



Competency-Based Learning Materials (CBLMs)
on
Industrial Automation
Light Engineering Sector

Skills for Industry Competitiveness and Innovation Program (SICIP)
Finance Division, Ministry of Finance

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The Competency Based Learning Material (CBLM) for Industrial Automation serve as a foundational document for the development of lesson plan, session plan, teaching materials, and assessment tools specifically tailored for the Light Engineering sector. This document ensures that training activities align with industry requirements, enabling individuals who successfully meet the established standards through assessment to become qualified professionals in relevant roles within the sector.

Developed under the Skills for Industry Competitiveness and Innovation Program (SICIP), this document addresses the skills requirements critical for Industrial Automation. It is owned by the Finance Division of the Ministry of Finance of the People's Republic of Bangladesh.

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CBLM Development Committee

To develop this CBLM, a dedicated team was formed that included external experts and was led by the PIU, SICIP-BITAC Project. The team conducted a detailed task analysis based on the performance criteria outlined in the Competency Standards (CSs) for Industrial Automation, while also considering the needs of the trainees.

Following the task analysis, the components of the CBLM were developed through a series of consultation meetings and workshops. As a result, the CBLM for Industrial Automation was successfully developed. Finally, a validation meeting was held with subject matter experts, and the material was formally validated.

Experts Involved

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Introduction

Purpose of the CBLM

The purpose of this Competency-Based Learning Material (CBLM) is to provide structured, practical, and hands-on training in Industrial Automation for learners in the Light Engineering sector. It is designed to equip participants with the knowledge, technical skills, and workplace competencies required to perform effectively in modern automated industrial environments.

This CBLM follows a Competency-Based Training (CBT) approach, ensuring that learners not only acquire theoretical knowledge but also demonstrate mastery through practical application. By completing the course, participants will be competent in key occupational areas such as relay logic control, PLC programming, industrial sensors and actuators, HMI integration, pneumatic and hydraulic systems, VFD operation, and PLC-based control system design.

The ultimate aim is to build a skilled workforce that meets industry demands, enhances productivity, and supports sustainable industrial growth in Bangladesh.

Who the CBLM is for (Audience)

This CBLM is intended for:

Technical and vocational students specializing in Electrical, Electronics, Mechatronics, or Industrial Engineering.

Industry workers and technicians who are upgrading their skills to meet modern automation requirements.

Supervisors and foremen in the Light Engineering and manufacturing industries who need to understand automation systems for improved productivity.

Entrepreneurs and small industry owners seeking to implement automation solutions in their operations.

Fresh graduates or job seekers who want to enhance their employability in the industrial automation sector.

No advanced background in automation is strictly required, but learners should have basic knowledge of electricity, electronics, and safety practices.

How to Use this CBLM

Follow the Units and Competencies: The CBLM is organized into generic, sector-specific, and occupation-specific competencies. Learners should progress step by step, completing each unit in sequence.

Engage in Hands-on Activities: Each module includes practical tasks and exercises designed to reinforce learning. Learners are encouraged to practice repeatedly until they demonstrate competency.

Use as a Self-Learning and Reference Guide: While the CBLM is intended for guided training, learners may also use it independently for review and reinforcement.

Assessment and Feedback: At the end of each unit, learners will be assessed through practical demonstration, written tests, and oral questioning. Trainers should provide immediate feedback and coaching to close learning gaps.

Trainer's Role: Trainers should facilitate learning by demonstrating tasks, supervising practice, guiding discussions, and ensuring a safe learning environment.

Learner's Role: Learners should actively participate, practice diligently, maintain safety, and collaborate with peers during team-based activities.

By the end of this course, learners will have the competencies required to work confidently in automated industrial environments and contribute to the advancement of the Light Engineering sector.

Module 1: Execute Electrical Sequence Circuit and Control using Relay Logic



Contents of Module

Module Description

This unit covers the knowledge, skills and attitudes required to execute electrical sequence circuit and control using relay logic. It specifically includes the tasks of interpreting relay logic operation, performing mechanical switching operation, executing timer and counter application, constructing latch, DOL and star delta, and performing automatic forward reverse operation.

Minimum Time: 60 Hours



Learning Outcome

- 1.1. Interpret Relay Logic Operation
- 1.2. Perform Mechanical Switching Operation
- 1.3. Execute Timer and Counter Application
- 1.4. Construct Latch, DOL and Star Delta
- 1.5. Perform Automatic Forward Reverse Operation



Performance Criteria

1. Fundamental concepts of relay logic are identified and explained according to industrial automation principles.
2. Components of relay logic circuits are identified.
3. Relay logic components' functions are described.
4. Operation of relay logic circuits is interpreted.
5. Common relay logic symbols and notations are identified.
6. Application of relay logic in industrial automation processes is described.
7. Mechanical switching devices are identified and described.
8. Mechanical switching operation procedures are followed.
9. The contact status is checked using multimeter.
10. Boolean logic operation using relay is executed.
11. Switching devices are operated as per the control system design.
12. Mechanical switches are inspected and tested for proper functioning before and after operation.
13. Timer and counter applications are selected based on control system needs.
14. Timer and counter settings are configured according to application requirements
15. Timer and counter operations are executed following standard procedures.
16. Timer and counter outputs are monitored and verified.
17. Faults or deviations in timer and counter performance are identified.
18. Circuit diagrams for latch, DOL, and star-delta configurations are interpreted.
19. Latch circuits are constructed by connecting relays, contacts, and coils as per standard wiring diagrams.
20. DOL starter circuits are assembled ensuring proper connections for motor start and stop functions.
21. Star-delta starter circuits are constructed following established wiring procedures.
22. Circuits are tested for correct operation.
23. Control circuit for forward and reverse operation is interpreted.
24. Automatic forward and reverse operation are executed using timer and counter.
25. Operation is tested to verify smooth and correct transition between forward and reverse motion.

26. Faults or abnormalities during operation are identified and reported for corrective actions.

Learning Outcome 1.1 – Interpret Relay Logic Operation



Content

- Contact States (Inputs): Normally Open (NO) contacts must be ON (closed) for current to pass. Normally Closed (NC) contacts must be OFF (open) for current to pass.
- Coil Activation (Outputs): If current reaches the output coil (()), the coil energizes (turns ON).
- State Change (Feedback): An energized coil causes all of its associated contacts throughout the diagram to change state: NO contacts close, and NC contacts open, influencing the logic of other rungs.



Assessment Criteria

- Ability to Map Diagram to Logic Gates
- Predicting Output State Based on Inputs
- Understanding Latching/Sealing Circuit Function



Necessary Equipment

- Relay

- Magnetic Contactor
- Timer
- Switch
- Load
- Auxiliary Device



Learning Activity 1.1-1

Learning Activity	Resources/ Instructions/ References
Interpret Relay Logic Operation	• Information Sheet: 1.1-1 • Self-Check: 1.1-1 • Answer Paper: 1.1-1 • Job Sheet 1



Information Sheet 1.1-1

Learning Objective: The learner will be able to read and interpret standard relay ladder diagrams, correctly identifying the components and explaining the logical sequence of operation for simple control circuits.

Safe working practices in Electrical Sequence and Control

Safe working practices are essential when dealing with electrical sequence circuits and control systems, as these involve direct interaction with live electrical components, wiring, and control devices. Before beginning any task, workers must strictly follow **Occupational Health and Safety (OHS) procedures**, including the use of appropriate personal protective equipment (PPE) such as **insulated gloves, safety shoes, and protective eyewear**. Electrical panels and circuits should always be **de-energized, locked out, and tagged out (LOTO)** before performing maintenance or wiring activities to prevent accidental electric shock. Clear labeling of circuit diagrams and components minimizes confusion during installation and troubleshooting. **Proper grounding, correct wire sizing, and insulation checks** are mandatory to avoid **hazards like short circuits, overloading, and fire risks**. Safe working practices also include maintaining a **tidy workspace, avoiding wet or damp conditions** while working, and ensuring that tools and test instruments are rated for electrical use. By adhering to these practices, technicians can protect themselves, their colleagues, and equipment, while ensuring reliable and efficient operation of electrical sequence and control systems.

Personal Protective Equipment (PPE) for Electrical Hazard

Working with electricity exposes technicians to risks such as electric shock, burns, arc flash, and fire. To minimize these hazards, it is essential to wear the correct Personal Protective Equipment (PPE) at all times. The following PPE is commonly used for electrical safety:

Insulated Gloves and Sleeves – Protect against electric shock when handling live wires or equipment.

Safety Footwear – Electrically insulated safety shoes or boots prevent current from passing through the body to the ground.

Protective Clothing / Arc-Rated Clothing – Flame-resistant coveralls or arc-rated garments provide protection against arc flash and fire.

Safety Helmet (Hard Hat) – Protects the head from falling objects and may include dielectric protection against accidental contact with live parts.

Safety Goggles or Face Shield – Shields eyes and face from sparks, flashes, or flying debris during electrical work.

Hearing Protection – Required in areas where loud electrical equipment or arc blasts may occur.

Insulated Tools – Although not worn, insulated tools are part of essential PPE to prevent accidental conduction.

Using the right PPE does not replace safe work practices, but it serves as an added layer of protection. All PPE must comply with international or national safety standards (e.g., ASTM, IEC, or ISO) and should be inspected regularly before use.

Common Electrical Hazards

Working with electricity in industrial automation involves various risks that can cause injury, damage to equipment, or even loss of life if not managed properly. The most common electrical hazards include:

Electric Shock – Occurs when current passes through the body due to direct contact with live wires or faulty equipment. Even low voltage can be dangerous.

Arc Flash – A sudden release of electrical energy through the air that can cause severe burns, blindness, and damage to hearing.

Fire and Explosions – Overloaded circuits, faulty wiring, or short circuits can ignite fires or cause explosions, especially in environments with flammable materials.

Burns – Direct contact with overheated conductors, equipment, or arc flashes can result in thermal or electrical burns.

Faulty or Damaged Insulation – Cracked, worn-out, or exposed wires increase the risk of short circuits and electric shock.

Wet or Damp Conditions – Moisture conducts electricity, raising the risk of shock and equipment damage when working in humid or wet areas.

Improper Use of Electrical Equipment – Using damaged tools, bypassing safety devices, or overloading outlets can create hazardous situations.

Inadequate Grounding – Poor or missing grounding can result in leakage currents and dangerous voltage buildup on equipment surfaces.

Understanding these hazards is the first step toward preventing accidents. Safe work practices, proper use of PPE, regular equipment inspection, and adherence to Occupational Health and Safety (OHS) standards are critical to reducing these risks.

Power Supply

A **power supply** is the fundamental source of electrical energy that drives industrial automation systems, including relays, PLCs, sensors, actuators, and control circuits. In electrical sequence and control applications, power supplies provide the necessary voltage and current to operate devices safely and reliably.

Power supplies are generally categorized into:

AC Power Supply – Derived from mains electricity (commonly 220V/50Hz or 110V/60Hz, depending on the region). It is often used for motors, large equipment, and some control systems.

DC Power Supply – Provides a stable direct current (e.g., 24V DC), commonly required for PLCs, sensors, control relays, and electronic circuits. DC power supplies may come from rectifiers, batteries, or switch-mode power supply (SMPS) units.

Uninterruptible Power Supply (UPS) – Ensures continuous power during outages or voltage fluctuations, protecting sensitive automation equipment from unexpected shutdowns.

Isolated/Regulated Power Supplies – Used when stable and noise-free voltage is critical, especially in precision control and instrumentation systems.

A power supply converts electrical energy from the mains into a usable form for automation devices. The process typically involves several stages:

1. **AC Input (220V/110V)** – Standard mains electricity enters the system.
2. **Rectifier (AC → DC)** – Converts alternating current (AC) into pulsating direct current (DC).
3. **Filter** – Smooths out ripples in the DC signal using capacitors or inductors.
4. **Regulator** – Provides a stable and constant DC voltage regardless of fluctuations in input or load.
5. **DC Output (e.g., 24V DC)** – Powers PLCs, relays, sensors, actuators, and control circuits.

The diagram below illustrates this flow from AC input to regulated DC output.

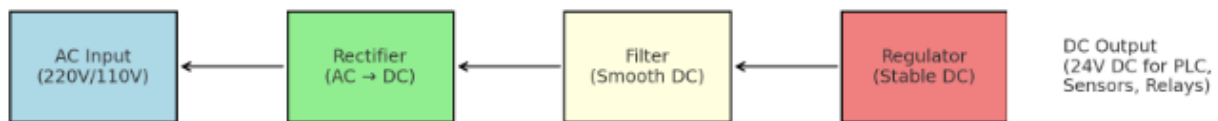


Fig: Typical Power Supply System in Industrial Automation

Electrical Protection Devices

Electrical protection devices are essential components in industrial automation systems, as they safeguard people, equipment, and circuits from damage caused by overcurrent, short circuits, overloads, voltage fluctuations, and earth faults. Their role is to detect abnormal conditions and disconnect or isolate the faulty circuit to prevent hazards such as electric shock, fire, or equipment failure.

Fuse

A **fuse** is the simplest and oldest form of electrical protection device. It is designed to protect electrical circuits and equipment from **overcurrent** conditions, such as short circuits or overloads. A fuse contains a thin metallic wire or strip that melts and breaks the circuit when excessive current flows through it. This action prevents further damage to equipment and reduces the risk of fire.

Types of Fuses

- Cartridge Fuse – Cylindrical, enclosed fuse for industrial use.
- Plug Fuse – Commonly used in domestic wiring.
- High Rupturing Capacity (HRC) Fuse – Used in high-voltage or heavy-duty industrial applications.
- Resettable/Polyfuse – Automatically resets after the fault condition is removed.

Advantages

Low cost, simple to use, fast response to short circuits.

Limitations

Must be replaced after blowing, not suitable for repeated protection, and less precise compared to circuit breakers.

Applications in Industrial Automation

- Protection of **control circuits** and low-power devices.
- Safeguarding **transformers, PLC input/output modules, sensors, and relays.**
- Used in **motor starters and lighting circuits** as backup protection.



Fig: Different Types of Fuses

Miniature Circuit Breaker (MCB)

A **Miniature Circuit Breaker (MCB)** is an automatically operated electrical protection device that protects circuits from **overcurrent** caused by overload or short circuit. Unlike fuses, which must be replaced after they blow, an MCB can be easily **reset** after tripping, making it more reliable and convenient in industrial automation systems.

Key Features:

- Rated for low voltage applications (typically up to 100A).
- Provides quick disconnection to prevent equipment damage.
- Can be manually switched ON or OFF.
- Offers better precision and reusability compared to fuses.

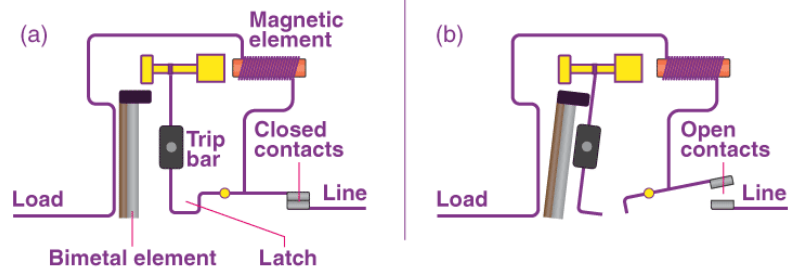


Fig: MCB & It's Working Principle

Working

An MCB trips and disconnects the circuit when current exceeds the safe limit. It uses two mechanisms:

- **Thermal Trip (Bimetallic Strip):** Protects against overload by heating and bending the strip, which trips the breaker.
- **Magnetic Trip (Electromagnetic Coil):** Protects against short circuits by creating a magnetic force that instantly trips the breaker.

Principle

Advantages of MCB

- Easy to operate and reset after a fault.
- Provides reliable protection for long-term use.
- More sensitive and accurate compared to fuses.
- Compact design, suitable for distribution boards and control panels.

Applications in Industrial Automation

- Protecting **PLC power supplies, control wiring, and relay logic circuits.**
- Safeguarding **lighting, heating, and small motor loads.**
- Commonly used in **distribution boards** to protect branch circuits.

Molded Case Circuit Breaker (MCCB)

A **Molded Case Circuit Breaker (MCCB)** is a heavy-duty electrical protection device designed to safeguard electrical circuits, equipment, and systems from **overload, short circuit, and ground fault conditions**. MCCBs are suitable for applications where higher current ratings and adjustable protection are required, typically up to **2,500A**. Unlike MCBs, which are used for small-scale protection, MCCBs are widely used in industrial and commercial power distribution systems.

Key Features:

- Handles medium to high current ratings (typically 100A – 2,500A).
- Adjustable trip settings for flexible protection.
- Equipped with arc extinguishing chambers to safely interrupt fault currents.
- Resettable and reusable after tripping.
- Robust molded case housing provides insulation and mechanical protection.



