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MASTER THESIS

Control and visualization of one axis drive

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- 1) Get familiar with SIEMENS PLCs and their configuration
- 2) Set the communication between the PLC and the servodrive
- 3) Create a program in the PLC to control a single axis drive (speed and position loop + acceleration and brake ramps)
- 4) Create a simple visualization of the drive status on the HMI panel

Bibliography / sources:

- [1] SIEMENS datasheets
- [2] Dury B. The Control Techniques Drives and Controls Handbook 2nd Edition, IeT
- [3] Wiedauer J. Electrical Drives, Siemens

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ABSTRACT

This project is mainly focused on the Siemens TIA software, S7 1200 PLC module, and its application to control the motor with visualization of the automated process from the HMI touch panel, where we can monitor and control the process and set some parameters. This demonstration of the application is created with the PLC module, HMI touch panel, power module, and supporting components for communicating between the components and the computer. The aim of the project will focus on the creation of the ladder logic program code in the TIA software, connection of all the above-mentioned modules by industrial communication bus with Profinet, and basic overview of the parts used in this project.

KEYWORD

S7 1200 PLC module, KTP 700 basic hmi panel, TIA portal software, motor control.

ABSTRAKT

Tato práce je zaměřena především na software Siemens TIA, PLC modul S7 1200 a jeho aplikaci pro ovládání motoru pomocí vizualizace automatizovaného procesu z dotykového panelu HMI, kde můžeme monitorovat a řídit proces a nastavovat některé parametry. Tato ukázka aplikace je vytvořena pomocí modulu PLC, dotykového panelu HMI, výkonového modulu a podpůrných komponent pro komunikaci mezi součástmi a počítačem. Cílem projektu bude vytvoření logického programového kódu v softwaru TIA, propojení všech výše uvedených modulů průmyslovou komunikační sběrnici s Profinetem a základní přehled částí použitých v tomto projektu.

KLÍČOVÁ SLOVA

PLC modul S7 1200, základní hmi panel KTP 700, software portálu TIA, řízení motoru.

Contents

List of Figures	8
LIST OF ABBREVIATIONS	3
Introduction	1
2 Programmable logic controller overview.....	3
2.1 Relay based system and need of PLC.....	3
2.2 History of plc	4
2.3 Programable Logic Controller	6
2.3.1 Working Principle OF PLC (PLC Scan cycle)	7
2.4 Programing Language of PLC	16
2.4.1 Ladder Diagram (LD):	17
2.4.2 Function Block Diagram (FBD):	18
2.4.3 Structured Text (ST):	18
3 Communication Networks:	20
3.1 Sensor Bus Network.....	20
3.2 Device Bus Network	20
3.3 Control Bus Network.....	20
3.4 Enterprise Networks	21
3.5 Profibus:	21
3.6 Profinet:	22
3.7 Ethernet:	22
4 Sensors:.....	24
4.1 Optical Encoder:.....	24
4.1.1 Incremental Encoder:.....	26
4.1.2 Absolute Encoder	28
4.2 Proximity Sensor	31
4.2.1 Optical proximity sensor	31
4.2.2 Description of part used	33
5 TIA PORTAL (Totally Integrated Automation Portal).....	45
6 Description of project:	48
6.1 Problem Description:	48
6.2 Problem Solution	48

6.3 Making of project:.....	50
6.4 Visualization in HMI panel	55
6.5 Online monitoring of rotation of motor:	57
7 Conclusion.....	58
References:	59

List of Figures

Figure 1: block diagram of PLC [6].....	8
Figure 2: Discrete AC input module block diagram [6]	12
Figure 3: Simplified diagram for a single input of a discrete AC input module [6]	13
Figure 4: Discrete AC output module block diagram.[6].....	13
Figure 5: Simplified diagram for a single output of a discrete AC [6]	14
Figure 6: Analog input module circuit [6]	15
Figure 7 Typical analog I/O control system [6].....	16
Figure 8: Standard IEC 61131 languages associated with PLC programming [6]	16
Figure 9: Ladder logic diagram.....	17
Figure 10: Function block diagram.....	18
Figure 11:The main components of an optical encoder [16]	24
Figure 12:Arrangement of components of the encoder [16]	25
Figure 13:Working of the optical encoder [16].....	25
Figure 14:Optical Disc with its track [19]	26
Figure 15:Incremental encoder cw and ccw waveform [19].....	26
Figure 16:Quadrature output of the incremental encoder [16].....	27
Figure 17:A 4-bit binary system absolute encoder disk.....	29
Figure 18:A 4-bit Gray code absolute encoder disk.....	30
Figure 19:Thru beam method [16]	32
Figure 20:Diffuse reflective proximity sensor [16]	33
Figure 21: Description of S7 -1200 PLC module [14].....	35
Figure 22: Diagram of connection between PLC and other modules.	36
Figure 23: wiring diagram, of a selected PLC module [23].....	38
Figure 24: connection diagram for STO interface [23].....	39
Figure 25: Nameplate of SINAMICS V90 Servo Converter [23].....	39
Figure 26: Serial number description of SINAMICS V90 Servo Converter [23].....	40
Figure 27connection Diagram of SINAMICS V90 Servo Converter	41
Figure 28: SIMOTICS S-1FL6 Servo Motor.....	42
Figure 29: Discription of HMI panel [KTP700 Basic, 6AV2 123-2GB03-0AX0] [25]	43
Figure 30:Portal view of TIA software	46
Figure 31:Project view TIA software.....	46
Figure 32: Basic connection diagram of PLC and motor.....	48
Figure 33: Control diagram of reverse -forward control of motor.....	49
Figure 34: TIA portal window	50
Figure 35: TIA portal window	51
Figure 36: TIA portal window	51
Figure 37: TIA portal window	52
Figure 38: TIA portal window	52
Figure 39: TIA portal window	53
Figure 40: TIA portal window	53
Figure 41: TIA portal window (network view).....	54
Figure 42: Ladder Logic program to control motor.....	54
Figure 43: HMI simulation screen	55

Figure 44: PLC and HMI tag table..... 56
Figure 45: Online monitoring In TIA portal with PLC and HMI screen 57

List of tables

Table 1: Gray code and binary code equivalent to decimal number	30
Table 2: Technical specification of the power supply module [20]	34
Table 3: Technical specification of the compact switch module	34
Table 4: Technical specification of PLC [14]	37
Table 5 Specification of SIMOTICS S-1FL6 Servo Motor	42

LIST OF ABBREVIATIONS

LED	Light emitting diode
AC	Alternating current
PLC	Programmable logic controller
DC	Direct current
HMI	Human machine interface
IP	Internet protocol
LAN	Local area network
SCADA	Supervisory control and data acquisition

Introduction

Industries have rapidly changed in recent decades. Automation plays a vital role in the manufacturing industry specifically where repeatability is of great issue. In today's extremely competitive industrial world, many companies endeavor to implement a cost-effective, reliable, and efficient method of production to survive. Production Process using automation can replace the manual system being used in the industry and decrease human intervention, and time delay. An example is a bottle filling unit in which bottles are shifting on the conveyor belt to be automatically detected at the predetermined location and get it filled by any chosen liquid and also after getting filled the queued bottles get a chance to be filled. In this unit after once a process starts by operator conveyor belt started to rotate and bottles being shifted on the precisely determined location and stop without further interference. In this, we can achieve step by step control of the conveyor belt with drive speed control. If this process is done manually it will need more time and also the quantities will be reduced.

Automation in the Industrial process has obtained significance because it ensures precise control of the industrial process, higher productivity, good quality standard, minimal human interventions, and optimum utilization of accessible resources and manpower. In large industrial units production process can be completely automated in which start-up and shut down of critical types of equipment done by PLC. A PLC makes sure that a machine only works when all the necessary conditions for the secure start-up of the system process are has built up and secure functioning of the process even in the unpredictable condition. PLC monitors the essential conditions for safety when the machine is in operating mode and trips whenever any abnormality takes place in the system. The use of PLCs in industrial processes reduce production cost and increases reliability and quality [1]. Such a system is monitored by skilled people and the intervenes come in the process only in case of failure. Automation of an industrial process can not possible without the PLC, HMI, Sensors, and various types of drives. The electric motor is the most commonly used prime mover in the industry. These motors consume about 30–40% of the total world power output and about 90% of the power consumed in the industry. In most applications, the electric motors are equipped with control equipment by which motor's characteristics can be controlled with respect to various load requirements. The combination of an electric motor, control device, and energy transmitting shaft form an electrical drive. The technology of electrical drives with speed

and motion control is continuously being developed to save electrical energy used in the industry. This drives convert electrical energy from the main power supply or another power source such as a battery into mechanical energy and transmit the resulting force into motion. A drive controls the speed, motion, and torque of the rotary load applications such as rolling mills, machine tools, transportation systems, robots, etc. In Automation for precision control, various types of drives are used such as servo-hydraulic and pneumatic drives, and piezoelectric drives. Nowadays in the automation system, servo drive has become an essential part to achieve motor's desire position, speed, and torque, etc. To control the position of the motor, the drive should perform rotary as well as linear movement. AC servo motors have been mainly used for such purpose due to its highly efficient motion control property [2]. Induction motor, Permanent-magnet synchronous motor, dc brushless motor, and switched reluctance motor are included in the ac servo family. Due to advancements in magnetic materials such as rare earth magnets and semiconductor power devices, Permanent magnet synchronous motors (PMSMs) are increasingly used in drive systems required in the industrial automation process where accurate motion control is needed for, and tracking accuracy should be accurate even with dynamic load conditions. PMSMs have many advantages compare to asynchronous and synchronous motors, such as high torque, power density, better dynamic performance, no need for excitation, low rotor loss, high power factor [3]. These advantages make PMMS suitable for high-performance drives used in robotics and automated machine tools [4].

2 Programmable logic controller overview

A programmable logic controller (PLC) can perform complex control functions of many types. Between 1965 to 1970 first commercial PLC was developed and its use covered automotive industry assembly lines, chemical plants, jet engines industry. Today PLCs are used in various applications and industries such as conveyors system, robotics industry, manufacturing, and process control plants. This chapter is intended as a short introduction to the field of PLC and its development over the past 50 years, hardware architectures, and the advantages from its use compare to other options for process control.

2.1 Relay based system and need of PLC

In the old days, the machinery was only controlled by only relays. A relay is an electromagnetic switch with a coil and a set of connected contacts, which can be either NC (normally closed) or NO (normally open). When a voltage is applied to the coil, the coil creates an electromagnetic field. This field generates a force that pulls the contacts of the relay, causing them to open or close the controlled external circuit connection[khaled]. So, for example, to control the supply of motor relay used to connect between motor and supply source. There were so many motors and ON/OFF power switches in the factory that were required to control. To control all these there were many electrical control panels each filled with lots of wire and relays, motor controls, and so on. To control properly all these relays had to be wired in a specific way because the control logic to run the process (system) was reliant on how all of the relays and devices were wired. The whole system wiring would have to be changed to change the installed process. This was costly and undesirable. In the case of failure, the process (system) would have to be shut down and technicians would have to troubleshoot all of the wired relays. There was also very costly and time-consuming.[sten]

The PLCs made it possible to eliminate repetitive hardwiring related with the old relay-based control system, and also have made it possible to wired relay and devices single time and just change the program to change how the process operated. To create logic, timing, and counting function PLC programming is used. PLC-based systems require less space and inexpensive compares to the equivalent old relay-based systems. Relays are still used in modern control systems, but rarely used for logic [6].

2.2 History of plc

Just a couple of decades back (the time before the PLCs), all industrial production and process control, and automated equipment relied on inflexible and expensive electromechanical relays, coils, and contacts based hardwired logic circuits on panels. It was difficult, costly, and labor-intensive to modify the relay-based logic control system because of that system required to be rewired by skilled technicians to do moderately changes to the control systems. And due to this reason between 1965 – 1970, a requirement to structure more dependable and more flexible control systems became evident.

General Motors was among the first to recognize a need to replace hard-wired relay control systems. In 1968, GM's Hydromantic division developed the specifications of the design criteria for the “standard machine controller” and circulated in the market that could replace the hard-wired relay system.[5] This proposal model just had to replace the relay-based system but it also had to be:

- The device had to work in an industrial harsh environment (dirt, humidity, vibration, electromagnetism, etc.). So the device must be durable.
- The device must be easily maintained and designed to use a programming language in the ladder diagram form already known to technicians and electricians.
- The device had to be flexible and modular by implementing circuit (components) modifications and expandability easily with a change in software.
- The device input and output terminal was designed in such a way that skilled technicians or electricians could easily connect field wiring.
- The new solid-state system had to be flexible as a computer and priced competitively with the relay logic system[5].

This proposal first successfully achieved by Bedford Associates of Bedford, Massachusetts. They made a first PLC named the “084” – a number related to the company's eighty-fourth project on January 1, 1969 [6]. The credit went to the Richard (Dick) Morley for the development of the first PLC. He worked for Bedford Associates. Then Bedford Associates started a new company for this new (084) product: Modicon (Modular Digital Controllers). In 1977 The Modicon was sold to Gould Electronics and later to Schneider Electric, the current owner.[6]. The first PLC could able to do start/stop control only. The operations included start/stop control of devices and industrial

processes for repetitive operations. However, the 084 controller was far better than the relays. It was easily installed with less space and energy, had a diagnostic function that aided troubleshooting which was not in a relay-based system.

Later on, capabilities and features of plc were improved with the advancement in microprocessor technology and software programming techniques. Advancements made the PLC able to perform such applications like more complex motion and process control and with high speed. Presently, there are so many manufacturers produce PLCs, Table 1. Many companies make several PLCs models that vary in size, cost, and needs of particular applications.

Sr. No	Manufacturer	Sr. No	Manufacturer
1	Siemens	8	Panasonic
2	ABB	9	Idec
3	Schneider (Modicon)	10	Keyence
4	Rockwell (Allen-Bradley)	11	Toshiba
5	Mitsubishi	12	Koyo
6	GE-Fanuc	13	Beckhoff
7	Omron	14	Bosch Rexroth

2.2.1 PLC Development

The first PLC was able to work with input and output signals, relay coil/contact internal logic, timers, and counters. Then PLC continued to develop with the features one-shots, analog input, and output signals, improved timers, and counters, mathematic functions, PID (Proportional-Integral-Derivative) functionality. Within the development of functionality of the PLC, programming devices and communications also saw rapid growth. The first programming devices were big. Later, small programming devices came into the market, but soon they also were replaced with programming software operating on a computer. The first windows- based PLC programming software package developed by Host engineering, named AutomationDirect’s DirectSOFT. This enabled to program PLC in computer and also allowed troubleshooting and testing quickly and easily. With the MODBUS protocol communication started using RS-232 serial communications. Later several automation protocols added to communicate with RS-485, DeviceNet, Profibus, and

other serial communication. The use of serial communications and protocols allowed PLCs to be connected with other PLCs, HMI (Human to Machine Interfaces), drives, and SCADA (Supervisory Control and Data Acquisition). Currently, EtherNet/IP (for Industrial Protocol) has gain popularity.

2.4.2 Today's PLCs

Lost of advances in the PLC industry increasing today. The below-mentioned list indicates several recent PLC improvements:

- The most popular advancement in the PLC industry is speed and memory capacity. Scan times become faster using an advanced microprocessor. Significantly reducing sizes and costs of solid-state memory have made possible PLC with enhanced memory capacity.
- More numbers of input/output (I/O) terminal provide efficient space interfaces at a reduced cost.
- Advanced interfaces have allowed several types of equipment to be networked directly to the controller. Such interfaces contain strain gauges, thermocouples, and fast-response inputs.
- Complex calculations in various control applications that require balancing, gauging, and statistical calculations are possible due to floating-point math.
- Communication with other control systems, production reports, and diagonalization of their own failures and process failure is also possible because of advancement in PLC.

These improvements have made PLCs in meeting today's demands for higher quality and productivity.[5]

2.3 Programable Logic Controller

Programmable Logic Controllers (PLCs) are generally explained as miniature industrial computers which comprise software, hardware, and integrated microprocessor unit has its own operating system used to carry out various industrial control functions (automatic tasks). PLCs are designed with digital and analog inputs and outputs with suitable to industrial environment temperature ranges, electrical noise, and vibration proofing to be able to respond to the states of the controlled process. PLC receives input from the plant/machine via sensors and transmitters and continuously

monitors the state of input devices, then evaluates those inputs to execute the logic programmed in its memory and generates useful outputs, to control the state of devices connected as outputs (i.e. actuators and final control devices). In PLC there are different types of input peripherals. One type is an analog input if the signal (i.e. temperature, pressure, or another quantity expressible in a continuous measuring interval) supplied to the inputs is continuous via analog sensor or transmitters. Another type is digital input if the discontinuous signal (i.e. two states: on / off) is fed to the inputs of the controller via limit switches, safety buttons, and similar elements which can generate a discontinuous signal. The digital output peripherals take on / off states as the output such as a motor contactor, lights, and solenoid valves. The analog output peripherals take a value as a varying control signal from a specific interval, such as drive speed control, panel meters, and analog flow valves. The solution performed by PLC is an example of a real-time system since input devices of the PLC are sampled and according to that input image table is updated in real-time. In PLC input instruction in the form of the ladder programming language or computer's software instruction are decoded in CPU. The loaded program in the PLC memory resolves predefined logic and updates the status of the output logic table so that output devices are operated in real-time corresponding to the updated output table values [7]. To perform a real-time solution, response to input condition must be produced as an output result within a bounded time.

2.3.1 Working Principle OF PLC (PLC Scan cycle)

In the PLC all system activity control by CPU through its processor and memory system. The CPU comprises a microprocessor, chip for the memory and other integrated circuits to control logic, monitoring, and communications. The CPU performs various roles. During programming mode, the CPU modifies the logic according to the downloaded logic from a PC. In run mode, CPU executes the downloaded program and run the process. Data from the field devices is processed, and then the CPU performs the stored program repeatedly. The time requires to complete one cycle through the stored program is called scan time and it is in the range of 1/1000th of a second, depending on your program. The input/output peripheral is physically connected to field devices and it enables the interface of input and output devices with the CPU. One scan cycle contains four steps that are continuously taking place in a repetitive loop.

