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MASTER

In **Control Engineering**

Option: **Control Engineering**

Title:

PLC and HMI Based Monitoring and Control of an Induction Motor using VFD Drive and PROFINET Protocol

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Abstract

Various applications in industrial automation require accurate and effective motor speed control. This project addresses this need by developing a motor speed control system utilizing a variable frequency drive (VFD), programmable logic controller (PLC), and human-machine interface (HMI). To achieve variable speed control, the study examines the operating characteristics of AC motors and their fundamental concepts, as well as the way VFDs manipulate the provided AC power. It delves into the capabilities of PLCs, highlighting how they receive control signals and direct the VFD to perform the desired motor functions. The integration of an HMI offers a user-friendly interface for system monitoring, speed set point adjustments, and fault identification. Additionally, the project incorporates the PROFINET protocol to ensure efficient and reliable communication between the PLC, VFD, and HMI. The implementation includes detailed system design, programming, and configuration. Results demonstrate the effectiveness of the integrated system in achieving accurate and responsive motor speed control, underscoring the advantages of using VFD, PLC, HMI, and PROFINET technologies in industrial automation.

Dedication

To my beloved parents, the pillars of my life, Your unconditional love, unwavering support, and countless sacrifices have paved the way for my success. This report is a reflection of your endless encouragement, which has been the driving force behind my academic pursuits.

Mom, your love, nurturing guidance, and unwavering belief in me have been my guiding light through every challenge. Your resilience and strength have taught me invaluable lessons in perseverance and determination.

Dad, your wisdom, hard work, and vision have been a constant source of inspiration. Your teachings have instilled in me the values of integrity, discipline, and the relentless pursuit of knowledge.

Words cannot adequately express my gratitude for the countless sacrifices you have made to ensure that I had every opportunity to excel. This achievement is a testament to your unwavering devotion and the countless hours you have invested in my growth and well-being.

To my two little sisters, Your presence in my life has been a constant source of strength, reminding me that I am never alone, and that together, we can overcome any obstacle that stands in our way.

To all my Family and my friends ,and the loved ones. This project is a culmination of the love, sacrifice, and support from all of you. It stands as a testament to the power of determination and the collective efforts of those who have walked alongside me on this incredible journey.

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Above everything, thanks to Allah, the Almighty and Most Merciful giving me the wisdom, persistence, and potency to complete this project.

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List of Abbreviations

VFD	Variable frequency Drive.
PLC	Programmable logic controller.
HMI	Human machine interface
V	Voltage.
I	Current.
RPM	Rotations per Minute.
PWM	Pulse width modulation
DTC	Direct Torque Control
FOC	Rotor field-oriented control
NS	Synchronous speed
NB	Base speed
VVVF	Variable voltage variable frequency
IGBT	Insulated-gate bipolar transistor
CPU	Central Processing Unit
MPC	Model Predictive Control

General Introduction

Industrial automation and control systems play a crucial role in modern manufacturing processes, ensuring efficient operation, consistent product quality, and improved productivity. In recent years, the integration of programmable logic controllers (PLCs), human-machine interfaces (HMIs), and variable frequency drives (VFDs) has become increasingly prevalent, enabling precise monitoring and control of various industrial processes, including motor-driven applications.

Induction motors are widely employed in industrial settings due to their robustness and energy efficiency. However, their efficient operation and precise control require advanced drive systems and communication protocols. Variable frequency drives (VFDs) have emerged as a critical component in modern motor control systems, allowing for seamless speed and torque regulation by adjusting the frequency and voltage supplied to the motor.

Alongside the advancements in motor control technology, industrial communication protocols have also evolved to facilitate real-time data exchange and control between various components of an automation system. PROFINET (Process Field Network), an industrial Ethernet-based protocol, has gained significant traction due to its high-speed data transfer capabilities, deterministic behavior, and ease of integration with a wide range of devices.

This thesis aims to explore the integration of a PLC, HMI, and VFD drive for the monitoring and control of an induction motor, leveraging the PROFINET protocol for communication.

The work is divided into three chapters:

- Chapter one which provides a foundational understanding of the significance of speed control in induction motors and explores various methods employed.
- Chapter two sets the stage for understanding the core components of our automation system, which are AC motors, PLCs, and VFDs.
- Finally, in the last chapter, we discuss the hardware and software configurations necessary for the project's effective execution as we offer a full design and implementation of the motor's monitoring and control system.

Chapter 1:

General Overview

1.1 Introduction

AC motors are integral to industrial automation, powering a wide range of machinery and processes, from conveyor belts and robotic systems to pumps and compressors. The precise control of speed and torque in these motors is crucial for several reasons. Firstly, speed control ensures the consistent operation of automated systems, directly impacting production quality and efficiency. For example, maintaining a stable motor speed in manufacturing is essential for producing high-quality products at a steady rate. Similarly, torque control is vital for applications requiring precise force adjustments, such as in automotive assembly lines where bolts must be tightened to specific torque settings.

Furthermore, effective speed and torque control can greatly enhance energy efficiency, a critical concern for industries aiming to reduce operational costs and their environmental footprint. Variable Frequency Drives (VFDs) are essential in this context, allowing for fine-tuning of motor speed and torque to match application requirements, thereby minimizing energy wastage. Programmable Logic Controllers (PLCs) complement VFDs by providing the necessary logic and control sequences to dynamically adjust motor parameters based on changing operational conditions.

Despite advancements in VFD and PLC technologies, optimal speed and torque control remains challenging. Traditional control methods often lack the precision and responsiveness needed under varying load conditions. This highlights the need for advanced control strategies that can seamlessly integrate with VFDs and PLCs to improve the performance and reliability of AC motors in automation applications. Addressing these challenges not only enhances the efficiency and reliability of industrial processes but also unlocks new opportunities for innovation and productivity in automation systems. This research aims to develop and implement such advanced control strategies, leveraging VFDs and PLCs to achieve superior control over AC motor operations.

1.2 Basic Principles of Motor Control

The basic principles of motor control in industrial automation focus on the precise regulation of speed and torque in AC motors to ensure optimal performance and efficiency. Speed control, which is vital for maintaining consistent operation in automated systems, is commonly achieved using Variable Frequency Drives (VFDs) that vary the frequency and voltage supplied to the motor. Additionally, voltage control and closed-loop feedback systems are utilized to fine-tune motor speed. Torque control, essential for applications requiring accurate force adjustments, employs methods such as Direct Torque Control (DTC) and Field-Oriented Control (FOC) to directly manage the motor's magnetic flux and torque. Sensorless control techniques, which estimate torque without direct measurement, enhance control precision. Integrating speed and torque control with advanced algorithms like Model Predictive Control (MPC) and adaptive control strategies further enhances motor performance under dynamic load conditions. Programmable Logic Controllers (PLCs) are crucial in implementing these control strategies, providing the necessary logic and control sequences. By addressing challenges such as system stability, dynamic load variations, and energy efficiency, these principles ensure reliable and efficient motor operation across a wide range of industrial applications

1.2.1 Speed Control

We come across speed control of electric motors everywhere in a modern society. The list of speed control comprises a wide range of appliances, beginning with household electrical appliances used in the garden and garage, and ending with large industrial plants with conveyor belts, pumps and machine tools.

1.2.1.1 Methods of Speed Control

- **Simple Voltage Control :** Available voltage control methods include control by a transformer or by phase control. Figure 1.1 shows when voltage is controlled by using a transformer. This method is not so easy to do with an AC speed control motor. Alternately, the AC voltage can be adjusted by setting the ON/OFF time of every half cycle of the AC voltage (50 or 60Hz) applied to the motor using a switching element (thyristor or triac) that can directly turn on and off the AC voltage as shown Figure 1.2 and Figure1.3. Speed control is obtained by the phase control method by controlling the r.m.s. value of the AC voltage [1].

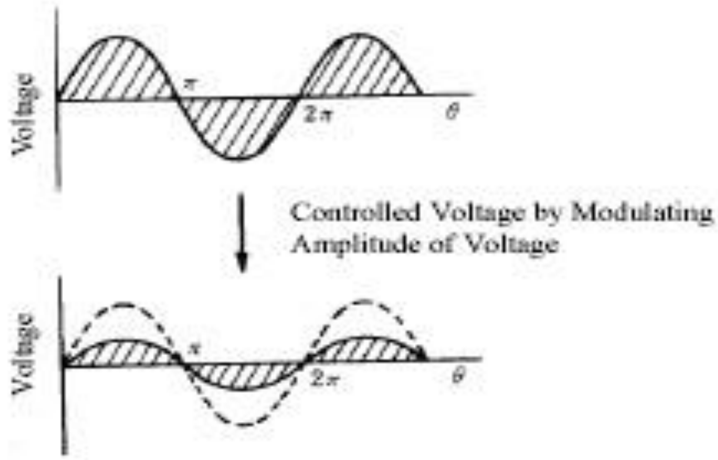

Figure 1.1:Voltage Change by Transformer.

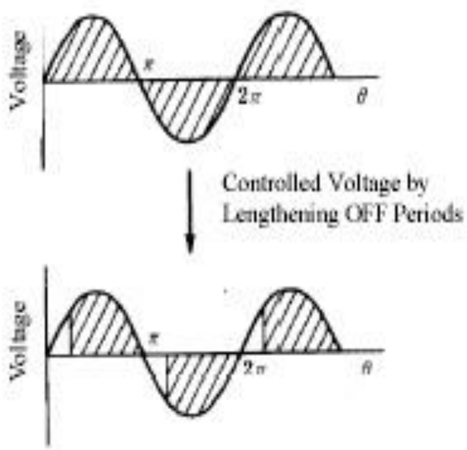

Figure 1.2:Voltage Change by Phase Control.

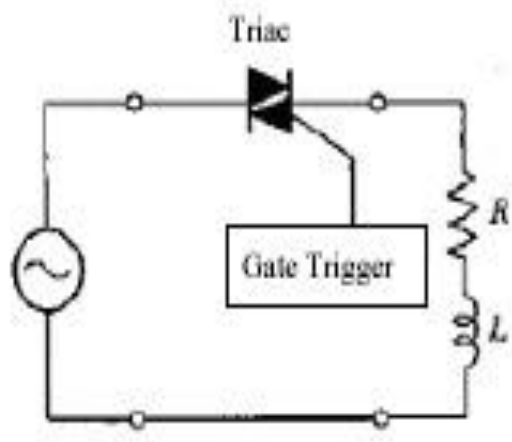

Figure 1.3:Triac Control Circuit

- **Variable Frequency Drives (VFDs)** : A Variable Frequency Drive (VFD), also known as a Variable Speed Drive, Adjustable Frequency Drive, or Inverter Drive, is a device used to run AC motors at variable speeds and provide smooth starting by ramping their speed. VFDs adjust motor speed by tuning the frequency, which in turn changes the RPM of the induction motor. The operation of a VFD occurs in three stages: the converter section, the filtering stage (DC bus), and the inverter section. Initially, the three-phase AC voltage is converted to DC using diodes. This DC voltage is then filtered with capacitors to smooth it out. Finally, the DC voltage is converted back to AC voltage using transistors acting as switches, which turn the voltage on and off by changing the switching firing angle. The desired motor speed is achieved by setting the frequency according to the formula 120f/p, where the motor speed is directly proportional to the frequency. For example, providing a 50Hz frequency achieves full speed, while providing a 25Hz frequency achieves half speed. This ability to control speed precisely makes VFDs essential in many industrial applications [3].

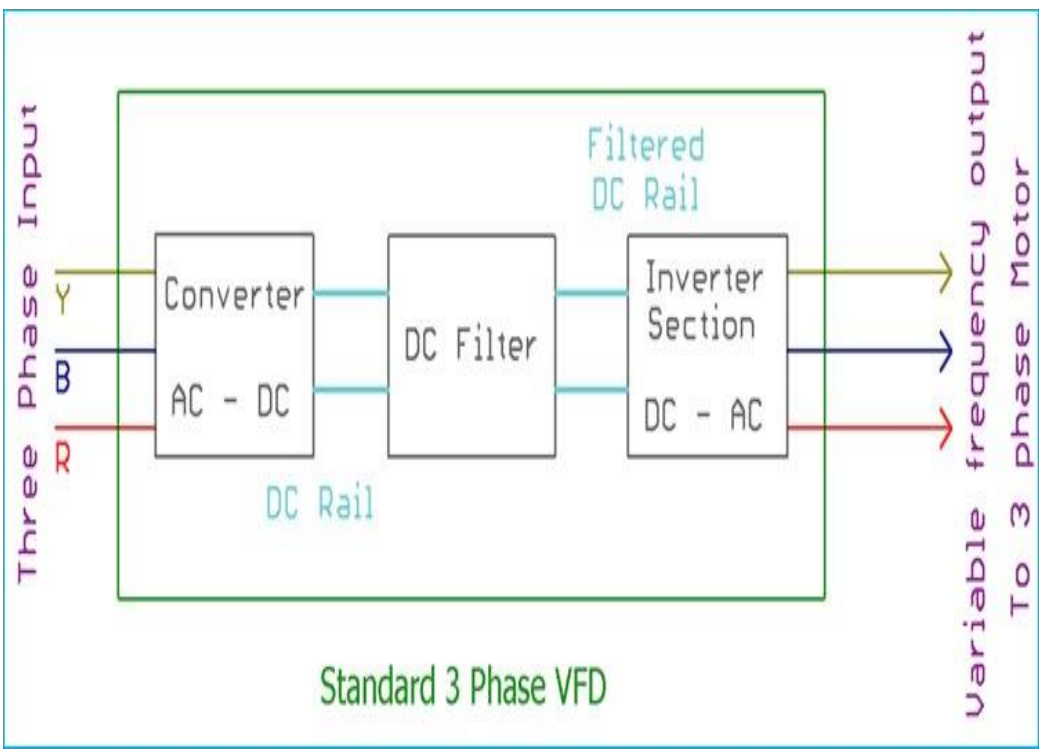

Figure 1.5: Variable Frequency Drive

Main Advantages of using VFDs :

The primary benefit of using a Variable Frequency Drive (VFD) lies in its capability to precisely regulate the speed and torque of electric motors. Here are several key advantages of implementing a VFD [4]:

-Energy Efficiency: VFDs contribute to energy savings by adjusting the motor speed to meet the required load. By controlling the frequency and voltage supplied to the motor, VFDs optimize motor operation, lowering energy consumption and minimizing waste during periods of low demand. This enhanced energy efficiency can result in substantial cost savings for applications that need variable speed operation.