Fig: MCCB

Working Principle

MCCBs operate by sensing abnormal current flow:

- **Thermal Mechanism (Bimetallic Strip):** Provides overload protection by tripping when excessive current flows for a prolonged period.
- **Magnetic Mechanism (Electromagnetic Coil):** Provides instantaneous protection during short circuits.
- **Electronic Trip Unit (in advanced MCCBs):** Allows precise adjustment of protection settings (overload, short circuit, earth fault).

Advantages of MCCB:

- Suitable for heavy-duty industrial loads.
- Adjustable protection settings for different applications.
- Provides reliable protection for power distribution systems.
- Capable of interrupting high fault currents.

Applications in Industrial Automation:

- Protecting **main power feeders and large motor loads**.
- Safeguarding **distribution panels, PLC cabinets, and automation equipment**.
- Used in **factories, manufacturing plants, and heavy machinery control systems**.
- Ideal for **backup protection** in combination with MCBs and fuses.

Air Circuit Breaker (ACB)

An **Air Circuit Breaker (ACB)** is an electrical protection device designed to protect low-voltage electrical circuits from overcurrent, short circuits, and electrical faults. Unlike MCBs and MCCBs, which are commonly used for residential or small industrial applications, ACBs are used for **high-current and large-scale industrial power distribution systems**.

Working Principle

When a fault occurs, the ACB senses the overcurrent or short circuit through its trip unit. It then operates the mechanism to **separate the contacts**, creating an electric arc that is immediately extinguished using air. This interrupts the current flow and protects the circuit.

Features & Advantages:

- Suitable for high-current applications (hundreds to thousands of amperes).
- Can be **manually or automatically operated**.
- Offers reliable protection for industrial machinery and power distribution panels.
- Can be equipped with auxiliary contacts for remote monitoring.
- Often has adjustable trip settings for **overload and short-circuit protection**.

Applications:

- Main incoming feeders of **industrial plants**.
- Large **power distribution boards**.
- Protection of **motors, transformers, and generators**.

Leakage Current Circuit Breaker

A **Leakage Current Circuit Breaker (LCCB)**, also known as a **Residual Current Circuit Breaker (RCCB)** or **Earth Leakage Circuit Breaker (ELCB)**, is a protective device that detects **leakage current** (current flowing to earth) and disconnects the circuit to prevent **electric shock and fire hazards**. Unlike MCBs or MCCBs, LCCBs do **not protect against overcurrent**; their primary function is leakage detection.

Construction:

- **Current Transformer (CT):** Detects imbalance between live (phase) and neutral currents.
- **Trip Mechanism:** Activates when leakage current exceeds the preset threshold.
- **Contacts:** Opens the circuit quickly to interrupt the fault current.
- **Test Button:** Allows periodic testing of the device for proper operation.

Working Principle:

1. In a normal circuit, the current flowing through the phase conductor equals the current returning through the neutral.

2. If a leakage occurs (e.g., due to insulation failure or a person touching a live part), the returning current is **less than the outgoing current**.
3. This imbalance is detected by the LCCB.
4. The trip mechanism immediately opens the contacts, **cutting off the supply** and preventing electric shock or fire.

Features & Advantages:

- Protects **humans from electric shocks**.
- Prevents **fire hazards due to leakage currents**.
- Fast response time (typically 20–40 ms).
- Sensitive to low leakage currents (common ratings: 10 mA, 30 mA, 100 mA, 300 mA).
- Can be used in **residential, commercial, and industrial installations**.

Applications:

- Residential electrical panels to protect occupants.
- Industrial machinery where leakage currents could be dangerous.
- Hospitals, laboratories, and damp areas where safety is critical.
- Protection of electrical equipment against insulation faults.

High Rupturing Capacity Fuse (HRC Fuse)

A **High Rupturing Capacity (HRC) Fuse** is a type of fuse designed to safely interrupt **very high fault currents** without causing damage to the circuit or surrounding equipment. Unlike ordinary fuses, HRC fuses can carry normal current continuously but operate rapidly when a severe short circuit occurs.

Construction:

- **Fuse Element:** Usually made of silver, copper, or an alloy, enclosed in a heat-resistant ceramic body.

- **Ceramic Body:** Provides mechanical strength and high heat resistance.
- **Quartz Powder / Arc Quenching Medium:** The fuse is filled with quartz powder or similar materials, which absorb the heat and extinguish the arc when the fuse blows.
- **End Caps / Terminals:** Metallic caps at both ends for secure electrical connection.

Working Principle:

1. Under normal conditions, the fuse element carries the rated current without overheating.
2. When an overcurrent or short circuit occurs, the fuse element **melts quickly** due to excessive heat.
3. The arc produced during melting is absorbed and extinguished by the **quartz powder**, ensuring safe interruption.
4. This prevents damage to connected equipment and ensures system protection.

Features & Advantages:

- Can safely interrupt **extremely high fault currents** (up to tens of kiloamperes).
- Very **reliable and consistent** operation.
- Compact and easy to install.
- Provides **current-limiting action** (reduces peak fault current).
- Ensures fast and safe operation in case of short circuit.

Applications:

- Protection of **transformers, motors, and switchgear**.
- High-capacity **industrial power distribution systems**.
- Backup protection in **circuit breakers**.
- Used in **automobiles, UPS systems, and heavy electrical equipment**.

Relay

Electronic relays are devices that open/close the contact point through the electromagnetic force that comes from the flowing current in their electronic coils. Generally relays are used in the sequence circuits, branch and connection of circuits, low voltage power input and interruption. Electronic relays flow currents to acquire the electromagnet state and the state when the current does not flow and loses its electromagnetic state it is called demagnetization.

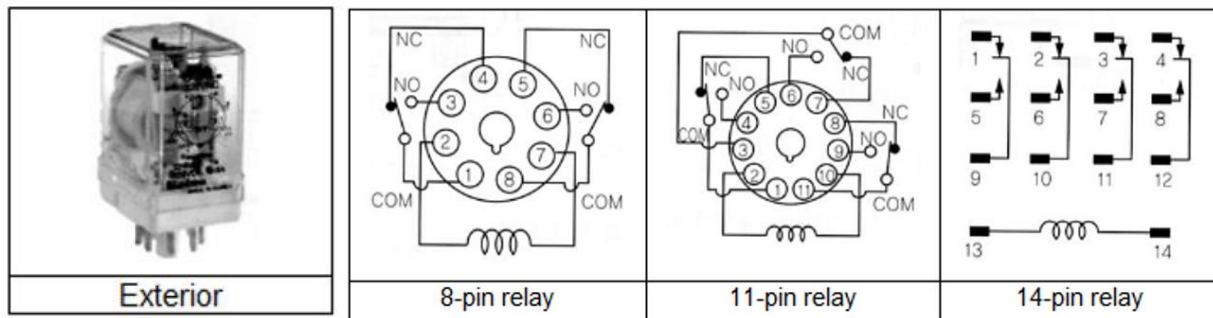


Fig: Relay & Types

5 Pin Relay

A 5-pin relay is a commonly used electromechanical switch that allows you to control a high-current circuit using a low-current signal. It is widely used in automotive, industrial, and home automation applications.

Basic Components of a 5 Pin Relay

1. **Coil:** The electromagnet that activates the relay when voltage is applied.
2. **Common (COM):** The moving part of the relay that connects to either the Normally Closed (NC) or Normally Open (NO) terminal.
3. **Normally Closed (NC):** A terminal that is connected to COM when the relay is not energized.
4. **Normally Open (NO):** A terminal that is connected to COM when the relay is energized.
5. **Control Pins:** The pins connected to the coil for activating the relay.

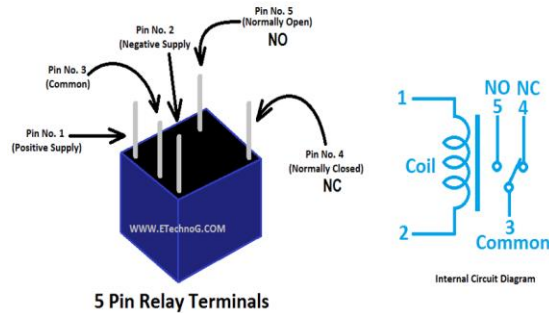


Fig: 5 Pin Relay & structure

8 Pin Relay

An 8-pin relay is typically used in more complex electrical systems where additional connections or configurations are required. These relays are often found in applications like automation systems, industrial controls, or where multi-pole switching is needed.

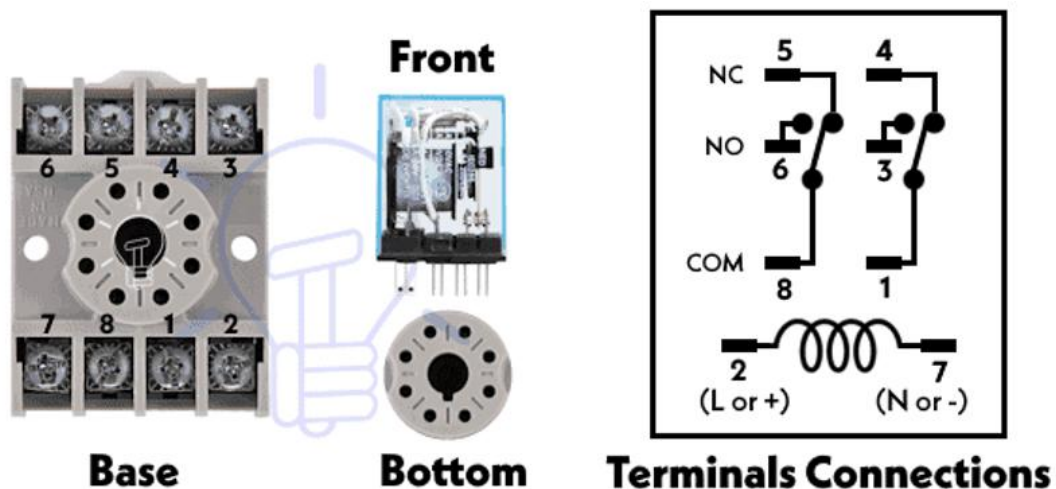


Fig: 8 Pin Relay & Structure

11 Pin relay

An 11-pin relay is typically a multi-function relay used in industrial control systems and automation applications. It allows for more complex connections and is commonly associated with time delay relays, multi-pole relays, or other specialized relays.

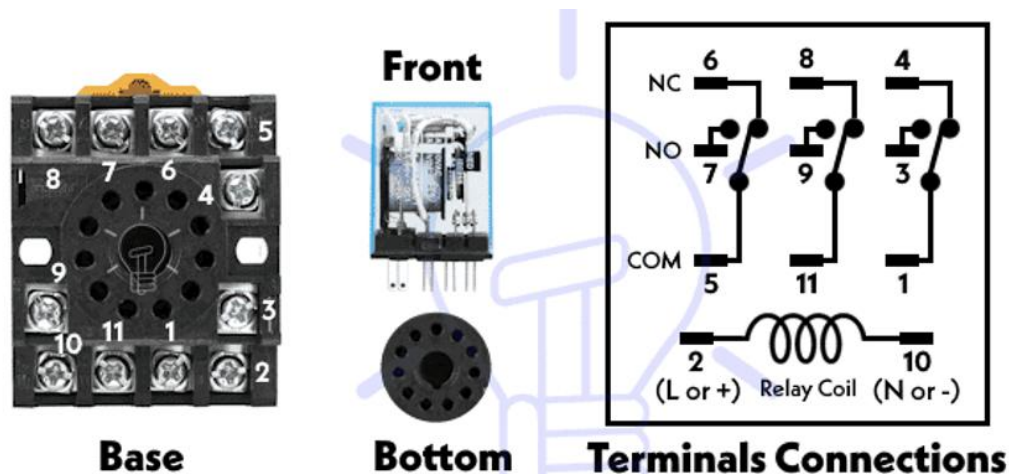


Fig: 11 Pin Relay & Structure

14 Pin Relay

A 14-pin relay is typically a versatile, multi-functional relay designed for complex applications where multiple circuits need to be controlled simultaneously. These relays are commonly used in industrial automation, control systems, and advanced logic circuits. They often support configurations like 4PDT (Four-Pole Double-Throw) or are used in timer relays or sequencing applications.

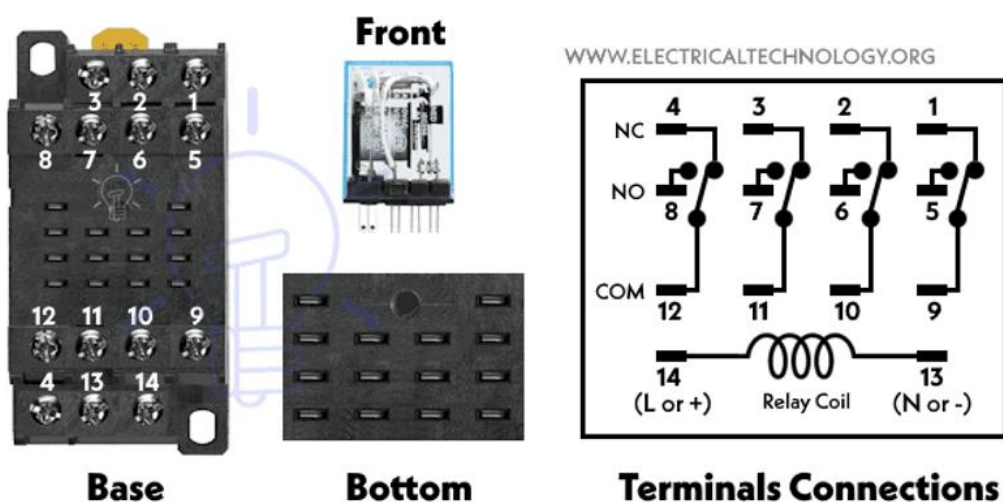


Fig: 14 Pin Relay & Structure



Self-Check 1.1-1

1. Name three specific items of Personal Protective Equipment (PPE) that workers must use when dealing with live electrical components.
2. According to the text, what are the four stages of conversion in a typical power supply system after the AC Input?
3. What is the primary function of a Leakage Current Circuit Breaker (LCCB), and what kind of hazards does it prevent?
4. What are the two mechanisms an MCB (Miniature Circuit Breaker) uses to trip and disconnect the circuit?
5. Besides Electric Shock, Arc Flash, and Fire/Explosions, what are two other common electrical hazards mentioned in the text?
6. What is the function of a relay in sequence circuits, and what are the two electromagnetic states mentioned?



Answer Paper 1.1-1

1. Three specific items of Personal Protective Equipment (PPE) are insulated gloves, safety shoes, and protective eyewear.
2. The four stages are: Rectifier (AC $\rightarrow$ DC), Filter, Regulator, and DC Output (e.g., 24V DC).
3. The primary function of an LCCB is to detect leakage current (current flowing to earth) and disconnect the circuit to prevent electric shock and fire hazards.
4. An MCB uses a Thermal Trip (Bimetallic Strip) to protect against overload and a Magnetic Trip (Electromagnetic Coil) to protect against short circuits.
5. Two other common electrical hazards are Burns (thermal or electrical burns) and Faulty or Damaged Insulation (increasing the risk of short circuits and electric shock).
6. Relays are used in the sequence circuits, branch and connection of circuits, low voltage power input and interruption. The two states are the electromagnet state (when current

flows) and demagnetization (when current does not flow and the coil loses its electromagnetic state).

	Job Sheet 1
Qualification	Industrial Automation
Learning Unit	Identification of Ratings of Power Supply, Relay, MC and Motor
Trainee Name	
PPE	Safety glasses, Insulated gloves (for potential handling/inspection of powered equipment), Work boots, and appropriate work clothes.
Tools & Equipment	Multimeter (Digital/Analog), Magnifying glass, Cleaning cloth/brush, Permanent marker/Tagging system, and a variety of Power Supply, Relays, Motor Contactors (MC), and Motors for inspection.
Notes	1. ALWAYS confirm power is OFF (LOTO) before physical inspection. 2. Record all ratings (Voltage, Current, Power, Frequency) clearly. 3. Pay special attention to coil voltage on relays/MCs and Full Load Amps (FLA) on motors. 4. Use the magnifying glass for small print on nameplates.
Procedure	1. Safety First: Apply LOTO to all components being inspected. 2. Power Supply: Locate the nameplate/label. Record Input Voltage/Frequency, Output Voltage (DC/AC), and Max Output Current (Amps). 3. Relay: Identify the device. Record Coil Voltage and Contact Rating (Volts/Amps) for NO/NC contacts. 4. Motor Contactor (MC): Identify the device. Record Coil Voltage and Rated Operational Current (Ie) for the main power contacts. 5. Motor: Locate the nameplate. Record Voltage, FLA (Full Load Amps), Horsepower (HP) or Kilowatts (kW), Speed (RPM), and Service Factor.

