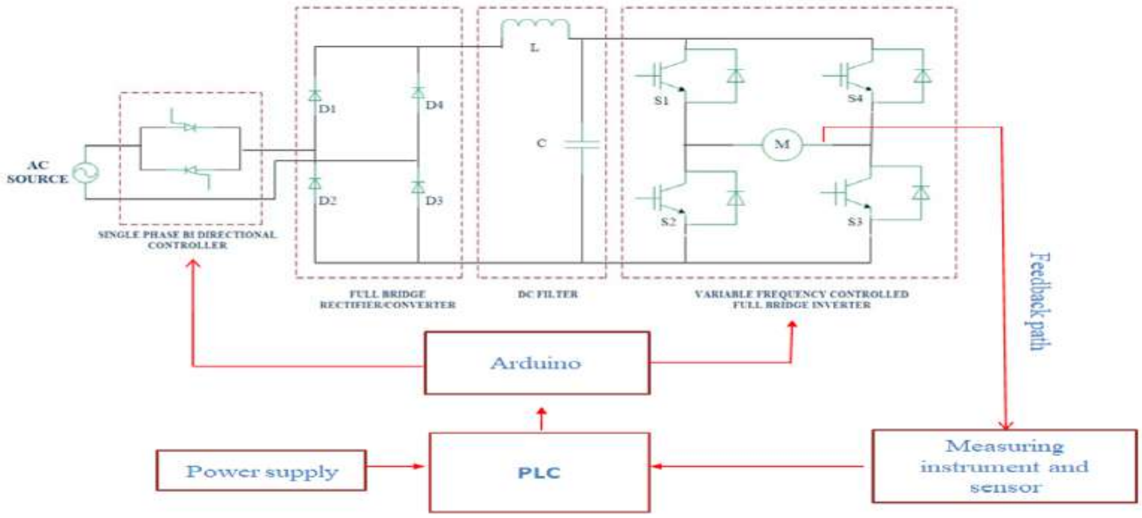


Figure 3.15: SCADA system for induction motor using PLC

3.5 Wiring diagram

Wiring diagram of designed project is given below:

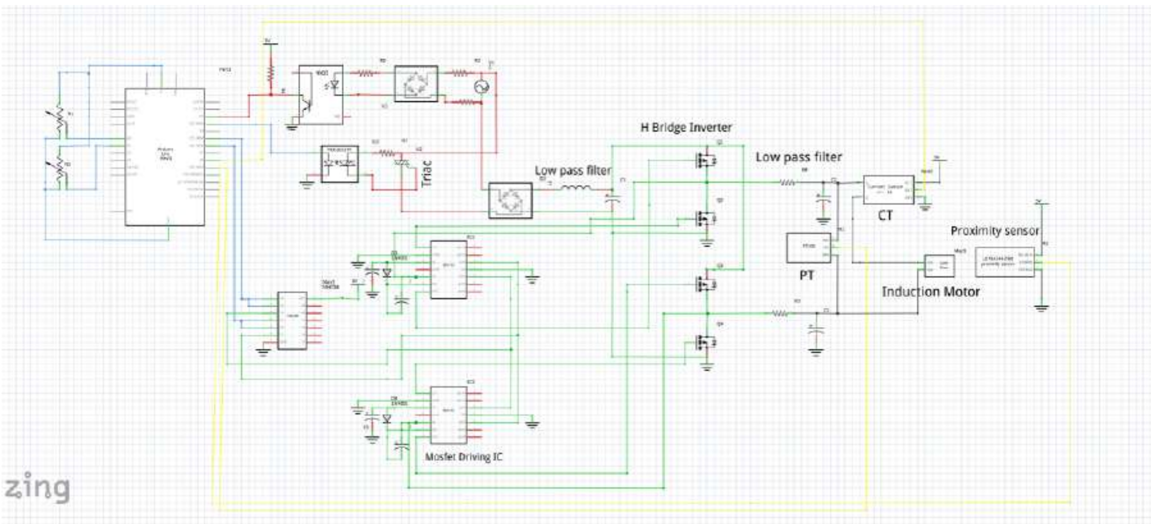


Figure 3.16: Diagram of designed project

3.6 Component selection

Component selection is a critical aspect of the supervisor control and monitoring system for the induction motor using PLC. When choosing components, several factors need to be considered. The PLC should be selected based on its compatibility with the required inputs and outputs, processing power, memory capacity, and communication capabilities. The 4A2D module needs to be compatible with the chosen PLC, ensuring proper signal types, communication protocols, and data resolution. The GUI system should be user-friendly, customizable, and able to display and modify necessary parameters. The Arduino microcontroller must be compatible with the PLC and capable of handling the required tasks, considering the number of digital and analog inputs/outputs, processing power, and communication options. VVVFD techniques like PWM can be implemented, requiring appropriate power electronics components such as transistors or IGBTs. The AC voltage controller should effectively regulate output voltage based on control signals from the Arduino, considering voltage rating, response time, and reliability. A suitable rectifier is needed to efficiently convert AC to DC, considering current and voltage ratings, efficiency, and application suitability. A DC filter is necessary to smooth the rectified DC waveform, ensuring a stable and consistent DC voltage output. The H-bridge inverter should be selected based on power requirements, voltage and current ratings, switching frequency, and protection features. An appropriate IR beam sensor is needed for accurate motor speed measurement, considering detection range, accuracy, and compatibility with the chosen PLC. Ensuring compatibility between components, considering power ratings, communication protocols, and integration capabilities is essential. Thorough research, referring to datasheets, consulting experts, and considering project-specific requirements are vital for informed component selection.

Table 3.2: Components used for VVVFD

Sr #	Component name	Model	Quantity
1	Induction motor(IM)	Signal phase squirrel cage IM	1
2	PLC	fatek Fbs 32 mar	1
3	PLC module	FBs-4A2D.	
4	PLC module	Ethernet Module	1
5	Arduino	Arduino nano	
6	Buck converter	...	1
7	Current transformer	Acs712	1
8	RPM sensor	Ir beam sensor	1
9	MOSFET driver IC	IC IR2112	2
10	Opto coupler	4N32 or PC 847	1
11	MOSFET	Irf740	4
12	Diode		4
13	Capacitor		10
14	Triac	BT139	1
15	Triac driver IC	Moc3021	1
16	Induction motor	Squirrel cage	1

3.6.1 Programmable logic controller (PLC)

Programmable logic controller (PLC) is a specialized digital computer used in industrial and manufacturing processes to automate control systems. It is designed to monitor and control machinery and equipment in real-time, allowing for efficient and reliable operation. A PLC consists of three main components: the central processing unit (CPU), input modules, and output modules. The CPU serves as the brain of

the PLC and executes the control program. Input modules receive signals from sensors and other devices, converting them into digital data that the PLC can process. Output modules transmit signals to actuators and other devices to control various industrial processes. The control program in a PLC is typically created using ladder logic, a graphical programming language that represents logic functions and control sequences through a series of interconnected symbols. PLCs offer several advantages over traditional relay-based control systems. They provide greater flexibility and scalability, allowing for easy reconfiguration and expansion of control systems. PLCs also offer faster response times, improving overall system performance. Additionally, they are highly reliable due to their robust design, which includes redundant components and built-in error detection and recovery mechanisms. PLCs can be interfaced with various industrial devices and networks, such as sensors, motors, human-machine interfaces (HMIs), and supervisory control and data acquisition (SCADA) systems. This enables seamless integration with other automation systems, facilitating data exchange and centralized monitoring and control.
PLC model:fatek fbs32 mar Ac:
FBS-32MAR2- AC.Some of the Key features of FATEK PLCs are as follows

- User friendly and powerful instructions
- Integrated high-speed counters with counting frequency up to 920 KHz
- High-speed timers High-speed timers
- Powerful Communication Features

Figure 3.17: PLC

3.6.2 PLC FBs-4A2D module

Modules are designed to expand the analog input and output capabilities of PLCs, enhancing their versatility and flexibility. As, our proposed project involves the need to monitor and control analog signals, such as voltage, current, and RPM of Induction motor so the using of FBs-4A2D module can be beneficial. It enables the PLC system to interface with analog sensors, actuators, or other devices, and perform advanced control strategies based on analog signals. Its analog input and output capabilities enable precise measurement, control, and optimization of motor variables, ensuring efficient motor operation, and facilitating advanced monitoring and control strategies and enabling PLC to handle a wider range of industrial applications that require precise analog measurement, control, and monitoring.

Figure 3.18: PLC module

I/O Capabilities
The FBs-4A2D module offers the following I/O capabilities:

- **Analog Inputs** The module supports analog input signals, allowing the PLC to read continuous values from various sensors or devices. It typically has 4 analog input channels, which can be configured to accept different signal types such as voltage or current. The specific input signal range and resolution may vary depending on the module and configuration.

- **Analog Outputs** The module also provides analog output channels, enabling the PLC to generate continuous analog control signals. It typically offers 2 analog output channels, which can be used to drive actuators or control devices that require analog control signals. The output range and resolution may vary depending on the module and configuration.

- **Digital Inputs and Outputs** In addition to analog I/O, the FBs-4A2D module may also include digital input and output channels. These digital I/O channels can be used to interface with discrete devices such as switches, push buttons, and indicator lights. The specific number and configuration of digital I/O channels may vary depending on the module.

- **Communication** The FBs-4A2D module communicates with the PLC's central processing unit (CPU) through a communication bus or backplane. It typically uses a standardized communication protocol such as RS-485 or Modbus to exchange data between the module and the PLC CPU.

- **Configuration and Programming** The FBs-4A2D module is typically configured and programmed using dedicated software provided by the PLC manufacturer. Through the programming software, you can assign I/O addresses, set the signal type, scaling, and other parameters for each I/O channel.