-Process Control and Flexibility: it provide precise motor speed control, enabling accurate adjustments to meet specific process requirements. This precision enhances process regulation, improves product quality, and boosts overall system performance. Additionally, VFDs offer the flexibility to adjust motor speeds across a wide range, allowing adaptation to different operational conditions and optimizing performance for various tasks.

-Soft Start and Stop: VFDs enable smooth and controlled motor starts and stops by gradually increasing voltage and frequency. This approach eliminates the mechanical stress and current surges that occur with direct-on-line starts, thereby extending the lifespan of the motor and connected equipment, reducing mechanical wear, and preventing system damage.

-Improved Motor Protection: it ensure motor and equipment protection. These include detecting overloads, monitoring voltage and current, guarding against short circuits, and managing thermal overload. Through continuous monitoring of motor behavior and swift responses to irregularities, VFDs mitigate motor damage, minimize operational interruptions, and bolster overall system dependability.

-Reduced Mechanical Components: VFDs streamline control systems by replacing clunky mechanical components like throttling valves, dampers, and belt-and-pulley setups. These traditional methods often require frequent maintenance and repairs. VFDs offer a more efficient and simpler electronic solution for controlling flow rate or speed, leading to a more reliable and cost-effective system in the long run.

Overall, the primary advantage of using a Variable Frequency Drive (VFD) lies in its ability to optimize energy consumption, deliver precise control, improve process efficiency, and safeguard motors and equipment. These benefits make VFDs the preferred option for applications requiring variable speed control, where energy savings and process optimization are crucial.

1.2.2 Torque Control:

Direct torque control (DTC):

The induction motor's electromagnetic torque and stator magnetic flux can both be independently controlled by direct torque control. The desired torque and flux values are considered as inputs in the DTC, which reduces the sensitivity associated with the variation of the parameters and eliminates the need for feedback speed [5]. The fundamental idea of DTC is the direct selection of a space vector and respective control signals, to control instantaneously the electromagnetic torque and stator flux magnitude.

The DTC presents the following disadvantages:

- Difficulty controlling torque and flux at extremely low speeds
- High current and torque ripple
- Variable switching frequency
- High noise level at low speed.

Rotor field-oriented control (FOC):

Fast torque response can be achieved by decoupling the motor's torque and magnetic flux using the field-oriented control (FOC) control technique. The FOC technique, in contrast to scalar control, can adjust the amplitude, frequency, and location of the space vectors of the voltages, currents, and magnetic flux. It does this by using equations and models of the induction motor dynamic state. By using this technique, the torque and magnetic flux control can be separated.

1.3 Conclusion:

This introductory chapter has illuminated the importance of precise speed and torque control in numerous industrial automation applications. Explored how these control factors directly impact efficiency, product quality, and safety within these systems. Furthermore, we explored many methods of torque and speed control. We talked about conventional techniques like voltage control while also emphasizing their limitations. Next, we highlighted the effectiveness and adaptability of variable-frequency drives (VFDs) for speed and torque control. In the next chapter, we will go more deeply into the principles of AC motors, VFDs, and PLCs, giving you a strong basis for understanding their interactions and functions.

Chapter 2:

Background and Fundamentals

2.1 Introduction:

This chapter provides an overview of the fundamental components integral to our system: AC motors, Variable Frequency Drives (VFDs), and Programmable Logic Controllers (PLCs). We will explore the basic principles, operational characteristics. Understanding these fundamentals is crucial for grasping the advanced control and monitoring techniques discussed in subsequent chapters.

2.2 Ac Induction Motor Fundamentals :

The most popular motors used in industrial motion control systems are AC induction motors. as well as in primary electrical household equipment. The primary benefits of AC induction motors are their straightforward and durable design, low cost, simple maintenance, and direct connection to an AC power source.

There are numerous varieties of AC induction motors on the market. Certain applications are more suitable for certain types of motors. Despite being simpler to construct than DC motors, the speed and torque management of the many kinds of AC induction motors require a greater understanding of these motors' features and design [6].

2.2.1 Basic Construction and Operating Principle :

An AC induction motor, like other motors, consists of an internal rotating rotor and a permanent outside part called the stator separated by a precisely designed air gap.

The rotors of almost all electrical motors rotate due to magnetic field rotation. Only a three-phase AC induction motor's stator naturally generates a spinning magnetic field due to the supply's characteristics. DC motors generate rotating magnetic fields through mechanical or electrical commutation. This spinning magnetic field is produced by additional electrical components in a single-phase AC induction motor.

Any motor has two sets of electromagnets inside of it. The AC supply that is linked to the stator windings of an AC induction motor causes one set of electromagnets to develop in the stator. According to Lenz's law, the alternating supply voltage creates an Electromagnetic Force (EMF) in the rotor (much as the voltage is induced in the transformer secondary), creating a second set of electromagnets and giving rise to the term "induction motor." Torque, or twisting force, is produced by the interaction of these electromagnets' magnetic fields. The motor thus turns in the direction of the generated torque.

2.2.1.1 Stator:

A number of thin cast iron or aluminum laminates make up the stator. Figure 2.1 illustrates how they are punched and fastened together to create a hollow cylinder (stator core) with slots. These slots are filled with coils of insulated wire. An electromagnet, or two poles, is formed when an AC supply is applied to each grouping of coils and the core it surrounds. An AC induction motor's internal stator winding connection determines how many poles it has. Direct connection between the stator windings and the power supply is made. They are interconnected internally such that a spinning magnetic field is produced when an AC source is applied.

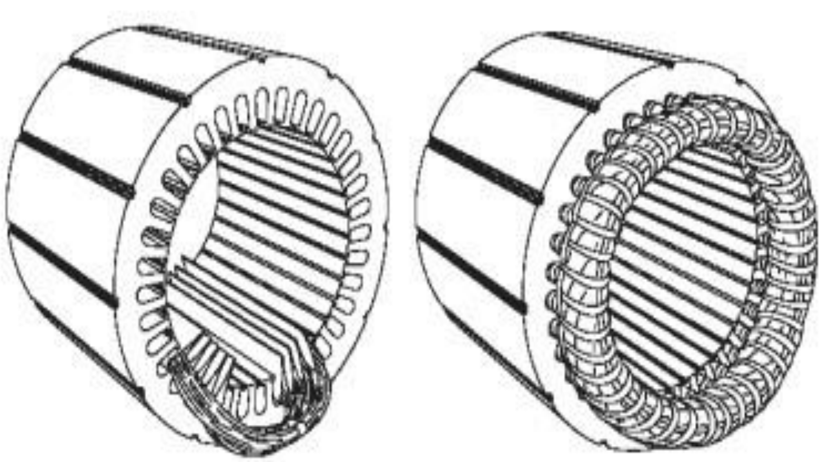

Figure 2.1:Typical stator

2.2.1.2 Rotor:

The rotor is made up of numerous thin steel laminations, with aluminum or copper bars evenly spaced around its perimeter. In the prevalent squirrel cage rotor design, these bars are both mechanically and electrically connected at each end by rings. Roughly 90% of induction motors use squirrel cage rotors because of their robust and straightforward design. This rotor has a cylindrical laminated core with parallel axial slots, each slot containing a bar composed of copper, aluminum, or an alloy. As seen in Figure 2.2, these rotor bars are permanently short-circuited at both ends by the end rings. The rotor gets its name from the whole assembly that has a squirrel cage-like appearance. The shaft and rotor slots are not precisely parallel. They receive a skew instead for two key reasons.

First and foremost, the goal is to lower slot harmonics and magnetic hum to quiet the motor.

The other reason is to assist in decreasing the rotor's tendency to lock. The direct magnetic attraction between the rotor and stator teeth causes them to stay locked beneath one another. This occurs when there are the same numbers of rotor and stator teeth.

The rotor spins on the shaft thanks to bearings at both ends. One end of the shaft is typically extended to connect and drive the load.. On the non-driving end of some motors, there may be an auxiliary shaft where speed or position sensors can be mounted. There is an air gap between the stator and the rotor, via which energy is transferred from the stator to the rotor via induction. The rotor and load are forced to revolve by the torque that is generated. The rotating concept is the same regardless of the kind of rotor that is used.

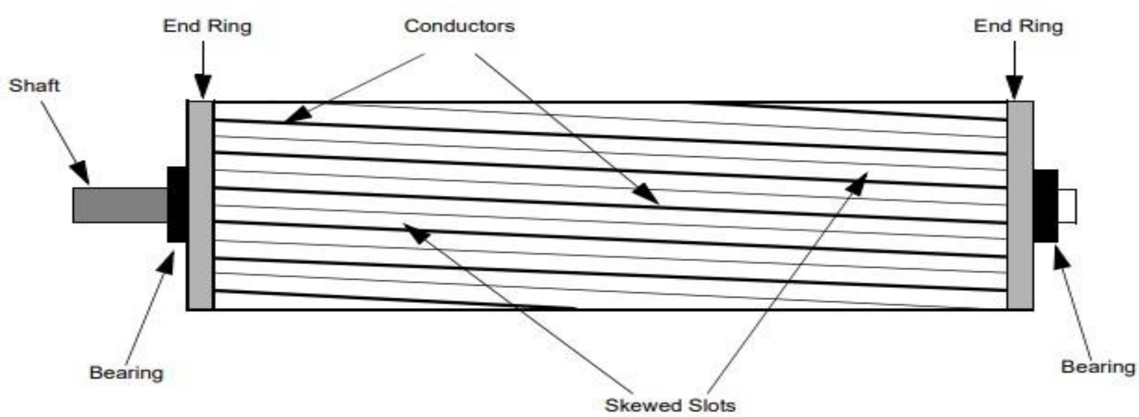

Figure 2.2:A Typical squirrel cage rotor

2.2.1.3 Speed of an Induction Motor:

At a synchronous speed (NS), the magnetic field generated in the stator revolves.

$$\mathrm{Ns} = 120 \times \mathrm{f/p} \quad \text{………………………………………………………………………} \quad (2.1)$$

Where:

NS = the synchronous speed of the stator

Magnetic field in RPM

P = the number of poles on the stator

f = the supply frequency in Hertz

Because of the induced voltage, an alternating magnetic field is created in the rotor.

The rotor begins to move in the same direction as the stator flux and attempts to catch up with the spinning flux in order to decrease the relative speed with regard to the stator. In actuality, though, the rotor is never able to "catch up" to the stator field. The stator field's speed is greater than the rotor's. We refer to this speed as the Base Speed (Nb).

The difference between NS and NB is called the slip. The slip changes as the load changes. The rotor will slow down or slip more when the load increases. The rotor will accelerate or reduce slip as the load decreases. The slip can be calculated using the following formula, which is represented as a percentage:

$$\%slip = \frac{Ns-Nb}{Ns} \times 100 \quad \text{……………………………………………………………..} (2.2)$$

where:

Ns = the synchronous speed in RPM

Nb = the base speed in RPM

2.2.2 Types of AC Induction Motors:

Generally, induction motors are categorized based on the number of stator windings. They are:

• Single-phase induction motor.

• Three-phase induction motor.

2.2.2.1 Single-Phase Induction Motor:

The single-phase induction motor is not self-starting. The primary winding is supplied with a single-phase AC current, which also generates a pulsing magnetic field. These motors are produced in huge quantities for use in residences, workplaces, industries, etc. and are intended to run on a single-phase supply [7].

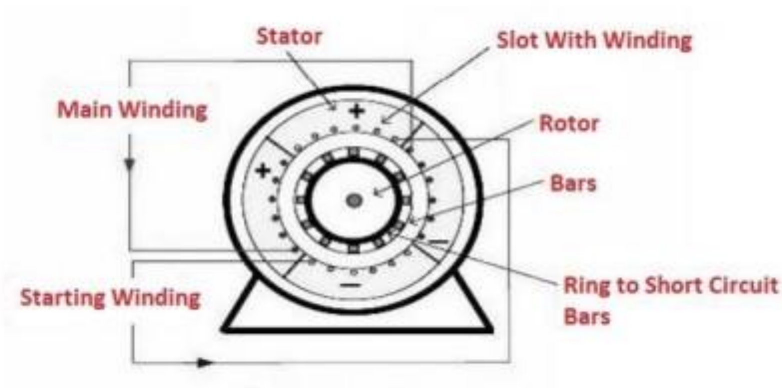

Figure 2.3:Single phase induction motor

Working Principle :

These kinds of AC motors have a stator winding that receives a single-phase AC feed. A sinusoidal pulsating magnetic field results from this.

After a while, the field polarity reverses, and the alternating current might not give the motor the necessary winding. However, the motor's rotational speed will be restricted if it is powered by an outside source [8].

There are four types of single phase induction motors [9]:

- **Split phase induction motor:** This type uses a special winding arrangement to create a rotating magnetic field and start the motor.

- **Capacitor-start induction motor:** It employs a capacitor to create a phase difference, enabling the motor to start smoothly**.**
- **Capacitor-run induction motor:** This motor utilizes two capacitors to enhance its starting and running performance.
- **Shaded pole induction motor:** This simple motor design uses shading coils to create a rotating magnetic field, making it economical but less powerful.