	6. Documentation: Check all recorded values against system specifications (if available). Clean and tag components if necessary. 7. LOTO Removal: Safely remove LOTO after procedure completion.
Trainee's Signature	
Assessor's Signature	
QA Signature	
Assessor's Comment	

Learning Outcome 1.2 – Perform Mechanical Switching Operation



Content

- Relay Logic Fundamentals: Understand the basic operation, construction, and types of electromechanical relays (e.g., normally open/NO, normally closed/NC contacts, coil).
- Circuit Diagrams and Schematics: Learn to read and interpret standard relay ladder diagrams, including power and control sections, and common control elements like pushbuttons, limit switches, and indicator lights.
- Safety Procedures and Lockout/Tagout (LOTO): Recognize and apply essential electrical safety practices before, during, and after performing switching operations on control panels.



Assessment Criteria

- Operational Correctness
- Adherence to Safety Protocols
- Circuit Verification



Necessary Equipment

- Relay
- Magnetic Contactor
- Switch
- Load
- Terminal
- Multimeter
- Wire Stripper



Learning Activity 1.2-1

Learning Activity	Resources/ Instructions/ References
Perform Mechanical Switching Operation	• Information Sheet: 1.2-1 • Self-Check: 1.2-1 • Answer Paper: 1.2-1 • Job Sheet 2



Information Sheet 1.2-1

Learning Objective: The learner will be able to read and interpret standard relay ladder diagrams, correctly identifying the components and explaining the logical sequence of operation for simple control circuits.

Electrical Switching and Controlling Devices

In industrial automation and electrical systems, switching and controlling devices are essential for **starting, stopping, protecting, and regulating electrical circuits and equipment**. These devices ensure safe operation, efficient control, and reliable performance of machines and power distribution systems. Electrical switching and controlling devices are components that are used to **manually or automatically connect, disconnect, or regulate the flow of electric current** in a circuit. They can operate at different voltage and current levels depending on the application.

Switch

A switch is a fundamental electrical component used to control the flow of electric current in a circuit. In its simplest form, a switch can either complete an electrical circuit, allowing current to flow, or interrupt the circuit, stopping the current. Switches are essential for operating and controlling a vast array of electrical devices and systems, from simple light fixtures to complex industrial machinery.

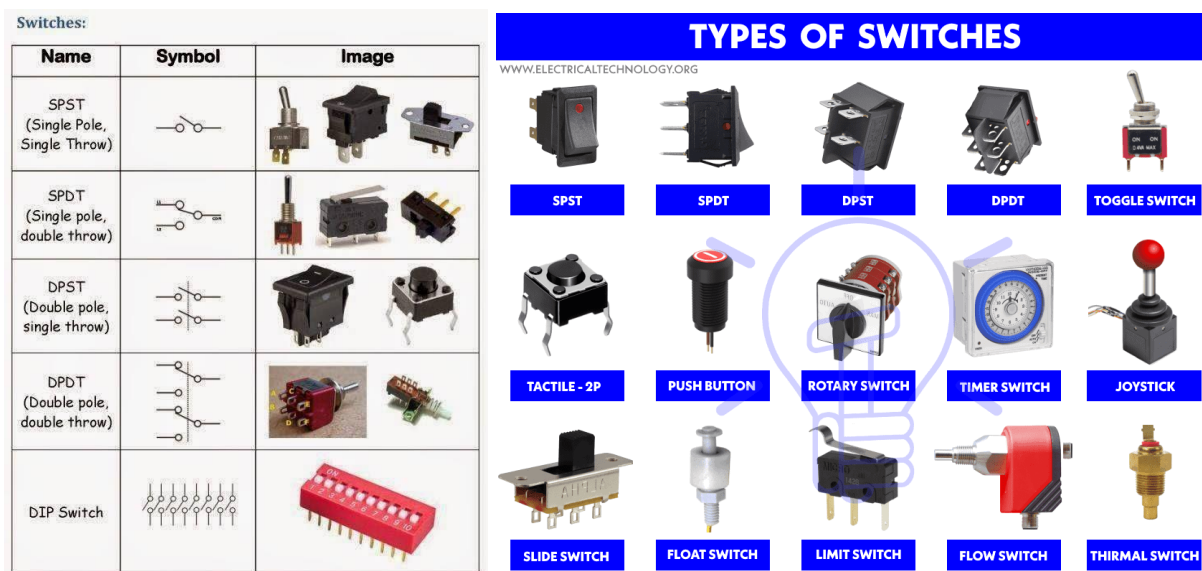


Fig: Types of Switches

Toggle Switch

The toggle switch is used for opening/closing the circuit by handle operation and used as the power switch. A protruded lever is operated in a straight-line motion and when hands are released from lever the operation section (press button or handle) and contact point operation state (operation condition) is maintained. Connection terminals used the soldering types or tie rods types to connect and the switch is used for low capacity power switches.

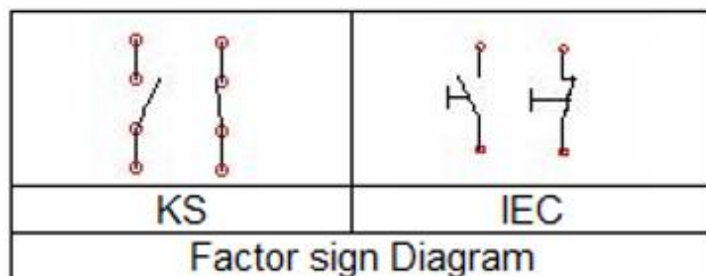


Fig: Toggle Switch and Symbol

Key Switch

Since the handle can be fixed, in circuits that require security the operation can be made only through the use of the keys.

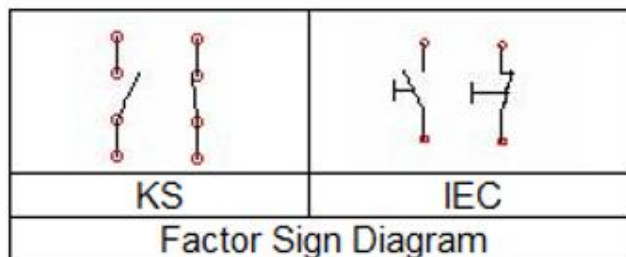
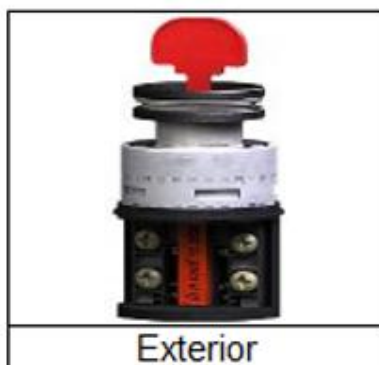


Fig: Key Switch

Cam Switch

Cam switch is a plug composed of the CAM and contact point, since it has several devices attached to one body and its availability is much higher than the dream switch and much smaller in size. Cam switch are enclosed types which prevents oxidation and dust from penetrating. These switches are used mainly for changeovers in ammeters and voltmeters.



Fig: Cam Switch

Push Button Switch

By pushing the button, the contact point device section is turned on/off and the circuit is turned on or off. There are 2 types of push buttons, the restoring type where the button is restored to the original state when it is released with the help of the spring and the maintaining type where the once pushed button maintains its state.



Fig: Push Button Switch

Foot Switch

Foot switches are used in situations when both hands are occupied in operation to operate or stop the machine which is made possible by installing the micro switch in the footboard. There is an operation suspension device in the footboard and a foot switch protection cover is attached to it. Application examples can be easily found in the industrial fields such as electric sewing machines, press machines, etc.

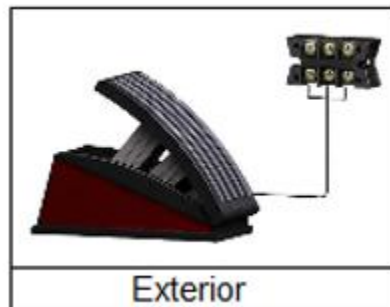


Fig: Foot Switch

Forward Reverse Switch

Mostly used in forward-reverse switch in motors. It may also be used for the forward and reverse operation of the motor and the order for operation is FOR (normal rotation), STOP, REV (reverse rotation).

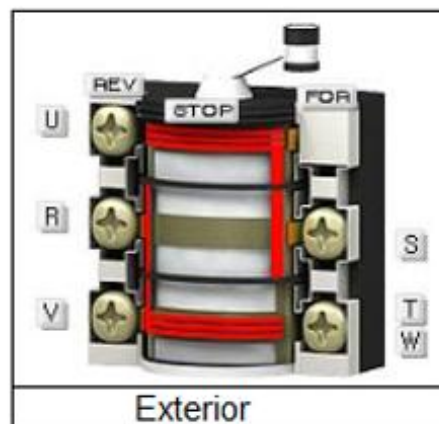


Fig: Forward Reverse Switch

Emergency Switch

At times of emergency when all circuit needs to be shut down, the emergency switch which is the red projected switch can be pressed and maintained. The switch is restored by turning the switch to the right.



Fig: Emergency Switch

Micro Switch

Micro switches are a small sized switch that have the contact instrument built in the molded case and has pressure detection, action instruments and is operated by the set force and movement. The contact instrument is placed within an insulated case with an actuator in the outer side. Micro switches are small in size and used for the same purpose as the limit switch.

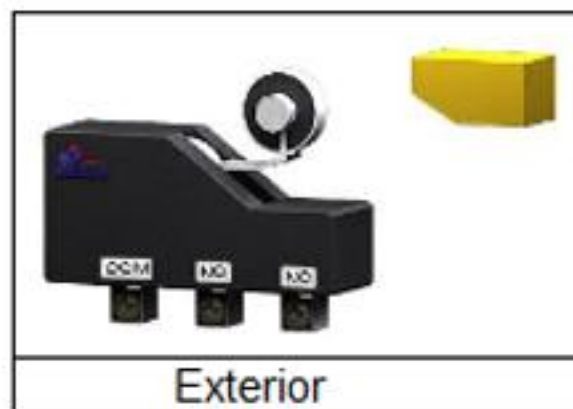


Fig: Micro Switch

Limit Switch

Limit switch which uses the touch action of the sequence control is the most widely used detection switch for detecting the location of the object for control, limiting the driving distance and for transferring the processes. When the switch comes in contact with the action detectable part the contact moves and the contact turns on/off. There is A Contact and B contact. The cam detects the processing situation at the designated location and detects whether the dog is placed in the designated locations.

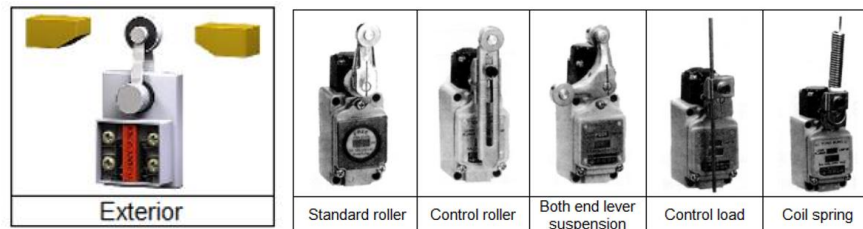


Fig: Limit Switch and types

Photo Switch

Photo switch can be divided into the transmittance section which generates the light and this light is reflected, transmitted, absorbed and shielded by the object and the light intercepted in the interception section gives off the ON/OFF signal. Photo switches are sensors that use luminous elements (PN junction elements such as GaAs, CaAlAs, Gap, etc) in the transmittance section to transfer electric energy into light which can inspect the targeted object and the light changes shown by the object is received and transferred or amplified (elements like photodiode, photo transistor etc) into electric signals.



Fig: Photo Switch

Proximity Switch

Proximity switches control the by turning on/off the electric circuit which is connected to the detection head and metallic objects that approach the detection head can be detected by using the magnetic field without making mechanical contact. High frequency oscillation type proximity types that use high frequency magnetic field are most widely used. High frequency oscillation types use the method where high frequency is oscillated in the detection section and when the object approaches the oscillating power change caused by the eddy-current loss are detected and starts its operation.

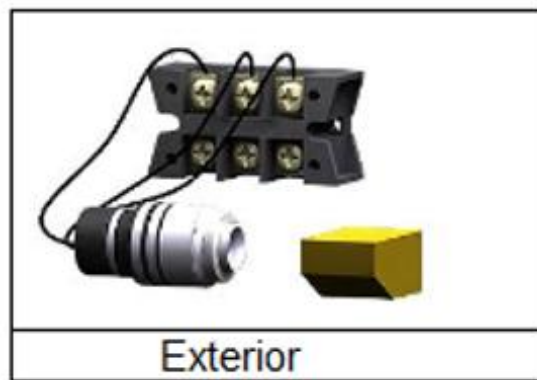


Fig: Proximity Switch

Cover Knife Switch

Knife switches are operated by manually moving the handle the electric circuit opens or closes. This type of operation switches maintains its open/close state even when the hands are off the switch. Switches that are operated by manually opening/closing the circuit like the knife switch, the contact points are called the manually operated switch contact point. Knife switches are mostly used in short circuits of low voltage circuits and for opening/closing the load current and at the same time for the purpose of protecting over currents combined with the wiring fuses.



Fig: Cover Knife Switch

Floatless Switch

Also called the floatless relay, the floatless switch is used in plants when controlling the liquid level. The floatless switches is used for multipurpose such as agricultural water, filtration plant, sewage treatment plant and water & sewage in ordinary homes. Floatless switches are small and light making it easy to install and is mostly operated by 220V of input voltage and 8V of electrode voltage (secondary voltage).

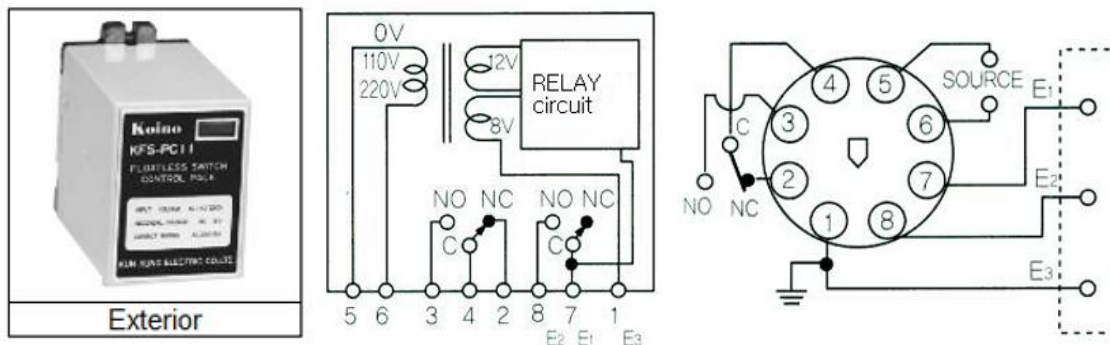


Fig: Floatless Switch and Structure

Terminal Block

The terminal block is used in the connection of the control board and operation panel, and is called the terminal or socket. Various methods are available, such as the terminal block connection method, ring method, and press panel compression method. The number of wires and rated current in the terminal block must be considered when using the rated value.



Fig: Terminal Block

Thermal Overload Relay

The thermal relays which are also called the thermal overload relay is a relay that operates the contact point when current over the set point flows. These relays are mostly used in motor protection from overloads. When excess current (overcurrent in the motor) flows in the heater inserted in the main circuit using the bimetal's bending principle in heat it is used to shut down the protective circuit and to prevent fire damage in the motors. According to the heat transferring method, it can be divided into the series, semi-indirect, and parallel types.

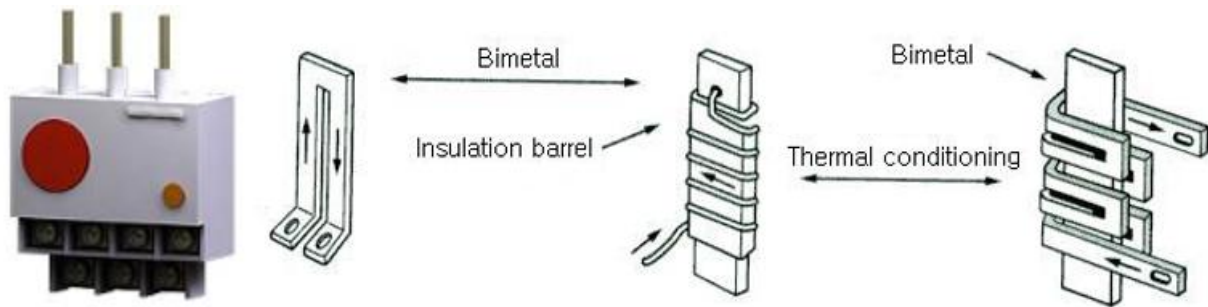


Fig: Thermal Overload Relay & Structure

Electronic Overcurrent Relay

Electronic overcurrent relay shows definite actions compared to the thermal heater relay, and it perfectly prevents frost formation and single-phase operation caused by overcurrent. Actual load current check and precise current adjustment is possible by using the current adjustment knob and lamp. Since the delay time and operation are independent of each other, the operation time may be selected to make perfect protection possible. The test function is built in, which makes operation test and circuit test possible, and through the condenser drop method, selection power consumption can be lowered, and in the cartridge type transformer's the cartridge number can be adjusted, which can enlarge their scope of use. And with the built-in of the signal output circuit, there are no malfunctions in the inching and wave load. And with the thermal compensating circuit inside it, it can be safe.