- **Input Scan:** Detects the state of all input devices that are connected to the PLC in Input image register (IIR).

- **Program Scan:** Executes the user-created program instructions in sequence (left to the right - top to bottom for ladder logic).
- **Output Scan:** Output Image Register (OIR) is updated appropriately and PLC transfers the data related with OIR to physical output terminals to operate all output devices. This will change the physical position of output devices located in the plant/machine.
- **Housekeeping:** PLC communicates with programming devices and performs internal diagnostics. PLC makes sure that the system (the program memory, firmware, and expansion modules) is working properly. It also updates internal special memory registers.

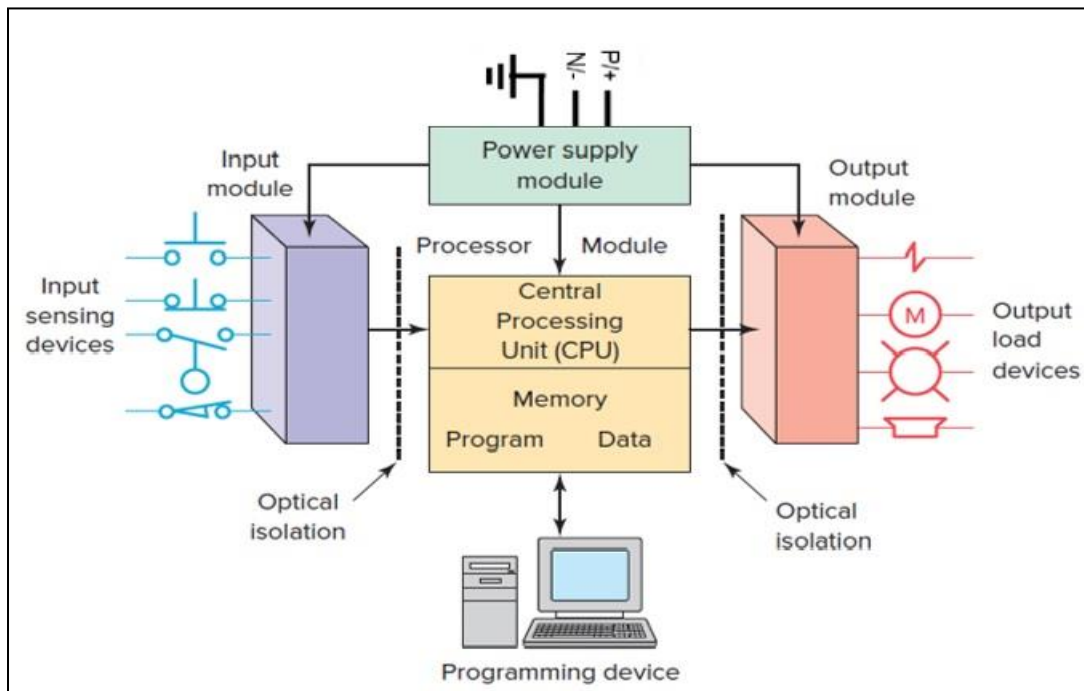


Figure 1: block diagram of PLC [6]

A PLC is a specialized industrial computer. It contains mainly all the basic computer components such as the Central Processing Unit, Memory, power supply, programming device, and input/output interfacing module. It also contains software simulated, vast numbers of separate relays, counters, timers, and data storage units[8]. PLC architecture is a combination of hardware and software.

2.3.1.1 CPU

The processor (CPU) is the heart of the PLC. The processor generally specified according to the memory required. One-bit processor PLCs are enough for dealing with logic operations. PLCs with Word processors are required to deal with calculation, controlling and recording, processing text and numerical data, and the simple processing of signals in binary code. The processor consists of the microprocessor, system memory, serial communication ports for printer, and in some cases, power supply to supply power the processor and I/O modules can be included in the CPU unit or maybe a separately mounted unit. In a PLC typical scan starts with the CPU reading the status of inputs (sensing devices). Then, it executes the user program commands from memory. After the completion of execution is, the status of all outputs is updated. After that CPU carry out internal diagnostic and communication tasks. As long as the PLC is in the run mode this process is repeated continually.[6]

2.3.1.2 Power Supply

Modules that plug into the rack of the PLC get a DC supply from the power supply. In a small PLC system, the power supply also supplies the power to field devices. In large PLC systems, this power supply does not supply power to the field devices, but External alternating current or direct current supplies power to field devices. The primary source of power for the PLC is the main power supply. With this main power supply, there is usually a battery backup as well. This battery backup will provide power to the memory of the PLC in case of a supply failure [6]

2.3.1.3 Programming Device:

A programming device is a key peripheral in a PLC system used to write a program. The two basic types of programming devices are a handheld device and a personal computer [6]. Hand-held programming devices are compact, inexpensive, and used to program small PLCs. They must be plugged into a PLC to be used to write and monitor programs. They can be used easily for troubleshooting equipment, monitor the status of inputs and outputs, modifying programs, and transferring programs to multiple machines onto the factory floor which eliminate the requirement

of a personal computer at the factory floor[jon ste]. They cannot display all logic on the screen show. They can display only two to four rungs of logic [6].

Personal computers are widely used as a programming device in conjunction with the PLC manufacturer's programming software. The Personal Computer with appropriate PLC programming software offers offline simulation, online (real-time) program monitoring, documentation, and troubleshooting the controlled system. Users can test a program before physical hardware installation[jon sten]. The PLC processor can be connected with the personal computer via a serial or parallel data communications link, or Ethernet. The PC can display one or more ladder rungs (logic) of the control program on the screen during programming or testing [6]. Programming devices do not need to be plugged to the PLC if the programming device is not in use.

2.3.1.4 Memory

The memory system located in the CPU of PLC. Memory is used to stored sequences of the programs, and addressable memory locations for storage of data. During the writing, process data are stored in memory with appropriate location and while during reading process data retrieved from memory. In Memory location, a binary word can be stored. A word generally consists of 8 bits, 16 bits, and 32 bits which depend on the manufacturer of PLC. The part of data (information) stored separately as bits (in the binary numbering format 1 or 0) in memory elements of PLC. Eight bits make up one byte. The amount of memory required is determined by the complexity and structure of the program. The size of memory specified in terms of increments of K units, where 1K unit represents 1024 bytes (word) of storage location, 2K includes 2048 location, 4k contains 4096 location, and so on. [5]. In general PLC memory system is composed of two memories such as system memory and user memory. The system memory is a read-only memory (ROM) that provides permanent storage for the operating system and fixed data used by the CPU. By the manufacturer of PLC, the operating system is installed in ROM as system memory. This memory controls the system software which is used by the user to program the PLC [6]. This part of the memory is not available for the user to modify. The user memory is a random access memory (RAM) that gives storage for the user's program data. User memory is used to store the status of inputs and outputs, addresses that would be set aside for input and output addresses, values of

timers and counters, and other internal devices[8]. Users can change the programs and data stored in user memory. RAM is generally kept with a battery so that a loaded program is not lost when the system power supply is switched off. Latest PLC includes Electrically Erasable Programmable Read-Only Memory (EEPROM) which does not require a battery[9].

2.3.1.5 Input / output unit

In plc two types of The input and output (I/O) interface used: fixed or modular. The fixed type is associated with typical small or micro PLCs that come in one package with no separate, removable units. The number of I/O connections is fixed within each I/O terminals and cannot be changed.

In The modular type, there is a rack to hold the I/O modules so the Modular I/O is separated by compartments in to which number and type of I/O modules can be varied. When a module attached to the rack, it makes an electrical connection with a series of contacts called the internal data bus also called a backplane, installed at the rear of the rack. The processor of PLC is also connected to the backplane and can communicate with all the modules in the rack [6]. The I/O section of a PLC provides the interface between field devices and the CPU. Input interface modules receive signals from the machine or process devices and convert them into appropriate signals that can be used by the controller [10]. Output interface modules convert controller signals into external signals used to control the machine or process. Input and output modules mainly classified as analog and discrete.

2.3.1.6 Discrete I/O modules

This is the most common type of I/O interface. **Digital signals** have only two states—ON and OFF. Discrete I/O provides the PLC with ON/OFF control. They operate on both AC and DC voltage ran and they provide the PLC with ON/OFF, yes/no, true/false indication, and allow only ON or OFF responses. The input signals are provided by devices such as proximity switches, pushbuttons, float switches, etc. output signal controls the devices that require simple on/off switching such as lights, relays, solenoids, and motor starters. Discrete I/O module gets a high current supply by user-supplied power, which is required for a load of on output module. And for proper operation modules get power for its electronic circuit board from the backplane of the rack into which they are plugged. These power supplies for modules typically varied such as 3 A, 4 A, 12 A, or 16 A, which depending on the number of modules and its type.

2.3.1.6.1 Input module

Figure 2 shows the block diagram for one input circuit of an AC discrete input module, which is composed of two basic parts: the power and logic section. Internally PIC usually operates at 5v DC and the field devices such as solenoids, motor starters, limit switches, etc. are operating at voltage up to 110 V AC [11]. The combination of these two types of voltages can cause damage to the PLC components due to the voltage spike.

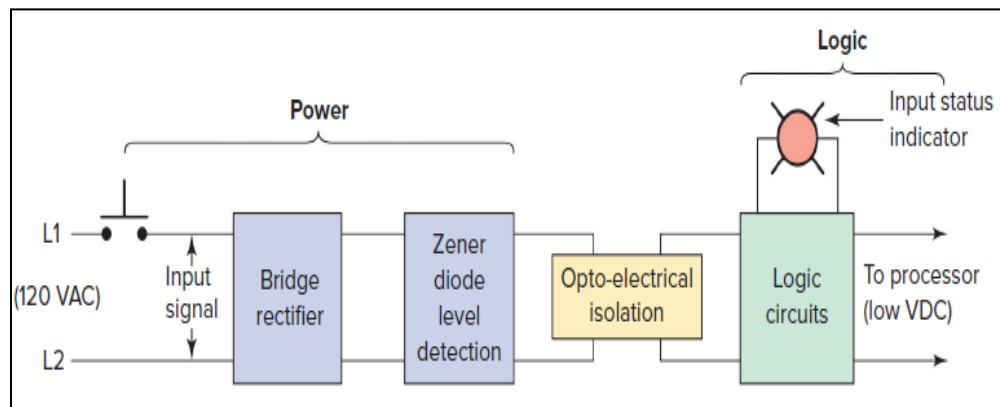


Figure 2: Discrete AC input module block diagram [6]

To avoid this, an optical isolator is used with I/O module to provide electrical isolation between the incoming field signal from the processor [12]. Digital signal processed by the logic circuits to the processor. Figure 3 shows the simplified diagram for a single input of a discrete AC input module [6]. If the push-button is pushed, the bridge rectifier receives 120V AC. Then bridge rectifier supply low-level DC to LED of the optical isolator.

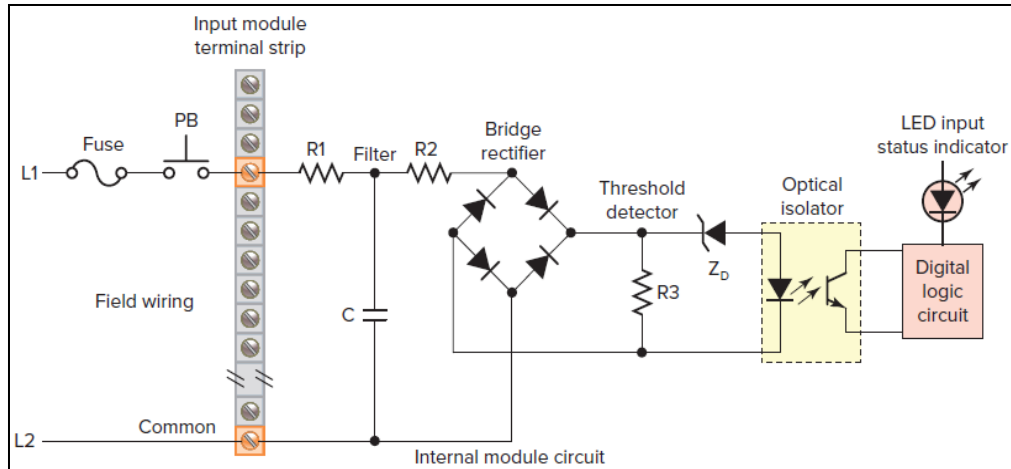


Figure 3: Simplified diagram for a single input of a discrete AC input module [6]

To set the minimum threshold level of voltage Zener diode (ZD) is used. Phototransistor switches into conduction, when it strikes by LED, the pushbutton status communicated in logic to the processor [6].

2.3.1.6.2 Output module

Figure 4 shows the block diagram for one output of a discrete output module. It also has two basic parts: the power and logic section, which are coupled by an isolation circuit. Output modules give the line isolation between the processor and the external field devices.

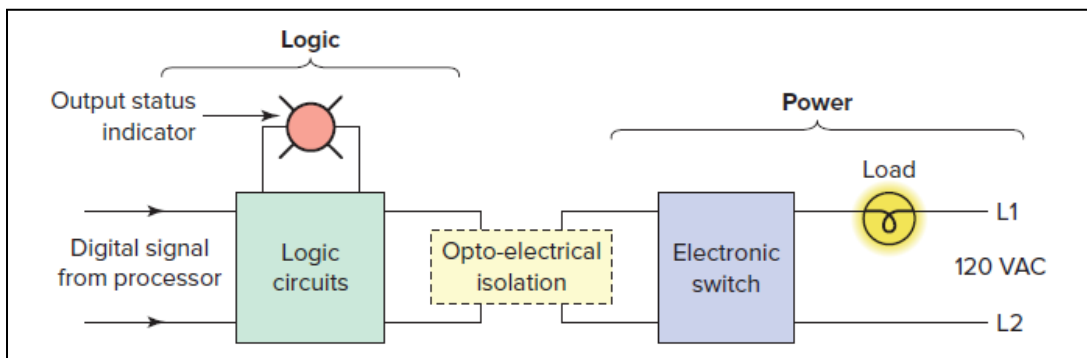


Figure 4: Discrete AC output module block diagram.[6]

The output interface turns the output load device on or off. Output status determines by a logic circuit. Status of an output signal indicates by LED. The figure 5 shows a clarified diagram of the module. In this, the processor controls a light-emitting diode to signal a solid-state device to

connect the load to the line [12]. If the load is operated by direct current, a transistor output is used to control DC field devices. If the load is operated by alternating current, a triac output is used to control AC devices [6].

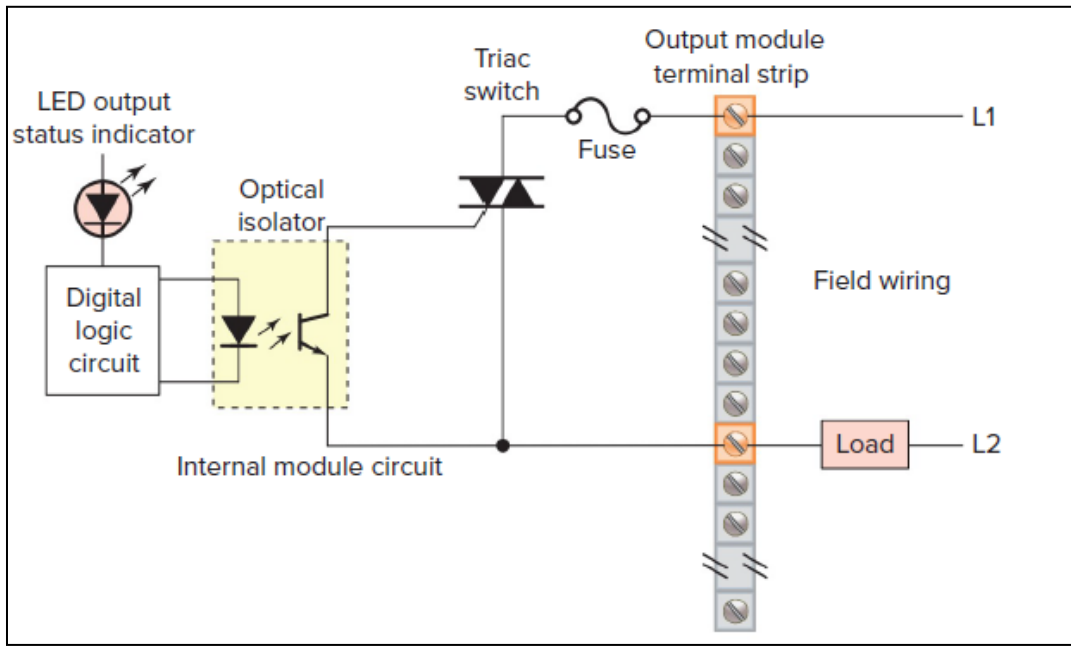


Figure 5: Simplified diagram for a single output of a discrete AC [6]

2.3.1.7 Analog I/O modules

Analog I/O modules ranges vary from 0 to 20 mA, 4 to 20 mA, or 0 to 10 V. There are voltage sensing and current sensing Analog I/O modules. Analog input modules allow 4, 8, or 16 devices to be interface with the PLC. Modules have a switch to choose a type of input whether current or voltage input. A varying physical quantity such as temperature, speed, level, flow, weight, pressure, and position over a specific range measured by analog sensors and generate electrical (voltage or current) signal corresponding to the measured physical quantity. For example, the analog sensor may measure level over a range of 0 to 100 m, and output a corresponding voltage signal that varies between 0 and 20 mV. One main factor is the resolution of an analog module. The accuracy of the input measurement or output response is high with a higher resolution. The resolution of an analog module defines as the smallest change in the value of the input signal that can be sensed.