It's important to consult the specific documentation and datasheet provided by the manufacturer of the FBs-4A2D module for precise details, including the supported signal ranges, resolution, and compatibility with different PLC models.

3.6.3 Ethernet module

The ethernet module is utilized to enable communication and networking capabilities within the PLC system. It serves as an interface that allows the PLC to connect and exchange data with other devices and systems over an Ethernet network. The ethernet module is configured to establish communication over the ethernet network by setting up network parameters such as IP address, subnet mask, and gateway. This ensures proper connectivity and enables the PLC to communicate with other devices on the network. With the ethernet module in place, data transmission becomes possible between the PLC and external devices. The module facilitates the exchange of data packets using the Ethernet protocol, which involves organizing the data into frames with source and destination addresses, payload, and error detection codes.

The ethernet module enables the PLC to communicate with devices such as sensors, motor controllers, and human-machine interfaces (HMIs). This allows for the monitoring and control of various parameters, including current, voltage, and RPMs of the induction motor.The ethernet module also supports messaging protocols such as TCP/IP and UDP, which are essential for transmitting data over the network. This enables the PLC to send and receive data packets, making it possible to monitor the current RPMs of the motor and compare them with the desired RPMs set through the GUI. Additionally, the Ethernet module may provide network services such as DHCP for automatic IP address assignment and DNS for name resolution. These services enhance the network connectivity and simplify the setup process, allowing for seamless integration of the PLC into the ethernet network.

Figure 3.19: Communication Module for PLC

3.6.4 Arduino

The arduino nano is a compact and versatile microcontroller board that is based on the ATmega328P microcontroller chip. It is part of the arduino family of development boards and is designed for projects that require a small form factor and low power consumption. With its unique features and capabilities, the arduino nano has gained popularity among hobbyists, students, and professionals alike.

Key features of arduino

- **Microcontroller** The arduino nano utilizes the ATmega328P microcontroller chip, which operates at 16 MHz. It provides 32KB of flash memory for storing code, 2KB of SRAM for data storage, and 1KB of EEPROM for non-volatile storage.

- **Compact Design** The nano board is characterized by its small size, typically measuring around 45mm x 18mm. This compact form factor makes it suitable for projects with limited space or those requiring portability.

- **Connectivity** The board features a USB interface for programming and serial communication. It also includes digital input/output (I/O) pins, analog input pins, and PWM pins, enabling seamless integration with various sensors, actuators, and electronic components.

- **Power Options** The nano board incorporates a built-in voltage regulator, allowing it to be powered via a USB connection or an external power source. It operates within a voltage range of 6V to 20V, making it compatible with different power supplies.

- **Programming** Arduino nano can be programmed using the Arduino Integrated Development Environment (IDE). This user-friendly IDE supports the development of code in the C/C++ programming language. It includes a vast library and a range of functions to simplify the programming process.

- **Shield Compatibility** The nano board is compatible with most Arduino shields, which are additional boards that can be stacked on top to provide additional features or functionality.

- **Applications** The arduino nano finds applications in various fields, such as robotics, home automation, Internet of Things (IoT) projects, sensor monitoring systems, data logging, and prototyping. The arduino nano is highly regarded for its small size, versatility, and ease of use. It offers a rich set of features and ample community support, making it an excellent choice for both beginners and experienced users in the realm of electronics and programming.

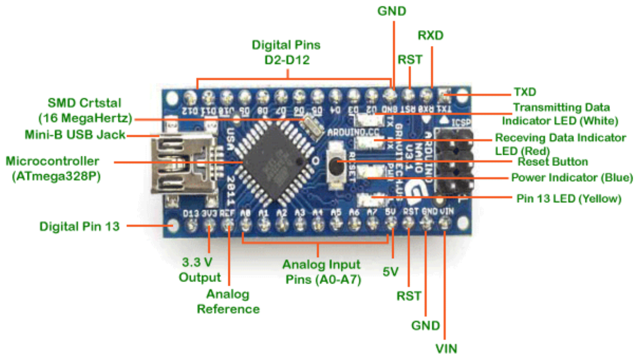


Figure 3.20: Arduino

3.6.5 Dc to Dc Buck converter

A buck converter, also known as a step-down converter, is a type of DC-DC converter used to efficiently lower the voltage level from a higher input voltage to a lower output voltage. It is widely used in various electronic devices and power systems. In the proposed project, a buck converter is employed alongside Arduino for voltage integration. The purpose of the buck converter is to convert the input voltage of 24V to a regulated output voltage of 5V. This specific voltage conversion is necessary because Arduino operates reliably at 5V. By employing the buck converter, the system ensures compatibility between the PLC, Arduino, and the induction motor, enabling seamless integration and efficient control of the motor system.

Figure 3.21: Buck converter

3.6.6 Current transformer

The ACS712 current sensor is a widely used Hall-effect based current transformer that allows for accurate and non-intrusive measurement of current in electrical systems. It is designed to provide a linear output voltage proportional to the AC or DC current passing through the sensor. The ACS712 employs a highly sensitive Hall-effect sensor to detect the magnetic field generated by the current-carrying conductor. This magnetic field is converted into an electrical signal, which is then amplified and conditioned to provide an output voltage proportional to the measured current. One of the key advantages of the ACS712 is its ability to measure both AC and DC currents with high accuracy and low power loss. It offers a wide range of current measurement options, typically available in amperes (A), and supports various current ranges to suit different applications.

Figure 3.22: Current transformer

3.6.7 Voltage divider

A voltage divider is an essential electronic circuit that divides an input voltage into smaller fractions. It is constructed by connecting two or more resistors in series, and the resulting output voltage is obtained at the connection point between them.

3.6.8 RPM sensor

The IR beam sensor is a commonly used device for measuring the RPM (rotations per minute) of an induction motor. It utilizes the principle of interruption of an infrared beam to detect the rotational speed of the motor.
Operating Principle: The IR beam sensor consists of an infrared transmitter and receiver pair. The transmitter emits a continuous infrared beam, while the receiver detects the intensity of the reflected beam. When an object, such as a rotating disc or reflective tape, interrupts the beam, the receiver detects a change in intensity, indicating a passing event.

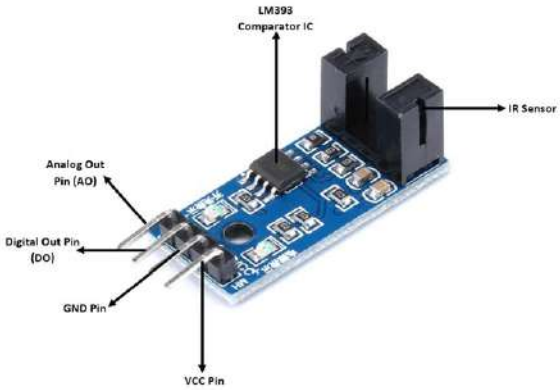


Figure 3.23: IR beam (LM 393) sensor

3.6.9 MOSFET

The IRF740 is a power metal-oxide-semiconductor field-effect transistor (MOSFET) that is commonly used in a variety of applications requiring high power switching. It is designed to handle relatively high currents and voltages, making it suitable for use in power electronics and switching circuits. The IRF740 MOSFET has a low on-resistance, allowing for efficient power handling with minimal voltage drop across the transistor. It operates in enhancement mode, meaning that a positive voltage applied to the gate terminal enhances the flow of current between the drain and source terminals. With a high voltage rating, typically around 400V, the IRF740 can handle high voltage applications, making it suitable for use in power supplies, motor control circuits, inverter systems, and other high-power switching applications. Its robust construction and thermal characteristics enable it to handle significant power dissipation. Overall, the IRF740 MOSFET is a popular choice in various high-power switching applications due to its high voltage rating, low on-resistance, and ability to handle substantial currents. Its robust design and efficient performance make it suitable for demanding applications where high power switching is required. The IRF740 MOSFETs are employed as switching devices in a full bridge inverter configuration.

Figure 3.24: IRF 740

3.6.10 MOSFET driver IC

The IR2112 is a highly integrated and efficient MOSFET driver IC designed for driving high-power MOSFETs and IGBTs in various power electronics applications. The IR2112 is capable of high-frequency operation, enabling fast and precise switching of MOSFETs. With its integrated features, protection mechanisms, and high-performance characteristics, the IC enables accurate and efficient operation of power devices in various power electronics applications.

Figure 3.25: IRf2112 IC

3.6.11 Opto coupler

The 4N25 is an optocoupler, also known as an optoisolator. It consists of an infrared LED (emitter) and a phototransistor (detector) enclosed in a single package. The device provides electrical isolation between the input and output circuits. When an electrical signal is applied to the LED, it emits infrared light that activates the phototransistor, allowing current to flow through the output circuit. The 4N25 typically operates with a forward voltage (Vf) of around 1.2V and a maximum current (If) of 60mA.

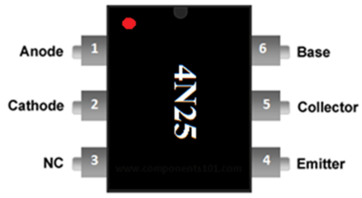


Figure 3.26: 4N25 IC

3.6.12 Diode

The IN4007 is a standard rectifier diode used for converting alternating current (AC) to direct current (DC). It allows current to flow in only one direction, blocking the reverse current. The diode operates with a maximum repetitive reverse voltage (Vrrm) of 1000V and a maximum forward current (If) of 10A. The IN4007 is commonly used in rectification circuits, voltage clamping, and reverse voltage protection.