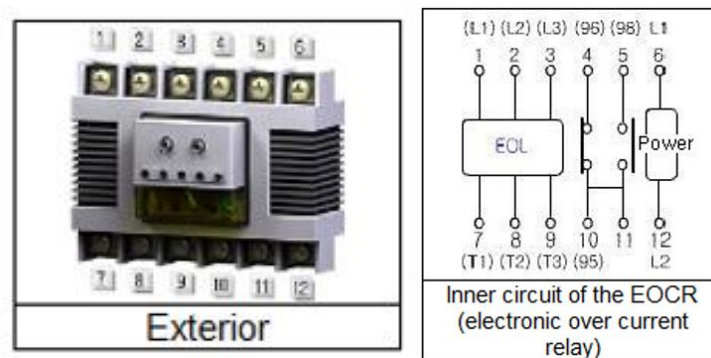


Fig: EOR & Structure

Power Relay

The power relay is produced to make opening/closing possible instead of the electromagnetic contactors. And like the relay, handling is easy and can be used anytime the base is inserted. Compared to the electromagnetic contactor, which is difficult to inspect in times of failure, the power relay can be inspected for any failures when the control box is being manufactured or during failures, which gives it a time-saving advantage.

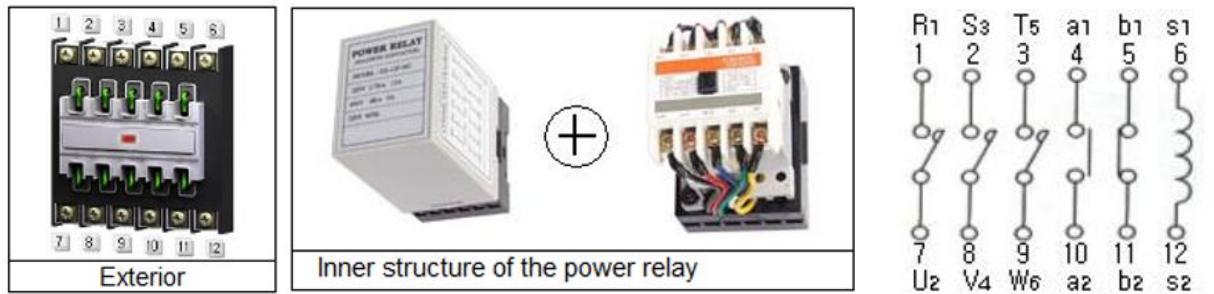


Fig: Power Relay & Structure

Time Delay Relay/ Timer

A Time Delay Relay (TDR) is a type of relay designed to delay the opening or closing of its contacts after a control signal is applied or removed.

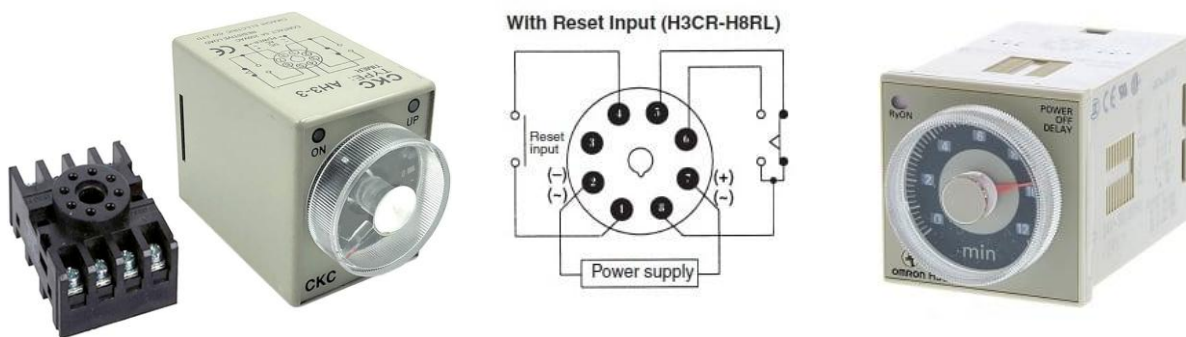


Fig: Time Delay Relay/ Timer

On-Delay Timer

An on-delay timer is a type of timer relay that waits for a set period of time after a control signal is applied before changing the state of its contacts. Once the set time has elapsed, the timer "times out," and its contacts change state (e.g., normally open contacts close, and normally closed contacts open). The contacts remain in this new state as long as the control signal is present.

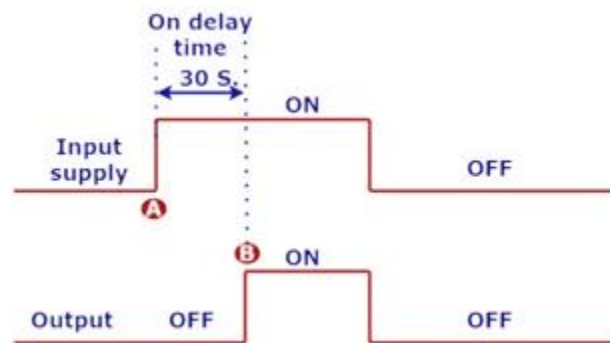


Fig: On-Delay Timer Cycle

Off-Delay Timer

An off-delay timer is a timing relay that keeps a device energized for a preset period of time after the control signal is removed. Unlike an on-delay timer, which waits to turn something on, an off-delay timer allows something to continue running for a while after it's been turned off. This function is also known as "delay-on-break" because the delay begins when the circuit is broken.

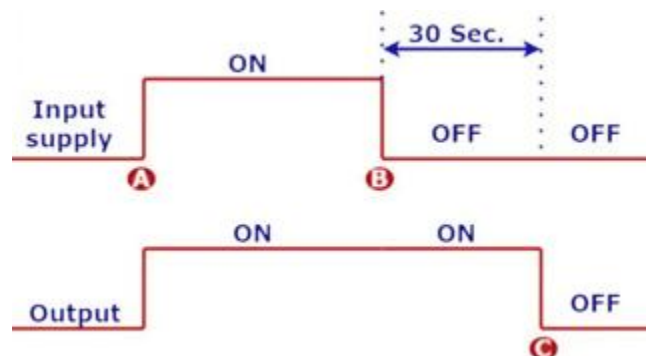


Fig: Off-Delay Timer Cycle

Pulse Timer

A pulse timer, also known as a one-shot timer, is a type of timer relay that, when triggered, energizes its output for a specific, preset duration. The key characteristic of a pulse timer is that the output pulse length is independent of the input signal duration. It generates a single, timed pulse regardless of whether the input signal is a momentary press or a continuous-on signal.

Retentive Timer

A retentive timer, also known as a Retentive Timer On (RTO), is a type of timer that "remembers" or retains its accumulated time even if its input signal is interrupted or power is lost. This is in contrast to a standard on-delay timer, which resets its accumulated value to zero whenever its input signal goes false.

Counter Relay/ Counter

A counter relay is a type of relay that activates its output after a predefined number of input pulses or events have been counted.



Fig: Counter Relay/ Counter

Up Counter

An up counter, often abbreviated as CTU, is a type of instruction used in programmable logic controllers (PLCs) and other digital control systems that counts discrete events. The counter

increments its value by one each time its input receives a signal, such as a rising edge from a sensor or a button press.

How It Works

An up counter has three main components:

- **Count Up (CU) Input:** This is the trigger. Each time this input transitions from a false to a true state (a "rising edge"), the counter's accumulated value increases by one.
- **Reset (R) Input:** This input is used to manually reset the counter's accumulated value back to zero. When this input is true, the counter is reset.
- **Preset Value (PV):** This is the target number of events the counter is configured to count.
- **Accumulated Value (ACC):** This is the current count of events.
- **Done Bit (DN):** This is an output that becomes true when the accumulated value is equal to or greater than the preset value. This "done bit" is often used to trigger a subsequent action in the program.

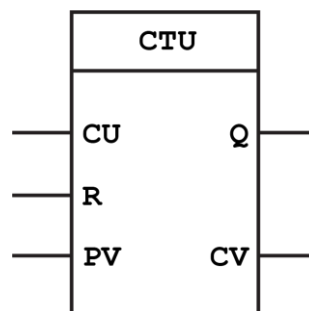


Fig: CTU in PLC

Down Counter

A down counter, or CTD in PLC programming, is a counter that decreases its accumulated value by one each time its count input is triggered. It is used to count down from a preset number to zero.

How It Works

A down counter has three key components:

- **Count Down (CD) Input:** This is the trigger. Each time this input transitions from a false to a true state (a "rising edge"), the counter's accumulated value decreases by one.
- **Load (LD) Input:** This input is used to initialize the counter's accumulated value to the preset value. When this input is true, the counter is loaded with its preset value, allowing the countdown to begin.
- **Preset Value (PV):** This is the target number of events from which the counter will count down.
- **Accumulated Value (ACC):** This is the current count of events.
- **Done Bit (DN):** This is an output that becomes true when the accumulated value reaches zero. This "done bit" is often used to trigger a subsequent action in the program, such as stopping a process or activating a light.

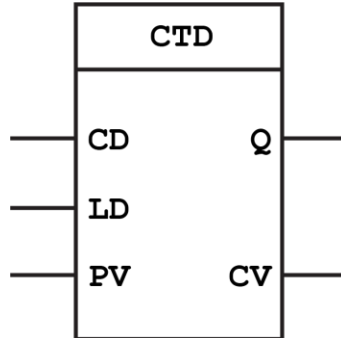


Fig: CTD in PLC

Magnetic Contactor (MC)

A magnetic contactor is an electrically controlled switch used for switching an electrical power circuit. It's similar to a relay but is designed to handle much higher current loads, making it ideal for industrial applications like controlling electric motors, heating systems, and large lighting circuits.

Components

- **Coil:** The electromagnet that creates the magnetic field to operate the contacts.
- **Contacts:** These are the switching parts. They include **main contacts** for the high-power load and **auxiliary contacts** for the control circuit. Most contactors have normally open (NO) main contacts.
- **Arc Chute:** A device designed to extinguish the electric arc that forms when the contacts open under a heavy load, which prevents damage to the contacts and prolongs the contactor's life.
- **Housing:** A non-conductive, fire-resistant enclosure that protects the internal components and insulates the operator from the live parts.



Fig: Magnetic Contactor

How It Works

The operation of a magnetic contactor is based on electromagnetism. It consists of a coil (an electromagnet) and a set of contacts (both fixed and movable).

1. **De-energized State:** When the coil is not energized, the main contacts are held open by a spring, interrupting the power circuit. The auxiliary contacts, if present, are in their normal state (either open or closed).

2. **Energized State:** When a control voltage is applied to the coil, it creates a strong magnetic field. This field attracts a movable iron core, which in turn pulls the movable contacts to connect with the fixed contacts.
3. **Circuit Closed:** The closing of the main contacts completes the power circuit, allowing a large current to flow to the load (e.g., a motor). At the same time, any auxiliary contacts will also change their state, which can be used for interlocking or signaling.
4. **De-energized State:** When the control voltage is removed, the magnetic field collapses, and the spring pushes the contacts back to their original position, opening the circuit and safely cutting off power to the load.

Applications

Magnetic contactors are used extensively in various industries due to their reliability and ability to handle high-power loads.

- **Motor Control:** They are a core component of motor starters (like DOL starters), providing a safe way to turn motors on and off and often paired with an overload relay for protection.
- **HVAC Systems:** Used to control compressors and fans in large heating, ventilation, and air conditioning units.
- **Lighting Control:** Ideal for managing large-scale lighting systems in commercial buildings, stadiums, and factories.
- **Power Distribution:** They regulate the power supply to different sections of an electrical network.

Programmable Logic Controller (PLC)

The relay timer and counter recently used in the control panel have been replaced by semiconductor elements such as LSI, transistors, etc, which carry out the relay controlling function. Basic sequence control and numerical calculation functions have been added to make the program control possible. The start and end (SCAN) in the memory of the program can be executed by the logic, which is a strong autonomous control device.

The role of the PLC is to sequence control (traditionally a basic function), PID control, Analog control, positioning control, etc. Most PLCs have the basic calculation function, such as AND, OR calculation in the contact points, timer/counter calculation, etc, and application calculation functions such as subroutine, SHIFT, MASTER CONTROL, data calculation, etc.

Initially, the developed PLC was a simple logic controller that controlled the program, but later it carried out more advanced functions such as arithmetic operation, output device control, and communication function. Former relays had the disadvantages of low reliability and the time and expenses when changing the controlling system; inspection and trial operation period can now be saved. Presently the PLC programming is possible, and a friendlier environment can be provided to users and on-site monitoring using various graphs, data can be processed by graphs, etc is now possible. Problems regarding the process and various data can now be collected. The PLC is used in nearly all industrial fields, which are turning into factory automation, making it smaller and more economically priced. When the PLC is controlling the machine or devices, the PLC must make sure the object of control and a program are made so that the PLC can make judgments. PLC program specifications are presently established; however, there are a lot of differences according to the manufacturer and type.



Fig: Programmable Logic Controller (PLC)

Electrical Load Device

An electrical load is any device or component in a circuit that consumes electrical energy and converts it into another form of energy, such as heat, light, or motion. Loads are essential for a circuit to perform useful work.

Lamp/ LED

The lamps are installed in the distribution panel or controlling panel, operation panel, to show the voltage coming in and to display the operation, stop, and failure state of the machine through various lamps. It can be divided into lamps that have trans built-in and those that do not have trans built-in, and the lighting switch that has the push button switch attached.

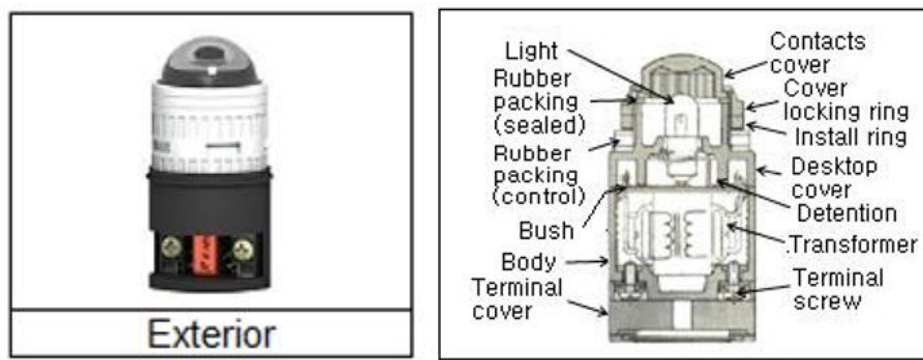


Fig: Lamp & Structure

Bell

Bells are used to deliver signals and they are mostly installed in instruments and devices to show whether a failure has occurred or in any abnormal situations. The bell ends an alarm ring independently or together with the failure display lamp to the user and used in cases when it is necessary to immediately stop the machine or device from failures or in cases like fires, etc that have the danger of developing into disasters. Voltage used in ordinary indoor bells is mostly a weak current of 6-24V in the bell transformer; however, large-scale bells are operated by 220V alternating current. The diameter of the bell is around 6-12cm. The bigger the size, the volume is bigger.

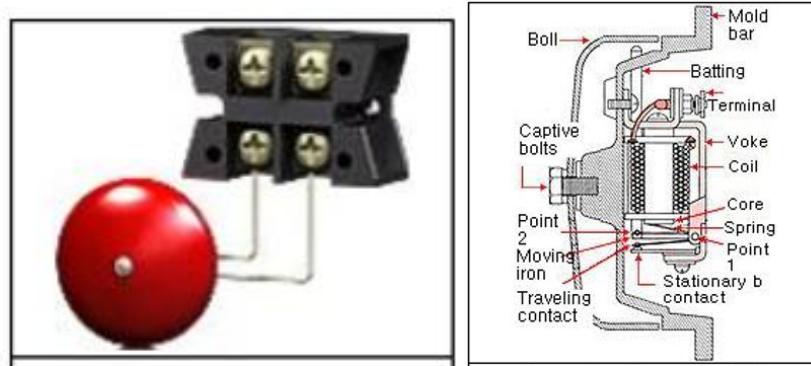


Fig: Bell & Structure

Buzzer

Buzzers are devices that are a combination of an electromagnet and a vibrating reed to give out a signal tone, and current is developed by direct power.