Shielded twisted pair cable is normally used for wiring analog input signals because of the low voltage level of the signal. The analog output signal of the field devices is usually connected to

transmitters via a transducer. A Transducer converts a variable signal into a low-level electrical signal. This low-level signal is amplified by a transmitter. Then the transmitter sends that analog signal to the analog module, as shown in figure 6.

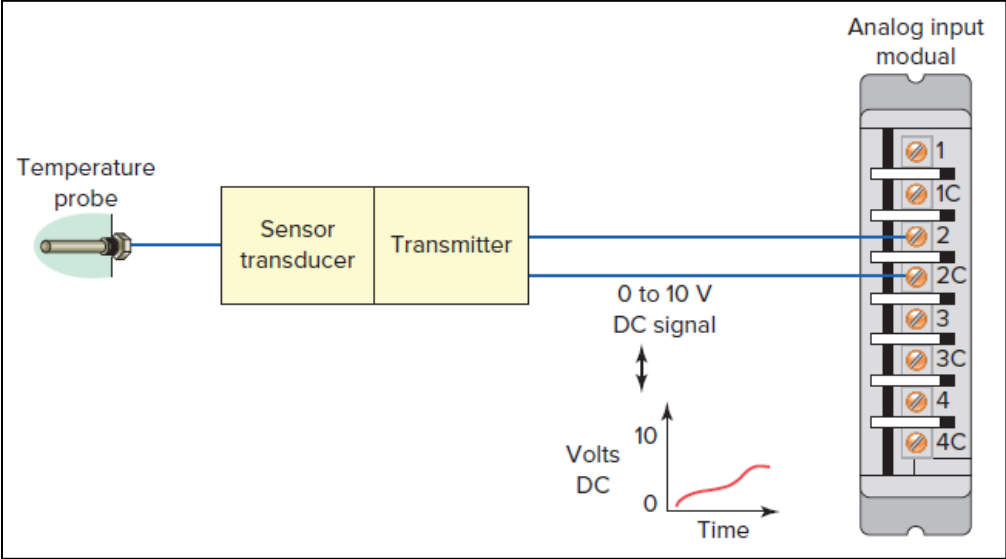


Figure 6: Analog input module circuit [6]

The analog output interface module receives digital data from the processor, which are converted into analog voltage or current by a digital-to-analog (D/A) converter to control analog field devices that respond to analog signals such as instruments, control valves, chart recorder, electronic drives. Analog output ranges vary from -5 to 5 V, -10 to 10 V, 0 to 5 V, 0 to 10 V, 4 to 20 mA, or 0 to 20 mA. The figure 7 shows the application analog I/O modules in a PLC control system. In this application by controlling the valve opening, PLC controls the amount of fluid-filled in the tank.

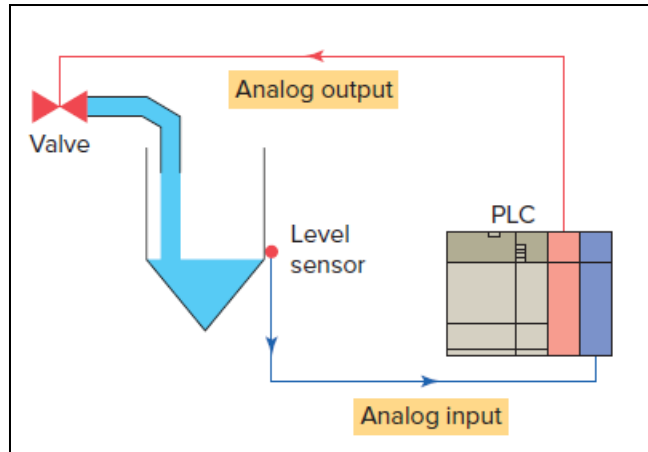


Figure 7 Typical analog I/O control system [6]

PLC used analog output from the processor to control the valve. When the level of fluid reaches the preset point in the tank, As the fluid level, the processor changes the state of output which adjusts the valve position to maintain a set point of the fluid in the tank. [6]

2.4 Programing Language of PLC

PLC programming language is a method by which the user can communicate to the PLC. According to the standard IEC 61131, various languages are used in PLC programming as shown in figure 8.

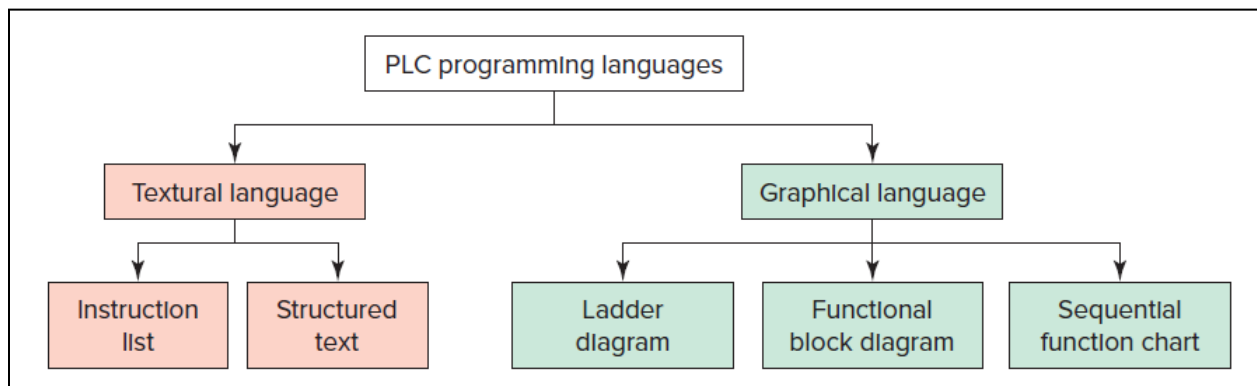


Figure 8: Standard IEC 61131 languages associated with PLC programming [6]

2.4.1 Ladder Diagram (LD):

Ladder diagram is a symbolic representation of instructions arranged in rungs similar to ladder formatted schematic diagrams of the old relay system.

Ladder diagram language is the most commonly used to define control actions with the relay contacts and coils, and other functions as block instructions. A ladder diagram program would look like an electric circuit because of symbols in a diagram that looks similar to schematic symbols of electric devices. It consists of two vertical lines represent the power rails (power supply), and horizontal lines are the rungs of the ladder and connecting the power rails. The circuits are connected between the power rails.

In a ladder diagram for a logic continuity, power must flow from the left side verticle across a rung. The instruction of logic can be divided into input and output instructions. There starting of rung must be with input or inputs (control action) such as opening or closing the contacts of switch and the end must be with at least one output such as a contactor coil of the motor [13]. Devices at rungs are indicated as their normal condition. Normally open contact switch that is shown as open and normally closed contact is shown closed on the ladder diagram. Figure 9 shows the ladder diagram. Starting with the input as a normally open contact of START push button and a normally closed contact of STOP pushbutton. Rung terminates with the output (relay coil), denoted by the symbol (). The ON contact (used for latching purpose) is the contact of the output relay coil.

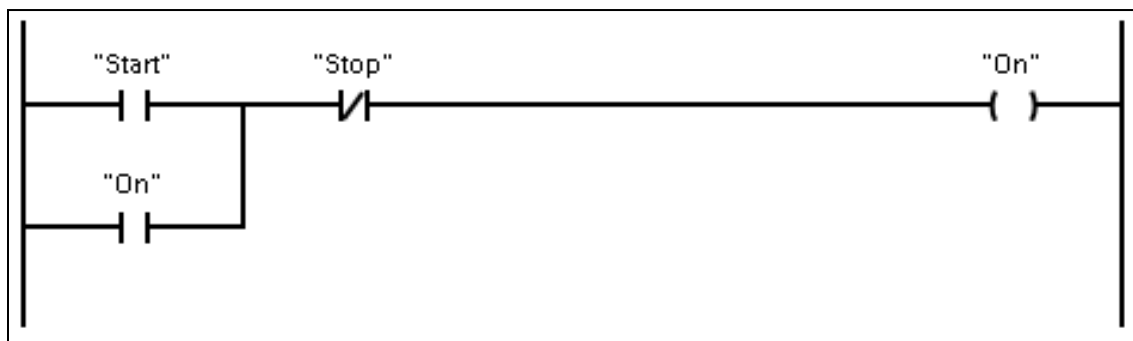


Figure 9: Ladder logic diagram

When the contact of the input START button close, there is an output. However, the ON contact associated with the output coil becomes close because of the energized output relay coil. These ON contact make an OR logic gate system with the input START contact. Thus, even if the input

START button opens, the circuit remains closed and maintains the output energized. After a pressing of the STOP button output will de-energized and the circuit becomes open. [8]

2.4.2 Function Block Diagram (FBD):

The function block diagram is explained as a graphical language for the depiction of process flow and data through simple and complex interconnecting blocks on-screen to achieve a particular function. This type of programming is mainly used in process control applications where extensive data handling and calculations are required[steners].

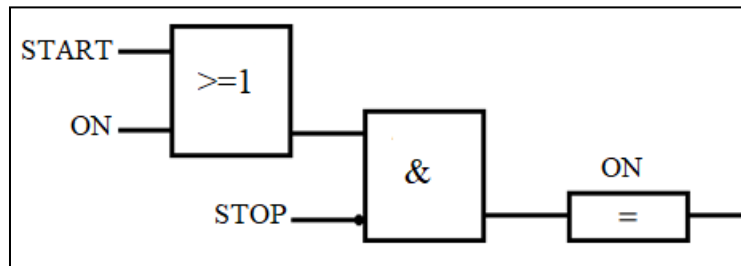


Figure 10: Function block diagram

There are many types of reusable blocks are available as software elements to perform various tasks such as counters, timers, and logic. A function block performs an operation (makes a decision or calculation) on one or more input values and produces one or more output values. Data flow is from the left (inputs), through the block, and the to outputs[terry]. Figure 10 shows the function of the block diagram of the same application as described in the ladder diagram.[14]

2.4.3 Structured Text (ST):

The structured text programming method is high-level, a textual programming language similar to BASIC, C, or PASCAL with statements (commands) used to evaluate complex mathematical operation that other graphical languages could not express easily [6]. This method is more suitable for an advanced user because this language is not easy to monitor and troubleshoot [15]. For a particular application, a structured text program would be short compare to the ladder logic program[13]. In a structured text programming language, the program contains a series of statements in the form of assignments, expressions, instructions, constructs, and comments. This programming language is case sensitive and with the use of tabs and carriage returns, the program becomes easier to read. We can add comments related to the instruction in the program to describe

how it works, which will make a program easier to understand by someone else and later editing[15]. The structured text for the same application as a ladder diagram is as follows:

```
ON := (START AND NOT STOP)
      OR ON_2
IF START AND NOT STOP THEN
  ON := 1;
ELSEIF ON_2 THEN
  ON := 1;
END_IF;
```

3 Communication Networks:

Due to the complexity of today's control system, Various communication schemes require to integrate system components. It is necessary to exchange information between PLCs, I/O devices, human-machine interfaces (HMIs), and information technology (IT) in the communication network of the system. Fieldbus is used to recognize industrial networks. This network contains a different level. A simple field bus consists generally of four levels.

Level 1: sensor bus network

Level 2: Device bus network

Level 3: Control bus network

Level 4: Enterprise-level network or information level network.

3.1 Sensor Bus Network

This is the lowest level of the communication network's lowest level. within sensor bus networks field devices (proximity switches, pushbuttons, float switches, level optical sensors) that produce input signals to a PLC, are connected to one network cable. This network also transfers output signals from a controller over one cable to an actuator device. Field devices on a sensor bus network are connected to an I/O interface device, which is electrically connected to the bus and can control four input or output at one time. Generally, for the sensor bus network, AS-I (actuator–sensor interface) is used [16].

3.2 Device Bus Network

Device buses supply power to equipment and can control of discrete field devices over a single cable. This can control large numbers of sensors and actuators. Motor-control centers and Variable-speed drives are connected to them to control individual elements. Profibus-DP and DeviceNet are the most used device bus network.

3.3 Control Bus Network

At control bus network high-level data communication happens. It enables The PLCs to communicate with one another alongside HMI(Human Machine Interface) for the complete control of the network. On this network various types of information such as the position of

actuators, analog measurements can be exchanged, and communication is also provided for closed loops function. related to closed -loops with on-off and PID function. Profibus-PA, Profibus-DP, ControlNet are some of the examples for the control bus network.

3.4 Enterprise Networks

This is the highest level network that is driven by computers and collects the information from its lower level to handle vast amounts of information. At this level industrial Ethernet TCP/IP is commonly used.

In today's world at the field level, Fieldbus technology is the advanced communication network. Fieldbus technology provides distributed control between the field devices and PLC with a bidirectional communication system. According to the above networks, many types of Fieldbuses are available. such as Profibus, PROFINET, DeviceNet, ControlNet, As-I, Modbus, CANbus, and ethernet are used depends on the type of industry. These are the open communication protocol that enabled devices from different manufactures to communicate together. The protocol is a standard that specifies the format of digital data, data transmissions method. Some of these protocols which is mainly used with Siemens PLCs are discussed below.

3.5 Profibus:

Profibus define as a combination of two different word PROcess and FIeldBUS. It is widely operated as an open communication protocol in process and factory automation to provide networking of process devices. profibus is mainly based on the master-slave communication concept. In this concept master device on the network is in command and other devices (field devices) on the network are slaves. In the Profibus system, communication occurs between a master device such as controller and slave devices such as control valves, remote I/O devices, drives, and transmitters. Profibus comprises different industrial versions of itself namely, Profibus-DP (Decentralized Periphery), Profibus-PA (Process Automation), and Profibus-FMS (Fieldbus Message Specification).

PROFIBUS DP is used at a device-level and can control analog and discrete signals. Profibus-DP communicates over various physical layers such as RS-485, wireless, and fiber optics. The most common physical layer is RS-485 because it can transmit data at high speed such as from 9.6 Kbps to 12 Mbps with the proportional distances up to 100 to 1200 meters. For PROFIBUS DP mostly

DB-9 9-pin connector is used. Profibus-PA is mainly used for process automation and recommended to use in intrinsically safe areas. PROFIBUS PA is connected with the Manchester encoded Bus Powered (MBP) physical layer with twisted shielded pairs for both power and data communication. It can transmit data at 31.25 Kbps with a maximum length of 1900 meters.

3.6 Profinet:

ProfiNet provides industrial communications across Ethernet networks that have TCP/IP protocol and IP services based on the IEEE802.3 Ethernet standard. It uses the existing standards TCP, UDP, and IP protocol similar to Ethernet. The difference is that it takes place in real-time. The performance is comparable to the Profibus DP network and works at a speed of 100 Mbit / s for cable lengths up to 100m per segment. The response time of Profinet is less than 1 millisecond. PROFINET uses 4-core with two twisted pairs and an overall screen or shield cable and industrial-grade connectors such as RJ45 and M12. Only two devices can connect with one Ethernet cable. Ethernet Switches are used to make a branch connection from the device to the device. PROFINET devices required a device name to access by Profinet. The device name allocated by the user concerned to the device's function or its location. ProfiNet IO class is used to exchange data between the control system and IO devices with RT (Real-Time) and IRT (Isochronous Real-Time) requirements. ProfiNet CBA (component-based automation) class can communicate among controllers.

3.7 Ethernet:

Industrial Ethernet protocols such as PROFINET is based on the local area network (LAN) concept to ensure the exchange of specific manufacturing data correctly and on time to perform a specific task. A LAN is a collection of several computers and associated devices connected over a network in the same localized area. For the communication in LAN network various types of networking techniques are used such as Ethernet, Token Ring, Token Bus but Ethernet technology is mostly used for LAN. As a hardware medium in the communication of various devices in one network (LAN) Ethernet is used. Ethernet is used For Wiring in LANs is done by Ethernet which is based on IEEE 802.3 Ethernet standard. Ethernet implements the physical and data link layer in the Open Systems Interconnection (OSI) model of the network. In Current ethernet technology as a physical layer, two optical fibers use to allow full-duplex communication. Optical fiber cable that connects devices up to 10km distance with 100mbps to 1gbps transmission speed. Data link layer further

has two sublayers such as logical link control (LLC) and Media Access Control (MAC). LLC provides a logical dataflow control between the specific device and MAC provides LAN station addressing to identify each node according to the node's network interface cards (NICs) for accurate function [17]. The latest technology involves wireless Ethernet which involves radion frequency and infrared communication. In motion control application wireless Ethernet can be used to reach a particular hazard area of the network where some condition prevents cables to be used [18].

4 Sensors:

In industrial automation, various types of sensors are used for the detection of the presence of an object and measurement of the magnitude of something. They convert physical quantity variation into electric voltage and current signals which are capable of being handled by the controller and automation system. Sensors are usually classified according to their function. In motion control applications, mostly position sensors and speed/velocity sensors have used. An overview of some common sensors is covered in this topic.

4.1 Optical Encoder:

In the automation industry, an optical encoder is used to observe the position, direction of rotation, velocity, and speed of a rotary or linear operating system. An optical encoder consists mainly of four components: a light detector (sensor), light source, an optical disk, and electronic signal conditioning circuitry as shown in figure 11.