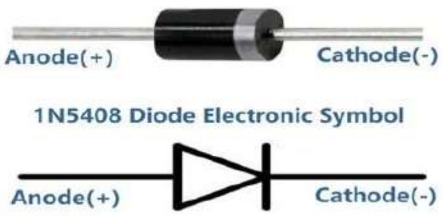


Figure 3.27: Diodes pin configuration

3.6.13 Moc 3021 Triac driver IC

The MOC 3021 is an optoisolator specifically designed to drive a triac. It includes an infrared LED and a phototriac in a single package. When the LED is activated, it triggers the phototriac, allowing current to flow through the main triac in the output circuit. The MOC 3021 is widely used to control AC power loads such as dimming lights or controlling motor speed. It typically operates with a forward voltage (Vf) of around 1.15V and a maximum current (If) of 60mA.

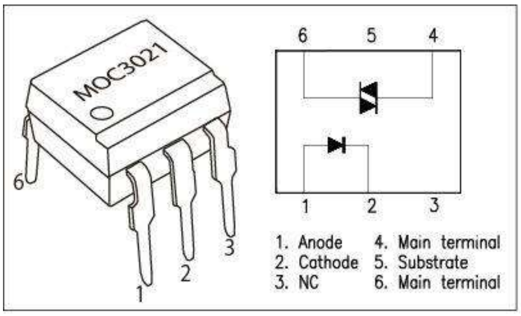


Figure 3.28: MOC 3021 Pin configuration

3.6.14 Triac (BT139)

The BT139 is a bidirectional triode thyristor or triac used for switching and controlling AC power. It allows current to flow in both directions, enabling control of AC power by triggering it at specific points in the AC waveform. The BT139 has a maximum voltage rating (Vdrm/Vrrm) of around 600V and a maximum current rating (It) of typically 16A. It is commonly used in applications such as motor control, lighting control, and power regulation.

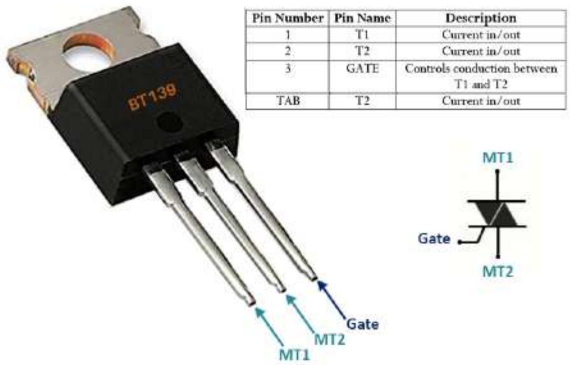


Figure 3.29: Triac Pin configuration

3.6.15 Single phase squirrel cage induction motor

The signal phase squirrel cage induction motor is a single-phase variant of the squirrel cage induction motor, widely utilized in diverse industrial and commercial applications due to its straightforward design, reliability, and sturdy construction.

Operating Principle:

Operating on the principle of electromagnetic induction, the signal phase squirrel cage induction motor comprises a fixed stator and a rotating rotor. The stator is comprised of laminated iron cores housing evenly spaced stator windings. These windings are typically arranged in a distributed manner around the stator slots. In contrast, the rotor is a cylindrical core constructed of laminated iron, embedding conductive bars, commonly known as the "squirrel cage." These bars are short-circuited at both ends, forming a closed loop.

Motor Construction:

The motor's stator is composed of laminated iron cores with distributed stator windings, while the rotor consists of laminated iron with an embedded squirrel cage composed of conductive bars that are short-circuited at each end.

Motor Operation:

When an alternating current (AC) power supply is connected to the stator windings, it generates a rotating magnetic field within the stator. This rotating magnetic field induces currents in the squirrel cage rotor bars through electromagnetic induction. Consequently, a magnetic field is produced within the rotor, interacting with the stator's rotating magnetic field.

The interaction between the magnetic fields generates torque, initiating the rotation of the rotor. The direction of rotation is determined by the phase relationship between the stator and rotor magnetic fields. The motor operates slightly below the synchronous speed, known as slip, which is necessary for torque generation.

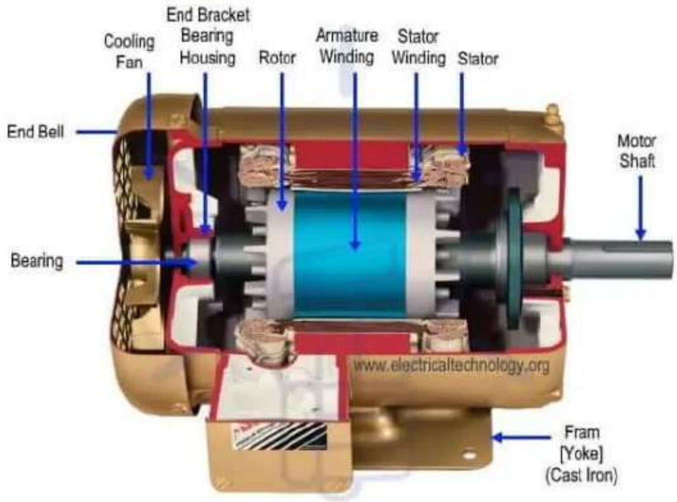


Figure 3.30: Structure of IM

3.7 Mathematical model

AC power flow controller

$$V_0(\text{RMS}) = V_s \sqrt{\frac{1}{\pi}\left[(\pi - \alpha) + \frac{\sin(2\pi)}{2}\right]} \tag{3.3}$$

The equation 3.3 calculates the RMS (root mean square) value of voltage, denoted as V_0(RMS), based on the peak voltage V_s and the parameter α. By adjusting α, which represents the angle or duty cycle, you can modify the shape and timing of the voltage waveform. The expression inside the square brackets determines the angular span of the waveform, accounting for the difference between π and α. The term $\frac{\sin(2\pi)}{2}$ simplifies to zero, and the overall expression is divided by π and square rooted. This equation provides a mathematical relationship for varying the input supply voltage.

Trigger angle (deg)	**Trigger angle (rad)**	**Vo(RMS)**	**Percentage**
0 degree	0	Vs	100% Vs
30 degree	$\pi/6$	0.9854 Vs	98.54% Vs
90 degree	$\pi/2$	0.7071 Vs	70.7% Vs
150 degree	$5\pi/6$	0.1698 Vs	16.98% Vs
180 degree	π	0 Vs	0 Vs

Low pass filter

$$\text{fc} = \frac{1}{2\pi RC} \tag{3.4}$$

Speed of IM

$$n = 120 \cdot \frac{f}{p} \tag{3.5}$$

Firing angle-controlled mapping and linearization over potentiometer.

$$y = mx + c \tag{3.6}$$

y= time in micro second (firing angle)
X=potentiometer 10 ADC value
Rang of y is 100us to 9900us.
Rang of x is 0 to 1023.

$$\boldsymbol{9900 = m * 1023 + c}$$

$$\boldsymbol{100 = m * 0 + c}$$

By solving above Eq.

$$\boldsymbol{c = 100}$$

$$\boldsymbol{m = 9.57}$$

3.8 Algorithm

Algorithm 1 Supervisory Control and Monitoring System for Induction Motor using PLC

Input: System startup **Output**: Motor operates at desired RPM
Procedure:
Step 1: Start the system
Step 2: Initialize the required variables and inputs
Step 3: Display the Graphical User Interface (GUI) to the user for entering the desired RPM value

Step 4: Read the user input for the desired RPM
Step 5: Transmit the entered RPM value to the Programmable Logic Controller (PLC)
Step 6: Compare the entered RPM with the motor RPM of the motor

while RPM does not match the desired RPM **do Step 7**: If the entered RPM $<$ than the motor RPM, adjust the voltage and frequency parameters to decrease the motor speed
Step 8: If the entered RPM is $>$ than the motor RPM, adjust the voltage and frequency parameters to increase the motor speed
Step 9: Check the tolerance range to ensure that the RPM remains within acceptable limits
Step 10: If the RPM falls outside the tolerance range, make further adjustments to the voltage and frequency to bring it back within the desired range
Step 11: Send the adjusted voltage and frequency signals to the inverter
Step 12: Monitor the RPM of the motor using a feedback loop
Step 13: Continuously compare the actual RPM with the desired RPM
Step 14: If there is a difference between the actual and desired RPM, adjust the voltage and frequency parameters accordingly
Step 15: Repeat Steps 11-14 until the motor's RPM matches the desired RPM
Step 16: Display the motor RPM, voltage, and current values to the user for monitoring purposes
Step 17: Continue monitoring the motor's RPM and make adjustments as necessary
Step 18: If the system is interrupted or stopped, end the program

3.9 Flow chart

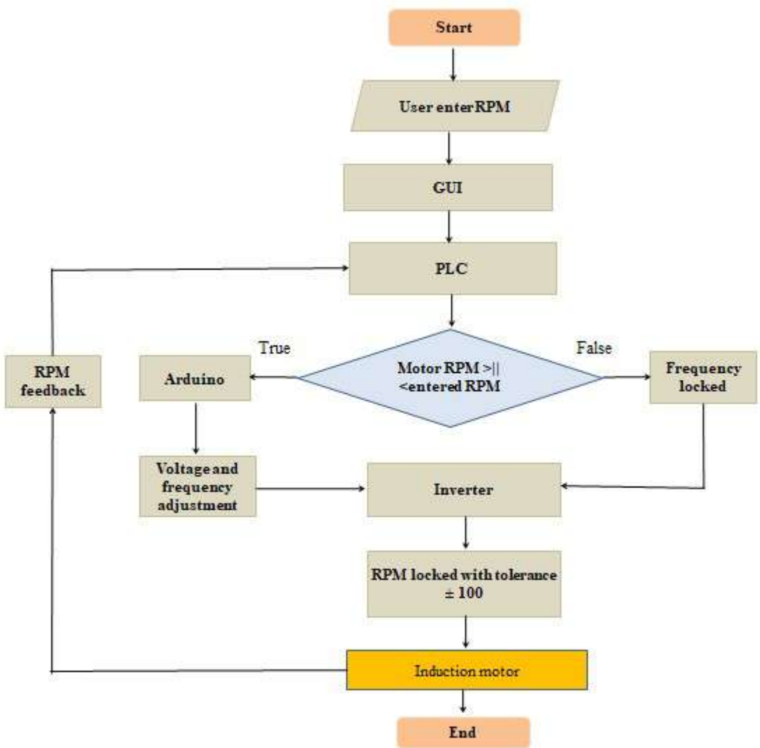


Figure 3.31: Flow chart for SCMS of IM

Explanation of flow chart

The flowchart outlines the step-by-step process for controlling the RPM of an induction motor in your project. It begins with the user entering the desired RPM value through the graphical user unterface (GUI). The entered value is then transmitted to the programmable logic controller (PLC), which serves as the central control unit.The PLC proceeds to the condition check block, where it compares the entered RPM with the current RPM of the motor. This comparison helps determine whether the entered RPM is greater or less than the motor's current RPM. If the condition is false, meaning the entered RPM is within an acceptable range, the flow moves to the frequency lock block. In the frequency lock block, the PLC adjusts the voltage and frequency parameters to achieve the desired RPM. By modifying these parameters, the system ensures that the motor operates at the target speed set by the user. The control signals for voltage and frequency are then sent to the inverter.