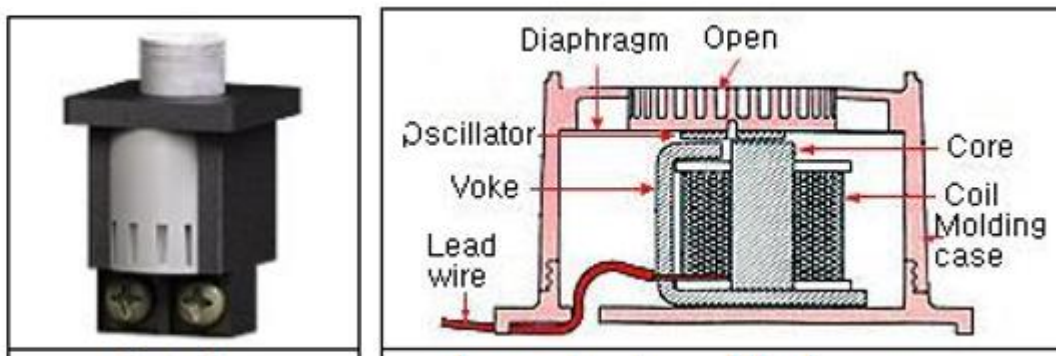


Fig: Buzzer & Structure

Motor

Motors convert electrical energy to mechanical energy to get rotational power. The starting and operation, appropriate model selection according to the load, are easy. Motors show low noise and vibration, and no exhaust pollution, and they are small and lightweight. Motors can be divided into the following types, and 90% of the motors used as the power source are the 3-phase induction motors.

		
Direct current motor	Single phase induction motor	3-phase induction motor

Fig: Motor & Types

Types of Motors

1. **Direct current motor:** When current is applied to the conductor in the magnetic field, it receives a force in the direction based on Fleming's left-hand rule, and the coil turns into conductors, which makes the current flow in both ends of the conductor in the opposite direction. When a rotation force is supplied, the rotation actions develop. The rotation force goes in proportion to the strength of the magnetic field and the current flowing in the conductor.
2. **Single-phase induction motor:** The single-phase induction motor's rotation principle uses the moving magnetic field, which makes the starting and operation rather complicated, and large power cannot be expected. The exterior and rotor types are the same as the 3-phase induction motor and are composed of 2 types of inner coils. Thus, it is composed of the main coil that develops the rotation force and the starting coil that makes the first rotation. And it can be divided into various types according to the method of developing mobility.
3. **3-phase induction motor:** Over 90% of the motors used as the power source are the 3-phase induction motor. 3-phase power develops the rotating magnetic field, and through this rotating magnetic field, the rotor starts rotation, which is why it is called the induction motor. In order to develop rotating magnetic fields, the induction motors are composed of a magnetic field system and a cylinder-type rotor, and according to the rotor type, they can be divided into the squirrel-cage and winding wire types. In small-sized machines, the squirrel-cage type is widely used.



Self-Check 1.2-1

1. What is the fundamental difference between the operation of a restoring type and a maintaining type push button switch?
2. In an industrial setting, when would a Foot Switch be primarily used?
3. What are the three main components of an Up Counter (CTU) used in PLCs, as listed in the text?
4. How does a Thermal Overload Relay protect a motor from overloads, and what is the principle it uses?
5. What is the primary function of the Arc Chute component within a Magnetic Contactor?
6. Explain the key characteristic that distinguishes a Pulse Timer from other timer relays.
7. What kind of objects can be detected by a Proximity Switch, and how does it detect them without mechanical contact?



Answer Paper 1.2-1

1. The restoring type push button switch is restored to its original state when the button is released with the help of a spring, whereas the maintaining type push button switch maintains its state once it has been pushed.
2. A Foot Switch is used in situations when both hands are occupied in operation to operate or stop the machine.
3. The three main components of an Up Counter (CTU) listed are the Count Up (CU) Input, the Reset (R) Input, and the Preset Value (PV).
4. The Thermal Overload Relay protects a motor by using the bimetal's bending principle in heat. When excess current flows in the main circuit heater, the bimetal bends to shut down the protective circuit, preventing fire damage in the motors.

5. The Arc Chute is a device designed to extinguish the electric arc that forms when the contacts open under a heavy load, which prevents damage to the contacts and prolongs the contactor's life.
6. The key characteristic of a Pulse Timer is that the output pulse length is independent of the input signal duration. It generates a single, timed pulse regardless of whether the input signal is a momentary press or a continuous-on signal.
7. A Proximity Switch can detect metallic objects by using a magnetic field (specifically, high frequency oscillation types use the oscillating power change caused by eddy-current loss) without making mechanical contact.

	Job Sheet 2
Qualification	Industrial Automation
Learning Unit	Connecting a relay coil using a power supply, switch, and indicator
Trainee Name	
PPE	Safety glasses, Insulated gloves (if working near energized terminals), and appropriate work clothing.
Tools & Equipment	DC Power Supply (or AC, matching the relay coil rating), Control Relay (with base/socket), Momentary Pushbutton Switch (or toggle switch), Indicator Lamp/LED (matching auxiliary supply voltage), Multimeter (DMM), Screwdriver set (Phillips/Flat-head), Wire stripper/cutter, and Wiring terminals/lugs with connecting wires.
Notes	1. VERIFY VOLTAGES: Ensure the relay coil voltage matches the power supply voltage and the indicator lamp voltage matches its auxiliary supply. 2. Wiring Standards: Maintain clean, neat, and secure wiring terminations. 3. Polarity: Pay attention to polarity when connecting DC coils and LED indicators.

	4. Safety: Follow all LOTO procedures before making or modifying connections.
Procedure	1. Safety/Preparation: De-energize the power supply and apply Lockout/Tagout (LOTO). Gather all necessary components and check ratings. 2. Wiring the Coil Circuit: Connect the power supply's positive terminal (or AC Line) to one side of the Pushbutton Switch. Connect the other side of the switch to Terminal A1 of the relay coil. Connect the relay coil Terminal A2 back to the power supply's negative terminal (or AC Neutral). 3. Wiring the Indicator Circuit: Identify a Normally Open (NO) auxiliary contact on the relay (e.g., Terminal 13-14). Connect the auxiliary power source (which may be the same control power supply) to Terminal 13. Connect Terminal 14 to one side of the Indicator Lamp/LED. Connect the other side of the indicator back to the negative/neutral of the auxiliary supply. 4. Verification: Double-check all wire terminations for tightness and correct polarity. 5. Testing: Remove LOTO, energize the control power supply. Press and hold the pushbutton switch. The relay coil should energize (audible click and/or visual flag) and the indicator lamp should light up. Release the switch; the relay should de-energize, and the indicator should turn off. 6. Final Documentation: De-energize and document the successful operation.
Trainee's Signature	
Assessor's Signature	
QA Signature	
Assessor's Comment	

Learning Outcome 1.3 – Execute Timer and Counter Application



Content

- **Timer and Counter Operation:** Understand the function, types (e.g., On-Delay, Off-Delay timers; Up/Down counters), and internal wiring of Industrial Control Timers (ICTs) and Counters used in relay logic.
- **Circuit Integration and Programming:** Learn how to connect and "program" (set time values/preset counts) timers and counters into ladder diagrams to achieve specific control sequence requirements.
- **Timing and Counting Applications:** Study practical examples such as sequencing motor starts, controlling dwell times, or batch counting, and learn to select the appropriate device for the task.



Assessment Criteria

- Application Accuracy
- Parameter Setting and Verification
- Troubleshooting and Correction



Necessary Equipment

- Relay
- Push Button

- Indicator Light
- Timer
- Counter
- Multimeter



Learning Activity 1.3-1

Learning Activity	Resources/ Instructions/ References
Execute Timer and Counter Application	• Information Sheet: 1.3-1 • Self-Check: 1.3-1 • Answer Paper: 1.3-1 • Job Sheet 3 - Job Sheet 5



Information Sheet 1.3-1

Learning Objective: The learner will be able to correctly wire and program industrial timers and counters in a control circuit to accurately execute time-based and count-based sequences required by an application.

Constructing a Counter Circuit

A counter circuit is a sequential logic circuit in digital electronics that counts and stores the number of clock pulses (transitions) it receives. It typically consists of interconnected flip-flops, which are one-bit memory elements, and often includes combinational logic for specific counting sequences or functions.

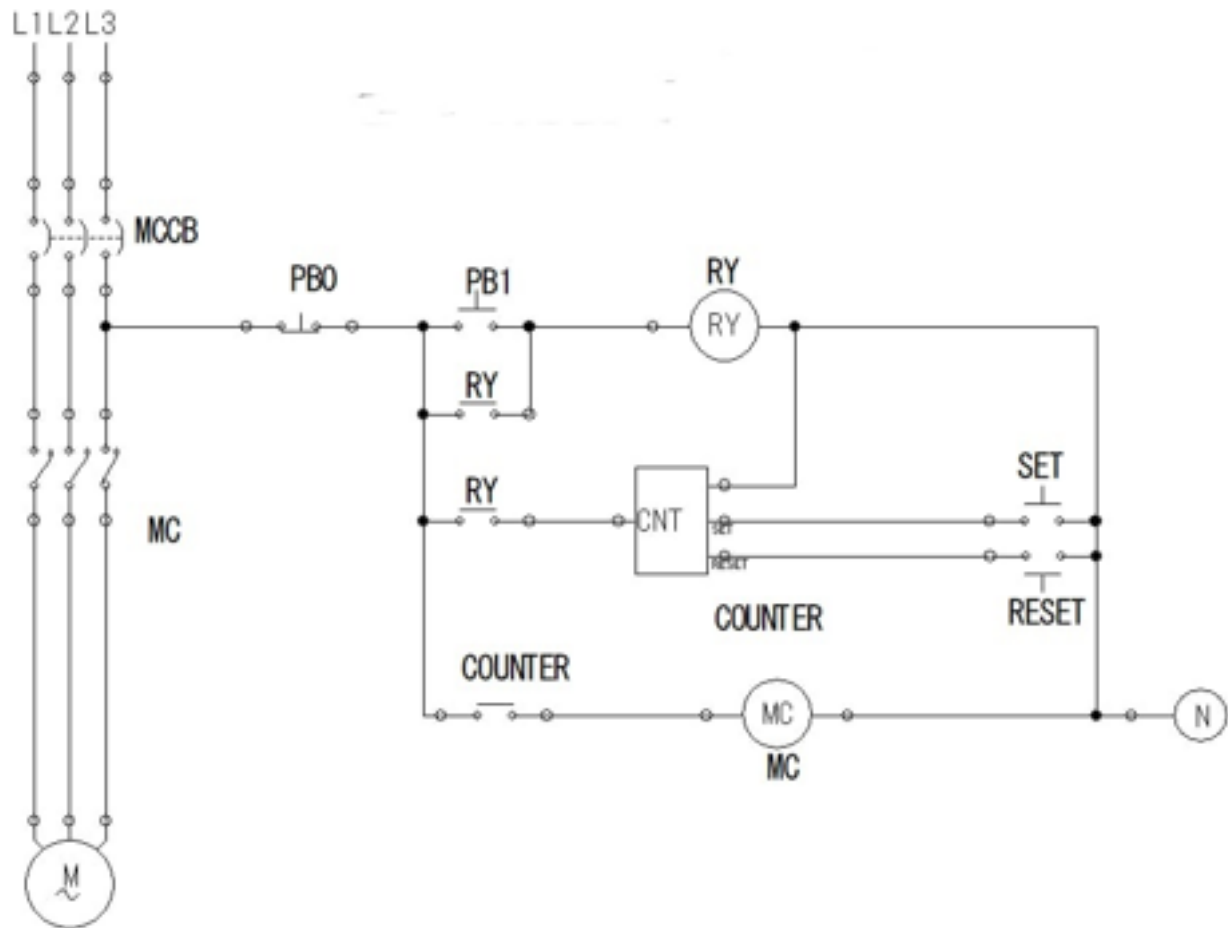


Fig: Counter Circuit

Constructing an Automatic Transfer Switch Circuit

An Automatic Transfer Switch (ATS) circuit is designed to automatically switch an electrical load from a primary power source (like the utility grid) to a backup power source (like a generator) when the primary source fails, and then switch back when the primary source is restored.

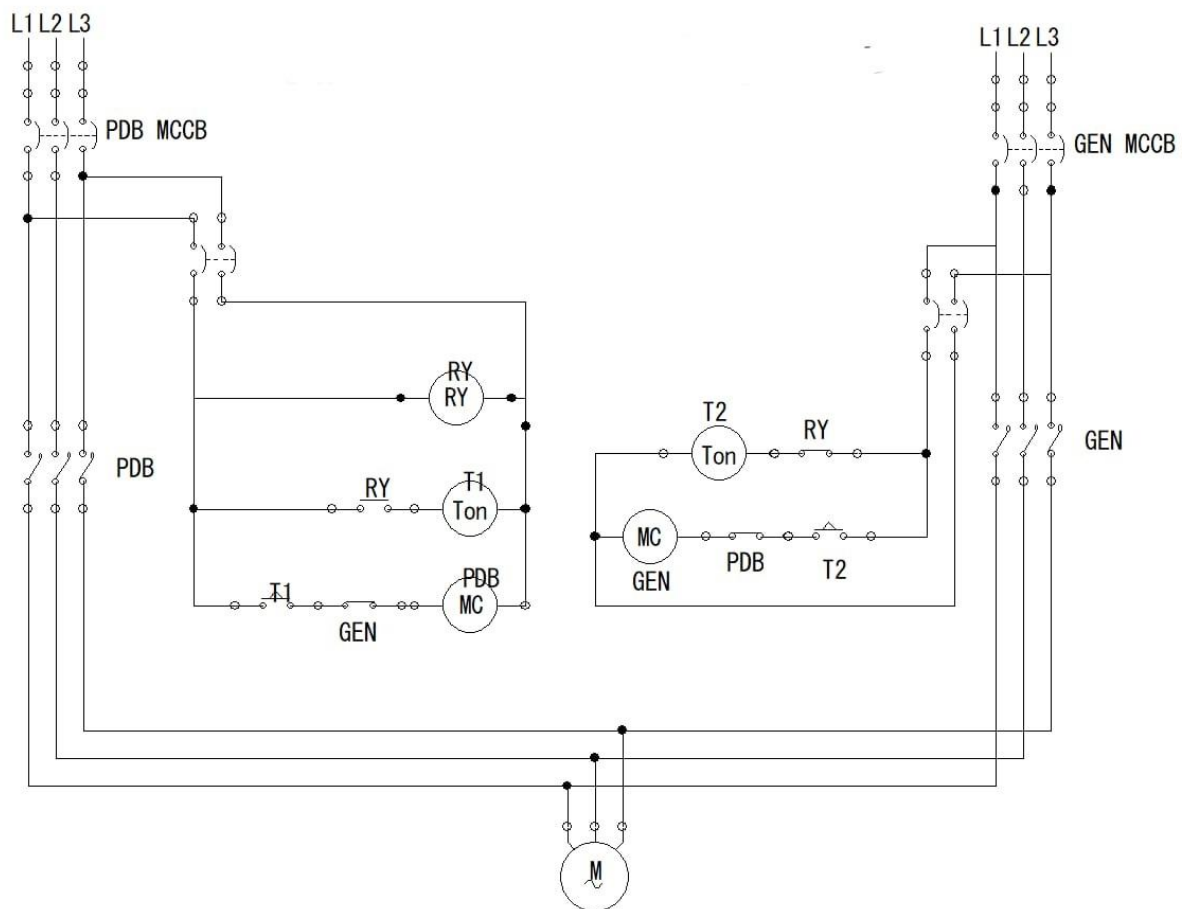


Fig: Automatic Transfer Switch Circuit

Constructing a Traffic Light Control Circuit

A traffic light control circuit is an electronic system designed to automatically cycle through the Red, Yellow (or Amber), and Green light sequence for regulating traffic flow.