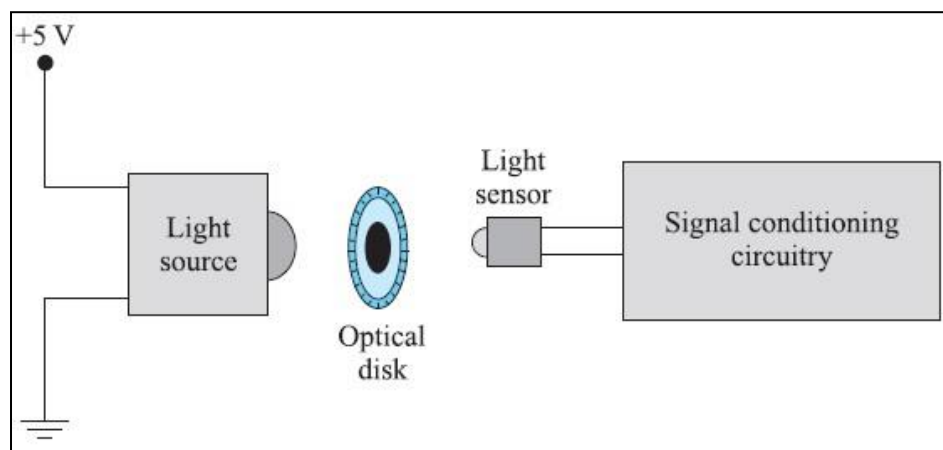


Figure 11: The main components of an optical encoder [16]

LED (light-emitting diode) is usually used as a light source. The light sensor is a phototransistor which detects the light transmitted by the LED. The optical disk is connected to the shaft of the rotating mechanism being measured and placed between the source of the light and sensor as shown in figure 12.

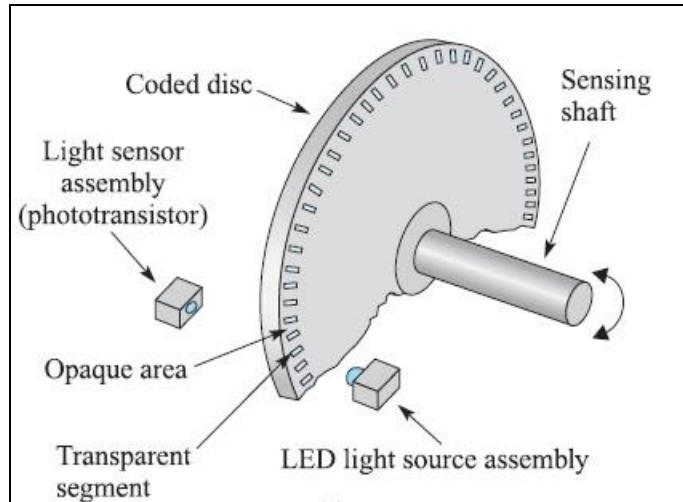


Figure 12: Arrangement of components of the encoder [16]

The optical disc has printed opaque and transparent regions. As the disk rotates along with the rotating shaft, the transparent part of the optical disk passes the light, and the opaque part of the disk blocks the light.

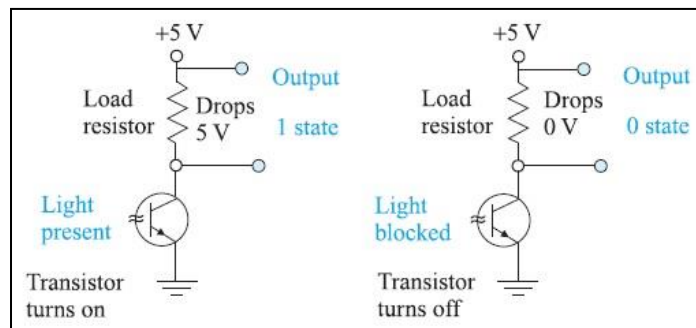


Figure 13: Working of the optical encoder [16]

Figure 13 shows that the phototransistor (light sensor) conducts only when the light passes from the transparent segment and strikes the base of the phototransistor. When the sensor conducts, the voltage at the sensor output goes high. When light is blocked, phototransistor (sensor) can not conduct and sensor output goes low. Schmitt triggers used in the conditioning circuit to convert phototransistor's output pulses into square waves. There are mainly two types of optical encoders are incremental encoder and absolute encoder. An incremental encoder is used to detect the changes in linear or angular displacement from some reference position. An absolute encoder is used to detect the actual angular or linear position.

4.1.1 Incremental Encoder:

Figure 14 shows an optical disk of an incremental encoder. It has three tracks of precisely imprinted lines around the outside of the disk. The number of lines is equivalent to the no of output pulses per revolution (360° revolution) of the encoder. The number of these lines determines the resolution of the encoder. The more lines on the optical disk, the higher is the resolution of the encoder. For example, if there are 400 lines on an optical disk, the encoder produces 400 electrical pulses per revolution.

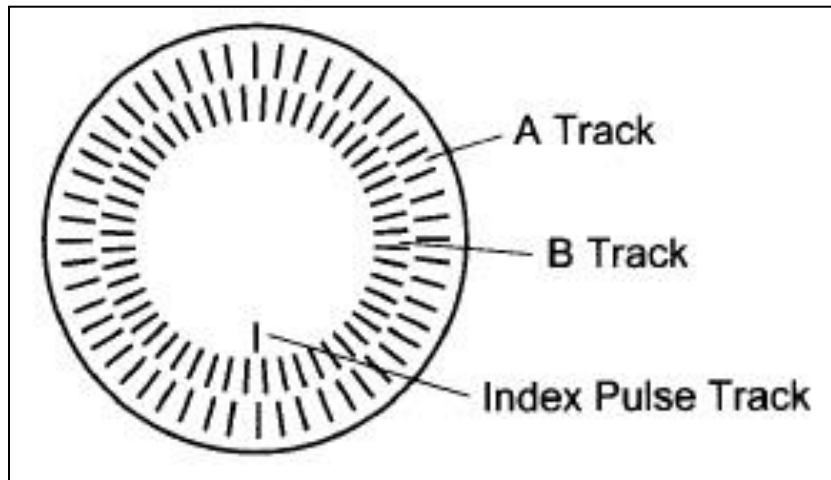


Figure 14:Optical Disc with its track [19]

The optical disc of an incremental encoder generally uses three tracks. The two tracks called the A and B track are one-quarter (90°) of cycle displaced from each other which provides pulses to indicate displacement. The third track called index pulse track is used to identify the home position. A separate (light source) and phototransistor (light sensor) are used for both the tracks A and B. Two light sensors(track A phototransistor and track B phototransistor) are aligned along the same radial line. When the encoder rotates, each track produces a continuous square wave pulses which are recorded by the counter (digital counter) circuit. Track A and track B are in quadrature.

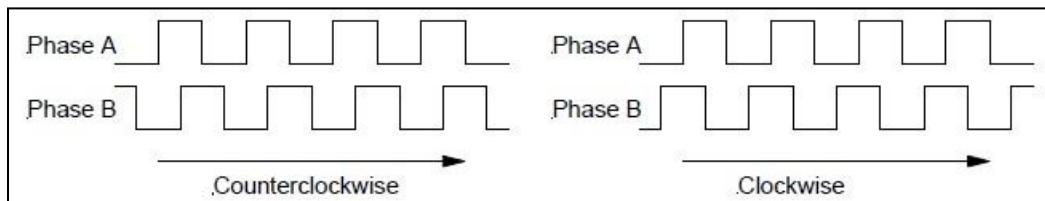


Figure 15:Incremental encoder cw and ccw waveform [19]

As a consequence of quadrature, The square wave produced from one track will lead or lag by 90° from the other track which depends on the direction of rotation. Track A square wave lags a track B squarewave when the disc rotates in a clockwise direction. Track A squarewave leads track B squarewave when the disc counterclockwise as shown in figure 15. To detect the displacement of a shaft from a reference point, a third track (index pulse track) is included in the encoder as shown in figure 16.

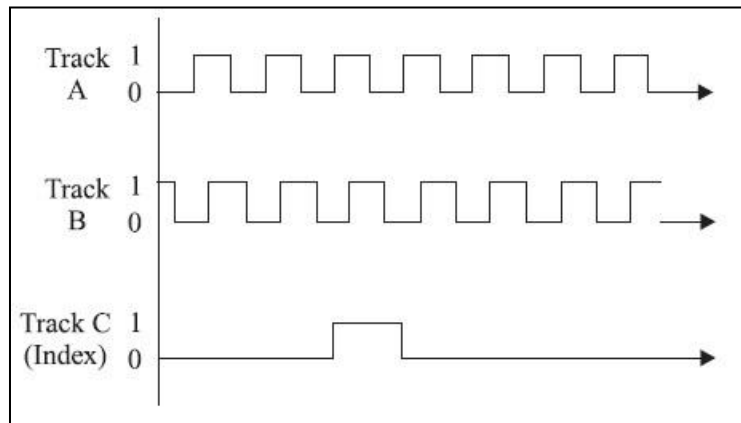


Figure 16: Quadrature output of the incremental encoder [16]

Index pulse track contains only one translucent line which produces index pulse (zero reference pulse) which is often used to search home position for an axis. This index pulse is produced once per revolution in either direction of rotation and it is also used for counting the total number of a full rotation. Pulses from tracks are given to an up-down counter or programmable controller input module. With quadrature detection, we can derive three modes called X1, X2, and X4 of the encoder's basic resolution. The X represents multiplication. The mode X1 contains only the number of off-to-on transitions pulses generated by Track A. For example, An encoder with 500 lines on the optical disc will produce 500 pulses per revolution. The mode X2 contains both the off-to-on and the on-to-off transitions of track A. Therefore, an encoder with 500 lines would have 1000 pulses per revolution. The X4 mode contains the off-to-on and on-to-off transitions pulses of both the tracks. Therefore, an encoder 500 lines would have 2000 pulse per revolution. The count of pulses gives information about the displacement from the reference point at any point. For example, the encoder produces 500 pulses per revolution. If the counter reads 100 count, the encoder has traveled 72 degrees; 150 would indicate 108 degrees; and 250 would indicate 180 degrees.

The main disadvantage of the incremental encoder is that when it is switched on, it only gives 1 or 0 as an output on its both track. This output does not provide information about the initial angular position of the shaft. This thing also happens in case of an interruption in the power of counter. It only gives the relative position information, with the wrong reference position being the angle of the shaft when the encoder was energized before. To get information for an absolute position, the encoder shaft must be homed after it is on or once power is restored in case of interruption of power. This could be done by index pulse which provides one pulse per revolution.

4.1.2 Absolute Encoder

In incremental encoder homing must be completed after the encoder switched on to know the position of an axis. But in an absolute encoder, the absolute position of the encoder shaft can be known when it switched on. In this absolute encoder, there is no need to do homing to get information absolute position. Figure 17 shows an optical disk of an absolute optical encoder. It has four distinct and concentric tracks that specified with a power of 2 (numerical weightage 2^n) and vary in size such as bigger at the center and become smaller at the outside edge. The tracks form a circular shape section with special code patterns. These sections indicate a particular position according to its code pattern. In the absolute encoder, there is individual phototransistor and light source are aligned with each track to derive the code. As the disk rotated with the shaft, the phototransistor produces parallel output in n bit (where n indicate the resolution of the encoder) pure binary pattern that is imprinted into the disk of encoder that shows the absolute position of the shaft. For example, one revolution of 4-bit (4 tracks) encoder disk produces sixteen different binary patterns from 0000 to 1111. Each of the 16 (2^4) patterns represents an angular range of $(360^\circ) / 16 = 22.5^\circ$ on the disk. An absolute encoder resolves to define as angular range covered by each output pattern.

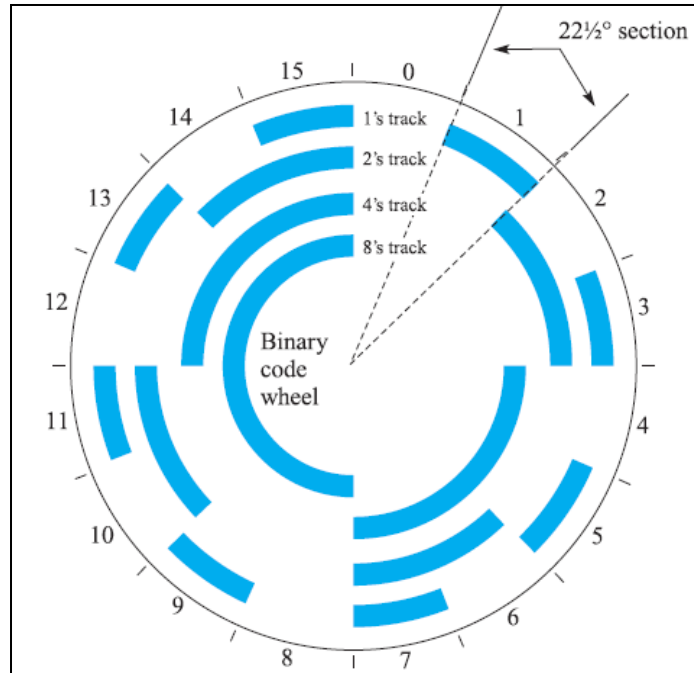


Figure 17:A 4-bit binary system absolute encoder disk

An absolute encoder with 6 to 20 bits (tracks) is common which provides resolution ranges from 5.625° to 0.00034° with 64 to 1,048,576 patterns per revolution. In the absolute encoder, one inherent problem experienced with the binary-coded disk. For example, when in 4-bit absolute encoder as the count increments from the 7th section (binary 0111) to the 8th section (binary 1000), notice that in this increment all output bits on the encoder need to change at the same time. However, due to small alignment errors between the phototransistors, all output bits may not change at the same time as increment occurs. As a result, we may read a wrong encoder position. It is difficult to manufacture a disk with sufficient precision to prevent the wrong switching times of output bits of an encoder. To solve this problem, a Gray code numbering system generally used. As shown in figure 18, the 4-bit Gray code absolute encoder has 16 (2^4) sectors. As same to binary code disk, in gray code disk also individual light sources and phototransistors are used for each of the four tracks (column).

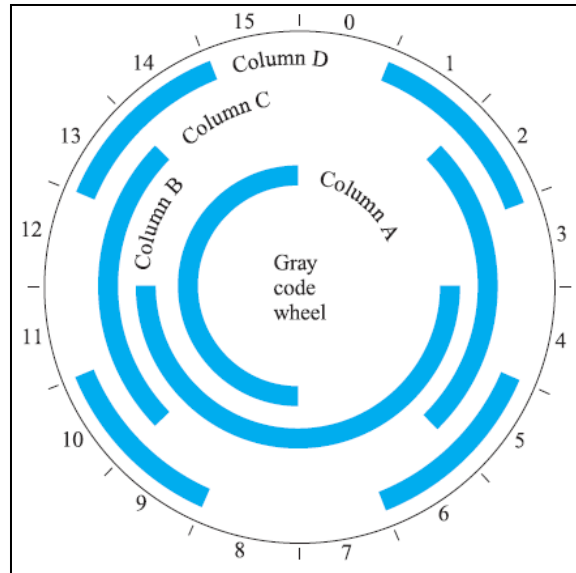


Figure 18:A 4-bit Gray code absolute encoder disk

As shown in table 1, in the Gray code system, only 1-bit changes at a time when the disk rotates from one section to the next section. This inherent feature makes this system the best choice for absolute encoder disk. Even if there is a small manufacturing defect in the precision of disk, due to only one bite change during one increment, the error would be only as one section in the position reading of encoder.

Table 1:Gray code and binary code equivalent to decimal number

Equivalent Decimal number	Gray Code according to ABCD columns	Binary number
0	0000	0000
1	0001	0001
2	0011	0010
3	0010	0011
4	0110	0100
5	0111	0101
6	0101	0110
7	0100	0111
8	1100	1000

9	1101	1001
10	1111	1010
11	1110	1011
12	1010	1100
13	1011	1101
14	1001	1110
15	1000	1111

In the absolute encoder, the absolute angle (position) of the encoder shaft can be measured by multiplying the equivalent decimal number of the binary or gray code output of the encoder times the resolution. For example, A 4-bit absolute encoder has an output of decimal number 13 equivalent to $(1101)_2$ or (Gray code: 1011). Therefore, the encoder shaft angle (position) is equal to $13 \times 22.5^\circ = 292.5^\circ$. Absolute encoders are used in applications in which homing the encoder shaft after power loss is not possible.

4.2 Proximity Sensor

Proximity sensors are discrete electronic sensors that detect the presence of various objects without physical contact. Proximity sensors work like a switch, the output turns on or off the secondary device, such as a coil of the contactor to switch large load current application. There are many types of proximity sensors are available such as an optical proximity sensor, magnetic proximity sensor, inductive and capacitive type proximity sensor. Some of them are explained in this section.

4.2.1 Optical proximity sensor

The most popular proximity sensors are optical sensors for giving a discrete output. This type of sensor uses light to detect the object's presence. The optical proximity sensor can detect mostly all types of opaque material as an object whether it is conductive, porous, or metallic. They can sense the object over long distances and in the vacuum field also. It consists of an emitter (light source) and receiver (receiving element) to detect the object. There are several methods to arrange the emitter and receiver physical position to detect the object according to the method of detection. The criteria for the particular method is depending on the detecting distances, mounting facility, characteristics of an object such as translucent, opaque, and reflectiveness. The optical proximity sensor has three types according to its working method.

4.2.1.1 Through-beam optical sensor:

This type of proximity sensor comprises emitter (light source) and receiver, each located on the opposite face of the object to be detected as shown in figure 19.