After passing through the inverter, the system performs a tolerance check to ensure that the RPM remains within a specified range. If the entered RPM falls outside the tolerance range, the PLC makes adjustments to the voltage and frequency to bring it back within the desired range.Finally, the adjusted voltage and frequency signals are fed to the induction motor, allowing it to operate at the desired RPM. Additionally, the RPM of the motor is continuously monitored by the system through a feedback loop, where the actual RPM is compared to the desired RPM. This feedback enables the PLC to make real-time adjustments as needed to maintain the motor's speed at the desired level.

Chapter 4

Results and discussion

4.1 Project implementation process

The implementation of the design of supervisor control and monitoring system for induction motor using PLC will involve a series of technical steps, which require expertise in electrical engineering and automation.

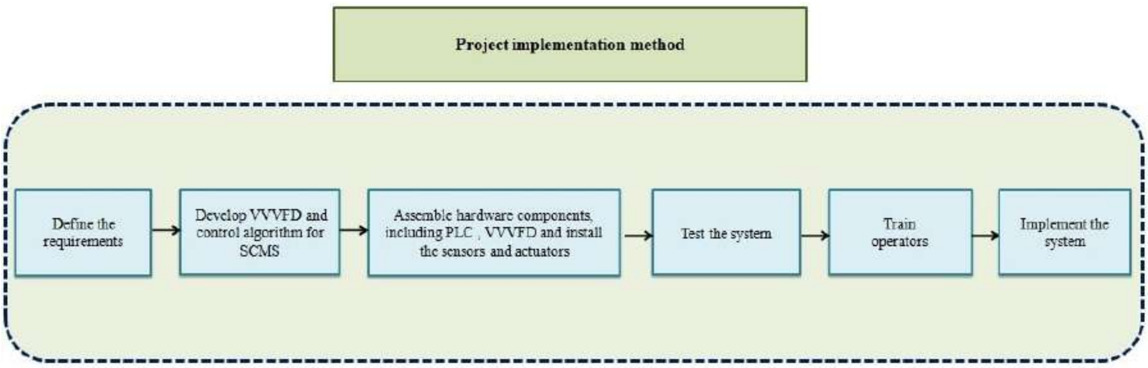


Figure 4.1: Project implementation method

1. **Define the requirements:** The first step is to define the requirements for the SCMS. This will involve identifying the desired output, the size of the IM, the parameters that need to be monitored, and the available resources for installation and maintenance.

2. **Develop VVVFD and control algorithm for the SCMS:** The VVVFD will control the voltage and frequency supplied to the induction motor, and the control algorithm will regulate the motor speed and torque. To achieve this, the control algorithm should be developed by programming the PLC using ladder logic or other programming languages. The algorithm should be designed to monitor various motor parameters such as voltage, current, and speed, and provide real-time feedback to the operator.

3. **Assemble hardware components,including PLC, VVVFD drive, Install the sensors and actuators:**

- Procure the necessary hardware components based on the system requirements and design.
- Assemble the hardware components according to the wiring diagrams and specifications.
- Sensors and actuators will need to be installed on the IM to monitor motor parameters and control the VVVFD. These components should be compatible with the PLC and properly integrated into the control system.
- Ensure that all components are installed correctly and properly connected.

4. **Test the system:** Once the sensors, actuators, and PLC are installed, the SCMS needs to be tested to ensure that it is functioning correctly.
5. **Train operators:** The operators of the IM should be trained on how to operate the SCMS, including how to monitor the system, troubleshoot problems, and make adjustments as needed.
6. **Implement the system:** Once the SCMS has been tested and operators have been trained, the system can be implemented on the IM for regular use.

4.2 Software design

4.2.1 Software tool

Proteus

Proteus has been utilized as a simulation tool to test and evaluate the performance of an AC voltage regulator and an H-bridge inverter for varying the frequency. Proteus allows to create a virtual circuit representation of these components and simulate their behavior.
By configuring the AC voltage regulator in proteus, simulate the regulation of AC voltage levels. This involves testing different input voltage scenarios and observing how the regulator adjusts the output voltage to maintain a desired level. Through the simulation, the accuracy and stability of the voltage regulation process.
Similarly, with the H-bridge inverter,simulate the variation of frequency. By adjusting the input parameters in the virtual circuit, such as the frequency control signals and modulation techniques, observe the resulting AC waveform and its frequency characteristics. This enables to analyze the performance of the inverter in generating the desired frequency output accurately.
Using proteus for testing the voltage and frequency aspects of project provides a convenient and efficient way to evaluate the performance of the AC voltage regulator and H-bridge inverter. By simulating various scenarios and observing the output results, fine-tune the design parameters, assess the system's stability, and ensure the desired voltage and frequency variations are achieved effectively.

Fv designer

The FV designer tool used to facilitate the setting of the desired RPM (rotations per minute) and monitor important parameters such as current, voltage, and motor speed. The FV designer tool serves as a graphical user interface (GUI) that enables intuitive control and real-time monitoring of the system.
With the FV designer,input the desired RPM value through the user interface, providing a convenient and user-friendly way to set the target speed for the induction motor. The tool allows you to enter the desired RPM value and transmit this information to the control system, facilitating precise speed control.
Furthermore, the FV designer enables to monitor critical parameters such as current, voltage, and motor speed in real-time. By utilizing the tool's monitoring capabilities, you can observe the actual RPM, voltage level, and current flow within the system during operation. This allows you to assess the system's performance, identify any deviations from the desired values, and make necessary adjustments as required.The FV designer tool provides a comprehensive and visual interface that enhances the overall control and monitoring of the induction motor system. It streamlines the process of setting the desired RPM and facilitates the continuous tracking of critical parameters, ensuring efficient operation and enabling prompt intervention in case of any discrepancies.

Arduino IDE

The arduino IDE (integrated development environment) is a software platform that provides a user-friendly interface for programming and controlling Arduino microcontrollers. The arduino IDE plays a crucial role in developing and uploading code that allows you to control the frequency and voltage for the system based on the signals received from the PLC module.
By utilizing the arduino IDE, write, compile, and upload code to the Arduino microcontroller. The IDE offers a simplified programming environment, making it accessible for both beginners and experienced developers.Write code in the arduino programming language, which is a simplified version of C++ with libraries specifically designed for interacting with Arduino boards. To control the frequency and voltage according to the PLC signal, Arduino IDE that communicates with the PLC module and reads the input signals. Based on the received signals, control algorithms and logic adjust the frequency and voltage parameters of the SCMS system. This may involve manipulating PWM (pulse width modulation) signals or utilizing specific Arduino libraries to interface with external components such as inverters or voltage regulators.

Winpro ladder

WinPro ladder is a software tool that is commonly used for developing ladder logic programs for industrial control systems. WinProladder has been employed to create ladder logic programs that facilitate the monitoring of various parameters such as current, voltage, and RPM (rotations per minute) of the motor. Additionally, it is utilized to generate control signals for RPM and establish interlocks between the required RPM and current RPM values.
Design the ladder logic diagrams that represent the control logic and sequencing of SCMS system. This involves creating rungs with different ladder logic elements such as contacts, coils, timers, counters, and comparators. These ladder logic elements

allow you to monitor the current and voltage levels of the motor, as well as measure the RPM using appropriate sensors. Furthermore, WinProladder enables the generation of control signals for RPM, which can store predefined instructions or parameters for the system's operation. This allows for efficient and reliable control of the motor based on predefined conditions or requirements. In addition, WinProladder facilitates the implementation of interlocks between the required RPM and the current RPM values. By utilizing ladder logic elements such as comparators and contacts, establish logical conditions that ensure the motor operates within the desired RPM range. This helps maintain safe and optimal operation of the motor.

4.2.2 Graphical user interface

The graphical user interface (GUI) implemented in the PLC module of project serves as a user-friendly interface to interact with the supervisory control and monitoring system for the induction motor. It allows to input and monitor various parameters such as the required RPM, measured motor RPM, voltage, and current. The GUI enhances the usability and functionality of the system by providing a visual representation of important information.
Through the GUI, conveniently set the desired RPM for the motor. This input is crucial for controlling the motor's speed and achieving the desired performance. The GUI allows you to enter the required RPM value, providing a simple and intuitive way to adjust and fine-tune the motor's operating speed. Monitor the motor's performance and ensure it is operating within the desired range. By visually presenting this data, the GUI provides a clear and immediate overview of the motor's operational parameters, enabling effective monitoring and control.