Applications of single-phase induction motors:

Induction motors with one phase are more commonly utilized in homes, businesses, and occasionally even in industries than those with three phases. In these types of situations, single-phase induction motors are preferred since they are more cost-effective and have a reduced power demand load. :

- Pumps
- Compressors
- Small fans
- Mixers
- Toys
- High-speed vacuums
- Electric shavers
- Drilling machines

2.2.2.2 Three Phase Ac Induction Motor

In both commercial and industrial settings, three-phase AC induction motors are often used. They come into one of two classifications: wound-rotor or squirrel cage motors.

These motors don't need a centrifugal switch, capacitor, start winding, or any other kind of beginning mechanism because they start themselves.

Their initial torque output ranges from medium to high. Compared to their single-phase equivalents, these motors have medium to high power and efficiency capacities. Grinders, lathes, drill presses, pumps, compressors, conveyors, printing equipment, farm equipment, electronic cooling, and other mechanical duty applications are among the frequently used applications [6].

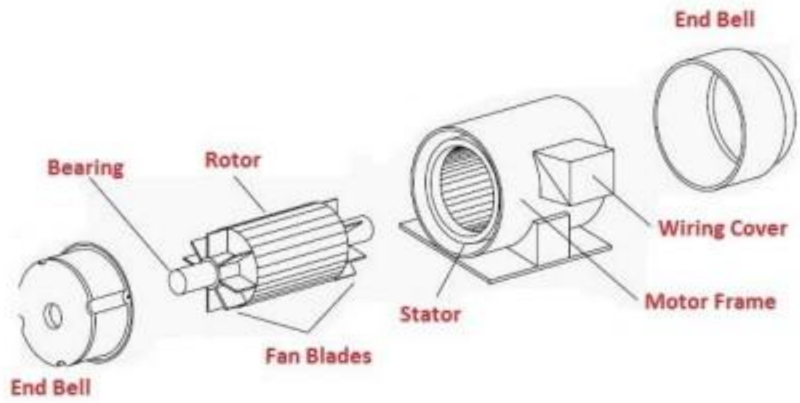

Figure 2.4:three phase induction motor

Working principle:

These kinds of ac motors generate a constant magnetic field with 120 displacements in a constant magnitude that spins at synchronous speed when they are charged by a three-phase supply through the stator winding.

The rotor conductors are cut by the fluctuating magnetic field, which causes a current to flow through them in accordance with the principles of Faraday's theory of electromagnetic fields. Current starts to flow through these rotor conductors as they get shorter [8].

Rotor conductors are positioned in a stator magnetic field. Consequently, a mechanical force applies on the rotor conductor in accordance with Lorenz force theory. As a result, every rotor conductor generates force; that is, the torque generated by all of the mechanical forces causes the rotor to move in the same direction as the spinning magnetic field.

The rotation of the rotor conductor in a wound-rotor motor can be explained by Lenz's Law, which states that induced currents in the rotor oppose the cause of their production. In this context, the resistance opposes the rotating magnetic field, causing the rotor to rotate in the same direction as the stator's rotating magnetic field. If the rotor speed exceeds the stator speed, no current is generated in the rotor because the relative motion between the rotor and the stator magnetic field is necessary for induction. The difference in speed between the stator and rotor fields is known as slip. Due to this relative speed difference, a three-phase motor is referred to as an asynchronous machine.

Squirrel cage induction motor :

A three-phase squirrel cage induction motor is a type of three-phase induction motor that operates on the principle of electromagnetism. It gets its name from its rotor, which is called a 'squirrel cage rotor' due to its resemblance to a squirrel cage.

The rotor, made up of a cylindrical assembly of steel laminations and incorporating highly conductive metals like aluminum or copper, generates a rotating magnetic field when alternating current flows through the stator windings. This phenomenon initiates a current within the rotor, leading to the formation of its magnetic field. This field then interacts with that of the stator, resulting in the production of torque.

The ease with which the speed-torque characteristics of a squirrel cage motor can be altered is one of its main advantages. All that has to be done is modify the rotor's bar shape. Industry uses a lot of squirrel cage induction motors because they are easy to regulate, self-starting, and dependable. [10]

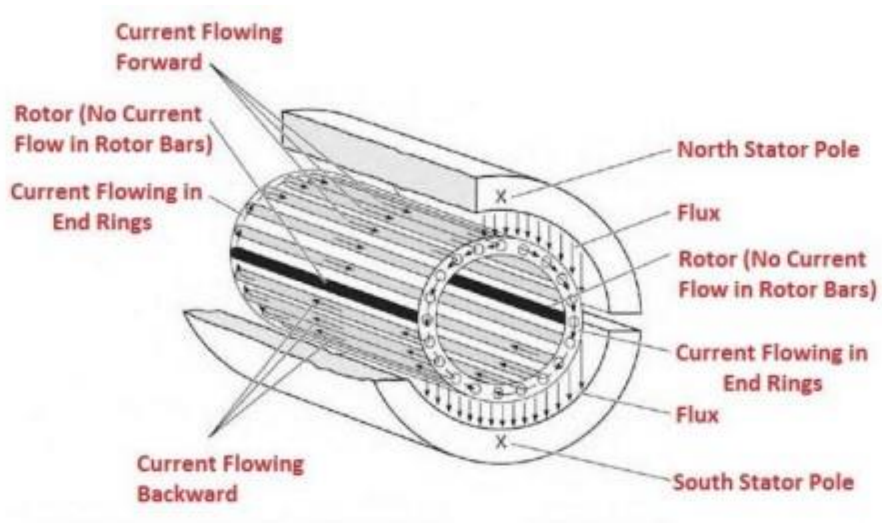

Figure 2.5: Squirrel cage induction motor

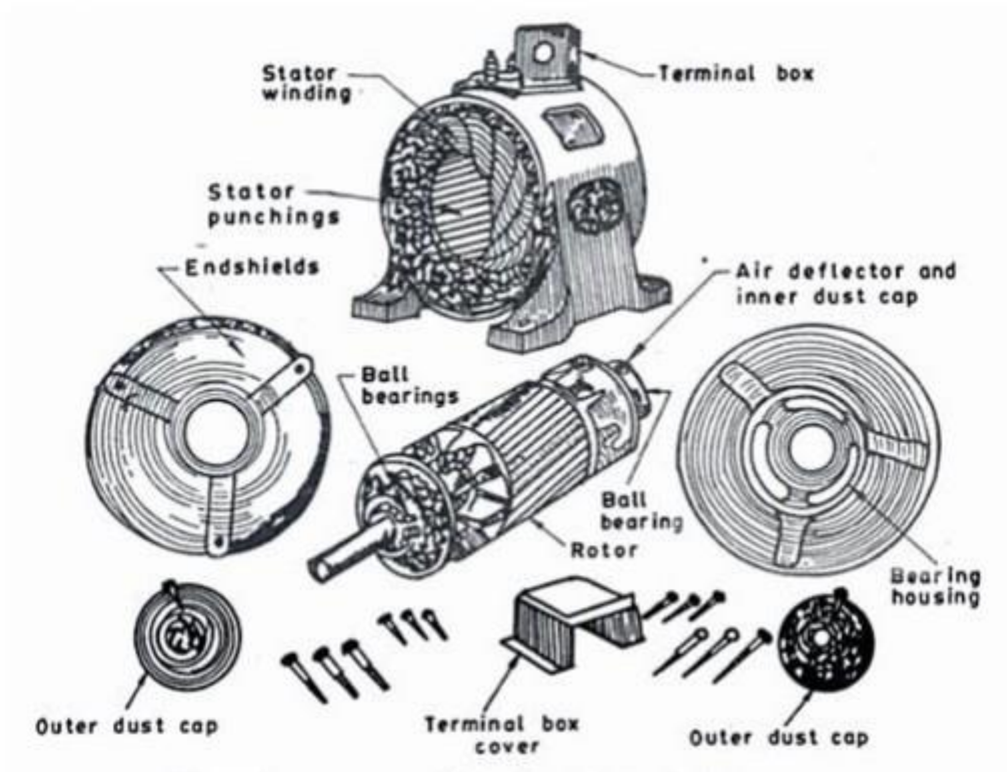

Figure 2.6:Component parts of small Squirrel cage induction motor

Working Principle:

When a three-phase supply is applied to the stator winding, it creates a rotating magnetic field in space, known as synchronous speed. This rotating magnetic field induces voltages in the rotor bars, causing short-circuit currents to flow through them. These currents generate their own magnetic field, which interacts with the stator's magnetic field. In response, the rotor begins to follow the rotating magnetic field to counteract the cause of the induced currents.

As soon as the rotor synchronizes with the rotating magnetic field, the rotor current drops to zero because there is no longer relative motion between the rotor and the magnetic field. Consequently, the rotor experiences no tangential force, causing it to momentarily lose synchronization [8].

After the disintegration of the rotor, the rotor current is re-induced when the relative motion between the rotor and the rotating magnetic field is restored. Thus, the tangential force is once more applied to the rotor's rotation, and the rotor once more begins to rotate the magnetic field. As a result, the rotor maintains a constant speed that is lower than the synchronous speed or speed of the spinning magnetic field.

Advantages of Squirrel Cage Induction Motor :

Here is the advantages of squirrel cage induction motor [11]:

- Rugged in construction
- Minimum maintenance
- No slip rings, brush gears, etc
- Trouble free performance
- Cheaper
- Comparatively to higher efficiency
- Medium starting torque can be achieved by utilizing a case rotor or a deep bar rotor.
- Comparatively improved pull-out torque and overload capacity.

Disadvantages of Squirrel-Cage induction Motor:

Although squirrel cage motors are very popular and have many advantages – they also have some downsides. Some disadvantages of squirrel cage induction motors are:

- Low starting torque.
- Higher starting current (5 to 6 time the full load current).
- Needs a stator.
- Not suitable for applications requiring high starting torque.

Application:

Induction motors with squirrel cages are widely utilized in several industrial settings. They work especially well in applications where the motor needs to run at a steady speed, start on their own, or require little maintenance [10].

Typical applications for these motors are:

- Centrifugal pumps
- Industrial drives (e.g. to run conveyor belts)
- Large blowers and fans
- Machine tools
- Lathes and other turning equipment

Wound-Rotor Motor :

An alternative to the squirrel cage induction motor, the slip-ring motor, also known as the wound-rotor motor, has a different rotor design but the same stator. The rotor windings of this motor are connected to slip rings, which permits the attachment of external resistors and contactors, in contrast to the squirrel cage motor. The effective rotor resistance in this configuration rises in direct proportion to the slip needed to produce the maximum torque (pull-out torque). Higher slip and pull-out torque can be obtained at lower speeds by introducing external resistance.

Low starting current can be enabled by high resistance since it can produce large pull-out torque at almost zero speed. When the motor achieves base speed, the external resistors are removed, allowing the motor to operate like a typical induction motor. Until then, the resistance is progressively decreased to fit the load needs as the motor accelerates. Because it requires a strong pull-out torque at low speeds and swift acceleration to full speed with little current draw, this motor type is perfect for high inertia loads[6].

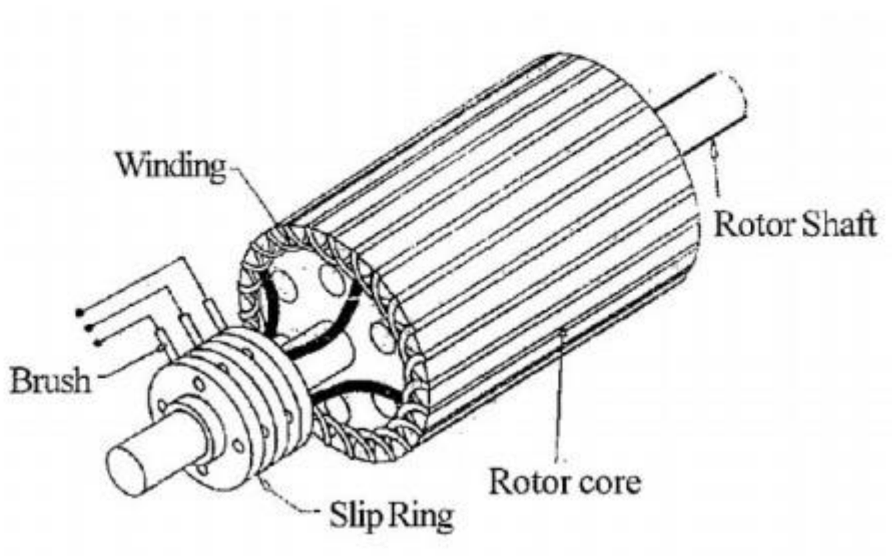

Figure 2.7:Wound rotor induction motor

Advantages of Wound-Rotor :

The advantages of the wound rotor are [11]:

- Much higher starting torque (by inserting resistance in rotor circuit)
- Comparatively lesser starting current (2 to 3 times full load current)
- possible to start under load requiring a high torque at startup
- Speed control (by varying resistance in the rotor circuit
- Reduces the starting current)
- Speed is resistance variable over 50% to 100% full load
- It can be initiated directly from the power source, as the resistance within the rotor circuit serves as a starting mechanism, lowering the initial current.

Disadvantages of Wound-Rotor:

- Higher cost
- Comparatively lower efficiency
- Higher degree of maintenance
- Extra losses in external resistances, especially when operated at reduced speed
- Extra slip ring, brush gears etc.
- More brush and slide ring maintenance required than with a squirrel case motor
- Higher exterior resistance losses, particularly when operating at a slower speed

Application:

Suitable for the majority of high-power industrial drives that need to start torque, like those that drive:

- Line shafts
- Lifts
- Pumps
- Generators
- Winding machines
- Mills etc.

2.3 Variable Frequency Drives (VFDs):

A Variable Frequency Drive (VFD) is a motor controller that adjusts the frequency and voltage supplied to an electric motor to control its speed. VFDs are also known as variable speed drives, adjustable speed drives, adjustable frequency drives, AC drives, microdrives, and inverters. The frequency, measured in hertz, is directly proportional to the motor's rotational speed (RPM). Therefore, increasing the frequency increases the RPM, while decreasing it lowers the RPM. When an application does not need the motor to operate at full speed, a VFD can reduce the frequency and voltage to match the motor's load requirements. This allows the motor speed to be adjusted based on the specific demands of the application[12].