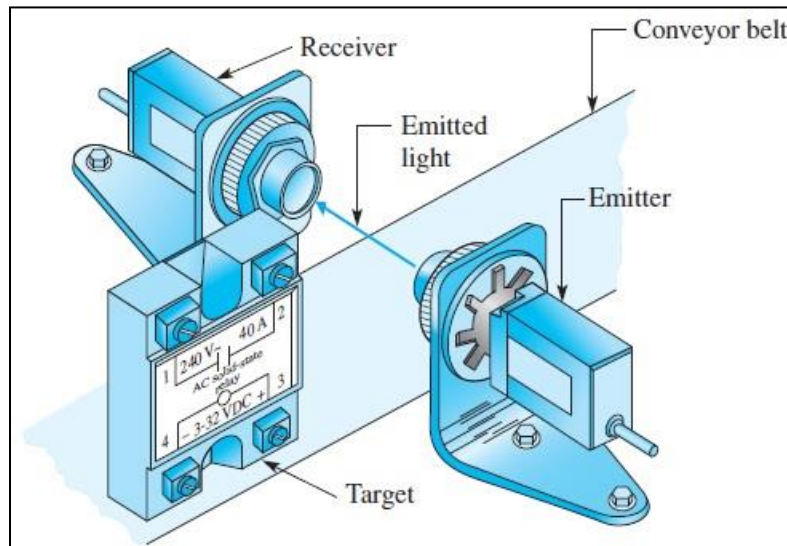


Figure 19:Thru beam method [16]

Emitter produced a lens- focused beam of light and it shines at the receiver that also consists focusing lens. In this method, the target (object) is mostly opaque. Therefore, the mode of detection is dark -on (light to dark). When an object passes between the source and detector (receiver), it breaks the light beam and the receiver turns on its output. This sensor is used in an application that needed a long operating range, accurate positioning sensing, and counting of parts. The main disadvantage of this type of sensor is that it can not detect the translucent or transparent objects and it requires separate wiring on both sides of the conveyor belt (transport system) for emitter and receiver as shown in figure 19. In some applications, this may be not feasible. over the lens. The drawback of using an aperture is that the transmitted light energy is reduced. The through-beam method is also known as a beam break [19].

4.2.1.2 Diffuse Reflective proximity sensor

The diffuse reflective proximity sensor contained light emitter and receiver inside the sensor as shown in figure 20. In this, the mode of detection is dark - off (dark to light). When an object faces the light beam from the emitter, the light beam is diffused (scattered) and returned to the receiver

to indicate object presence which, turns on its output. In the absence of an object, there is no light reflected towards the receiver.

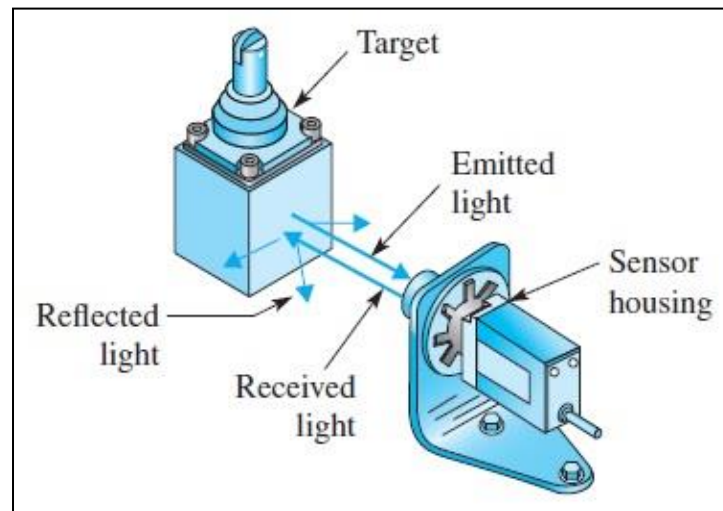


Figure 20:Diffuse reflective proximity sensor [16]

From the mounting point of view, Diffuse reflective proximity sensors are more convenient than through-beam sensors, because the emitter and receiver are positioned in the same unit, which makes wiring more simple and detection can be achieved only from the one side of the process. Detecting distance is limited for this sensor because the light beam is diffused (scattered) after blocked by an object, a small part of the transmitted light beam reaches to a receiver. This sensor doesn't operate properly with the transparent object, the object that has low reflectivity.

4.2.2 Description of part used

This project is a demonstration of a typical application of a PLC S7-1200 module in the automation industry. The PLC operates according to the program downloaded in its memory. The PLC module is connected to other components such as synchronous motor with permanent magnets (S-1FL6), Servo drive (V 90), and HMI (KTP 700 basic) via a communication line. Servo drive controls the rotor of the synchronous motor according to the signal of the PLC module. The servomotor has an encoder mounted on the shaft, which serves as feedback for drive control. Plc also connected with the SIM 1274 simulator which is used for debugging and monitoring the program without actual field devices.

4.2.2.1 Power Supply Module [SIMATIC PM1207]

This compact power supply module converts the nominal single-phase voltage of 120 V or 230 V with frequencies of 50 Hz and 60 Hz into 24 V DC, which is required for the CPU of the PLC S7 1200. It can supply current to the load up to 2.5 A. It has a LED on the front to indicate the status of the 24 V output voltage is present or not. This module does not PM 1207 does not need configuration. This module is 70 mm wide and does not require large space in conjunction with micro PLC S7 1200. Some technical data for this power module is listed below in **table 2**.

Table 2: Technical specification of the power supply module [20]

SIMATIC PM1207 Power Supply Module, 6EP1332-1SH71	
Supply voltage (AC)	120V or 230V
Rated line frequency	50 Hz or 60 Hz
Input current	1.2 A or 0.67 A
Rated output voltage (DC)	24 V
Rated output Current	2.5 A
Degree of protection	IP20

4.2.2.2 Compact switch module [SIMATIC NET CSM 1277]

The connection multiplier CSM 1277 unmanaged is used to connect several devices with PLC over Industrial Ethernet. The LEDs indicate the presence of the supply voltage and the port status. It has four RJ45 sockets for the connection of end devices or other network segments. For example to connect other programmable controllers or to connect HMI stations. These four sockets are marked as P1 to P4. It detects the rate of data transfer by itself and it is designed for 10/100 MBit/s. Standard or crossover cables can be used for this module. This module also does not need configuration. Some technical data for this power module is listed below in the **table 3**. [21] [22]

Table 3: Technical specification of the compact switch module

SIMATIC PM1207 Power Supply Module, 6EP1332-1SH71	
Supply voltage (DC)	24 V
Input current	1.2 A or 0.67 A
Transfer rate	10 Mbit/s, 100 Mbit/s
Degree of protection	IP20

4.2.2.3 PLC module SIMATIC S7-1200 with CPU 1215C DC / DC / DC

The module S7-1200 has four types of CPU such as CPU 1211, CPU 1212, CPU 1214, and CPU1215 which are different from each other in the supply voltage, the number of onboard available inputs and outputs, the memory size, and their expansion capability in each case in the versions DC/DC/DC, AC/DC/RLY, DC/DC/RLY. The first term in the version indicates module power supply (DC = 24 V direct current, AC =120/230 V alternating current). The second term indicates the operating voltage of onboard digital inputs (DC = 24 V DC). The third term indicates the type of digital outputs (DC = 24 V DC electronic, RLY = up to 30 V DC or up to 250 V alternating current with relay). For this project, I have chosen 1215C DC/DC/DC module which shown in figure 21. [14]

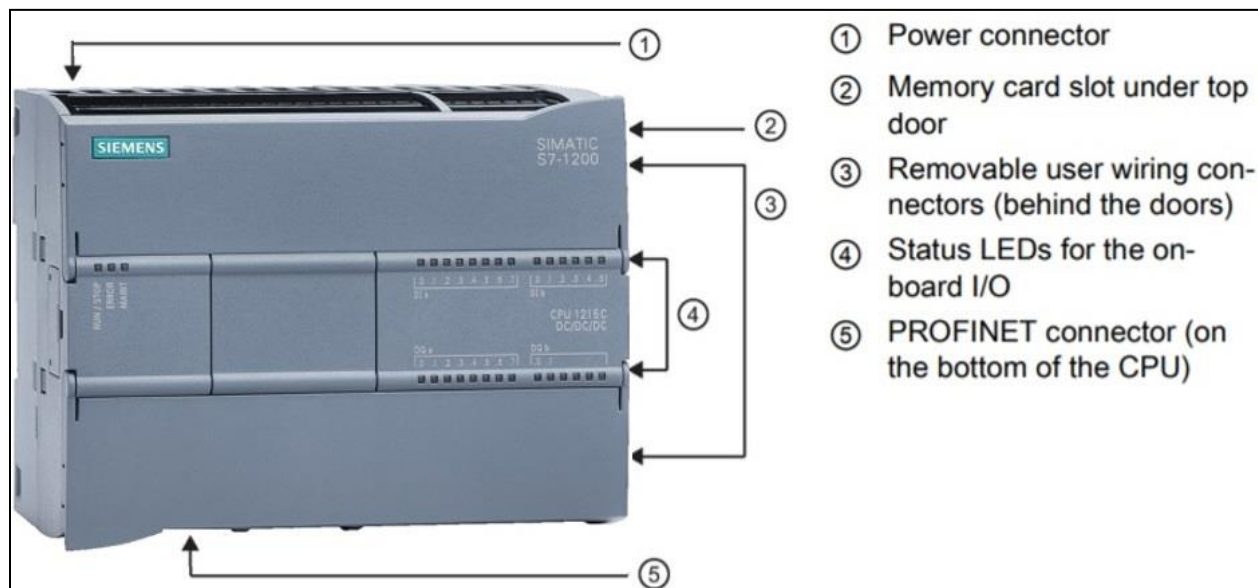


Figure 21: Description of S7 -1200 PLC module [14]

From figure 21, we can see that the CPU of the PLC module contains 14 digital inputs and 10 digital outputs for digital data. For analog data, it contains 2 analog inputs and 2 analog outputs. CPU also has a LED indicator for all types of inputs and outputs. The processor has 4 MB Flash-type internal memory with the possibility of expansion using an SD card. It has two Profinet ports. The data transfer rate strongly depends on the length of the cable used and the shield category. The manufacturer states a transmission speed is up to 100 Mbps. [14]

Figure 22 shows the connection of the PLC module with the power supply module and a compact switch module via ethernet cable, where the one PROFINET connection of PLC is used to connect PC and another one is connected to a compact switch module to connect other devices such as HMI and drive over the PROFINET network. In figure number 1 indicates 2 ports of the PROFINATE interface for PLC and number 2 indicates that 1 port from the total 4 ports is used in PROFINET connection with the PLC.



Figure 22: Diagram of connection between PLC and other modules.

Further technical data concerning power supply, voltage ranges of digital inputs of voltage type, current ranges of digital outputs of current type, resolution of analog inputs, outputs, and their voltage ranges are shown in table 4 [14]. Figure 23 shows the wiring diagram of the inputs, outputs, and power supply of the module. In that ① indicates that pin no 4 and 5 are for 24 V DC Sensor Power Out. According to manufacture "M" should be connected to chassis ground even if the sensor supply is not in use and for sinking inputs, we should connect "-" terminal of external 24 V supply to "1M" (shown in ②). For sourcing inputs, we should connect the "+" terminal of 24 V external supply to "1M".

Table 4: Technical specification of PLC [14]

PLC S7-1200 with CPU 1215C DC / DC / DC (6ES7215-1AG40-0XB0)	
Rated supply voltage (DC)	24 V
Input Current max.	1500mA
Load Voltage (DC)	24 V
Rated output voltage	1600mA
Work Memory	125 Kbyte
Load Memory	4 Mbyte (expandable with SD card)
Digital input-output	14 -10
Analog input-output	2 - 2
Analog input range	0 to 10 V
Analog Output range	0 to 20 mA
Interface Type	PROFINET
Cable length for digital input	500 m; 50 m for technological functions for shielded cable 300 m for unshielded cable
Cable length for digital output	500 m for shielded and 150 m for unshielded cable
Cable Length for analog input	100 m for twisted and shielded cable
Interface port	2 port

4.2.2.4 SINAMICS V90 Servo Converter

This converter is the main part of the optimized servo drive solution which is used for motion control application. This converter is used to control a three-phase permanent magnet synchronous motor (SIMOTICS S-1FL6 servo motor) with an inbuilt encoder. This motor is another part of the servo drive solution. This converter is available in single-phase and a three-phase variant with diverse converter frame sizes to cover a wide range of applications such as conveying and positioning. This converter needs two types of power supply to function. It needs a 24 V DC power supply for internal control function to run the drive. This 24 V DC control power supply is provided from a DC 24V SIMATIC PM1207 power supply module. [23]

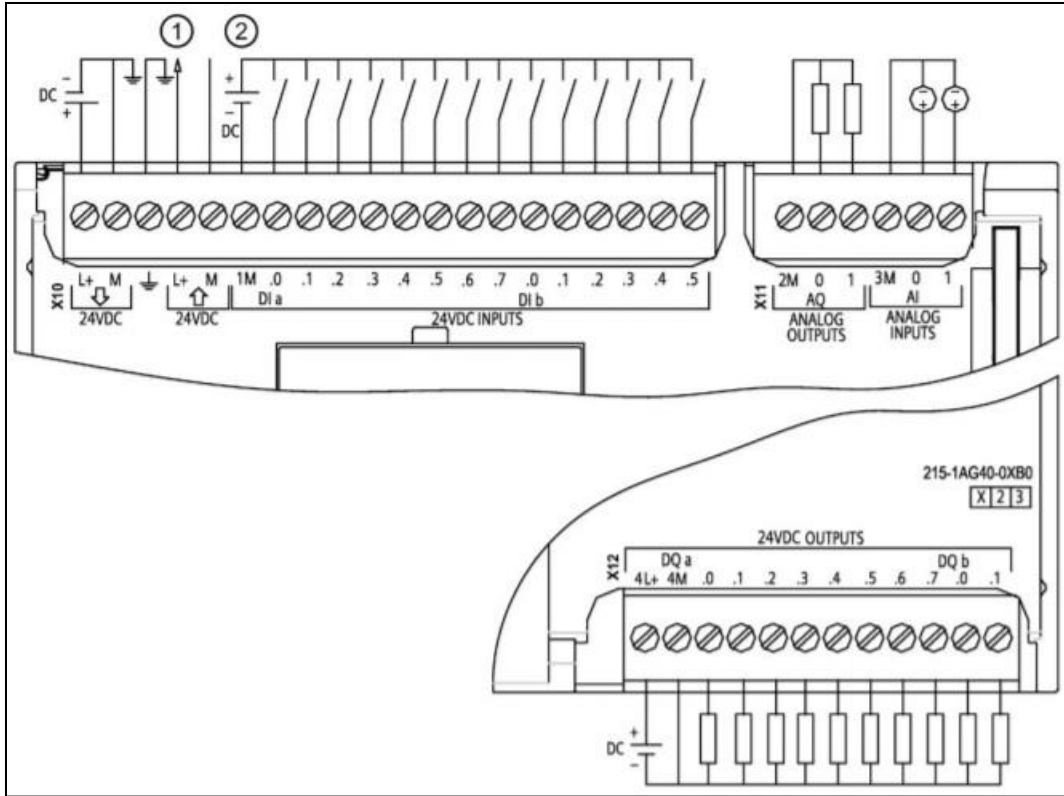


Figure 23: wiring diagram, of a selected PLC module [23]

The 24 V DC power supply is connected to pins marked as +24V and M which are on control voltage supply connector as shown in figure 27. This control voltage supply connector additionally contains 3 pins marked STO 1, STO +, and STO 2 for the STO (safe torque off) interface, which is short connected at the factory setting. To perform the STO function, we must take out the short-circuit stick before connecting the STO interfaces and we can connect the stop button between pins STO1 and STO +, or STO 2 and STO + as shown in figure 24. Here I have connected a Stop button between pins STO 1 and STO + which is activated by pressing. By using STO function the motor can thus be safely disconnected in the case of danger by pressing the button, which is connected to the STO interface. It is necessary to reset the converter by disconnecting it from the supply and control voltages after eliminating the cause of the dangerous condition.

The short-circuit stick should be kept as per the factory setting if we are not using STO function; otherwise, the motor will not be able to run.

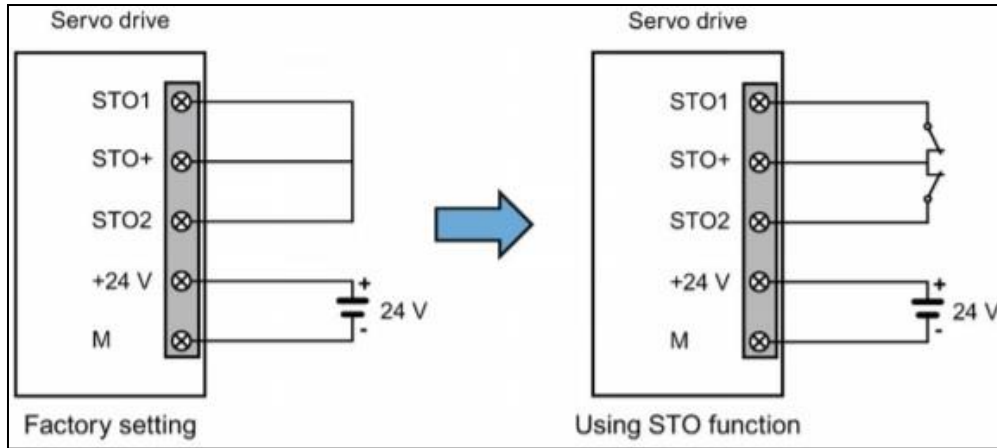


Figure 24: connection diagram for STO interface [23]

Converter also requires the single-phase or three-phase power supply and this supply is used to power the motor. This power supply can be provided utilizing a single-phase / three-phase network of 200 VAC to 240 VAC, 50/60 Hz. According to the documentation given in the manufacturer's manual, I connected the phase conductor to the L1 terminal and the neutral conductor to the L3 terminal. At the bottom of the drive, the PE protective conductor is connected to the ground terminal. The connection of the converter with the PLC is ensured via a PROFINET cable [23]. Figure 25 shows the nameplate of the converter. We can see important technical data from the converter nameplate [23].