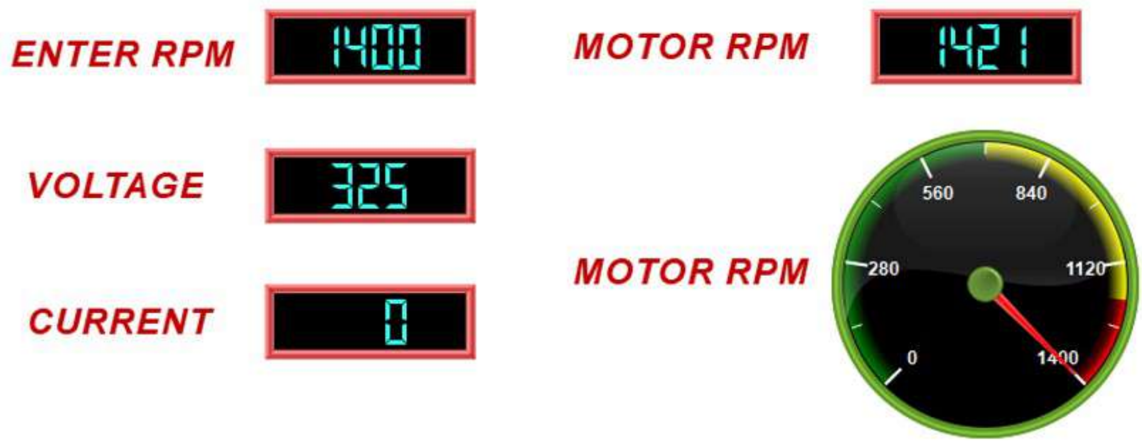


Figure 4.2: Graphical user interfaace

4.2.3 Ladder logic for controlling and monitoring of IM

The ladder logic designed for your project focuses on measuring the RPMs, current, and voltage of the induction motor, as well as generating the control signal to regulate the motor's speed and implement interlocking mechanisms. The ladder logic implements a systematic approach to ensure accurate measurement and control, promoting efficient and safe motor operation. To measure the RPMs, a specific ladder logic routine is implemented. This routine utilizes sensors such as an IR beam sensor or an encoder to detect the motor's rotational speed. The sensor output is processed within the ladder logic using appropriate rung conditions and instructions. The RPM measurement is then displayed or logged for further analysis or control purposes.

The ladder logic also includes routines for monitoring the current and voltage of the motor. Current and voltage sensors are incorporated into the circuit, and their outputs are processed within the ladder logic using appropriate instructions and comparisons. This allows for real-time monitoring of the motor's electrical parameters, ensuring they are within safe operating limits. Furthermore, the ladder logic implements control logic to regulate the motor's speed. This is achieved by comparing the measured RPMs with the desired RPMs set through the GUI or input interface. Based on the comparison, the ladder logic generates the appropriate control signal to adjust the speed of the motor through the VVFD. This control signal ensures that the motor operates at the desired RPMs, achieving the desired performance.

Interlocking mechanisms are also implemented within the ladder logic to ensure operational safety. This involves monitoring various parameters such as RPM, current, and voltage, and comparing them with predefined limits or thresholds. If any of these parameters exceed the defined limits, appropriate interlock routines are activated, such as triggering alarms, stopping the motor, or initiating protective measures to prevent any hazardous conditions. The ladder logic design incorporates logical instructions, timers, counters, and other programming elements to implement the desired functionalities. It follows standard ladder logic conventions and adheres to best practices for clear and organized programming structure. The ladder logic design for your project provides a systematic approach for measuring RPMs, current, and voltage, generating control signals, and implementing interlocking mechanisms. It ensures accurate measurement, efficient control, and operational safety of the induction motor.