Working Principle of Variable frequency drive:

The VFD controller is an electronic device made up of three parts: one that changes incoming AC current to DC current, a storage unit for the DC current, and another part that changes the DC current back to AC current at a variable speed.

The Converter is the primary sub-system of a Variable Frequency Drive (VFD). Six diodes make up this circuit, as the Figure below illustrates. As a result, when each diode opens and closes, we receive six current "pulses." The standard configuration for modern Variable Frequency Drives is known as a "six-pulse VFD."

In the second subsystem, the DC bus, equipped with large DC capacitors, filters out the AC ripple to provide a smooth DC voltage. The level of this DC voltage is determined by the AC line voltage feeding the drive, the extent of voltage imbalance in the power system, the motor load, the system's impedance, and the presence of any reactors or harmonic filters in the drive [13].

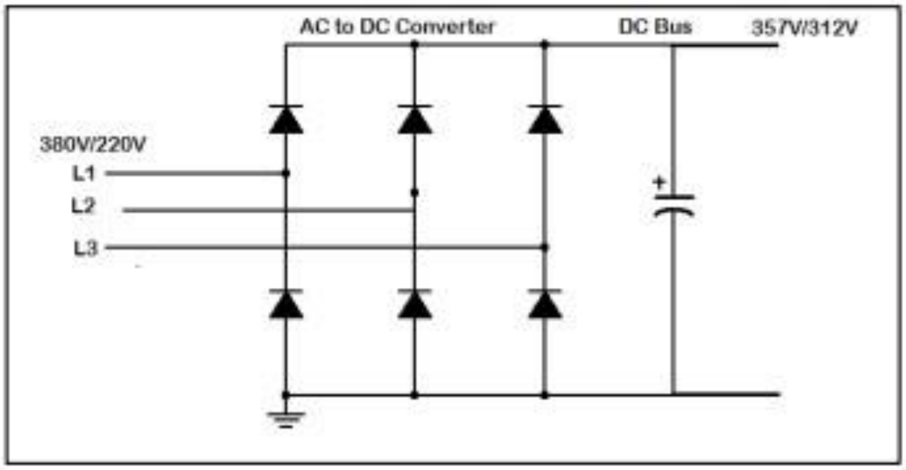

Figure 2.8: Three phase rectifier Diode Bridge with DC Bus

The inverter, the third subsystem of the drive, uses a variety of strategies and tactics. In this paper, we concentrate on the most popular strategy, Voltage Source Inverter (VSI) Pulse Width Modulation.

2.3.1 Pulse Width Modulation :

Pulse width modulation, or PWM, is the process used in the inverter section of the VFD to convert the DC voltage to the variable voltage variable frequency (VVVF) AC voltage.

The purpose of PWM control is to generate a sine wave current waveform output to produce torque in the motor.

To enable current flow between two motor phases, at least one transistor in the top section and one in the bottom section of the diagram must be activated. By using specific combinations of transistors, current can be directed in either direction between the phases. One of the advantages of using a VFD with PWM technology is the capability to regulate the current flowing through the motor winding, which results in adjusting the torque at the motor shaft when operating a rotating industrial motor. This is accomplished in the case of a VFD that uses PWM technology by altering the RMS voltage applied to the motor. The resulting RMS voltage across the motor phases can be regulated by varying the length of time each pulse is on and off. The 'width' of the pulse factors into the resulting RMS voltage output.

An longer pulse's "ON" time increases the RMS voltage during each phase.

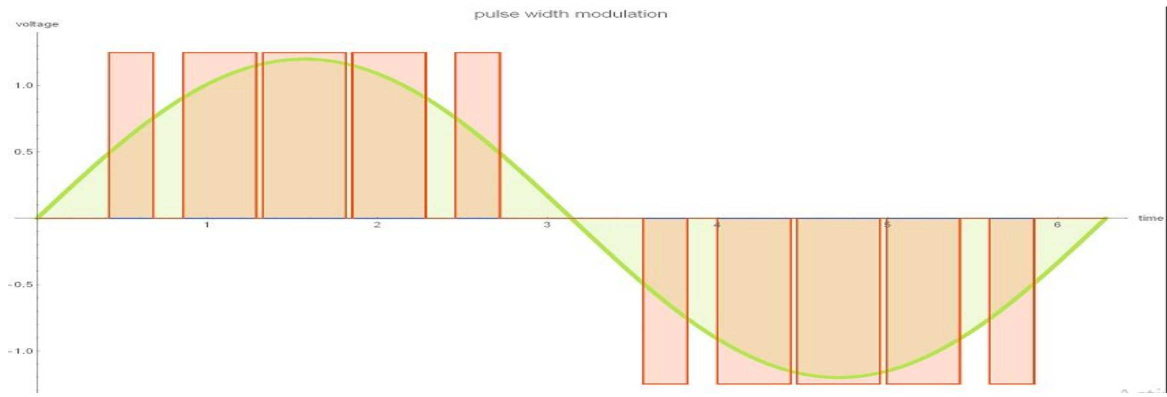

Figure 2.10:PWM representation with longer “ON” time.

A shorter pulse 'ON' time leads to a lower RMS voltage across the motor phases.

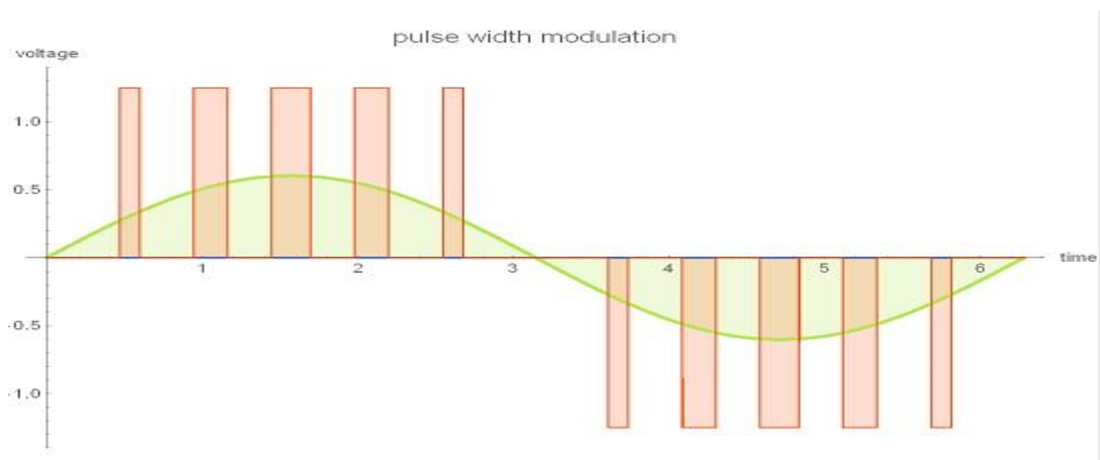

Figure 2.11:Figure PWM representation with shorter “ON” time

Therefore, the RMS voltage between the motor phases can be changed by varying the pulse width across each successive half wave. The resulting variable RMS voltage enables the VFD to adjust the current flowing between the motor phases. Additionally, the current waveform generated by the PWM process is affected by the IGBT switching frequency.

Advantages of the PMW Technique:

Here are some of the advantages of the PWM Technique [13]:

- Excellent input power factor due to fixed DC bus voltage.
- No motor cogging normally found with six-step inverters.
- Highest efficiencies: 92% to 96%.
- Compatibility with multi-motor applications.
- Ability to ride through a 3 to 5 Hz power loss.
- Lower initial cost.

Disadvantages:

- Motor heating and insulation breakdown in some applications due to high Frequency switching of transistors.
- Non-regenerative operation.
- Line-side power harmonics (depending on the application and size of the drive).

2.3.2 Advantages of Variable Frequency Drive :

Variable Frequency Drives (VFDs) have transcended geographical boundaries, finding application in diverse sectors like infrastructure, industry, power generation, and oil and gas. This surge in VFD adoption is fueled by two primary forces: the global focus on energy efficiency and the growing recognition of the benefits these drives offer.

Six primary benefits of VFDs are [15]:

- **Keeps starting current in control:** In order to prevent motor winding bending and heat generation, a VFD can start the motor at zero voltage and frequency. This contributes to a longer motor life.
- **Reduces power line disturbances:** Any power line voltage sag can have a negative impact on voltage-sensitive electronics including computers, proximity switches, and sensors. Voltage sag is eliminated by using VFDs.
- **Demands lower power on start:** An ac motor across the line requires a lot more power to start than one with a VFD. Industrial clients may be charged surge fees if they turn on these motors during periods of high electricity consumption. However, the problem can be

solved because VFD requires less starting power.

- **Helps in controlling operating speed and acceleration:** Applications like bottling lines, which handle easily tipped products, greatly benefit from a gradual increase in power. This enables conveyor belts to smoothly accelerate rather than jerking to full power suddenly. Additionally, the ability to adjust speed remotely through a controller is advantageous. Having control over speed and acceleration is a significant benefit for industries in production processes.
- **Limits and adjusts torque :** The torque can be limited and adjusted by the drive to ensure that the ac motor never exceeds this limit. This safeguards the process or product as well as the apparatus against harm
- **Saves energy and cost :** Compared to a motor running at constant speed for the same amount of time, a VFD controlling a pump motor that typically runs at less than full speed can save energy consumption. It also removes the requirement for mechanical drive components, which contributes to a total cost reduction.

2.4 Programmable logic controllers:

Also known as programmable controllers, or PLCs, are solid-state members of the computer family that perform control duties via integrated circuits rather than electromechanical components. In order to operate industrial machinery and processes, they can store instructions for tasks like sequencing, timing, counting, arithmetic, data manipulation, and communication. A conceptual diagram of a PLC application is shown in Figure 2.12.

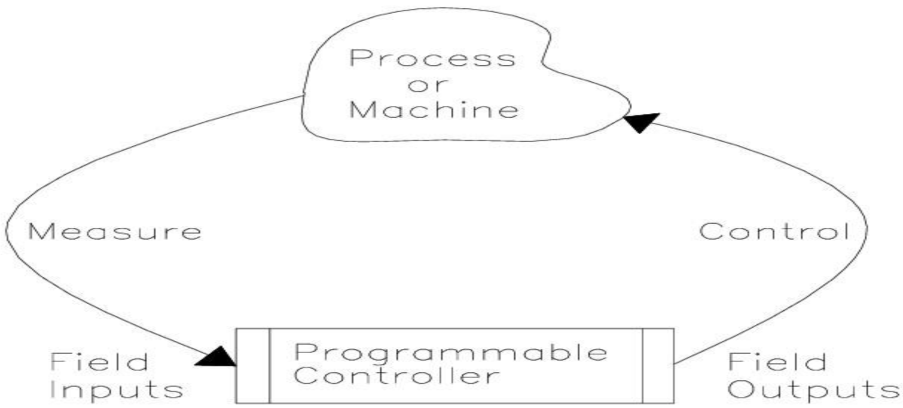

Figure 2.12:PLC conceptual application diagram

2.4.1 Principle of Operation :

A programmable controller, as illustrated in Figure 2.13, consists of two basic sections:

- The central processing unit
- The input/output interface system

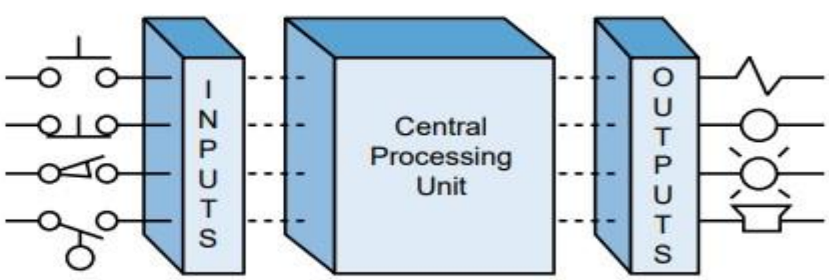

Figure 2.13:Programmable controller block diagram

The central processing unit (CPU) governs all PLC activities. The following three components, shown in Figure 2.14, form the CPU:

- The processor
- The memory system
- The system power supply

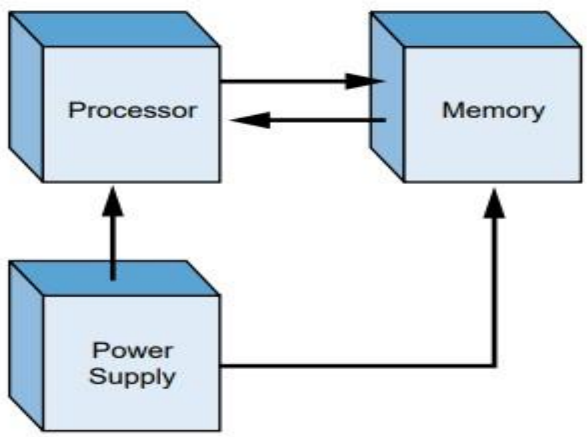

Figure 2.14:Block diagram of major CPU components

The operation of a programmable controller is relatively straightforward. The input/output (I/O) system is directly connected to the field devices involved in the machine or process control. These field devices can be either discrete or analog I/O devices, such as limit switches, pressure transducers, push buttons, motor starters, solenoids, and more. The I/O interfaces serve as the link between the CPU and the devices providing information (inputs) and those being controlled (outputs).

The CPU performs three tasks when it is operating: (1) it reads, or accepts, input data from field devices via input interfaces; (2) it runs, or carries out, the control program that is kept in the memory system; and (3) it writes, or updates, the output devices via the output interfaces.