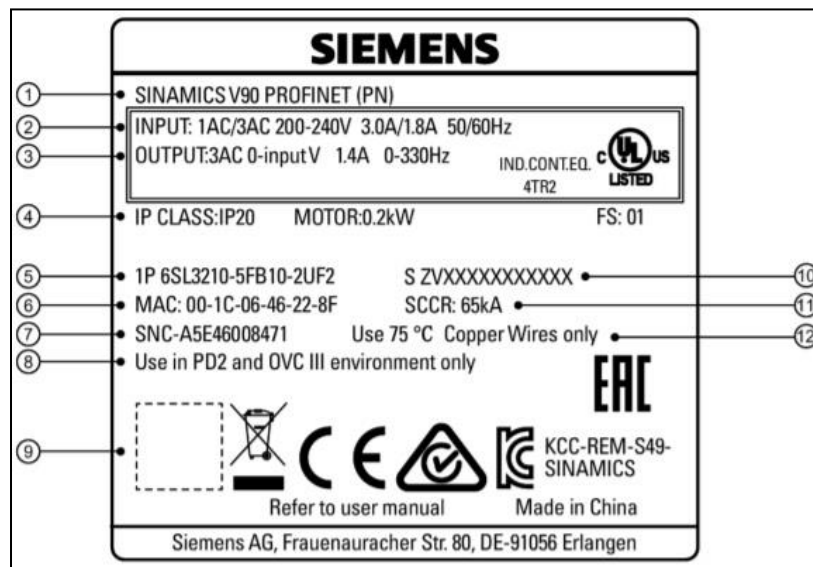


Figure 25: Nameplate of SINAMICS V90 Servo Converter [23]

- ① Inverter name
- ② Inverter power supply data (number of phases, voltage, current, and frequency)
- ③ Data of output quantities (number of phases, voltage range, maximum output current per phase and voltage output frequency range)
- ④ Information on inverter power, degree of protection
- ⑤ Serial number of the product
- ④ Information on inverter power, degree of protection
- ⑤ Serial number of the product
- ⑥ MAC address
- ⑦ Part number
- ⑧ Information on the degree of pollution and the magnitude of overvoltage (working conditions)
- ⑨ QR code for reading technical data by the operator's reading device
- ⑩ Product serial number
- ⑪ Rated short-circuit current
- ⑫ information on using the inverter only for motors with copper windings.

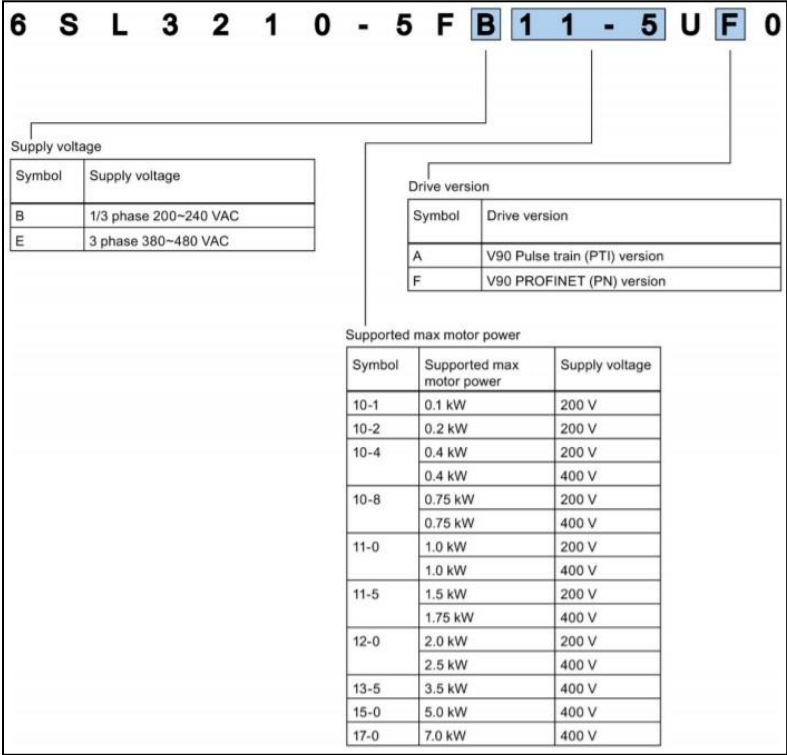


Figure 26: Serial number description of SINAMICS V90 Servo Converter [23]

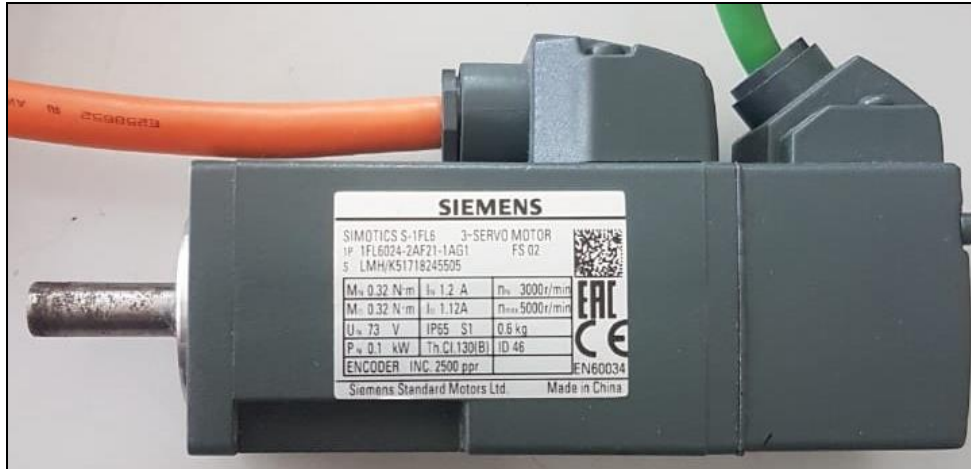


Figure 28: SIMOTICS S-1FL6 Servo Motor

The motor does not need an external cooling system and is designed for operation with a maximum relative humidity of 90% with condensation prevention. Some technical specification for this particular motor is described in **table 5. [24]**

Table 5 Specification of SIMOTICS S-1FL6 Servo Motor

SIMOTICS S- 1FL6 (1FL6024-2AF21-1AG1)	
Type of motor	Permanent-magnet synchronous motor
Cooling	Self-cooled
Rated Power	0.1 kW
Rated Torque	0.32 Nm
Maximum Torque	0.96 Nm
Rated Speed	3000 rpm
Maximum Speed	5000 rpm
Rated Frequency	200 Hz
Rated Voltage	73 V
Rated Current	1.2 A
Maximum Current	3.6 A
Moment of inertia	$0.052 \cdot 10^{-4} \text{ kg}\cdot\text{m}^2$
Moment of inertia (with brake)	$0.059 \cdot 10^{-4} \text{ kg}\cdot\text{m}^2$

4.2.2.6 HMI(Human Machine Interface) [KTP700 Basic, 6AV2 123-2GB03-0AX0]

The visualization of processes and states of the PLC programs takes place on a device called the HMI (Human Machine Interface), which is the name for communication between the operator and the device. We need to control some variables of the process in the plant. For example, to control to the direction of a PLC controlled motor in the plant. We could do that by changing the PLC program online. Another option is that with the HMI we could change the motor rotation from directly on the HMI screen. This is just one

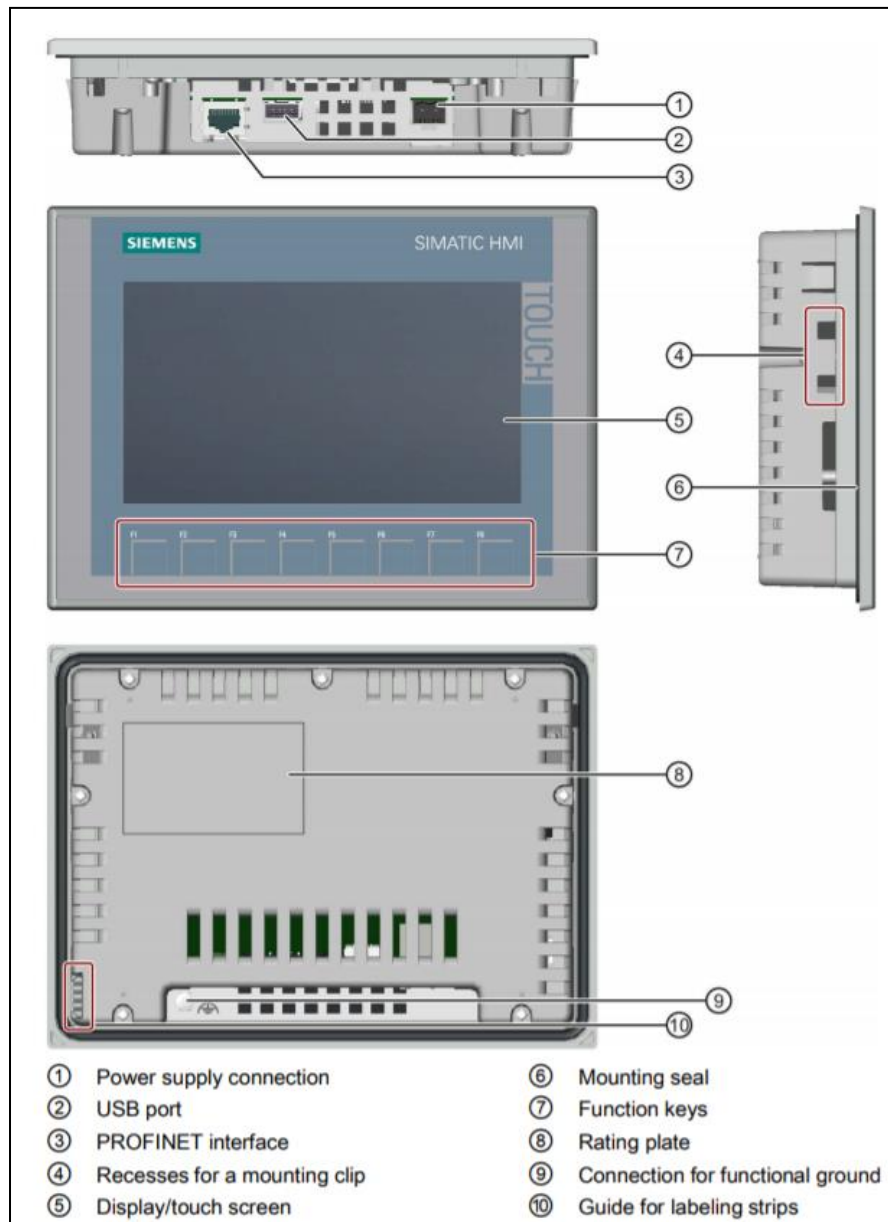


Figure 29: Discription of HMI panel [KTP700 Basic, 6AV2 123-2GB03-0AX0] [25]

scenario. An HMI is used for many roles. HMI also provides process (real-time) values over time with graphs. We can easily change process values with numeric keypad from the screen. It also provides communication channels for easy upload and download of programs. For a complex process, HMI provides an option to divide the complete process into subparts. Each part will be displayed on a separate screen and switching between these screens can be done by adding and programming a button on the touch screen. [25]

The figure shows the HMI panel (KTP700 Basic, 6AV2 123-2GB03-0AX0) which has 8 function buttons for easier operation and access to individual operations. This KTP 700 means it has a 7-inch display. It has a resolution of 800 x 480 pixels and is capable of displaying 65,536 colors (16 bits). This panel needed 24 V DC power supply with the permitted range 19.2 V to 28.8 V and incorrect connection may damage the HMI panel. It has a 256 MB data memory and 512 MB program memory. The manufacturer recommends using a copper conductor with a cross-section of 4 mm² for earthing. The RJ-45 connector is used for communication of the panel with other devices. The panel also consists of a USB port to connect external devices, such as a keyboard or mouse with USB 2.0. We can adjust the HMI panel either by directly using the touch screen or from a PC via an Ethernet cable connected between PLC module and HMI as shown in the figure with the installation of the appropriate software on the PC. The HMI panel must be treated as an ESD8 device during handling and installation because it is sensitive to electrostatic discharges and surges.[25]

5 TIA PORTAL (Totally Integrated Automation Portal)

.The TIA Portal is the total integration of the entire automation environment. TIA portal offers the following advantages:

- One common software environment that integrates all tasks and devices into one uniform user-friendly system with a central database.
- A common communication portal between all automation components which are participating in a particular process.

STEP 7 Basic V15.1 (TIA Portal V15.1) software is the programming tool for the automation systems. It provides a user-friendly environment to develop logic for the controller, visualization of the process by the configuration of HMI, to configure other SIMATIC devices, Testing, commissioning, operational/diagnostic functions, and set up network communication.

To configure the S7-1200 controllers with HMI panel and other SIMATIC components STEP 7 basic or professional can be used. To implement a solution for an automation and visualization task we can add real hardware automation components with a particular module's article numbers to the project from the hardware catalogs. To create a project TIA portal is used in which all components can be added from a library. The communication between the TIA software and other elements takes place via an Ethernet connection such as PROFINET bus systems which can be done by hardware configuration in software.

The TIA Portal has two main views: the portal view and the project view. At the start-up, it displays the portal view by default as shown in figure 30. which is task-oriented. Figure 30 shows the portal view which is indicated by number 2 at the bottom left, there is an option to switch to Portal view. Number 1 indicates the portals for a different task. Number 3 indicates the task for the selected portal. Number 4 indicates the description of the new project which is being created. In the Devices & networks portal, we can configure the programmable controllers. In the PLC programming portal, we can create the user program in the form of "blocks". The Visualization portal provides the tools for configuration and simulating the HMI panels. The Online & Diagnostics portal allows us to connect the PLC online. [14]

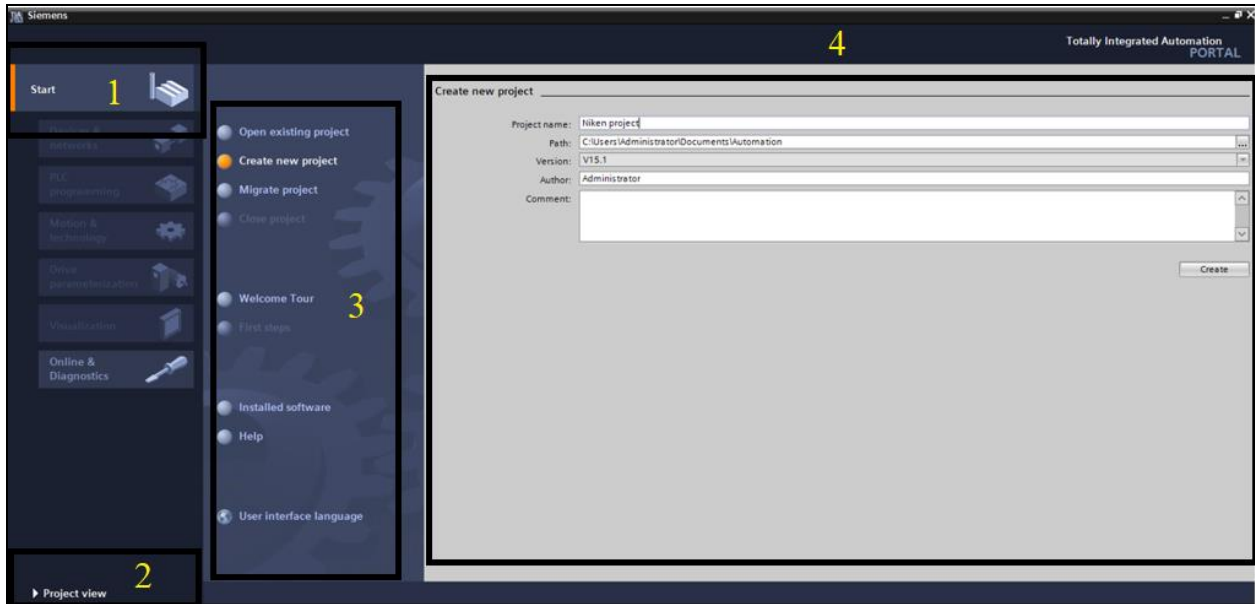


Figure 30:Portal view of TIA software

The project view is shown in Figure 31 which is an object-oriented view with multiple windows. This view is used to create hardware configuration, programming, HMI panel simulation, and

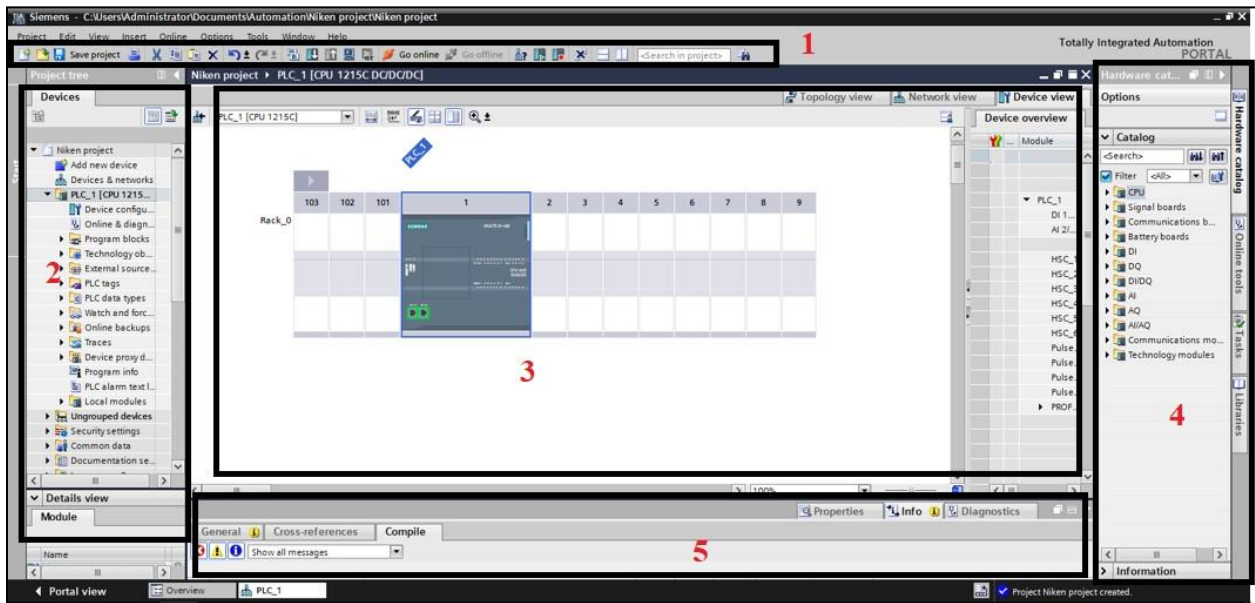


Figure 31:Project view TIA software

several other tasks. By default, the project view displays the following windows as shown in figure 31.