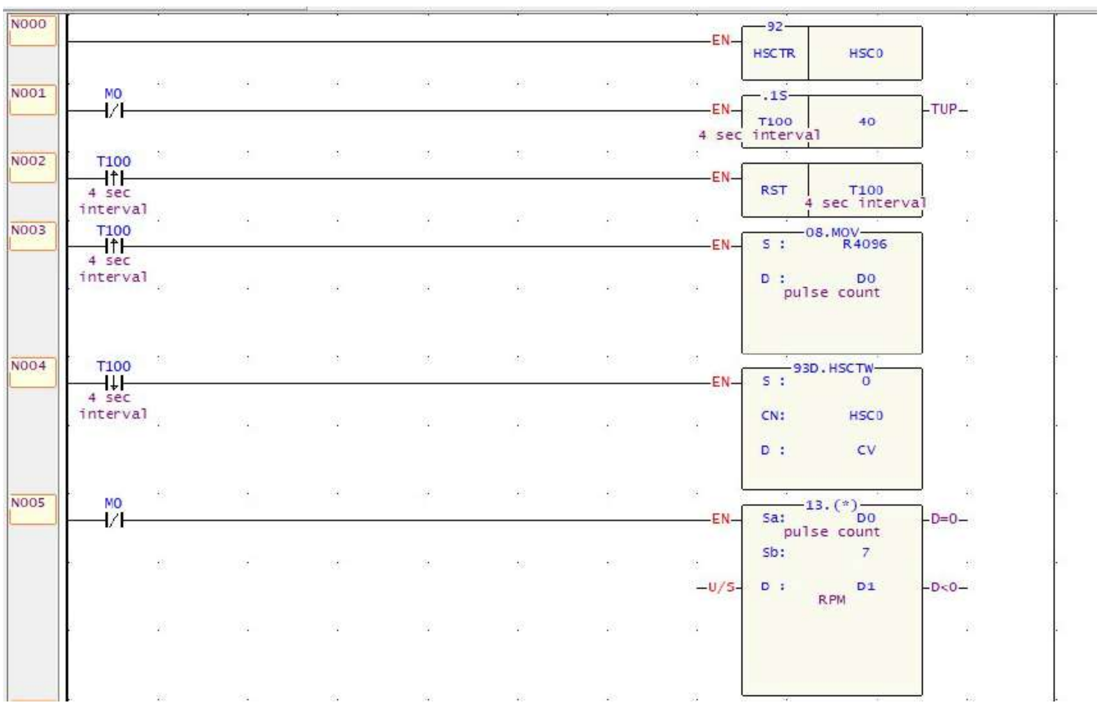


Figure 4.3: Motor RPM logic of IM

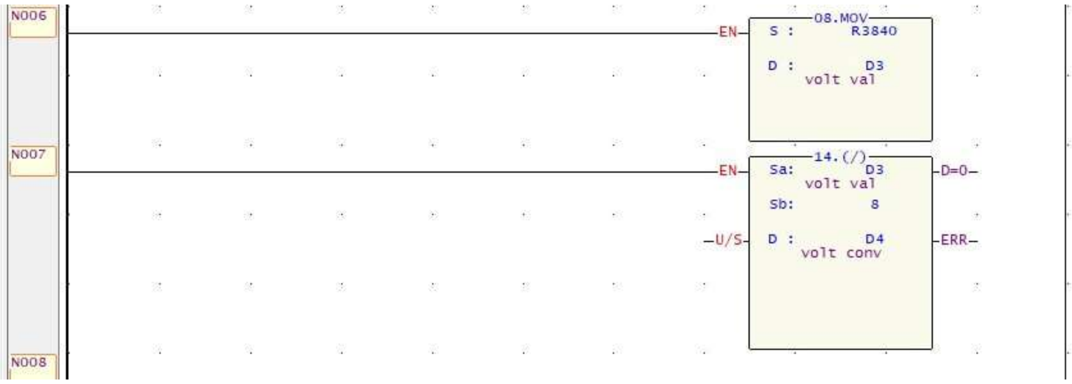


Figure 4.4: Logic for voltage measurement of IM

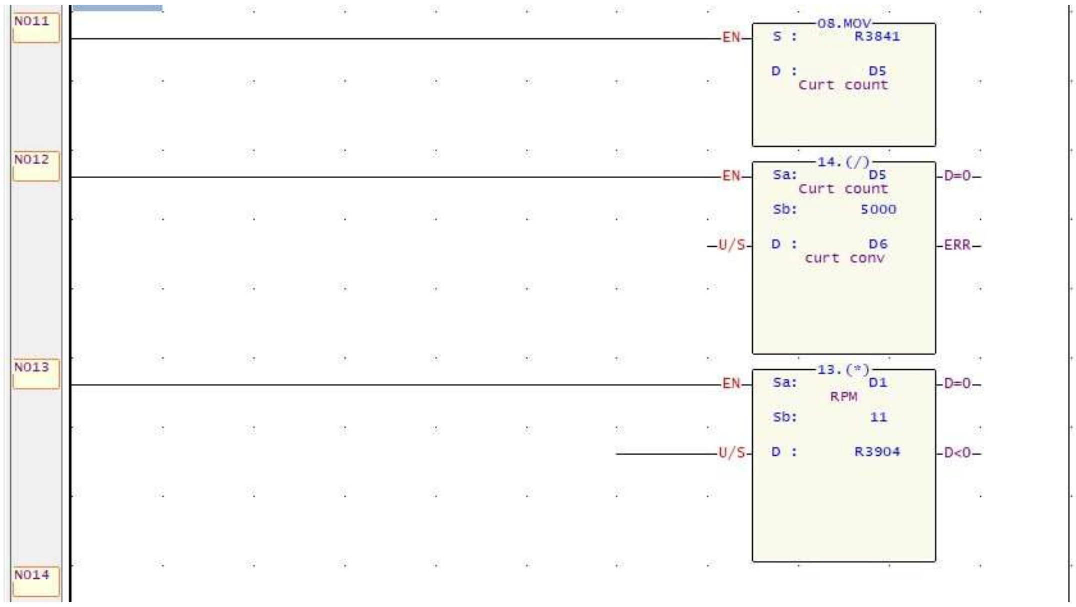


Figure 4.5: Motor Current monitoring logic

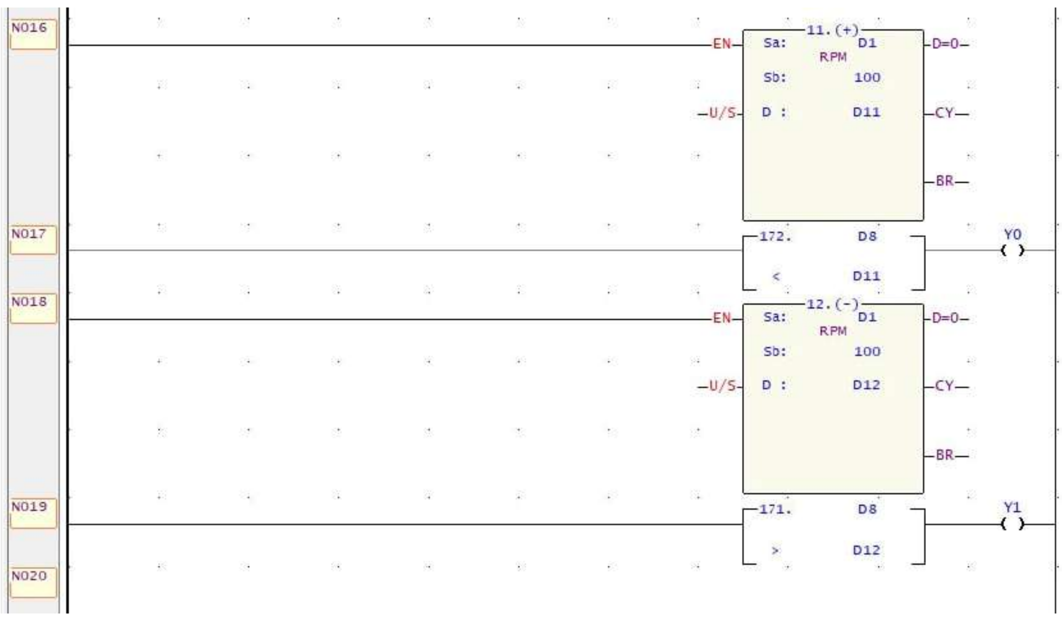


Figure 4.6: Interlocked RPM logic of IM

4.2.4 Software implementation of VFD

The system is designed for speed control of induction motor. SCADA system is implemented for better result of VVVFD to control induction motor speed. Simulation of variable frequency drive shown in Figure 4.7:
The VFD using arduino as a microcontroller controls motor speed by adjusting the switching frequency of an H-bridge inverter. The MOSFET 840 is used as the power switch, driven by the 1R2112 IC acting as a gate driver. Frequency variation is achieved by modifying the duty cycle of the switching signals generated by the microcontroller. The arduino microcontroller calculates and generates the necessary switching signals for the H-bridge inverter. The 1R2112 IC amplifies and buffers these signals to ensure proper MOSFET switching. The MOSFET 840 acts as the primary power switch in the H-bridge configuration, enabling bidirectional control of motor speed. The microcontroller determines the switching frequency by adjusting the duty cycle of the switching signals. The H-bridge inverter converts the DC input from a power supply into an AC output with variable frequency. It consists of four MOSFETs arranged in an H-bridge topology, allowing the motor to be driven in both forward and reverse directions. Controlling the MOSFET switching in the H-bridge adjusts the polarity and frequency of the AC output. Frequency variation is achieved by adjusting the duty cycle of the switching signals. The duty cycle represents the ratio of the on-time to the total period of the switching signals. Modifying the duty cycle changes the proportion of time the MOSFETs are in the on-state, effectively altering the frequency of the AC output. It's important to determine specific values and calculations for duty cycle and frequency control based on the motor's characteristics and desired performance. Implementing these values in the Arduino code allows for precise motor speed control and efficient operation

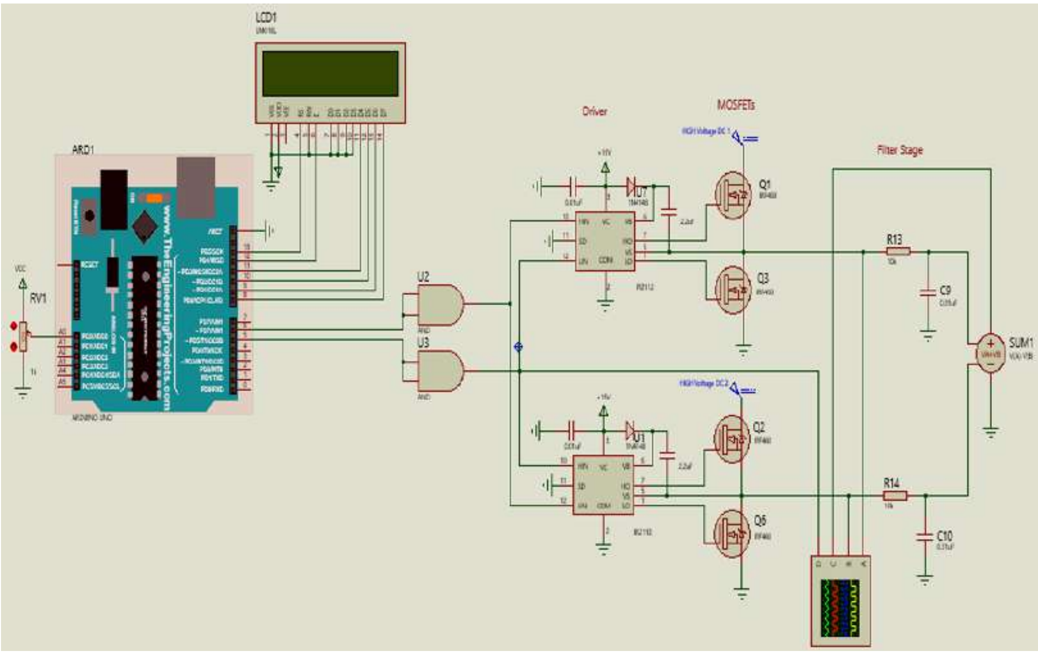
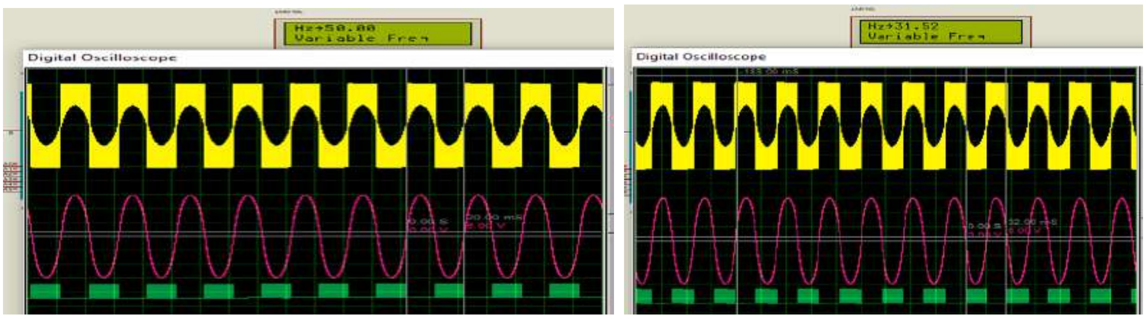


Figure 4.7: Simulation of variable frequency drive

4.2.5 VFD's results

The results of the VFD system using Arduino as a microcontroller can be observed through the provided images. Image A displays a waveform with a frequency of 50

Hz at a 100% duty cycle, while Image B shows a waveform with a frequency of 31.52 Hz at a 63.2% duty cycle.
Figure 4.8 Image (a): The waveform represents the AC output produced by the H-bridge inverter when the switching frequency is set at 50 Hz. The duty cycle of 100% indicates that the MOSFETs remain in the on-state for the entire duration of the switching period. This results in a continuous and uninterrupted flow of current, generating a waveform with a frequency equal to the set frequency of 50 Hz.
Figure 4.8 Image (b): The waveform corresponds to the AC output when the switching frequency is adjusted to 31.52 Hz. The duty cycle of 63.2% indicates that the MOSFETs are on for approximately 63.2% of the total switching period and off for the remaining time. This duty cycle variation leads to a shorter on-time and longer off-time, effectively reducing the average current flow and resulting in a lower frequency of 31.52 Hz.
These images demonstrate the ability of the VFD system to control the frequency of the AC output by manipulating the duty cycle of the switching signals. By adjusting the duty cycle, the microcontroller alters the proportion of on-time and off-time of the MOSFETs, thereby modifying the average current and affecting the resulting frequency. It is important to note that the specific frequencies achieved and duty cycles used will depend on the programming and configuration of the Arduino microcontroller, as well as the desired motor speed and application requirements.



(a) 50 HZ frequency on 100 % duty cycle (b) 31.52 frequecy on 63.2 % duty cycle

Figure 4.8: Results of variable frequency drive

Red color: Sinusoidal output voltage of H-Bridge inverter.

Yelow color: Output voltage in Square form.

Green color: PWM.

4.2.6 Software implementation of VVD

In the software implementation of the VVD (variable voltage drive), a simulation of the system can be visually represented through a graphical interface. The simulation provide a concise overview of the VVD drive's virtual representation. This visual representation showcases the dynamic behavior of the system, including the voltage variations and the corresponding motor response. Through this simulation, the effectiveness of the VVD drive in regulating voltage and controlling the motor can be observed.