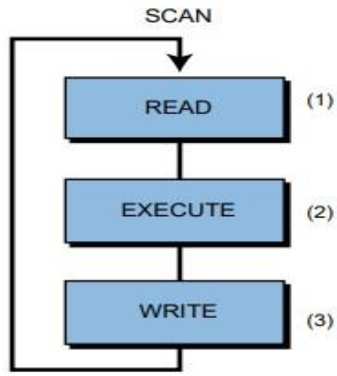

Figure 2.15:Illustration of a scan

This method of sequentially reading inputs, executing the program stored in memory, and updating the outputs is referred to as scanning. Figure 2.15 shows a graphical representation of a scan.

Field devices are connected to the controller through the input/output system as shown in Figure2.16 .The interface's primary function is to condition the numerous signals that are supplied to or received from external field devices. Terminals on the input interfaces are connected to incoming signals from sensors (such as limit switches, selection switches, analog sensors, push buttons, and thumb wheel switches). The terminals of the output interfaces are connected to devices that will be controlled, such as position valves, pilot lights, solenoid valves, and motor starters. All of the voltages needed for the various CPU portions to operate correctly are supplied by the system power supply[16].

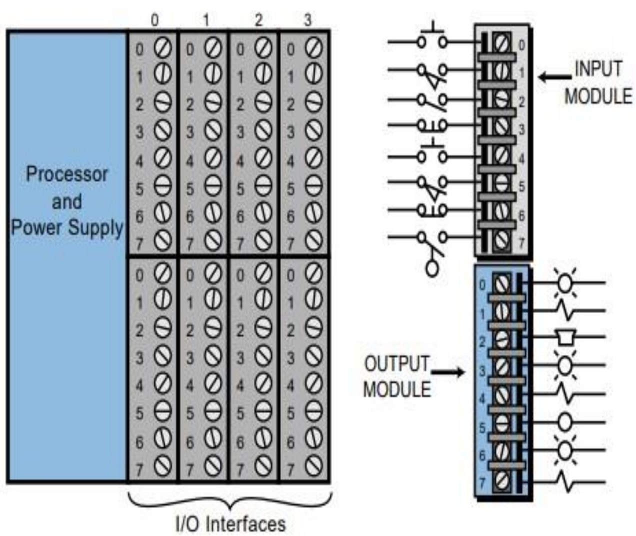

Figure 2.16:Input/output interface

2.4.2 PLC Programming Languages :

PLC programming languages come in five different varieties, all of which are included in the IEC (International Electrotechnical Commission) 61131-3 International Standard. This standard lists the following five categories of PLC programming languages:

- Ladder Diagram (LD)
- Function Block Diagram (FBD)
- Structured Text (ST)
- Instruction List (IL)
- Sequential Function Chart (SFC)

These are the five major types of PLC programming languages; however, Ladder Diagram (LDis the most widely used type[17].

2.4.3 Advantages of PLCs :

PLC architecture is often versatile and modular, enabling hardware and software components to expand as application needs do. If an application goes beyond the programmable controller's capabilities, the old hardware can be reused for a smaller application, and the unit can be readily replaced with one that has more memory and I/O capacity.Control solutions can benefit greatly from a PLC system's programmability, repeatability, and dependability. The advantages of programmable controllers increase with the user; the more you understand PLCs, the more proficient you will become in handling various control issues[16].

Here are some of the many features and benefits obtained with a programmable controller[18]:

- **Flexibility:** PLCs are perfect for dynamic industrial settings because they can be quickly updated and modified without requiring significant hardware or wire changes. They are very adaptable and simple to program and reprogrammed to meet changing needs.

- **Reliability:** they can run continuously for long periods of time without experiencing any problems because of their high level of reliability. They are made to resist extremes in temperature, humidity, and electrical noise because they are intended for use in industrial settings.

- **Scalability:** System sizes and complexity can be easily adjusted with PLCs by scaling them up or down. To increase the system's capabilities, more input and output modules can be added without causing major disruptions or reconfigurations.
- **Real-Time Operation:** they are essential in applications that need to react quickly, such as high-speed processes or safety systems. They can perform control tasks instantly and guarantee accurate and prompt reactions to input signals.
- **Integration:** Industrial processes may be efficiently controlled and monitored because to PLCs' ability to connect with a variety of input and output signal types. They provide smooth interaction with a variety of field devices, including switches and sensors.

- **Diagnostics:** Due to the strong diagnostic capabilities of PLCs,operators can immediately discover errors, monitor system performance, and resolve difficulties. Error-handling systems and integrated diagnostic tools make maintenance easier and decrease downtime.
- **Programming:** Developing and testing control logic is made easier with the help of PLCs' intuitive programming environments. By using simulation tools, engineers can lower the chance of error by confirming the behavior of the software before putting it into the real system.
- **Cost Effective:** PLCs simplify and reduce the cost of wiring, decrease installation time, and promote efficient resource utilization. They provide a more affordable solution for industrial automation compared to conventional hardwired control systems.
- **Communication Abilities:** Through their smooth connection with other automation systems and enterprise-level networks, PLCs facilitate a wide range of communication protocols. This makes centralized control, remote monitoring, and data interchange possible.
- **Safety Features:** In order to guarantee the secure running of industrial processes and to safeguard people and property, PLCs are essential. They can be programmed to carry out safety features including emergency stops, interlocking, and fault detection in addition to their inherent safety characteristics.

2.5 Conclusion:

In this chapter, we covered the fundamental principles of AC motors, variable frequency drives (VFDs), and programmable logic controllers (PLCs). We highlighted the importance of AC motors in industrial applications as we talked about their operational features and advantages. The capacity of VFDs to control motor speed, resulting in improved efficiency and energy savings, was highlighted. PLCs were investigated for their potential to replace complex wire systems with adaptable, programmable automation task solutions. This basic information prepares us for the practical application in the up-coming chapter and lays the groundwork for merging these technologies to create effective motor speed control.

Chapter 3:

System Design and Implementation

3.1 INTRODUCTION:

In this chapter, we move on from the theoretical foundations and fundamental concepts of AC motors, PLCs, and VFDs discussed in the previous chapters to the practical aspects of designing and implementing a motor speed control system. We are going to provide a comprehensive guide to the integration of these technologies, detailing the design, programming, and configuration processes required to achieve our objective. This program will be implemented on the S7-1212 PLC using G120 Siemens VFD on the software TIA PORTAL V16 from Siemens and GXU3512 Schneider HMI.

3.2 The System Block Diagram:

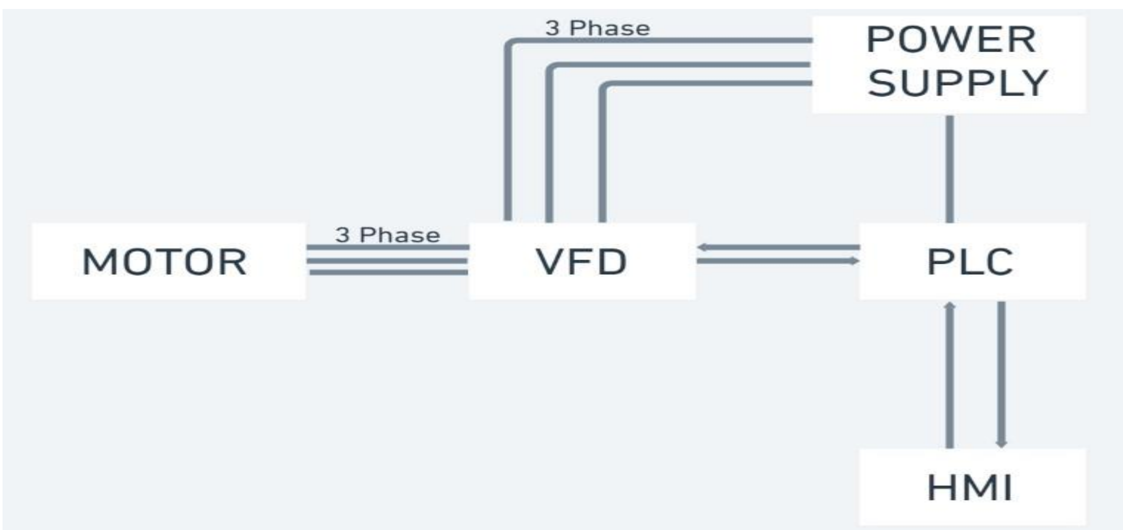

Figure 3.1: System block diagram

3.3 Hardware components:

3.3.1 The Siemens 1212 PLC :

The Siemens SIMATIC S7-1200 series PLC, specifically the 1212C AC/DC/Rly model, has been selected for this project due to its versatility, reliability, and wide acceptance in industrial automation. Its integration with other system components via PROFINET ensures smooth operation and effective control, making it a suitable choice for this application.

Figure 3.2:Plc1212c

Specifications:

- **CPU Type:** SIMATIC S7-1200 CPU 1212C
- **Power Supply:** 85-264V AC input
- **Digital Inputs:** 8 inputs (24V DC)
- **Digital Outputs:** 6 relay outputs (10A)
- **Communication Ports:** 1 PROFINET/Ethernet port
- **Memory:** 50 KB program memory, 2 MB load memory
- **Clock:** Real-time clock integrated

3.3.2 Siemens G120 Variable Frequency Drive:

For this project, the Siemens SINAMICS CU240E-2 PN with PM 240-2 power unit Variable Frequency Drive (VFD) was selected because of its advanced control features, easy integration, and compatibility with the chosen PLC. Precise motor speed regulation is provided by this VFD, making it ideal for a range of industrial applications, which is crucial for the success of the project.

Specifications :

- **Control Unit:** SINAMICS CU240E-2 PN
- **Power unit :** PM 240-2
- **Input Voltage:** 380-480V AC, 3-phase
- **Output Voltage:** 0-480V AC, 3-phase
- **Power Rating:** Suitable for motors up to 22 kW (depending on the specific model)
- **Communication Ports:** PROFINET interface, RS485 port
- **Frequency Range:** 0 to 650 Hz
- **Protection:** Overload protection; short-circuit protection, and thermal protection.

Figure 3.3:G120 VFD

The VFD possesses the following characteristics [19]:

- Wide power range from 0.55 to 2.50 kW.
- Three variants of frequency converters with voltages of 200V, 400V, and 690V.
- Additional security features: the SINAMICS G120 can be equipped with two types of safety packages - STARTER or Startdrive.
- The system easily integrates with a variety of applications.
- Modular design for easy connection and assembly.
- Enclosure rating of IP20 / IP55.
- Up to 11 digital inputs.
- 1 to 2 analog inputs.

The main advantages of using the SINAMICS G120 include an integrated safety function with a set of innovative features, a system for returning excess electricity to the power network, a new cooling principle, and compatibility with various types of automation.

3.3.2.1 VFD Control Methods:

Vector Control Method:

The technique of vector control is applied in variable-frequency drives (VFDs) to regulate the stator currents of brushless DC or three-phase AC motors. By using this method, the stator currents are determined to consist of two orthogonal components that may be seen as a vector. The torque is represented by one component, and the magnetic flux of the motor is represented by the other. Based on the flux and torque references supplied by the drive's speed control, the control system of the drive determines the reference values for these current components. It is common practice to use proportional-integral (PI) controllers to keep the measured current components at their reference values [20].

Scalar control methods:

For VFD control, scalar approaches optimize the motor flux and maintain a consistent magnetic field intensity to guarantee steady torque production. Scalar methods, also known as V/Hz or V/f control, change the voltage (V) and frequency (f) of power applied to the motor to maintain a fixed, constant ratio between the two. This results in a magnetic field intensity that remains constant regardless of motor speed.

The control method used in our project is Scalar Control, chosen for its simplicity and ease of implementation. This approach is cost-effective, dependable, and widely accessible, making it an ideal choice for our specific application.

3.3.3 Schneider HMIGXU3512 :

The advanced features and compatibility of the Schneider HMIGXU3512 with other system components led to its selection. The HMI plays a key role in providing an intuitive user interface that makes it easier to monitor and manage the motor control system effectively.

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Figure 3.5:HMI GXU3512

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Specifications:

- **Display:** 7-inch TFT LCD with 800 x 480 pixel resolution.
- **Processor:** ARM Cortex-A8, 600 MHz.
- **Memory:** 256 MB RAM, 512 MB Flash.
- **Communication Ports**: Ethernet, USB host and device, Serial ports (RS232/RS485).
- **Operating System:** Windows CE 6.0.
- **Input Voltage:** 24V DC.
- **Enclosure Rating:** IP65 (front panel).
- **Operating Temperature:** 0 to 50°C.

This HMI integrates into our system as follows:

- **Communication with PLC**: Connected via Ethernet to the Siemens 1212C AC/DC/Rly PLC, enabling real-time data exchange and control.
- **Monitoring and Control**: Provides operators with a visual interface to monitor motor status, adjust speed settings, and receive alerts.
- **Data Logging**: Capable of logging operational data for analysis and troubleshooting.
- **Parameter Adjustment**: Allows easy adjustment of VFD parameters to fine-tune motor performance.

3.3.4 AC Induction Motor:

The motor used in our system is an asynchronous three-phase AC induction motor, specifically a squirrel-cage type. This type of motor is widely favored in industrial applications due to its robustness, reliability, and simplicity in construction.

Figure 3.6:Squirrel cage motor

3.4 PLC Programming:

3.4.1 Tia Portal:

The Totally Integrated Automation Portal - TIA Portal offers unrestricted access to a complete portfolio, range of devices, and automation services, boosting productivity with simulation tools and enabling diagnostics and management functions. The TIA Portal enables engineers to construct complex automation systems by utilizing a comprehensive array of tools and features. Its user-friendly interface facilitates easy navigation, making it accessible to both novice and experienced users. it supports the efficient management of automation projects, enhancing productivity while simultaneously reducing costs and minimizing errors. Consequently, it stands out as a robust and versatile automation platform that has gained widespread acclaim among automation professionals worldwide. In our project we used tia portal v16 as shown in the figure3.7.