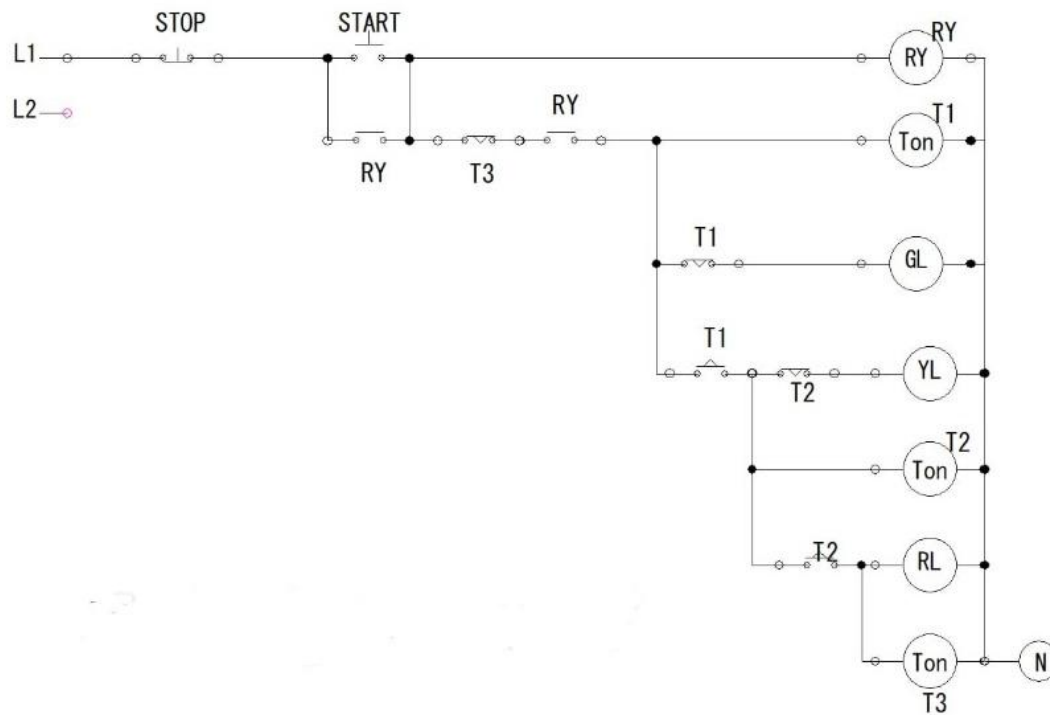


Fig: Traffic Light Control Circuit



Self-Check 1.3-1

1. What kind of logic circuit is a Counter Circuit in digital electronics?
2. What does a Counter Circuit count and store?
3. What is the main purpose of an Automatic Transfer Switch (ATS) circuit?
4. What are the two types of power sources that an ATS circuit is designed to switch between?
5. What is the primary component that a Counter Circuit typically consists of?
6. What is the function of a Traffic Light Control Circuit?
7. What is the specific sequence of lights that a Traffic Light Control Circuit is designed to automatically cycle through?



Answer Paper 1.3-1

1. A Counter Circuit is a sequential logic circuit in digital electronics.
2. It counts and stores the number of clock pulses (transitions) it receives.
3. The main purpose of an ATS circuit is to automatically switch an electrical load from a primary power source to a backup power source when the primary source fails, and then switch back when the primary source is restored.
4. The two power sources are a primary power source (like the utility grid) and a backup power source (like a generator).
5. A Counter Circuit typically consists of interconnected flip-flops.
6. A Traffic Light Control Circuit is an electronic system designed to automatically cycle through the Red, Yellow (or Amber), and Green light sequence for regulating traffic flow.
7. The circuit is designed to cycle through the Red, Yellow (or Amber), and Green light sequence.



Job Sheet 3

Qualification	Industrial Automation
Learning Unit	Constructing a Counter Circuit
Trainee Name	
PPE	Safety glasses, Insulated gloves (when connecting power circuits), and appropriate work clothing.
Tools & Equipment	Programmable Logic Controller (PLC) unit, PC/Laptop with PLC programming software, Input Device (e.g., limit switch or proximity sensor), Output Indicator (e.g., stack light or pilot lamp), Multimeter (DMM), Screwdriver set, Wire stripper/cutter, and connecting wires/cables.
Notes	1. Power Safety: Always confirm control power is OFF when wiring inputs/outputs. 2. Addressing: Ensure input and output addresses in the program exactly match the physical wiring terminals. 3. Sensor Check: Verify the input sensor (proximity or limit switch) is functioning correctly before connecting it to the PLC. 4. Reset: The counter circuit must include a separate RESET input for testing.
Procedure	1. Safety/Preparation: De-energize and apply LOTO to the control panel. Connect the PLC to the power supply. 2. Hardware Wiring (Inputs): Connect the Input Sensor (e.g., proximity switch) to a designated PLC input terminal (e.g., I:0/0). Connect a Momentary Pushbutton for the Counter Reset function to a separate PLC input terminal (e.g., I:0/1). 3. Hardware Wiring (Outputs): Connect the Output Indicator Lamp to a designated PLC output terminal (e.g., O:0/0). 4. Software Development: Open the PLC programming software. 5. Program Logic: Create the counter logic (CTU - Count Up function). Set the Input Sensor address (I:0/0) as the Counter Up (CU) trigger. Set the Reset Pushbutton address (I:0/1) as the Reset (R) trigger. Set the

	Preset Value (PV) (e.g., to 5 counts). Use the Done Bit (DN) of the counter to energize the Output Indicator Lamp (O:0/0). 6. Testing & Verification: Download the program to the PLC. Remove LOTO and energize the system. Manually activate the input sensor (CU) 5 times; the output light should illuminate on the 5th count. Press the Reset button; the count should return to zero, and the light should turn off. 7. Final Check: Document successful operation and adherence to the preset value.
Trainee's Signature	
Assessor's Signature	
QA Signature	
Assessor's Comment	

	Job Sheet 4
Qualification	Industrial Automation
Learning Unit	Constructing an Automatic Transfer Switch Circuit
Trainee Name	
PPE	Safety glasses, Insulated gloves (when connecting power circuits), and appropriate work clothing.
Tools & Equipment	Two Motor Contactors (MCs) (one for Normal, one for Emergency), Two Control Relays (or a small PLC), Control Power Supply, Toggle Switches (to simulate Normal and Emergency Source availability), Load Indicator (e.g., pilot lamp or buzzer), Multimeter (DMM), Screwdriver set, Wire stripper/cutter, and connecting wires/cables.
Notes	1. INTERLOCKING IS CRITICAL: The control circuit MUST include a mechanical and/or electrical interlock to prevent both Contactors (Normal and Emergency) from closing simultaneously.

	2. Source Simulation: The toggle switches are used to simulate the presence of voltage from the Normal Source and the Generator/Emergency Source. 3. Time Delay: A realistic ATS requires a Time Delay Relay for the generator to start and stabilize before transferring the load; include one if available.
Procedure	1. Safety/Preparation: De-energize and apply LOTO to the main and control circuits. Gather and verify the ratings of all components. 2. Power Circuit Wiring: Connect the output terminals of the two main Contactors (MC-Normal and MC-Emergency) to the single load (indicator lamp). Connect the power sources (simulated by switches) to their respective Contactors' input terminals. 3. Control Wiring (Relays/PLC): Wire the control circuit to monitor the status of the "Normal Source Available" switch. 4. Normal Source Logic: The control circuit should be designed so that when the Normal Source is available, the MC-Normal coil is energized. 5. Transfer Logic: If the Normal Source drops out, the circuit must include a logic delay (if using a Timer) and then energize the MC-Emergency coil, provided the Emergency Source is available. 6. Interlocking: Implement the interlock: Use a Normally Closed (NC) auxiliary contact from the MC-Emergency to break the coil circuit of the MC-Normal, and an NC auxiliary contact from the MC-Normal to break the coil circuit of the MC-Emergency. This prevents simultaneous closure. 7. Testing: Remove LOTO and energize the control power. A) Start with Normal Source ON; MC-Normal should close. B) Turn Normal Source OFF; the circuit should wait (if using a timer) and then close MC-Emergency (assuming the Emergency Source is ON). C) Turn Normal Source back ON; the circuit should switch back to MC-Normal (preferably with a brief delay).

	8. Final Documentation: Verify that the load indicator correctly follows the source, and the interlock prevents both contactors from closing at any time.
Trainee's Signature	
Assessor's Signature	
QA Signature	
Assessor's Comment	

	Job Sheet 5
Qualification	Industrial Automation
Learning Unit	Constructing a Traffic Light Control Circuit
Trainee Name	
PPE	Safety glasses, Insulated gloves (when connecting power circuits), and appropriate work clothing.
Tools & Equipment	Programmable Logic Controller (PLC) (or multiple Time Delay Relays), PC/Laptop with PLC programming software, Three Pilot Lamps/Indicators (Red, Yellow, Green), Control Power Supply (matching the lamp and PLC I/O voltage), Momentary Pushbutton (for Start/Stop/Fault Reset), Multimeter (DMM), Screwdriver set, Wire stripper/cutter, and connecting wires.
Notes	1. Sequence: The standard traffic light sequence is: Green → Yellow → Red (on one direction), and the opposite on the other. 2. Timing: Clearly define the time settings for each color (e.g., Green=10s, Yellow=3s, Red=13s). 3. Interlocking: Ensure that only one lamp in the circuit is energized at any given time to prevent short circuits or incorrect signaling. 4. Safety: Apply LOTO before wiring or component changes.

Procedure	1. Safety & Preparation: De-energize and apply LOTO. Gather components and verify indicator lamp voltages match the output power supply. 2. Hardware Wiring (Outputs): Connect the Red, Yellow, and Green indicator lamps to separate PLC Output terminals (e.g., O:0/0, O:0/1, O:0/2). 3. Hardware Wiring (Inputs): Connect the Start/Stop Pushbutton to a designated PLC Input terminal (e.g., I:0/0). 4. Software Development: Open the PLC programming software. 5. Program Logic (Timing): Use Timer instructions (TON) in a sequential chain. A) The Start button energizes Timer 1 (Green) for 10s. B) Timer 1's Done Bit (DN) starts Timer 2 (Yellow) for 3s. C) Timer 2's DN starts Timer 3 (Red) for 13s. D) Timer 3's DN resets Timer 1 to start the sequence again (creating a loop). 6. Program Logic (Output Control): Configure the output coil for each lamp based on the timers: Green Lamp is ON while Timer 1 is running and NOT Timer 2. Yellow Lamp is ON while Timer 2 is running. Red Lamp is ON while Timer 3 is running. 7. Testing & Verification: Download the program. Remove LOTO and energize the system. Press the Start button and confirm the sequence: Green → Yellow → Red → Green... 8. Final Check: Verify that the timing for each light is correct and that the Interlock logic prevents two lights from being ON simultaneously.
Trainee's Signature	
Assessor's Signature	
QA Signature	
Assessor's Comment	

Learning Outcome 1.4 – Construct Latch, DOL and Star-Delta



Content

- Control Circuit Design (Latch and DOL): Learn the fundamental wiring and logic for self-holding circuits (latch) using a relay's auxiliary contact, and the standard construction of a Direct On-Line (DOL) motor starter.
- Star-Delta Starter Principles: Understand the necessity and operation of the Star-Delta (Wye-Delta) starting method for large induction motors, focusing on the sequence control involving three contactors (Main, Star, Delta) and a timer.
- Component Selection and Connection: Identify the correct motor protection devices (e.g., thermal overload relay) and learn the specific power and control circuit wiring connections for all three starter configurations.



Assessment Criteria

- Functional Construction
- Safety and Protection Integration
- Sequential Operation (Star-Delta)



Necessary Equipment

- Motor Control Trainer/Panel
- Magnetic Contactor
- Timer
- Overload Relay
- Three-Phase Induction Motor

- Wiring Tools
- Multimeter



Learning Activity 1.4-1

Learning Activity	Resources/ Instructions/ References
Construct Latch, DOL and Star-Delta	• Information Sheet: 1.4-1 • Self-Check: 1.4-1 • Answer Paper: 1.4-1 • Job Sheet 6 – Job Sheet 9



Information Sheet 1.4-1

Learning Objective: The learner will be able to construct and wire the control and power circuits for a basic relay logic latch, a Direct On-Line (DOL) motor starter, and a time-delayed Star-Delta motor starter.

Latch Circuit

A latch is a type of electronic logic circuit that has two stable states and is used as a basic storage element (memory) for one bit of binary data (0 or 1).

- Function: Once the output state of a latch is set by a momentary input signal, it retains (latches) that state indefinitely until a reset or power-down signal is applied.

- Sequential Logic: Because the output depends not only on the current inputs but also on the previous state, latches are a fundamental component of sequential logic circuits.
- Types: The most common basic latches are the SR (Set-Reset) Latch and the D (Data) Latch.
 1. SR Latch: Built from cross-coupled NOR or NAND gates.
 2. D Latch (Data/Transparent Latch): A modification of the SR latch that eliminates the "invalid" state and is used for temporarily storing a data bit.

Interlock Circuit

An Interlock Circuit is a control system designed to prevent two or more actions from occurring simultaneously or to ensure that a sequence of operations follows a strict, safe order.

Its primary purpose is safety and equipment protection, ensuring that high-risk conditions (like a short circuit, collision, or machine damage) never occur due to conflicting commands.

Key Principles

1. Preventing Simultaneous Actions: If pressing Button A tries to turn on Motor 1, the interlock circuit ensures that Motor 2 (controlled by Button B) cannot be turned on until Motor 1 is verifiably OFF. This is common in reversible motor circuits.
2. Sequential Operation: The circuit enforces a necessary sequence, such as requiring a safety guard to be fully closed before the machine is allowed to start.

DOL Starter

A Direct-On-Line (DOL) starter, also known as an across-the-line starter, is a simple and commonly used method for starting a three-phase induction motor. It directly connects the motor terminals to the full line voltage of the power supply.

Working Principle:

The core idea of a DOL starter is to apply the full rated voltage to the motor's stator windings right from the moment of starting. When the start button is pressed, the contactor closes, establishing a

direct electrical connection between the power supply and the motor. This allows a large inrush current to flow into the motor, which in turn produces the necessary starting torque to begin rotation.

Advantages of DOL Starters:

- **Simple and Cost-Effective:** It has a straightforward design with fewer components, making it relatively inexpensive.
- **Easy to Install and Maintain:** The wiring and troubleshooting are generally simple.
- **Provides Maximum Starting Torque:** The motor receives the full voltage, resulting in 100% of its potential starting torque.
- **Easy to Understand and Operate:** The control mechanism with start and stop buttons is intuitive.

Disadvantages of DOL Starters:

- **High Starting Current:** The motor draws a very high inrush current (typically 5-8 times the full load current) at startup. This can cause voltage dips in the power supply system, potentially affecting other equipment.
- **High Starting Torque:** While sometimes an advantage, the sudden high torque can cause mechanical stress on the driven equipment.
- **Limited to Smaller Motors:** Due to the high starting current, DOL starters are generally suitable for motors with lower power ratings (typically up to 5-10 HP, but this can vary depending on the power system capacity). Starting larger motors directly can cause unacceptable voltage drops.

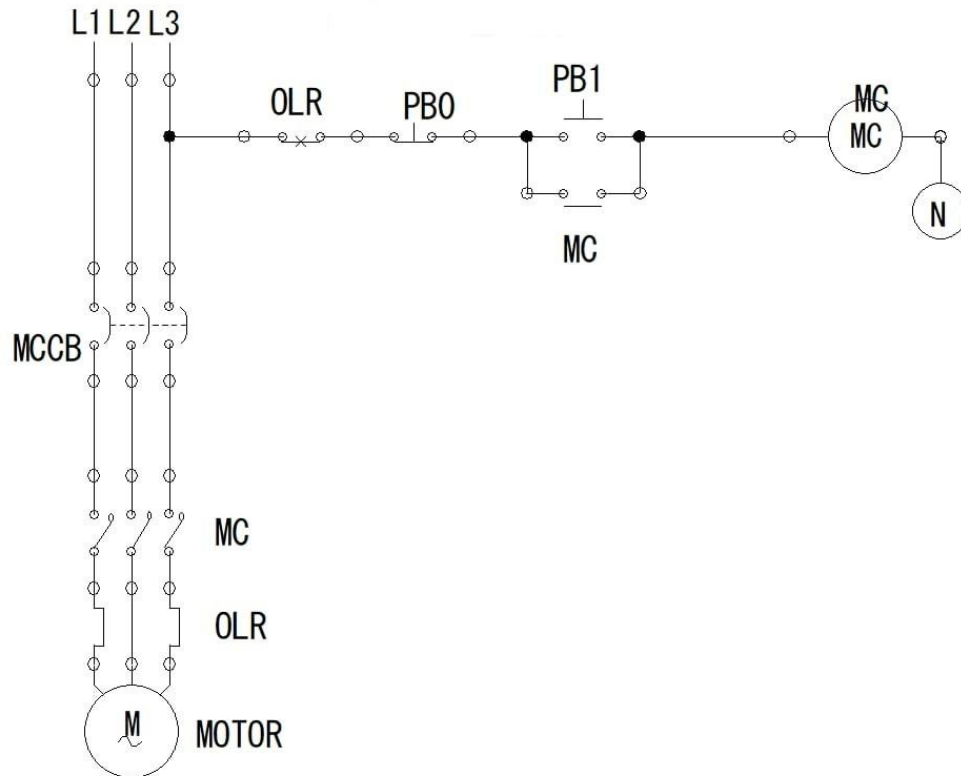


Fig: DOL Starter

Circuit Diagram:

A typical DOL starter circuit has two main parts: the power circuit and the control circuit.