Project Navigation (Tree):

The Project tree includes all components and data of a particular project. We can open all the components from there. The project tree indicated as number 2.

Working Area

In the working area, the components opened for editing are shown. These components include, for example, hardware modules, blocks, tag tables, screens of HMI, etc. working area indicated as number 3.

Task Cards (tools)

Task Cards include tools for configuring devices and programming. The content of the Task cards relies on the object shown in the working area. Hardware catalog is available if any hardware station is open and there are Task cards with instructions if any program block is open in the working area. This is indicated as number 4.

Inspector Window

Detail information of selected objects or on performed actions is shown in this window. We can also edit the properties of the selected objects here. It also shows all system messages such as any errors and warnings after an action is completed. The Inspector window is indicated as number 5.

Details View

The Details view shows the elements of the object selected in the project tree. These can be used in the active working area by dragging them from to the working area.

In the project view, all of these components in one place so we can easily access to every aspect of our project.

6 Description of project:

I have created the project to control 3 Phase Motor Control using PLC with the visualization in the HMI panel. I have written the ladder logic program for forward and reverse control for 3 Phase Induction motor.

I have tried to control the servo moto (Simotics S-1FL6) by Simatic V90 converter (servo drive) with PLC. But I faced a problem to configure servo drive in TIA Portal. So I decided to make a program to control the rotation of the motor.

6.1 Problem Description:

In the industries, lots of motors and conveyors are used for different purposes. Motors or conveyors need forward and reverse operation to achieve some work such as in material handling overhead crane.

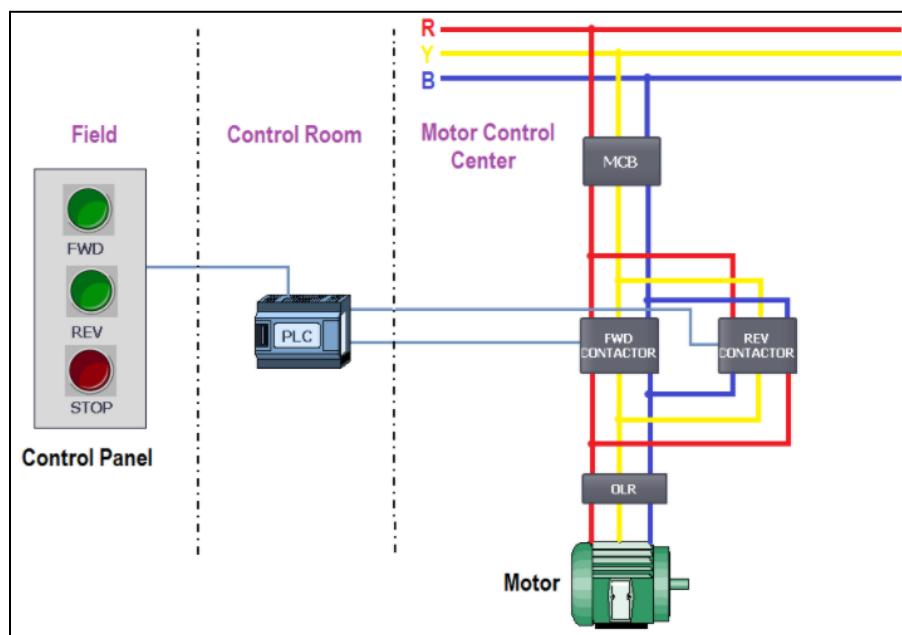


Figure 32: Basic connection diagram of PLC and motor

6.2 Problem Solution

We need to operate the motor in both directions for proper control of crane, which can be achieved by forward/Reverse control Logic program In PLC. I have considered one 3 phase motor as a field device to be controlled. As per the diagram I need to control forward and reverse contactor to change to the direction of motor rotation. I have also considered three pushbuttons i.e. for forward, reverse, and stop functions of the motor. So I can use FWD PB for forward operation, and REV

PB for reverse operation and STOP PB for stop function. I have also created these three push buttons on the HMI screen to control the motor. As per the figure 32 I have to energize the coil of the forward and reverse contactor to turn on the contactor, which will supply the power to the motor for the desired rotation.

I have used 8 pin SIM 1274 simulator which is connected to the terminal block of the CPU instead of the actual input signals from the field devices as shown in figure 22.

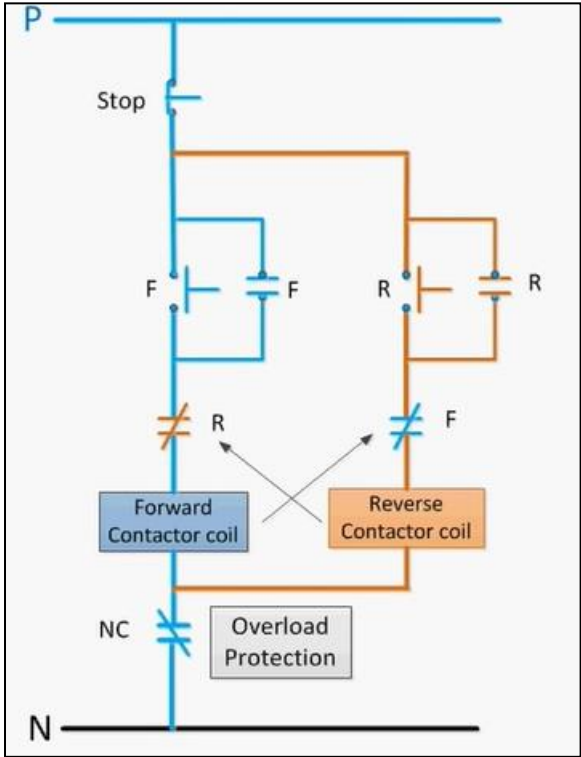


Figure 33: Control diagram of reverse -forward control of motor

PLC Inputs List:

- FWD PB : I0.0
- REV : I0.1
- STOP PB : I0.2
- Motor Trip : I0.3

PLC Outputs List

- Coil of forward contactor : Q0.0
- Coil of reverse contactor: Q0.1

6.3 Making of project:

To create a project I have used Siemens S7-1200 PLC and TIA Portal Software for programming and HMI for visualization.

To make a project, the first step after the starting of TIA Portal software is to create a new project by clicking on create a new project option as shown in the **figure**. Where we can enter the name and location path of the project. After that, the project will be created and opened and the following screen as shown in the **figure** will open automatically.

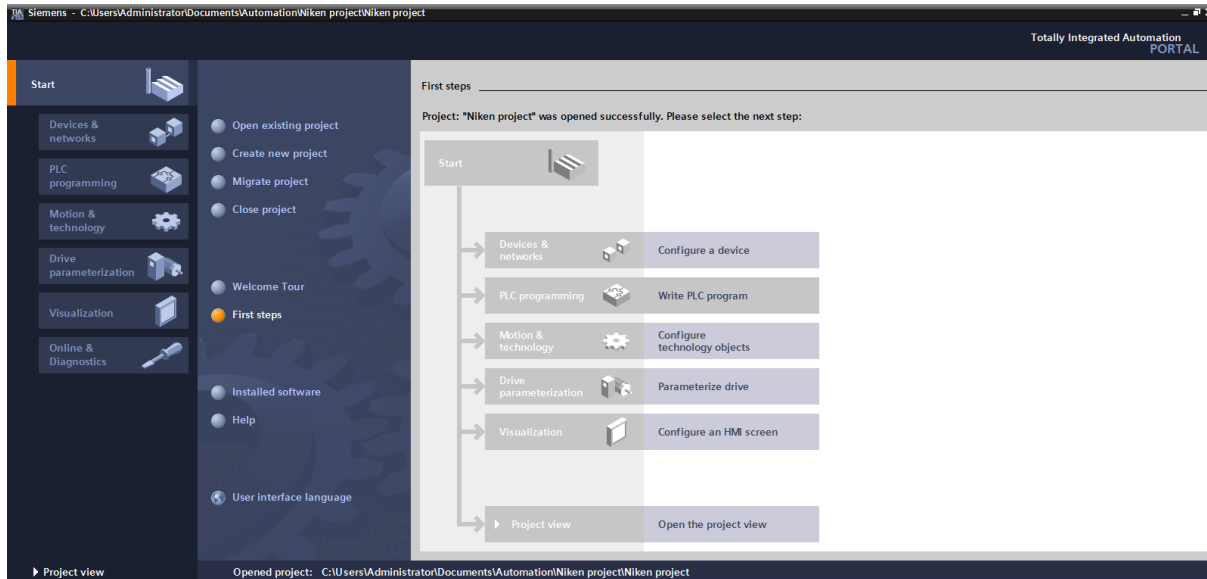


Figure 34: TIA portal window

After that by clicking on “Configure a device” the following screen will open as shown in figure 34. Where we can add specific devices such as PLC, HMI, and drives. After that by clicking on “Add new device” I have inserted the CPU module of my PLC according to its article number as shown in figure 35.

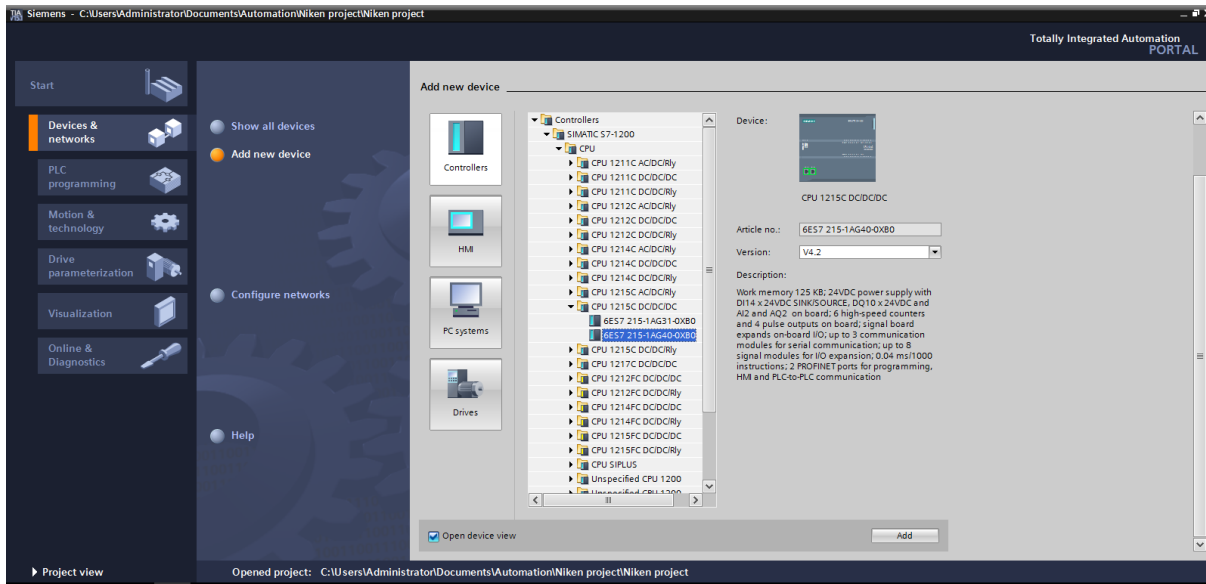


Figure 35: TIA portal window

After click on “Add”, TIA Portal now changes automatically to the project view and shows the selected CPU in the device configuration as shown in figure 36.

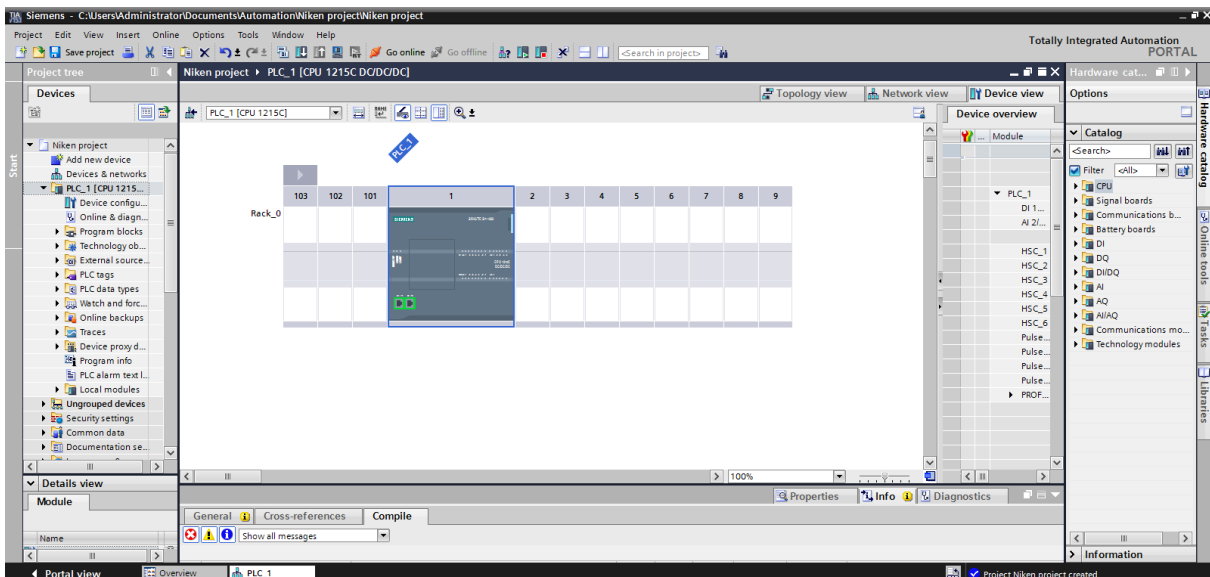


Figure 36: TIA portal window

After that, I configured the Ethernet interface of the CPU as shown in figure 37. To configure I have to select the CPU with a double-click and open the "PROFINET interface [X1]" menu in the "Properties" tab and then select the "Ethernet addresses" entry. Under "Interface networked with", only the "Not networked" is available but we can add an Ethernet subnet by clicking the "Add new

subnet" button. And after that save the project and click on the compile button.

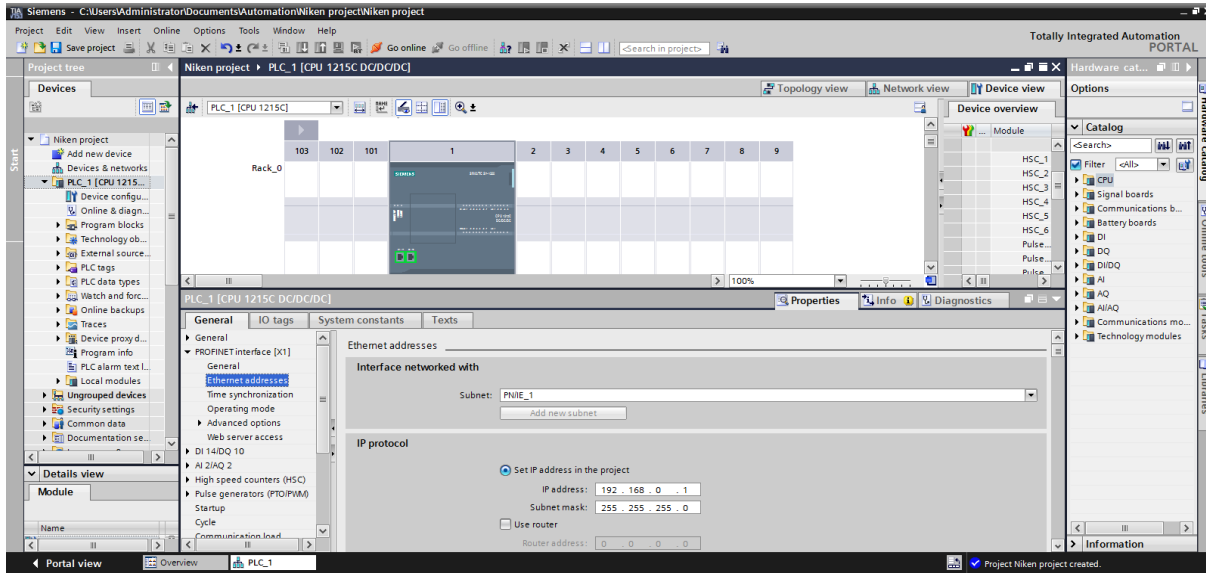


Figure 37: TIA portal window

After successful compilation, I downloaded the entire CPU by selecting the "CPU_1215C [CPU1215C DC/DC/DC]" folder and clicking on the "Download to device" button as shown in figure 38.