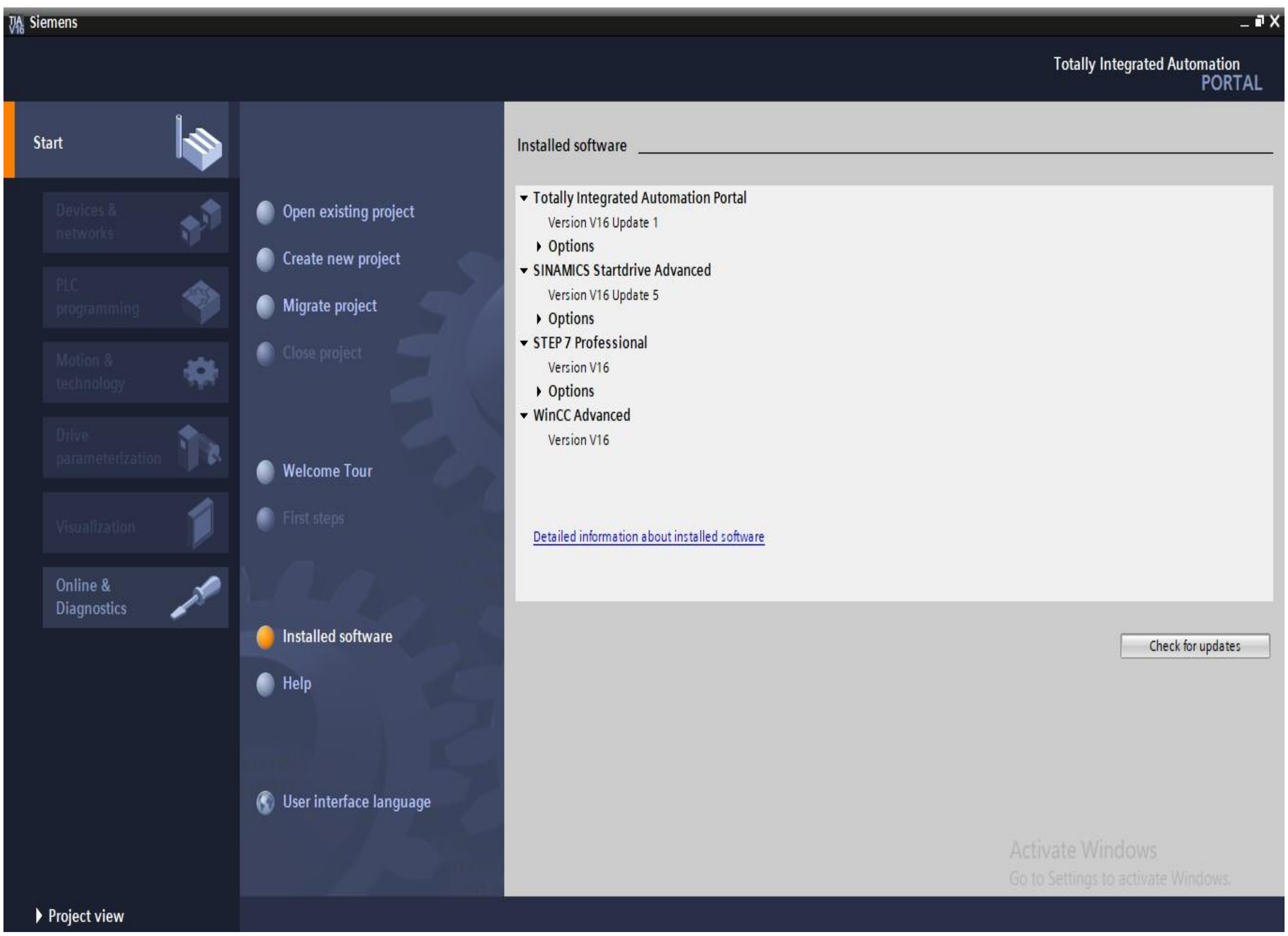

Figure 3.7:Tia portal

3.4.2 PLC Program :

The main part of our program that controls motor speed is the SINA_SPEED function block. This function block, was designed to make it simpler for industrial automation systems to precisely regulate motor speed.

Function blocks are modular programming components that are frequently used to simplify difficult control tasks in PLC (Programmable Logic Controller) programming. In particular, the SINA_SPEED function block uses sophisticated algorithms and control techniques designed to provide precise and responsive speed control.

Key features and functionalities of the SINA_SPEED function block include:

PID Control: The function block employs a Proportional-Integral-Derivative (PID) control algorithm to dynamically adjust motor speed based on feedback from sensors or other feedback devices. This allows for precise and stable speed regulation, even in variable operating conditions.

Acceleration and Deceleration Control: SINA_SPEED offers the motor smooth acceleration and deceleration mechanisms, guaranteeing progressive changes in speed to avoid abrupt variations or shocks to the system.

Diagnostic Capabilities:. It includes diagnostic features to monitor motor performance, detect faults or abnormalities, and facilitate troubleshooting.

Here is our program using Sina Speed block on figure 3.8

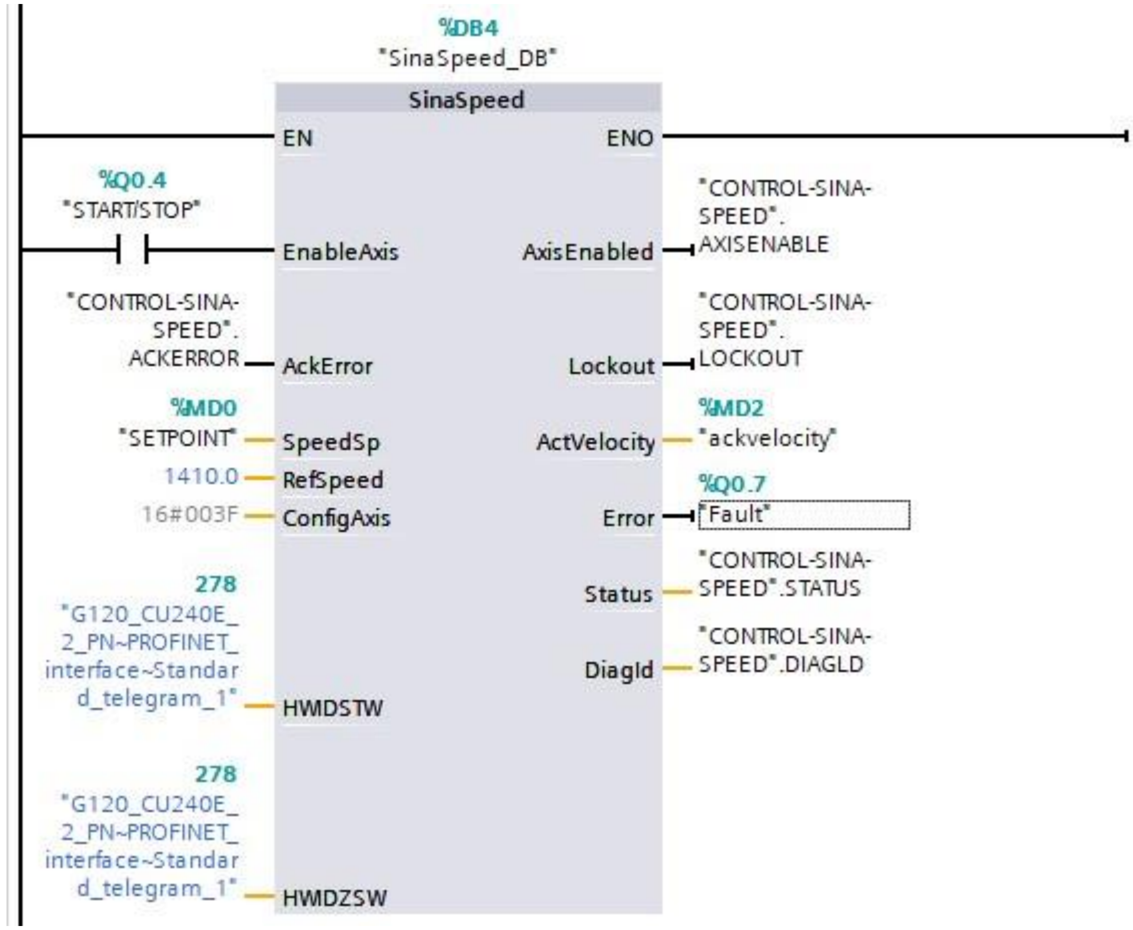

Figure3.8:Program using sinaspeed

The input and output parameters and its function of the block are:

Inputs :

- **EnableAxis :** Start/stop of the drive (assignment of drive control word 1 bit 0).
- **AckError :** Acknowledgment of errors in the drive (assignment of drive control word 1 bit 7).
- **SpeedSp :** Definition of the speed [1/min].
- **RefSpeed :** Reference speed of the drive. It must be identical with drive parameter.
- **ConfigAxis :** Assignment of the drive control word.
- **HWIDSTW :** Hardware ID setpoint value.

- **HWIDZSW :** Hardware ID actual value.

Outputs:

- **AxisEnabled :** Drive operation is enabled.
- **Lockout :** On-inhibit of the drive is active.
- **ActVelocity :** Actual speed of the drive.
- **Error :** Drive fault active.
- **Status :** Display of status values.
- **DiagId :** Expanded communication fault (error when calling up a command).

3.5 VFD Configuration:

The SIMATIC S7-1212 is operated as a PROFINET controller. For this, the PROFINET-capable SINAMICS G120 drive is used as PROFINET device and be controlled by the plc . the VFD and the PLC communicate with each other via the Profinet network in a PLC-controlled VFD system in order to control motor speed. Specifying up the setup includes mapping the I/O signals, specifying IP addresses and network settings in the Siemens TIA Portal, and connecting both devices to the Profinet network. The VFD adjusts the motor's speed in response to control commands from the PLC, including start/stop and speed references. The PLC receives status and feedback data from the VFD. This configuration improves the efficiency and dependability of the system by enabling accurate and real-time motor control.

Commissioning The VFD using the TIA Portal Commissioning Wizard :

The TIA Portal's commissioning wizard is an integrated tool designed to simplify the setup and configuration of VFDs. It guides users through a series of steps to ensure that all necessary parameters are correctly set, making the process efficient and reducing the likelihood of errors.

Note: As part of the comprehensive setup and configuration process for the VFD within the TIA Portal, it is essential to utilize the Start drive software. Start drive is an integral component designed specifically for commissioning and parameterizing Siemens drives. To effectively configure and commission our VFD, we ensure that Startdrive is downloaded and installed as part of our TIA Portal environment.

As shown in the figure.3.9 ,We enter the motor specifications

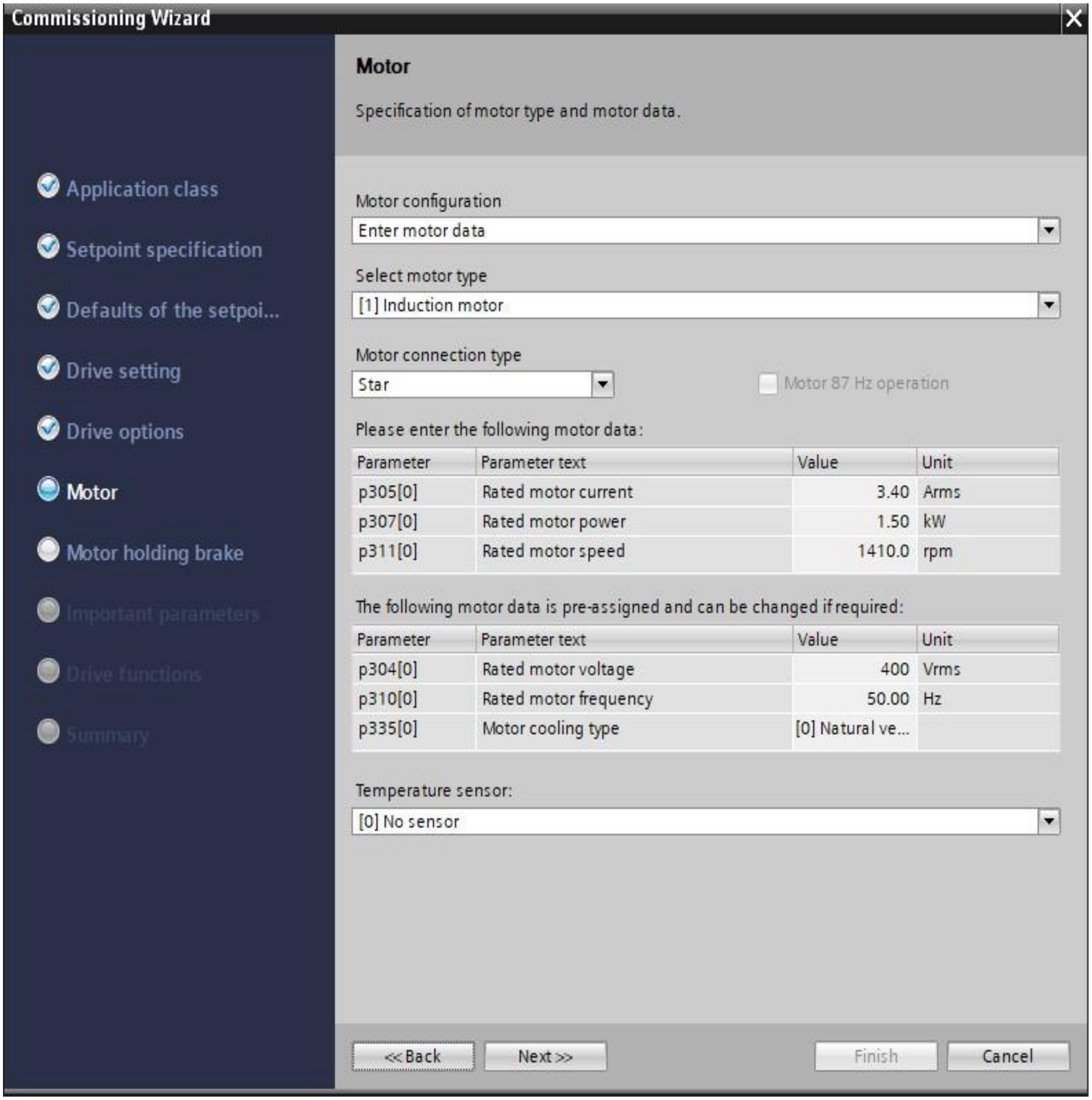

Figure 3.9:Motor data

The Figure.3.10 shows the summary page of the VFD commissioning wizard within TIA Portal. It simplifies the configuration by guiding engineers through a series of steps. It offers various application classes (standard, expert, dynamic), set point specifications (PLC control, analog source), motor parameter definition (type, connection, ratings), and drive function configuration. By following the wizard and selecting appropriate options, we can ensure all VFD settings are tailored to their specific application, reducing errors and streamlining the setup process. This contributes to the overall efficiency and effectiveness of Siemens TIA Portal for configuring automation systems.