The VVVFD (variable voltage variable frequency drive) simulation begins with the detection of zero crossings using a zero-cross circuit shown in Figure 4.9. This circuit incorporates rectification and the 4N25 IC (integrated circuit) to accurately identify the points where the alternating current (AC) waveform crosses the zero voltage level. This information is crucial for determining the firing angle or duty cycle required to achieve the desired motor speed. Based on the zero-cross detection, the input supply voltage for the VVVFD is adjusted. In this case, the input supply voltage is maintained at 220 V. However, by altering the firing angle or duty cycle, the effective voltage applied to the motor can be varied. The firing angle refers to the delay in triggering the TRIAC, a semiconductor device used for AC power control, during each half-cycle of the AC waveform. By triggering the TRIAC at different angles, the fixed AC input is converted into variable AC, allowing for precise control of the motor speed. A shorter firing angle or larger duty cycle will result in a higher average voltage being applied to the motor, increasing the speed. Conversely, a longer firing angle or smaller duty cycle will reduce the average voltage and decrease the motor speed. It is essential to note that in the VVVFD simulation, the firing angle or duty cycle is adjusted according to the specific requirements of the application. These requirements may include the desired motor speed, torque, or efficiency. By carefully controlling the firing angle or duty cycle, the system achieves the desired speed control and ensures optimal motor performance.

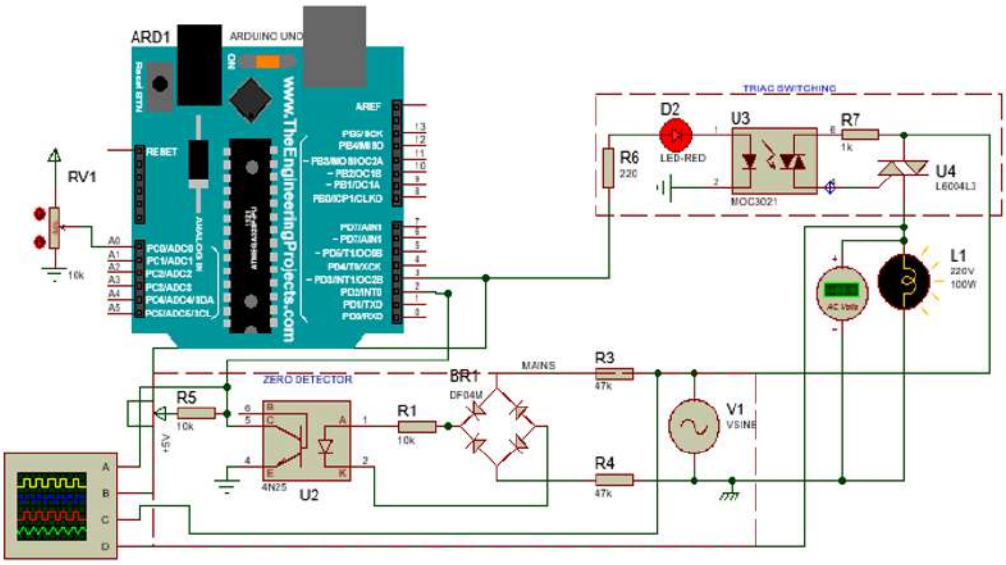


Figure 4.9: Simulation of variable voltage drive

4.2.7 VVD results

The VVD drive simulation results shown in Figure 4.10. When it is operated at a 50% duty cycle and supplied with an input voltage of 220 volts, the output voltage measured at the motor terminals was 110 volts. This simulation was performed using a triac circuit.

Operating the VVD drive at a 50% duty cycle means that the switching signals generated by the microcontroller or control circuit were ON for half of the total switching period and OFF for the remaining half. This balanced distribution of ON and OFF times ensured a symmetrical waveform and controlled the average voltage supplied to the motor. The measured output voltage of 110 volts represents the effective voltage applied to the motor. This voltage is determined by the control circuit's ability to regulate the triac's conduction angle. By adjusting the duty cycle, the control circuit determines the average voltage delivered to the motor, directly influencing its speed.

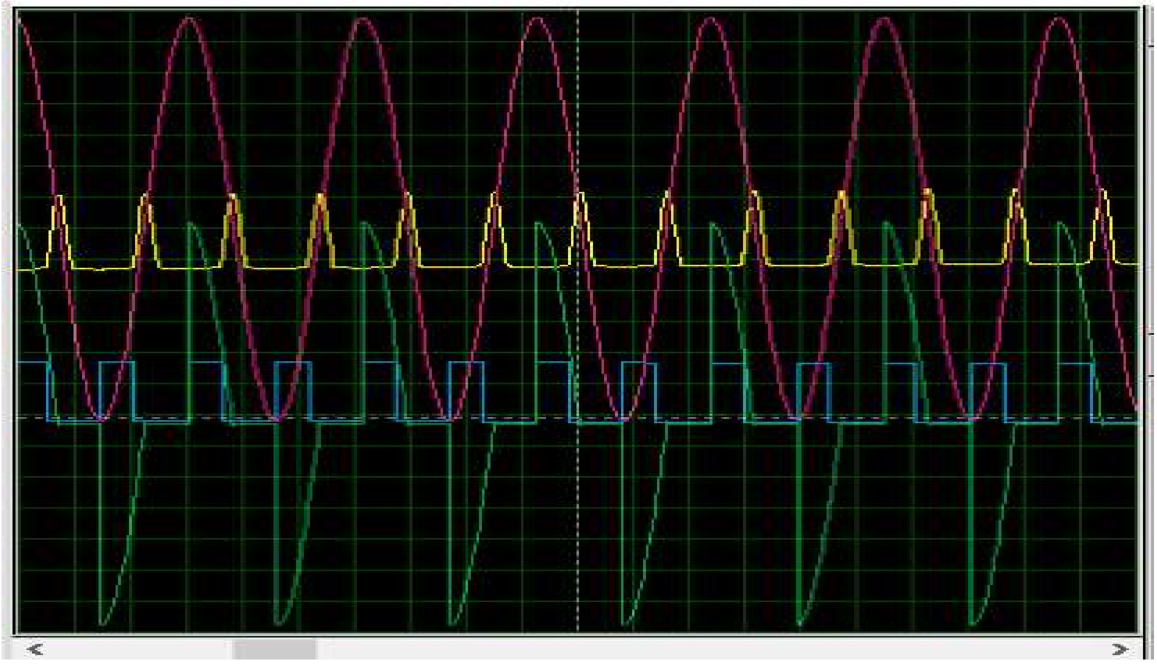


Figure 4.10: Output voltage at 50% duty cycle

- **Red color:** Input voltage (220V).
- **Yelow color:** Zero cross detection.
- **Blue color:** PWM.
- **Green color:** Output voltage (110V).

4.3 Hardware design

In the hardware design phase, specific components were carefully selected and integrated to create a robust system for supervisory control and monitoring of the induction motor. The hardware design process involved meticulous consideration of system requirements and the following key components:

- **PLC module selection:** A PLC module, specifically the 4A2D model, was chosen for its compatibility with the project's control requirements. The PLC module acts as the central control unit, facilitating communication between different hardware elements.
- **Arduino board integration:** An arduino board was incorporated into the design to enable precise control of voltage and frequency based on the signals received from the PLC module. The Arduino board serves as an interface between the PLC and the VVVFD.

- **Bridge inverter implementation:** The design includes an H-bridge inverter, which is responsible for converting the DC power into variable AC power with the desired frequency. The H-bridge circuitry utilizes MOSFETs for efficient switching and control.
- **Voltage regulation:** The hardware design incorporates suitable voltage regulators to ensure stable power supply and protect the system from voltage fluctuations. These components contribute to reliable voltage regulation.

Throughout the hardware design phase, extensive testing and validation were conducted to ensure the system's functionality and reliability. Simulations and prototyping were carried out to verify the performance of the hardware design, including voltage regulation, frequency control, and interlock mechanisms. The resulting hardware design provides a comprehensive solution for supervisory control and monitoring of the induction motor. It ensures precise control of voltage and frequency through the VVFD, enabling optimal performance and efficiency.

4.3.1 Hardware implementation of VVVFD

Figure 4.11: VVVFD

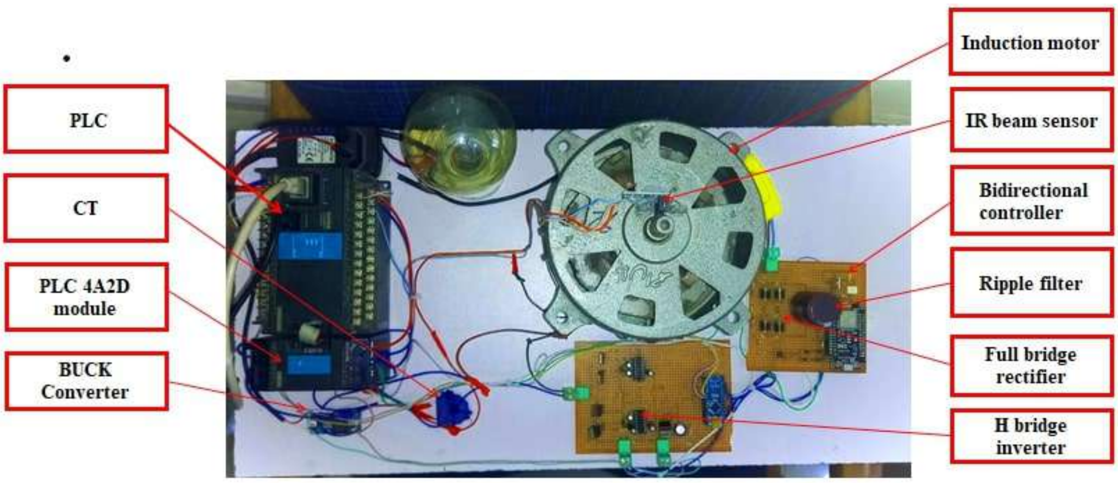


Figure 4.12: Hardware Design for Motor Control

4.3.2 VVVFD results

Results of VVD

A single-phase bidirectional controller using a TRIAC can control the power flow between an AC source and a load in both directions. The controller has three output levels, which correspond to different average power delivery to the load. These output levels are achieved by varying the duty cycle of the TRIAC.