- ❑ **Power Circuit:** This circuit directly feeds power to the motor. It includes the circuit breaker, the main contacts of the contactor, and the overload relay connected in series with the three phases of the power supply and the motor windings.
- ❑ **Control Circuit:** This circuit controls the operation of the contactor coil. It typically operates at a lower voltage for safety and includes the start and stop buttons, the auxiliary contact of the contactor (for latching), and the normally closed contact of the overload relay.

Power Circuit Components:

- ✓ **Circuit Breaker or MCCB (Molded Case Circuit Breaker):** For short circuit and overload protection of the entire circuit. Choose the rating according to the motor's full load current and starting current.
- ✓ **Contactor:** An electromagnetic switch that connects and disconnects the power supply to the motor. Select the contactor based on the motor's voltage and current rating. It will have main contacts (usually 3 normally open - NO) and auxiliary contacts (both NO and normally closed - NC).
- ✓ **Overload Relay:** Protects the motor from excessive current draw and overheating. It is selected based on the motor's full load current and has normally closed (NC) contacts in the control circuit.
- ✓ **Three-Phase Induction Motor:** The motor you want to control.
- ✓ **Wiring Cables:** Suitable for the current and voltage ratings of the circuit.

Control Circuit Components:

- ✓ **Stop Push Button:** Normally closed (NC) push button to interrupt the control circuit and stop the motor.
- ✓ **Start Push Button:** Normally open (NO) momentary push button to energize the contactor and start the motor.
- ✓ **Auxiliary Contacts of Contactor:** Typically one normally open (NO) contact used for latching or holding the contactor in the energized state.
- ✓ **Control Wiring Cables:** Smaller gauge wires suitable for the control circuit voltage (often 230V AC or lower).

Manual Star-Delta Starter using Switches

A Star-Delta starter is a reduced-voltage starting method used for three-phase induction motors. By initially connecting the motor windings in a star configuration, the voltage across each winding is reduced to approximately 58% of the line voltage. This results in a starting current that is one-third of what it would be if the motor were started with the windings directly connected in delta. After the motor reaches a certain speed (typically around 80% of its full speed), the connections are switched to a delta configuration, allowing the motor to receive the full line voltage and operate at its rated capacity. While most automatic Star-Delta starters use a timer to control the switching from star to delta, it is possible to construct a circuit without one. This type of starter is often referred to as a **manual** Star-Delta starter.

Advantages of a Manual Star-Delta Circuit:

- ✓ **Simplicity:** Fewer components compared to an automatic starter with a timer.
- ✓ **Cost-Effective:** Eliminates the cost of a timer relay.
- ✓ **Troubleshooting:** Potentially easier to troubleshoot due to the reduced number of components.

Disadvantages of a Timerless Star-Delta Circuit:

- ✓ **Reliance on Operator:** The timing of the switchover is dependent on the operator's judgment, which can lead to inconsistencies and potential problems.
- ✓ **Not Suitable for Remote or Automated Systems:** Requires manual intervention for the star-delta transition.

Circuit Diagram:

The Star-Delta starter circuit has two main parts: the power circuit and the control circuit.

- **Power Circuit:** This circuit connects the power supply to the motor windings in either a star or delta configuration through the contactors.
- **Control Circuit:** This circuit controls the sequence of operation of the contactors using push buttons, auxiliary contacts, and the timer. Interlocks are crucial in the control circuit

to prevent simultaneous energization of the star and delta contactors, which would cause a short circuit.

Components:

1. **Main Circuit Breaker (MCB) or Fuses:** To provide overcurrent protection for the entire circuit.
2. **Three Contactors:**
 - **Main Contactor (KM1):** Connects the power supply to the motor.
 - **Star Contactor (KM2):** Connects the motor windings in a star configuration.
 - **Delta Contactor (KM3):** Connects the motor windings in a delta configuration.
3. **Thermal Overload Relay (OLR):** To protect the motor from overloads.
4. **Start Push Button (Normally Open - NO):** To initiate the starting sequence.
5. **Stop Push Button (Normally Closed - NC):** To stop the motor.
6. **Changeover Switch (Manual or Mechanically Interlocked Push Buttons):** This is the key component that replaces the timer. It will have two positions:
 1. **Star Position:** Momentarily connects the star contactor.
 2. **Delta Position:** Connects the delta contactor after the motor has run in star for a sufficient time.
7. **Interlocking Contacts (Auxiliary Contacts on Contactors):**
 1. Normally closed (NC) auxiliary contacts on the delta contactor (KM3) in series with the star contactor coil (KM2) to prevent simultaneous energizing of both.
 2. Normally closed (NC) auxiliary contacts on the star contactor (KM2) in series with the delta contactor coil (KM3) to prevent simultaneous energizing of both.
8. **Wiring and Terminals:** To connect all the components.
9. **Three-Phase Induction Motor:** Designed for Star-Delta starting (must be able to be connected in both star and delta).

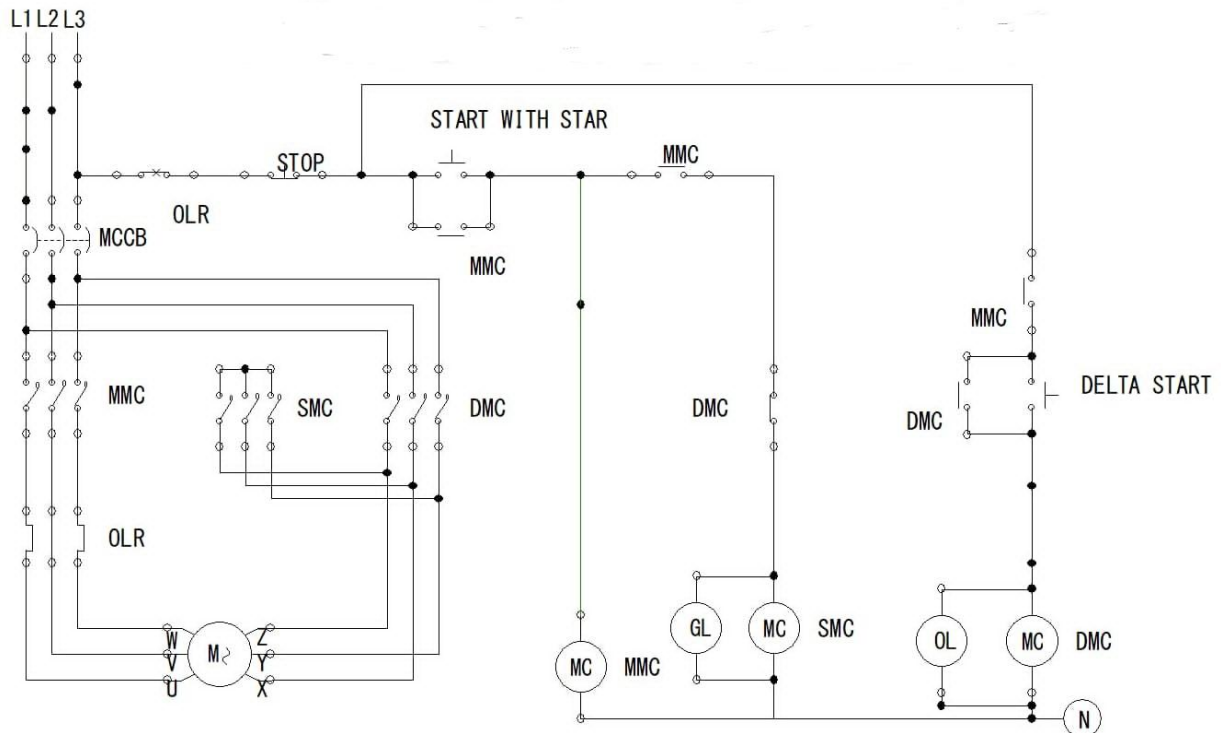


Fig: Manual Star-Delta Starter

Working Principle:

Starting (Star Connection):

- ✓ When the "Start" push button is pressed, the Main Contactor (KM1) and the Star Contactor (KM2) are energized simultaneously (assuming the changeover switch is momentarily placed in the "Star" position).
- ✓ The motor windings are now connected in a star configuration, reducing the voltage across each winding and thus limiting the starting current and torque.
- ✓ The Main Contactor (KM1) remains energized through its holding contact after the start button is released.
- ✓ The motor starts to run at a reduced voltage.

Transition to Delta Connection (Manual):

- ✓ After a short period (determined by the operator, typically a few seconds, allowing the motor to reach a sufficient speed), the operator manually moves the changeover switch to the "Delta" position.

- ✓ This de-energizes the Star Contactor (KM2) and energizes the Delta Contactor (KM3) (interlocks prevent simultaneous energizing).
- ✓ The motor windings are now reconnected in a delta configuration, and the motor receives the full line voltage, allowing it to produce its rated torque and run at full speed.

Stopping:

- ✓ Pressing the "Stop" push button de-energizes the Main Contactor (KM1), which disconnects the power supply from the motor, stopping it.
- ✓ The Star and Delta contactors are also de-energized.
- ✓ If a motor overload occurs, the Thermal Overload Relay (OLR) will trip, opening its normally closed contact in the control circuit of the Main Contactor (KM1), thus stopping the motor and providing protection.

Automatic Star – Delta Starter using Timer

Star-Delta Starting Principle:

- During the initial starting phase, the motor windings are connected in a star (Y) configuration. In this configuration, the voltage across each motor winding is reduced to approximately 57.7% of the line voltage. This results in a starting current that is about one-third of the current it would draw if started in delta. The starting torque is also reduced to about one-third.
- Once the motor reaches a certain speed (typically around 80% of its full speed), the connections are switched to a delta (Δ) configuration. In this configuration, each winding receives the full line voltage, and the motor runs at its rated speed and power.
- The transition from star to delta is usually controlled by a timer.

Circuit Diagram:

The Star-Delta starter circuit has two main parts: the power circuit and the control circuit.

- **Power Circuit:** This circuit connects the power supply to the motor windings in either a star or delta configuration through the contactors.
- **Control Circuit:** This circuit controls the sequence of operation of the contactors using push buttons, auxiliary contacts, and the timer. Interlocks are crucial in the control circuit to prevent simultaneous energization of the star and delta contactors, which would cause a short circuit.

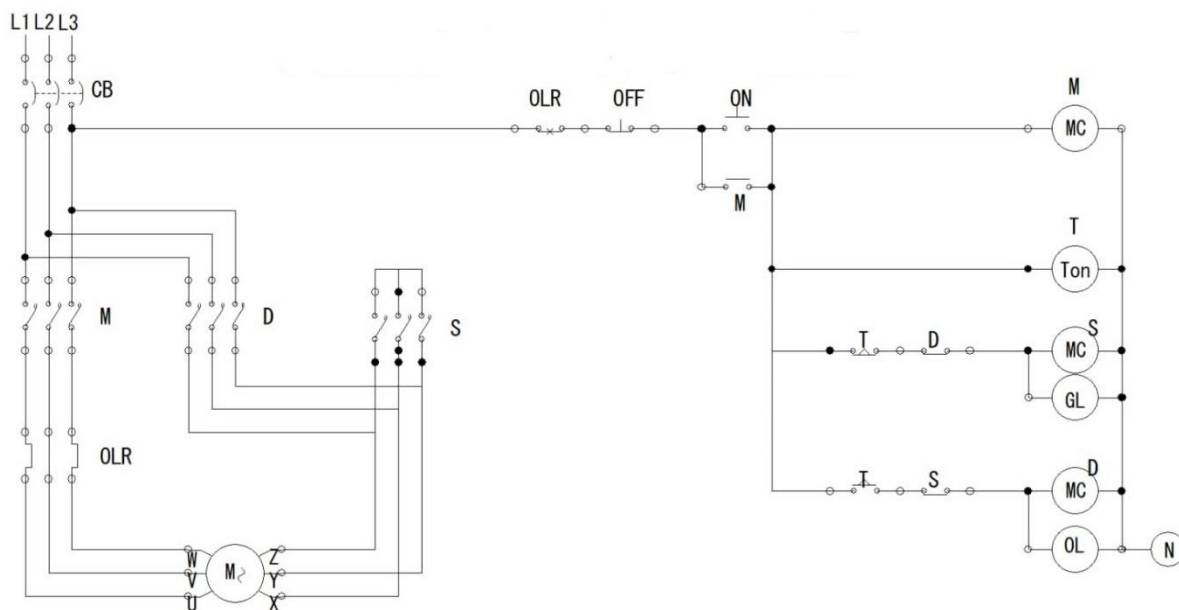


Fig: Automatic Star Delta Starter



Self-Check 1.4-1

1. What are the two most common basic types of latches, and what fundamental data storage function do they provide?
2. What is the primary purpose of an **Interlock Circuit**, and what two key principles does it enforce?
3. What is the **Working Principle** of a Direct-On-Line (DOL) starter?

4. What are the two main disadvantages of a DOL starter related to current and torque at startup?
5. What key component in a manual Star-Delta starter replaces the timer found in an automatic version, and what does it control?
6. In the control circuit of an automatic Star-Delta starter, why are **Interlocks** considered crucial?
7. During the initial starting phase of an automatic Star-Delta starter, what is the winding voltage reduced to, and what is the resulting starting current compared to a full delta start?



Answer Paper 1.4-1

1. The two most common basic types of latches are the SR (Set-Reset) Latch and the D (Data/Transparent) Latch. They provide the function of a basic storage element (memory) for one bit of binary data (0 or 1).
2. The primary purpose of an Interlock Circuit is safety and equipment protection. It enforces Preventing Simultaneous Actions and Sequential Operation.
3. The Working Principle of a DOL starter is to apply the full rated voltage to the motor's stator windings right from the moment of starting. The contactor closes, allowing a large inrush current to flow to produce the necessary starting torque.
4. The two main disadvantages are: High Starting Current (typically 5-8 times the full load current) which can cause voltage dips, and High Starting Torque which causes mechanical stress on the driven equipment.
5. The key component that replaces the timer in a manual Star-Delta starter is the Changeover Switch (Manual or Mechanically Interlocked Push Buttons). It is used to manually switch the connection from the Star Position to the Delta Position.
6. Interlocks are crucial in the control circuit of an automatic Star-Delta starter to prevent simultaneous energization of the star and delta contactors, which would cause a short circuit.

7. The winding voltage is reduced to approximately 57.7% of the line voltage, and the resulting starting current is about one-third of the current it would draw if started in delta.

	Job Sheet 6
Qualification	Industrial Automation
Learning Unit	Constructing a Latching Circuit
Trainee Name	
PPE	Safety glasses (essential), Insulated gloves (when connecting power circuits), and appropriate work clothing.
Tools & Equipment	Control Relay (or Motor Contactor) with a suitable Auxiliary NO Contact, Control Power Supply, Momentary NO Pushbutton (Start), Momentary NC Pushbutton (Stop), Indicator Lamp/Load, Multimeter (DMM), Screwdriver set, Wire stripper/cutter, and connecting wires.
Notes	1. Holding Contact: The core of the latching circuit is the Normally Open (NO) auxiliary contact of the relay/contacter wired in parallel with the Start button. 2. Stop Button: The Normally Closed (NC) Stop button is wired in series with the coil to interrupt power when pressed. 3. LOTO: Strictly follow Lockout/Tagout procedures before wiring or component changes.
Procedure	1. Safety & Preparation: De-energize and apply LOTO to the control power supply. Gather and verify all component ratings. 2. Coil Circuit Power In: Connect the control power source's positive (or Line) terminal to the common terminal of the NC Stop Pushbutton. 3. Series Wiring (Stop): Connect the output of the Stop Pushbutton to the input of the NO Start Pushbutton.