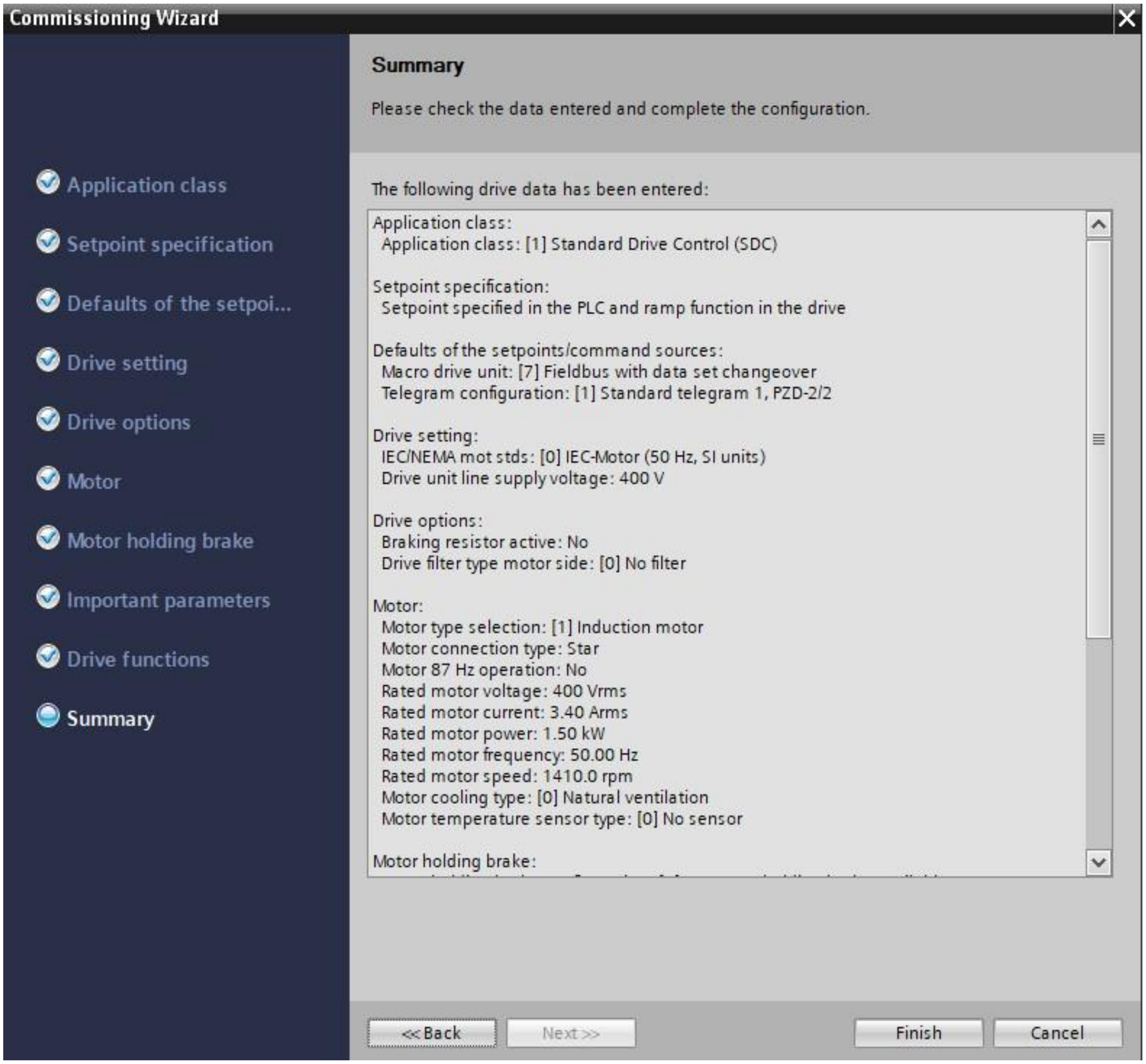

Figure 3.10:Summary of the configuration of the vfd

In our project, we use Standard Telegram 1 to control the VFD via the PLC using Profinet communication. Profinet enables high-speed, real-time data exchange essential for precise motor control. Standard Telegram 1 includes the Control Word for sending commands from the PLC to the VFD, the Status Word for receiving status updates from the VFD, the Set point Speed for transmitting desired motor speed, and the Actual Speed for monitoring the motor's real-time speed. This setup allows us to configure and commission the VFD efficiently using TIA Portal and Start drive, ensuring seamless integration and reliable motor control.

3.6 Industrial Communication protocol:

Data exchange between equipment in an industrial setting is known as industrial communication. This procedure is essential for gathering data, monitoring and controlling equipment, and improving operational effectiveness. Industrial communication networks can be wired or wireless and they use a variety of protocols to make communication easier, including Ethernet/IP, Profinet, Modbus, Profibus, and OPCUA.

3.6.1 PROFINET:

PROFINET (process field Net) is an industrial communication standard based on international standards which are designed for exchanging data between devices and controllers in an industrial control system. Here, controllers are PLCs, PACs, or DCSs whereas devices are vision systems, I/O blocks, RFID readers, process instruments, drives, proxies, etc. Since this is an open standard, so many manufacturers have designed PROFINET products like PACs, PLCs, Robots, Drives, IOs, Proxies & diagnostic tools.

PROFINET provides numerous advantages compared to other industrial communication technologies:

- **High Speed and Real-Time Communication:** PROFINET supports high-speed data transfer and real-time communication, which is essential for precise control and synchronization in industrial automation.
- **Scalability:** Profinet is scalable, making it suitable for both small and large-scale industrial systems, from simple machines to complex, interconnected manufacturing processes.
- **Flexibility:** It is compatible with many different devices and uses, such as safety systems,

motion control, and general automation jobs.

- **Global Standard:** As a widely adopted global standard, Profinet ensures compatibility and interoperability across various manufacturers and devices.

So these advantages make Profinet a preferred choice for modern industrial communication.

3.6.1.1 Standard Telegram:

In our project we used standard Telegram 1 which is a predefined communication protocol used in industrial automation to control VFDs via a Programmable Logic Controller (PLC) over the Profinet network. It facilitate the exchange of critical data at consistent intervals, establishing a cyclic communication protocol. Through Siemens standard telegrams, drives and PLCs can communicate vital information such as drive status (including motor speed, torque, and temperature), drive parameters (like set points, current limits, and acceleration), and error codes. This ensures continuous monitoring and control of the drive system.

3.6.1.2 Sending and Receiving Data with Standard Telegram 1:

Sending Data PLC to VFD:

Control Word (16 bits):

The PLC sends a Control Word to the VFD,which consists of various binary commands to manage the motor's operation. Each bit in the Control Word represents a specific command, such as starting, stopping, or changing the direction of the motor. For example, setting a particular bit might start the motor, while clearing it might stop the motor.

Set point Speed (16 bits):

The Set point Speed is the target speed for the motor, communicated from the PLC to the VFD. This 16-bit word defines the desired speed, enabling the VFD to adjust the motor accordingly. The value is typically expressed in RPM (Revolutions Per Minute) or another suitable unit.

Receiving Data VFD to PLC:

Status Word (16 bits):

The PLC receives a Status Word from the VFD that includes details about its present working state. Each bit in the Status Word indicates a specific condition, such as whether the drive is ready, running, in a fault condition, or in a specific operational mode. This feedback allows the PLC to monitor the VFD's status and take appropriate actions if necessary.

Actual Speed (16 bits):

The Actual Speed is the real-time speed of the motor, reported by the VFD to the PLC. This 16-bit word provides the current speed of the motor, enabling the PLC to compare it with the set point speed and make adjustments to maintain the desired operation. This feedback loop ensures precise and consistent motor control.

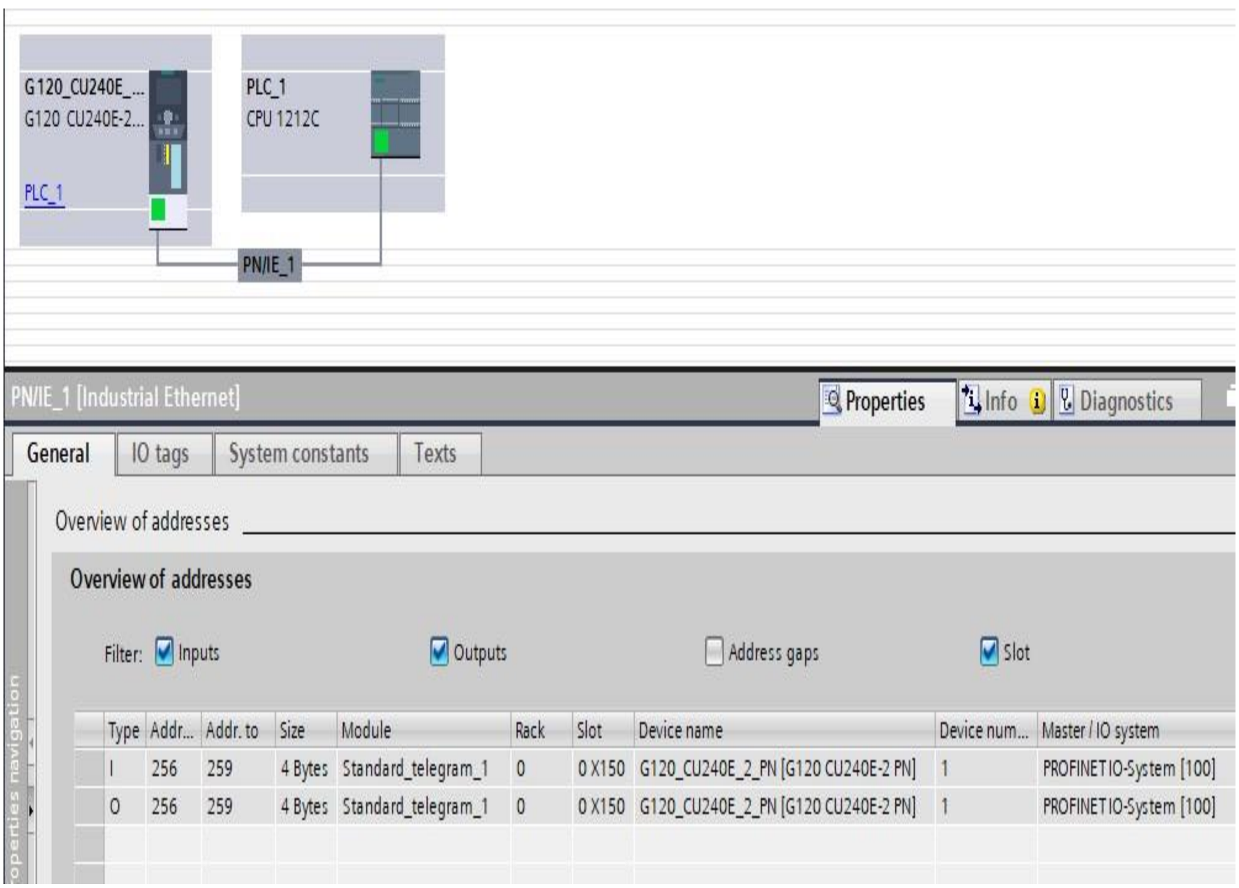

Figure3.11:Sending and Receiving Addresses with Standard Telegram 1

3.7 Analog Control Method :

There is an alternative method which is analog control. It is a traditional method used in industrial automation to manage various processes, including motor speed and torque control. This method relies on continuous signals, usually in the form of voltage (0-10V) or current (4-20mA), to convey control information from the PLC to the VFD. The VFD analyzes these analog signals and modifies the motor's voltage and frequency to regulate the induction motor's speed.

Programming the PLC to control the VFD via analog signals as shown in Figures 3.12 and 3.13 involves several steps:

Configure Analog Output Module: In the TIA Portal, configure the analog output module to generate the required signal (0-10V or 4-20mA).

Scale Control Signals: Use scaling functions to convert the desired motor speed or torque values into corresponding analog signals. This ensures that the control signal accurately reflects the required motor performance.

Program Control Logic: Develop the PLC control logic to manage the analog output based on the system requirements, such as adjusting motor speed in response to process conditions or operator inputs.

Send Analog Signals to VFD: Program the PLC to continuously send the scaled analog signal to the VFD, which adjusts the motor speed accordingly.