- At 25% duty cycle, the TRIAC is on for 25% of each AC cycle and off for the remaining 75%. This results in a lower average power delivered to the load compared to continuous operation.
- For 50% duty cycle, the TRIAC is on for half of each AC cycle and off for the other half. This delivers an average power equal to half of the maximum possible power.
- At 75% duty cycle, the TRIAC remains on for 75% of each AC cycle and off for the remaining 25%. This provides a higher average power compared to the 25% and 50% duty cycles.

By modulating the duty cycle of the TRIAC, the controller can precisely regulate the amount of power delivered to the load, enabling efficient control of AC power flow in both directions. This capability finds applications in various fields, such as motor speed control, dimming lights, and power converters, where precise and flexible power control is essential.

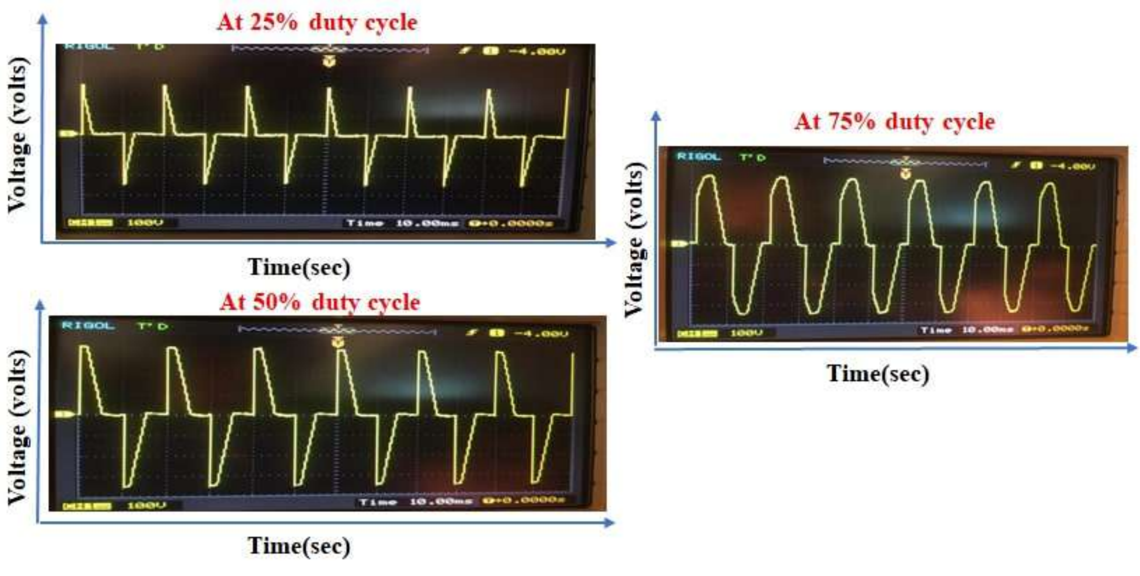


Figure 4.13: Output results of single phase bi-direction controller

Results of VFD

The single-phase H-bridge inverter has three outputs: a 50Hz pure sinusoidal wave, a square wave at a variable frequency for diverse applications, and a 35Hz square wave shown in Figure 4.14. The latter enables speed control of the induction motor through adjustable frequency drive (VFD), allowing smooth and efficient speed regulation, making it valuable for industrial applications.

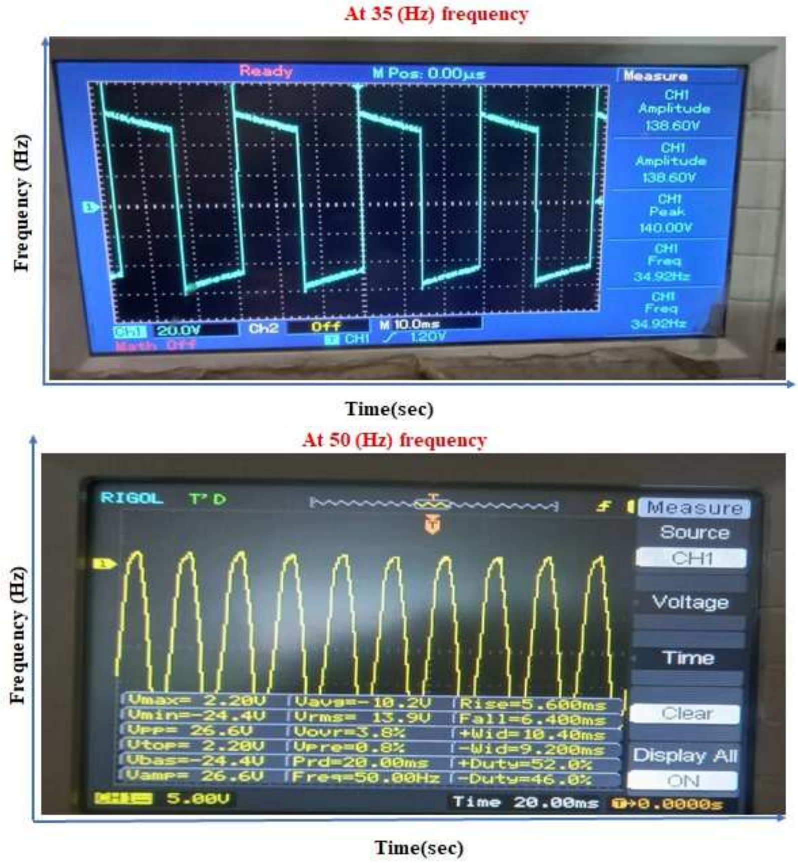


Figure 4.14: Output results of H-bridge inverter

Chapter 5

Conclusions

5.1 Conclusions, limitations and future recommendations

5.1.1 Conclusion

In conclusion, designed system is based on the supervisory control and monitoring system of an induction motor using PLC has successfully achieved its objectives and demonstrated effective implementation of advanced control techniques. By leveraging the capabilities of programmable logic controllers (PLCs), developed a robust and efficient system for monitoring and controlling induction motors, enabling enhanced performance, reliability, and energy efficiency. Through careful design and integration, our system provides comprehensive supervisory control, allowing operators to monitor critical motor parameters such as voltage, current, and speed in real-time. The PLC-based architecture ensures rapid data acquisition, precise measurement accuracy, and seamless communication with the motor, facilitating timely decision-making and proactive maintenance. Additionally, the implementation of a graphical user interface (GUI) provides intuitive and user-friendly access to system status, and control functions. Operators can conveniently interact with the system, visualize motor performance, set desired parameters, ensuring smooth operations.

The supervisory control and monitoring system for an induction motor using PLC is designed to provide efficient control and monitoring capabilities for a 1 Hp motor. The system incorporates the variable voltage variable frequency drive (VVVFD) technique to regulate the motor's speed, which can be varied between 650 and 1450 RPM. It operates within a frequency range of 22 to 48 Hz and a voltage range of 95 to 185 V. By implementing VVVFD, the system can dynamically adjust the voltage and frequency supplied to the motor, enabling precise speed control. This flexibility allows for optimal motor performance and adaptability to different operating conditions. The system includes a graphical user interface (GUI) that serves as a user-friendly platform for monitoring and control. The GUI provides real-time displays of critical motor parameters such as current, voltage, and RPM. It also allows the operator to set the desired RPM, enabling the system to maintain a constant speed based on the operator's requirements. Power handling is a crucial consideration for the system's design. The components and architecture of the VVVFD and PLC are carefully selected and rated to ensure the system can handle the power requirements of a 1 Hp motor. This ensures reliable operation and mitigates the risk of component failures.

5.1.2 Limitations

Here are some additional limitations for your project on the supervisory control and monitoring system of an induction motor using PLC:

- Limited fault detection and diagnosis: The system may have limitations in detecting and diagnosing complex faults or abnormalities in the induction motor. Certain faults may require more advanced diagnostic techniques or specialized sensors not included in the current system. of motor protection features. While the system focuses on monitoring and control, it may not incorporate comprehensive motor protection features. This could result in inadequate protection against overcurrent, overvoltage, or overheating conditions that could potentially damage the motor.

- Limitation of load capacity: The prototype of the supervisory control and monitoring system for the single-phase induction motor using PLC has limitations in handling greater loads due to the use of low-power components.

- Dependency on power supply stability: The system's performance may be sensitive to power supply stability. Fluctuations or interruptions in the power supply could disrupt the motor control and monitoring processes, leading to potential inaccuracies or inconsistencies in data acquisition and control actions.

- Cost constraints: As a student project, there are cost limitations associated with acquiring the necessary PLC modules and sensors for effective control and monitoring of the induction motor.

- Accurate control of speed: The system has a limitation in achieving accurate speed control, with a tolerance of approximately 50 RPMs.

It is important to consider these limitations during the planning and implementation of the project and explore potential mitigation strategies to address or minimize their impact on the system's effectiveness and performance.

5.1.3 Future recommendation

Looking towards the future, here are some recommendations to enhance the supervisory control and monitoring system of an induction motor using PLC:

- Integration of AI and machine learning: Incorporate advanced artificial intelligence (AI) and machine learning algorithms to enable predictive maintenance capabilities. By analyzing historical data and identifying patterns, the system can anticipate motor failures, schedule maintenance activities proactively, and optimize maintenance planning.

- Integration with industrial IoT: Connect the system to the Industrial Internet of Things (IoT) ecosystem to enable seamless data exchange and integration with other devices, systems, and cloud platforms. This integration facilitates comprehensive data analytics, remote monitoring, and centralized management of multiple motor systems.

- Implementation of advanced analytics: Utilize advanced data analytics techniques, such as data mining and pattern recognition, to extract valuable insights from the collected motor data. This can enable the identification of operational inefficiencies, performance optimizations, and energy-saving opportunities.
- Adoption of wireless sensor networks: Consider integrating wireless sensor networks to enable flexible and cost-effective monitoring of motor parameters, such as temperature, vibration, and humidity. Wireless sensors can provide a scalable and non-intrusive solution for data acquisition in industrial environments.

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