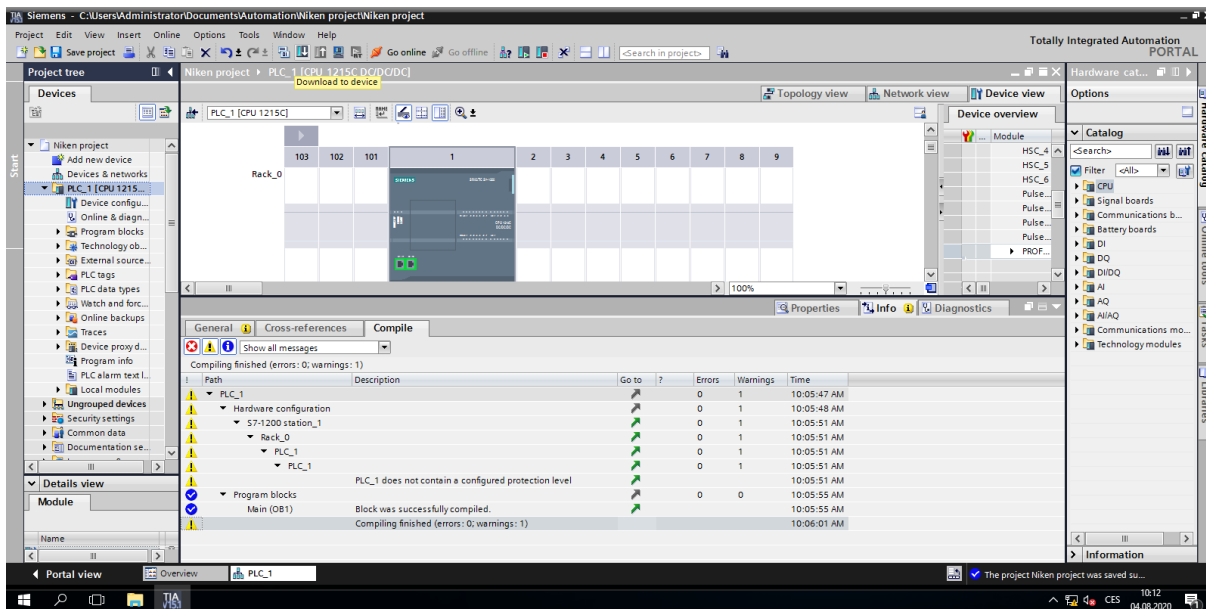


Figure 38: TIA portal window

After clicking the "download to device" button, extended download to the device window will open as shown in figure 39. Where we have to select interface type and If our CPU is shown in

the "Compatible devices in the target subnet" list, it must be selected. So I selected on my CPU and then clicked on load to download a device as shown in figure 39.

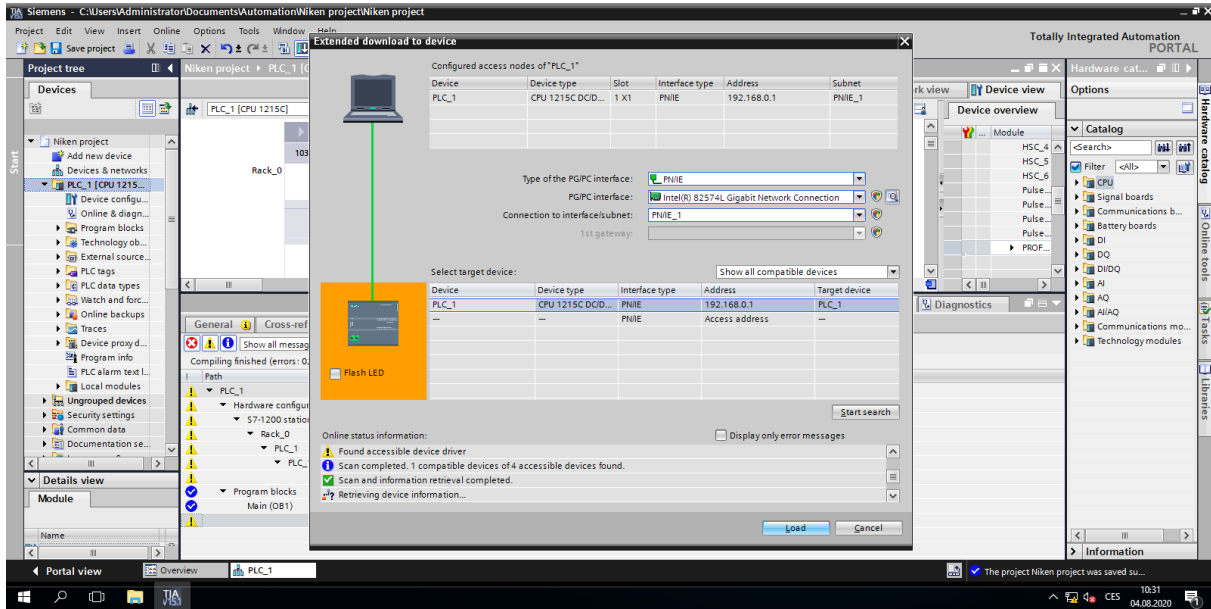


Figure 39: TIA portal window

The "Start all" option will be selected next before the download operation can be completed with by clicking on the finish button as shown in figure 40.

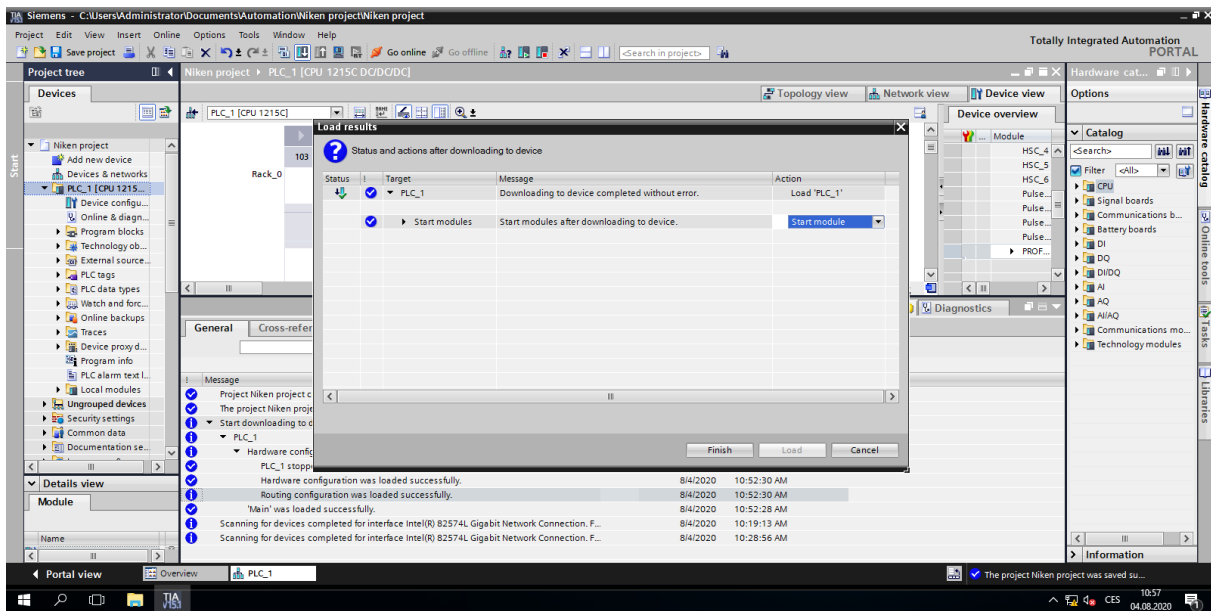


Figure 40: TIA portal window

Then I downloaded HMI like this way to the TIA portal and after that, I compiled all hardware (CPU and HMI) to configure the communication between them. After compiling we can see the CPU and HMI connected via PROFINET interface in the network view of the TIA Portal as shown in figure 41.

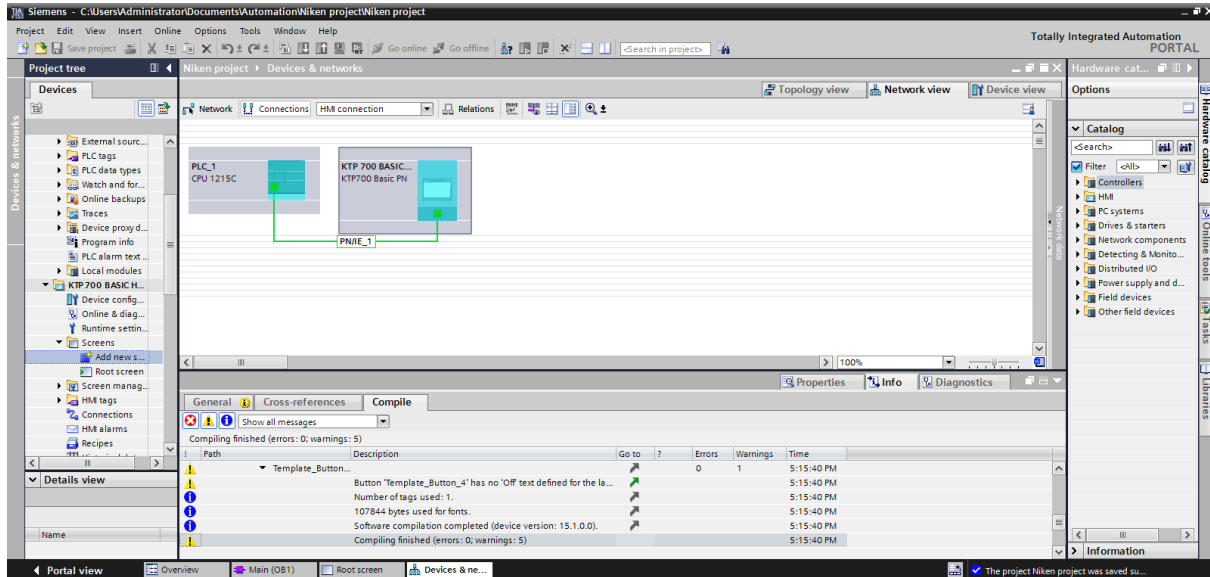


Figure 41: TIA portal window (network view)

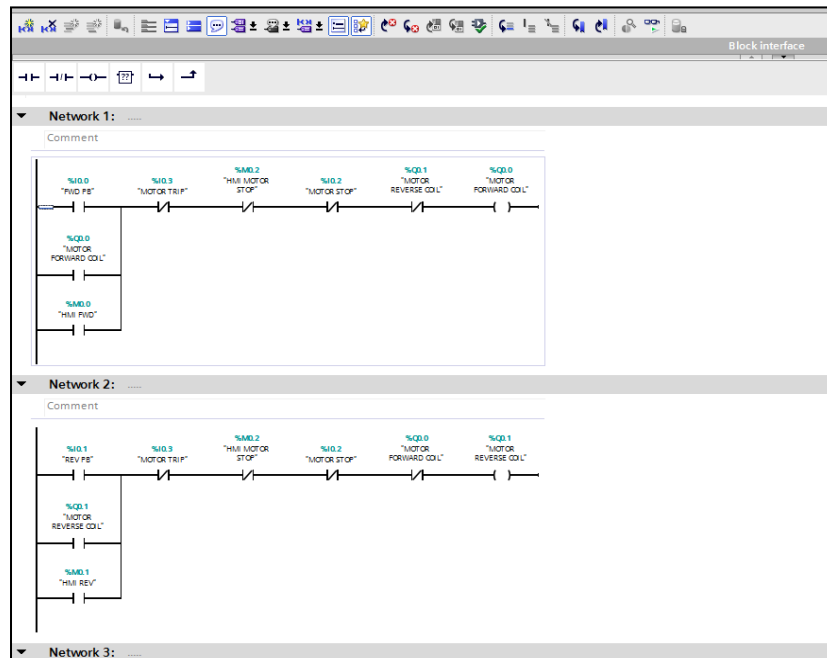


Figure 42: Ladder Logic program to control motor

After successfully compiling the hardware, I inserted the ladder logic program in the working area. After creating the entire entry in the main window as shown in figure 42, the project is checked which is then loaded into the PLC module's memory. After clicking on the Download to PLC icon located on the bar at the top of the screen, a window with connection options will appear, where and it is necessary to set the type of communication interface and computer adapter as shown in figure 39. All available devices are searched, in this case only the PLC module, After finding the PLC module, the program can be uploaded to the device.

6.4 Visualization in HMI panel

I have created the visualization of motor rotation and its control for HMI in the TIA Portal environment. I have created three push buttons and to control the motor and two round objects in the main screen of the HMI panel as shown in the figure 43. Many industrial automation components are available in the toolbox to simulate the HMI screen.

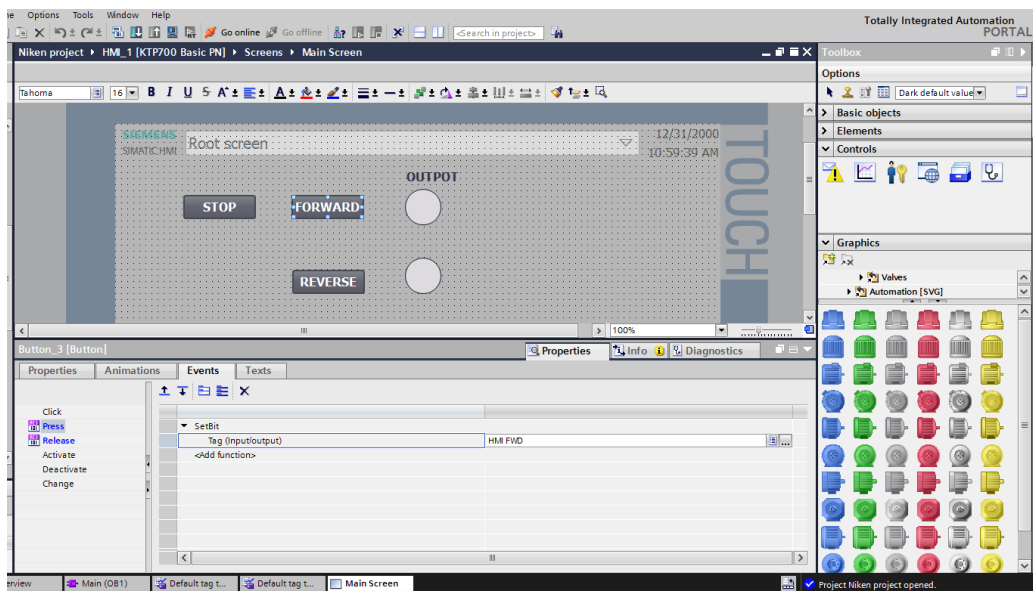


Figure 43: HMI simulation screen

As same as for the round object, we have to edit its appearance in its properties according to output state 1 and 0 for both the output coil (forward and reverse). From figure 44 we can see the PLC tag assigned to a particular button and object of HMI screen.

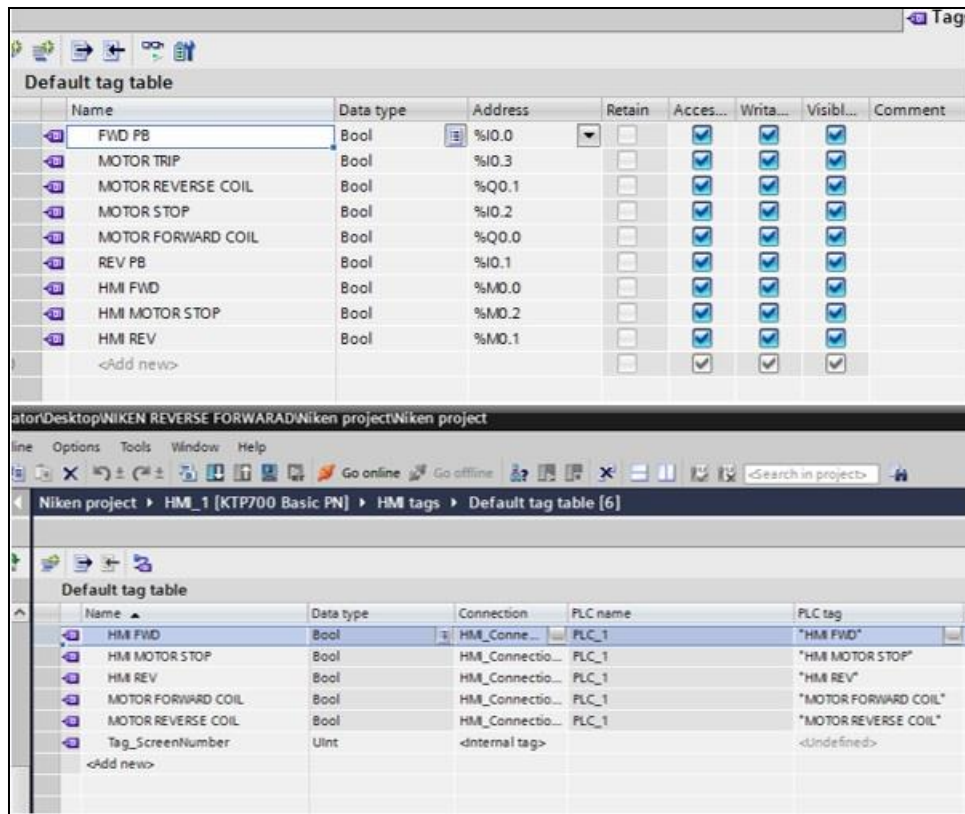


Figure 44: PLC and HMI tag table

Two round Objects are used to indicate the output of the motor either in forward or reverse direction. If we touch the forward button on the HMI screen, the motor will rotate in the forward direction and for a reverse button, the motor will rotate in a reverse direction. The round object will change their color if the output is enabled on either contact (forward or reverse) of the motor. If there is no output round object will not change its color. For this, we have to edit the properties of the push button and object according to the PLC tag as shown in figure 44. For forward button, we have to create events for button press and button release in its properties by providing an appropriate PLC tag of the input or output bit.

6.5 Online monitoring of rotation of motor:

In TIA Portal software we can monitor the events online without connecting the field devices. After switching to online mode (Go online icon), the line representing the electrical connections and the components (contactor coil) will turn green if they are connected to the power supply. From this, we can see which part and component are energized to verify the proper operation of switches, coils, and other components. From figure 45, we can see that the output coil of the forward contactor is energized which is done by touching the forward button on the HMI screen. We can see that indicator LED of the output Q0.0 on PLC is also on. In the HMI screen output object of the forward coil also turns on (becomes green from white).



Figure 45: Online monitoring In TIA portal with PLC and HMI screen

7 Conclusion

While working on this diploma project, I got acquainted with the TIA Portal software and individual components of the SIEMENS assembly. I gradually revived and added used devices to the project, where I have created a code to control motor rotation in ladder logic language with visualization of the process in the HMI control panel.

Although I have faced the problem in the task of controlling the drive. I could not able to configure drive with a communication protocol. For a potential follower, this project can serve as a guide to get acquainted with the TIA software and described components of Siemens, and one can try to configure the servo drive in the TIA portal and can control the servo motor in several ways. I have tried to put almost all the information from the comprehensive manuals of individual modules.

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