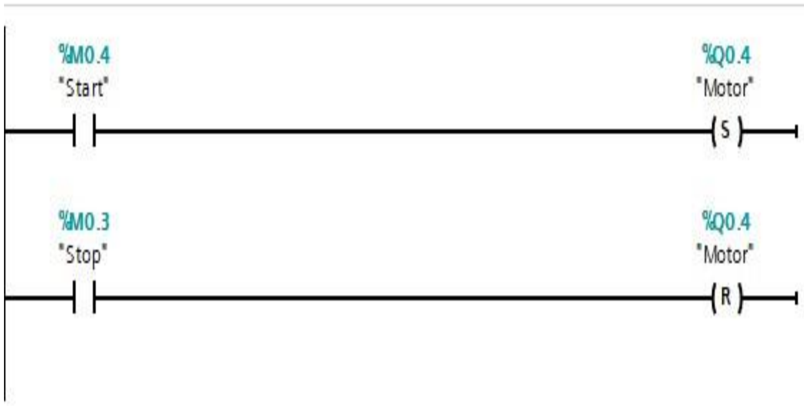

Figure 3.12: Start and Stop Motor

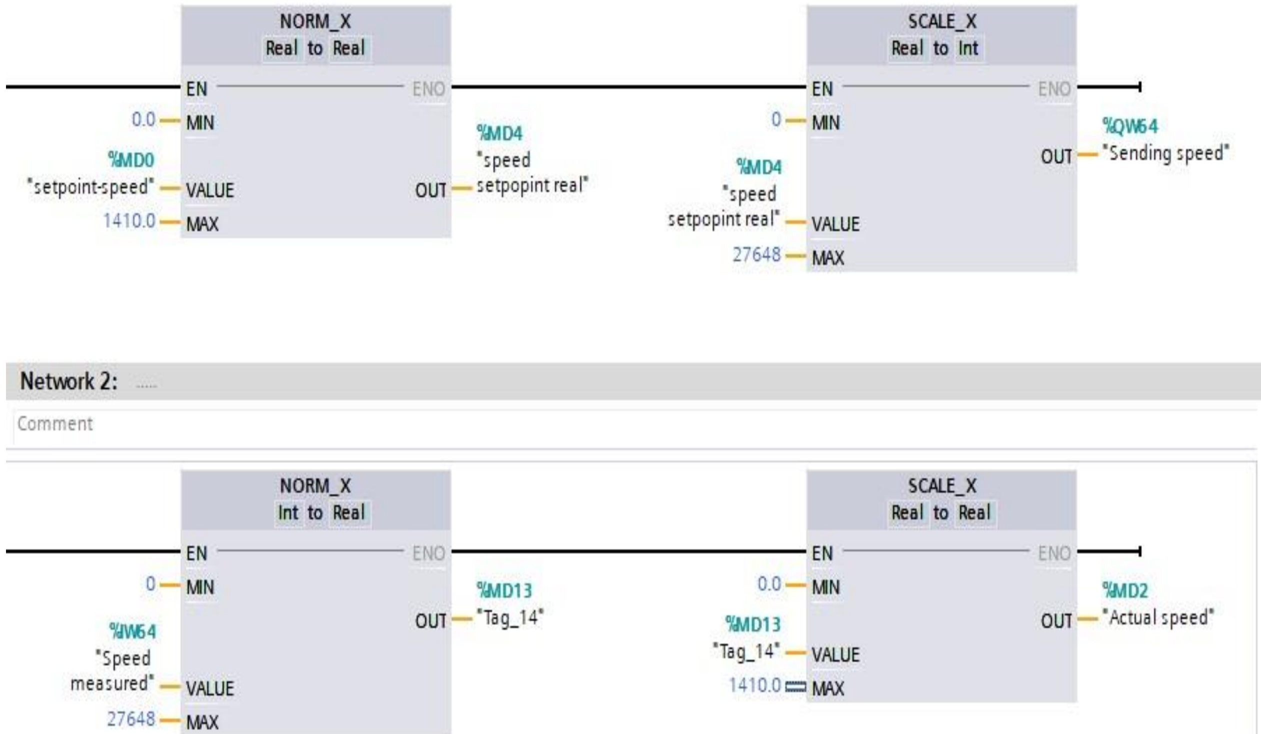

Figure 3.13:Speed set point and reading

We use the PROFINET protocol instead of analog control for this project due to its superior capabilities in precision, flexibility, and scalability. PROFINET provides high-speed digital communication, which allows for more complex and accurate control schemes, real-time data exchange, and advanced diagnostics, essential for optimizing the performance of the induction motor and VFD system. Unlike analog signals, which are susceptible to electrical noise and signal degradation over long distances, PROFINET ensures robust and reliable communication. Additionally, PROFINET supports easier integration of multiple devices and future scalability, making it a more versatile and forward-looking choice for modern industrial automation applications.

3.8 HMI Design:

We designed the HMI for the Schneider Electric HMI GXU3512 touchscreen panel using Vijeo Designer, their dedicated HMI programming software. Vijeo Designer offers a rich library of objects like buttons, gauges, and trend graphs, which we utilized to create informative and user-friendly screens. Communication protocols were configured within Vijeo Designer to ensure seamless data exchange between the HMI, PLC, and Vfd.As shown in the Figure 3.14 Our design to monitor and control the Motor.

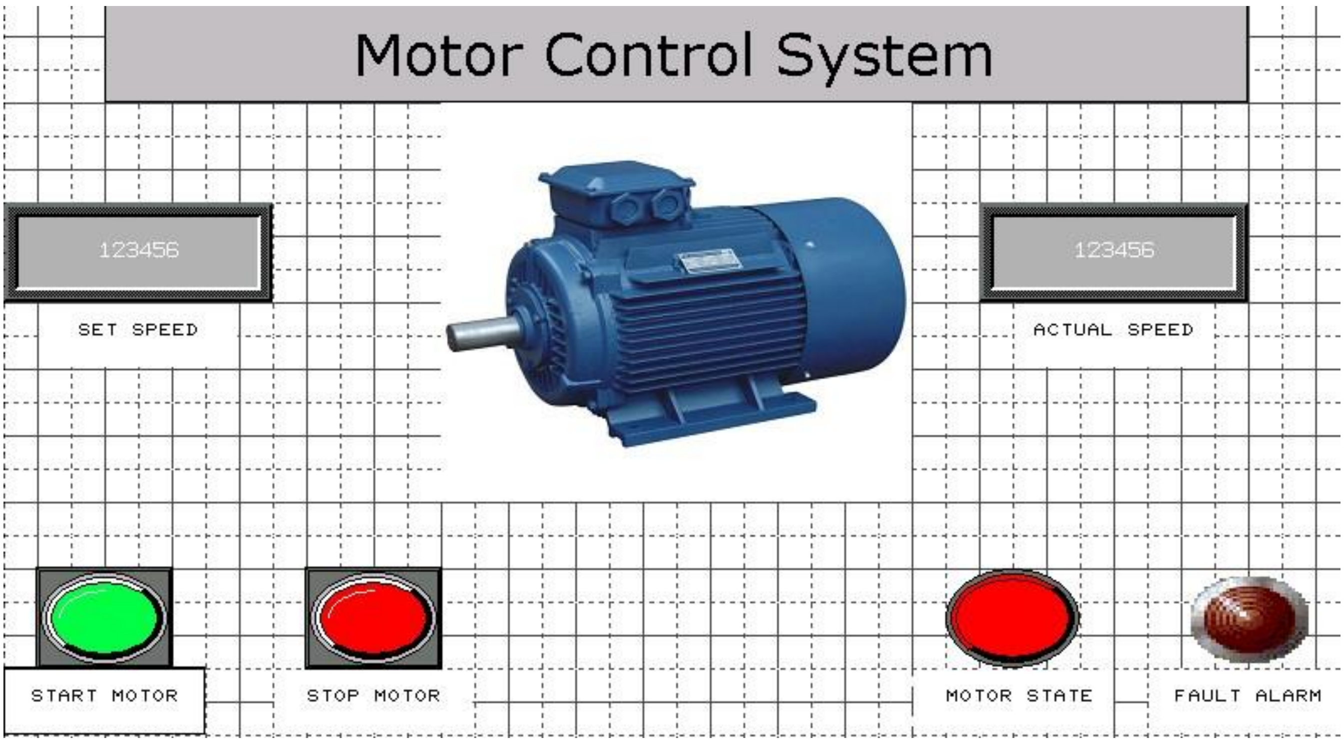

Figure3.14:Hmi design in vijeo designer

	Name	Data Type	Data Source	Scan Group	Device Address	Alarm Group	Logging Group
1	ACTUALSPEED	REAL	External	S71200CPU1212...	MW2	Disabled	None
2	FAULT	BOOL	External	S71200CPU1212...	Q0.7	Disabled	None
3	MOTORON	BOOL	External	S71200CPU1212...	M0.4	Disabled	None
4	MOTORSTATE	BOOL	External	S71200CPU1212...	Q0.4	Disabled	None
5	MOTORSTOP	BOOL	External	S71200CPU1212...	M0.3	Disabled	None
6	setspeed	REAL	External	S71200CPU1212...	MW0	Disabled	None

Figure3.15:Table of Variables of the hmi

3.9 Implementation Design:

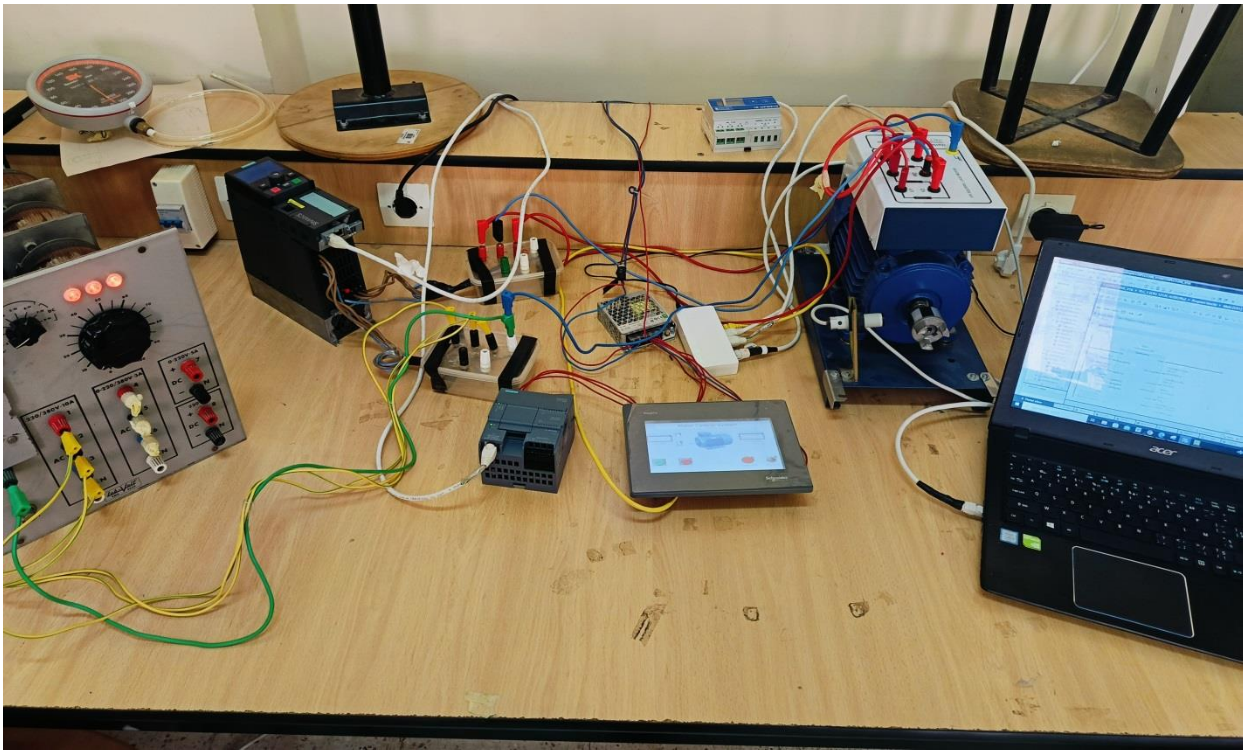

Figure 3.16: Test Bench

The implementation of our system for speed control and monitoring of an induction motor using the VFD and Profinet protocol, with the HMI for user interaction, was highly successful. The PLC communicated set point speed commands to the VFD via Profinet, with the VFD adjusting the motor speed accordingly. Using the SINA_SPEED function block, the system achieved precise and responsive motor speed control. The HMI provided real-time feedback, displaying critical data such as motor speed, motor state, and faults, allowing operators to monitor and adjust the system as needed. Our results demonstrated high accuracy, with minimal deviation from set point speeds, and excellent system responsiveness to changes in setpoint commands. The system operated reliably over extended periods, maintaining stable performance without significant faults. Profinet communication ensured efficient and consistent data exchange, contributing to the overall reliability and efficiency of the system. The efficient execution of our design and configuration shows its effectiveness, providing an appropriate resolution for accurate motor speed control in industrial applications.

3.10 Conclusion :

In this chapter, we present the detailed design and implementation of the monitoring and control system of the motor by addressing the hardware and software configurations essential for the successful implementation of the project. We have established a strong framework essential for the successful execution of our project objectives. This involved programming the PLC, configuring the VFD, and designing the HMI for efficient supervision and control.

General Conclusion :

In this final project, we have described the design and implementation of a PLC and HMI-based monitoring and control system for an induction motor using a VFD and PROFINET protocol. The integration of these modern automation technologies has demonstrated the capability to achieve precise speed control, efficient energy management, and enhanced operational visibility for industrial applications involving induction motors.

The system processes outlined in this thesis can serve as a valuable reference for researchers, engineers, and practitioners seeking to develop similar control systems or integrate advanced automation technologies. The modularity of the system allows for future expansions and adaptations to meet evolving industrial requirements.

There are numerous features and aspects that could be integrated into the implemented system. However, due to the considerable efforts and time dedicated to the software design and bug fixing, we were unable to implement them. These features could be utilized to enhance the system, such as:

- Torque Control: Implementing torque control to manage and adjust the motor's torque output and limit it.
- Temperature Monitoring: Including additional sensors for real-time temperature monitoring of the motor and drive components to prevent overheating and extend lifespan.
- Regenerative Braking: Adding regenerative braking capabilities to recover and reuse energy, enhancing overall energy efficiency.

Overall,the project was designed and implemented successfully, We hope that this work will be a valuable contribution to the field of industrial automation

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