	4. Parallel Wiring (Start & Latch): Connect the output of the Start Pushbutton to the relay coil terminal A1. This point is the first side of the parallel circuit. 5. Latching Connection: Wire a connection from the output of the Stop Pushbutton (or the input of the Start Pushbutton) to one side of the relay's NO auxiliary contact. Wire the other side of the NO auxiliary contact to relay coil terminal A1. This creates the holding path. 6. Coil Return: Connect the relay coil terminal A2 back to the control power source's negative (or Neutral) terminal. 7. Testing: Remove LOTO and energize the control power. A) Press and release the Start button; the relay coil should energize and stay ON (latched) via its auxiliary contact, and the Indicator Lamp/Load should activate. B) Press and release the Stop button; the coil power should be interrupted, and the relay should drop out, turning the load OFF. 8. Final Check: Confirm that the momentary press of the Start button latches the circuit and that only the Stop button can unlatch it.
Trainee's Signature	
Assessor's Signature	
QA Signature	
Assessor's Comment	

	Job Sheet 7
Qualification	Industrial Automation
Learning Unit	Constructing a DOL Starter Circuit
Trainee Name	
PPE	Safety glasses (essential), Insulated gloves (when connecting power circuits), and appropriate work clothing.

Tools & Equipment	Motor Contactor (MC), Thermal Overload Relay (TOR) (mounted to the MC), Control Power Supply (or control transformer), Motor (3-phase simulation or actual low-power motor), Momentary NO Pushbutton (Start), Momentary NC Pushbutton (Stop), Multimeter (DMM), Screwdriver set, Wire stripper/cutter, and connecting wires.
Notes	1. Protection: The Thermal Overload Relay (TOR) is critical for motor protection; ensure its current setting matches the motor's Full Load Amps (FLA). 2. Latching: The DOL circuit requires a latching contact (NO auxiliary contact of the MC) wired in parallel with the Start button. 3. LOTO: Strictly follow Lockout/Tagout procedures before wiring or component changes.
Procedure	1. Safety & Preparation: De-energize and apply LOTO to both the control and power circuits. Gather components and verify all voltage and current ratings. 2. Power Circuit Wiring: Connect the three-phase power source (L1, L2, L3) to the Motor Contactor's main power terminals (L1, L2, L3). Connect the Contactor's output terminals (T1, T2, T3) to the input of the Thermal Overload Relay. Connect the TOR's output terminals to the Motor terminals. 3. Control Circuit Wiring - Series Protection: Connect the control power source's Line to the NC Overload Contact (e.g., 95-96) of the TOR. Connect the output of the TOR's NC contact (96) to the NC Stop Pushbutton. 4. Control Circuit Wiring - Latch: Connect the output of the Stop Pushbutton to the NO Start Pushbutton input. Wire the output of the Start button to the Contactor coil terminal A1. 5. Control Circuit Wiring - Holding: Wire an NO Auxiliary Contact of the Contactor in parallel with the Start Pushbutton. This contact is wired from the output of the Stop button to Contactor coil terminal A1.

	6. Control Circuit Return: Connect the Contactor coil terminal A2 to the control power source's Neutral. 7. Testing: Remove LOTO and energize the system. A) Press and release the Start button; the Contactor should energize (latch), and the motor should run. B) Press and release the Stop button; the Contactor should de-energize, and the motor should stop. C) Trip Test: Push the manual Trip button on the TOR; the Contactor should drop out, and the motor should stop, proving the protection circuit works. 8. Final Check: Document that the motor starts, stops, and is protected by the overload relay.
Trainee's Signature	
Assessor's Signature	
QA Signature	
Assessor's Comment	
	Job Sheet 8
Qualification	Industrial Automation
Learning Unit	Constructing a Manual Star-Delta Circuit using Switch
Trainee Name	
PPE	Safety glasses (essential), Insulated gloves (when connecting power circuits), and appropriate work clothing.
Tools & Equipment	Six-Terminal Motor (must be capable of Delta operation at the supply voltage), Manual Star-Delta Changeover Switch (specific 3-position, multi-pole rotary switch), Thermal Overload Relay (TOR), Three-phase Power Supply, Multimeter (DMM), Screwdriver set, Wire stripper/cutter, and connecting cables.
Notes	1. Motor Requirement: The motor must have six accessible terminals (U1, V1, W1, U2, V2, W2) and its Delta rating must match the supply voltage.

	2. Sequence: The operator must manually switch from the STAR (Y) position to the DELTA (Δ) position after the motor reaches $\approx 80\%$ of its full speed. 3. LOTO: Strictly adhere to Lockout/Tagout procedures before wiring or component changes.
Procedure	1. Safety & Preparation: De-energize and apply LOTO to the power supply. Gather and verify motor and switch ratings. The TOR should be set to $0.58 \times$ Motor FLA. 2. Power Circuit Wiring - Input: Connect the three-phase supply (L1, L2, L3) to the input terminals of the TOR, and then from the TOR output to the input terminals (usually the common side) of the Manual Star-Delta Switch. 3. Motor Connections: Connect the motor windings' beginnings (U1, V1, W1) to the designated output terminals of the switch (these will be the main terminals). 4. Winding Ends (U2, V2, W2) Connection: Connect the motor windings' ends (U2, V2, W2) to the other designated set of terminals on the switch, which handles the Y (short-circuiting the ends) and Δ (connecting ends to opposite phases) configurations. 5. Switch Wiring - STAR Position (Y): In the Y position, the switch must internally connect the three winding ends (U2, V2, W2) together to a common point (neutral/star point) while the main phases (L1, L2, L3) are connected to the winding beginnings (U1, V1, W1). 6. Switch Wiring - DELTA Position (Δ): In the Δ position, the switch must internally connect the phases to the windings in a closed loop (e.g., L1 to U1 and W2, L2 to V1 and U2, L3 to W1 and V2). 7. Testing: Remove LOTO and apply power. A) Turn the switch to the OFF position. B) Manually switch to the STAR (Y) position; the motor should start with low torque and low current. C) Allow the motor to accelerate (e.g., for 5-7 seconds). D) Manually switch rapidly from Y to the DELTA (Δ) position; the motor should smoothly transition to full

	speed and full voltage/torque. E) Switch back to the OFF position to stop the motor. 8. Final Check: Document successful low-current starting in the Y position and proper running in the Δ position.
Trainee's Signature	
Assessor's Signature	
QA Signature	
Assessor's Comment	

	Job Sheet 9
Qualification	Industrial Automation
Learning Unit	Constructing an Automatic Star-Delta Circuit using Timer
Trainee Name	
PPE	Safety glasses (essential), Insulated gloves (when connecting power circuits), and appropriate work clothing.
Tools & Equipment	Three Motor Contactors (Main, Star, and Delta), Thermal Overload Relay (TOR), Off-Delay Timer Relay, Three-phase Motor (6-terminal), Control Power Supply (or transformer), Momentary Pushbuttons (Start/Stop), Multimeter (DMM), Screwdriver set, Wire stripper/cutter, and connecting wires.
Notes	1. Interlocking: Critical safety point: The Star and Delta contactors MUST have electrical and/or mechanical interlocks to prevent them from closing simultaneously (which would cause a short circuit). 2. Timing: The Off-Delay Timer determines the duration the motor runs in Star mode (low current) before switching to Delta mode (full voltage). Set this time based on the motor's acceleration characteristics. 3. TOR Setting: The TOR should be set to $0.58 \times \text{Motor FLA}$.

Procedure	1. Safety & Preparation: De-energize and apply LOTO to all power sources. Gather and verify ratings of all three contactors and the motor. 2. Power Circuit Wiring: Connect the three-phase supply through the TOR to the Main Contactor (MC-M) terminals L1, L2, L3. Connect the output (T1, T2, T3) of MC-M to the motor terminals U1,V1,W1. 3. Star/Delta Power Wiring: Connect the output terminals of the MC-M to the Delta Contactor (MC-D) and the Star Contactor (MC-Y). The output of MC-Y is short-circuited (tied together) to form the star point. The output of MC-D connects U2,V2,W2 in the Δ configuration. 4. Control Circuit Wiring - Start/Stop/Protection: Wire the Start/Stop latching circuit including the TOR NC contact (95-96) and the Stop Button in series with the Main Contactor (MC-M) coil. The Start button and an MC-M NO auxiliary contact are wired in parallel to latch MC-M ON. 5. Control Circuit Wiring - Timing & Interlocking: When MC-M energizes, it must: A) Immediately start the Off-Delay Timer. B) Immediately energize the Star Contactor (MC-Y) coil (using an MC-M NO contact) AND ensure the MC-D NC interlock allows current to pass. C) When the Timer times out, its NC contact opens to de-energize MC-Y. Its NO contact closes to energize the Delta Contactor (MC-D) coil, provided the MC-Y NC interlock allows current to pass. 6. Testing: Remove LOTO and energize the system. Press the Start button. A) MC-M and MC-Y should close simultaneously (Star mode). B) After the preset time delay, MC-Y must open, and MC-D must close (Delta mode). MC-M must remain closed throughout. C) Press the Stop button; all contactors should open. 7. Final Check: Confirm the correct sequence (M+Y$\rightarrow$M+D) and verify that MC-Y and MC-D are never closed at the same time.
Trainee's Signature	
Assessor's Signature	

QA Signature	
Assessor's Comment	

Learning Outcome 1.5 – Perform Automatic Forward Reverse Operation



Content

- Forward/Reverse Motor Control Logic: Understand the relay logic design required for reversing motor rotation, specifically focusing on the use of interlocks (mechanical and electrical) to prevent short circuits during transition.
- Power Circuit Wiring: Learn the critical wiring change in the three-phase power circuit (swapping any two supply lines, e.g., L1 and L3) that physically changes the direction of the motor's rotation.
- Automatic Sequence Implementation: Study and implement control circuits that incorporate timers or limit switches to automatically initiate the reversal sequence after a set time or upon reaching a specific position.



Assessment Criteria

- Safe Reversal Sequence
- Timed Transition Accuracy
- Circuit Troubleshooting



Necessary Equipment

- Motor Control Trainer/Panel
- Two Three-Pole Contactors
- Three-Phase Motor
- Control Elements and Timer
- Load
- Wiring Tools and Multimeter



Learning Activity 1.5-1

Learning Activity	Resources/ Instructions/ References
Perform Automatic Forward Reverse Operation	• Information Sheet: 1.5-1 • Self-Check: 1.5-1 • Answer Paper: 1.5-1 • Job Sheet 10 – Job Sheet 11



Information Sheet 1.5-1

Learning Objective: The learner will be able to design and implement the control logic for an automatic motor sequence, successfully performing safe, time-delayed forward and reverse operation using appropriate electrical interlocks.

Manual Forward-Reverse Starter using Switches

The direction of rotation of a three-phase induction motor can be reversed by interchanging any two of the three supply lines connected to the motor terminals. The reverse-forward starter circuit achieves this using two separate contactors: one for the forward direction and one for the reverse direction.

The Forward-Reverse starter circuit consists of two main parts: the power circuit and the control circuit.

- **Power Circuit:** This circuit connects the power supply to the motor through either the forward or reverse contactor. The forward contactor connects the phases in a specific sequence (e.g., L1-U, L2-V, L3-W), while the reverse contactor interchanges two of these phases (e.g., L1-W, L2-V, L3-U). The overload relay is placed in series with the motor.
- **Control Circuit:** This circuit controls the energization of the forward and reverse contactor coils. It includes start/stop buttons, auxiliary contacts for latching, and crucial electrical interlocks to prevent simultaneous energization of both contactors, which would cause a short circuit.

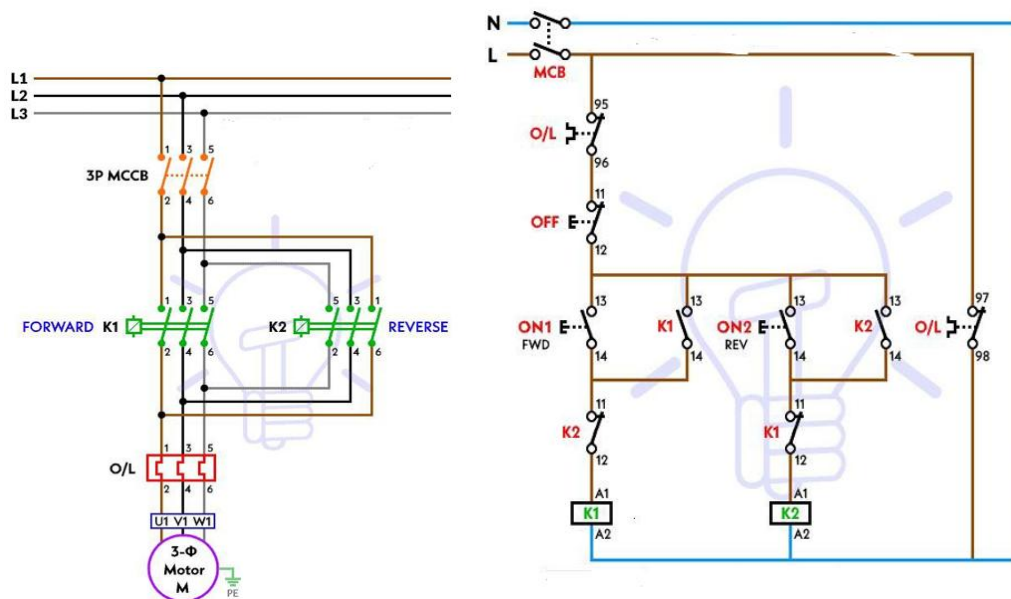


Fig: Manual Forward-Reverse Starter

Components:

Main Circuit Components:

- **Circuit Breaker or MCCB:** For short circuit and overload protection of the entire circuit.
- **Forward Contactor (KM1):** Connects the power supply to the motor for forward rotation.
- **Reverse Contactor (KM2):** Connects the power supply to the motor with two phases interchanged for reverse rotation.
- **Overload Relay:** Protects the motor from sustained overcurrent in either direction of rotation. It has normally closed (NC) contacts in the control circuit.
- **Three-Phase Induction Motor:** The motor you want to control.
- **Wiring Cables:** Suitable for the current and voltage ratings.

Control Circuit Components:

- **Stop Push Button:** Normally closed (NC) push button to interrupt the control circuit and stop the motor.
- **Forward Push Button:** Normally open (NO) momentary push button to energize the forward contactor.
- **Reverse Push Button:** Normally open (NO) momentary push button to energize the reverse contactor.
- **Auxiliary Contacts of Contactors:** Normally open (NO) contacts for latching and normally closed (NC) contacts for electrical interlocking.
- **Control Wiring Cables:** Smaller gauge wires suitable for the control circuit voltage.

Constructing an automatic Forward-Reverse Starter using Timer

This circuit builds upon the basic reverse-forward starter by adding a timing mechanism that periodically switches between the forward and reverse contactors. The core principle of reversing direction remains the same: interchanging any two of the three supply lines to the motor. The automatic switching is achieved using timers and their associated contacts in the control circuit.

Circuit Diagram:

The automatic reverse-forward starter circuit has the same power circuit as the manual version but a more complex control circuit involving timers.

- **Power Circuit:** Identical to the manual reverse-forward starter. The forward contactor connects the phases for forward motion, and the reverse contactor swaps two phases for reverse motion. The overload relay protects the motor.
- **Control Circuit:** This circuit uses timers to alternately energize the forward and reverse contactor coils. Interlocks (both electrical and preferably mechanical) are crucial to prevent simultaneous activation of both contactors. Latching circuits are used to maintain the energized state of the active contactor.

Components:

- **Power Circuit Components:**
 - **Circuit Breaker or MCCB:** For short circuit and overload protection of the entire circuit.
 - **Forward Contactor (KM1):** Connects the power supply to the motor for forward rotation.
 - **Reverse Contactor (KM2):** Connects the power supply to the motor with two phases interchanged for reverse rotation.
 - **Overload Relay:** Protects the motor from sustained overcurrent in either direction of rotation. It has normally closed (NC) contacts in the control circuit.
 - **Three-Phase Induction Motor:** The motor you want to control.
 - **Wiring Cables:** Suitable for the current and voltage ratings.

▪ **Control Circuit Components:**

- **Main ON/OFF Switch (Optional but Recommended):** A manual switch to enable or disable the automatic operation.
- **Stop Push Button:** Normally closed (NC) push button for emergency stop or manual override.
- **Start Push Button:** Normally open (NO) momentary push button to initiate the automatic reversing cycle.
- **Forward Timer (K1T):** An ON-delay or cyclic timer to control the duration of forward rotation.
- **Reverse Timer (K2T):** An ON-delay or cyclic timer to control the duration of reverse rotation.
- **Auxiliary Contacts of Contactors:** Normally open (NO) contacts for latching and normally closed (NC) contacts for electrical interlocking.
- **Auxiliary Contacts of Timers:** Normally open (NO) and normally closed (NC) contacts for controlling the contactors.
- **Control Wiring Cables:** Smaller gauge wires suitable for the control circuit voltage.

Constructing a manual Forward - Reverse with automatic Star - Delta Starter

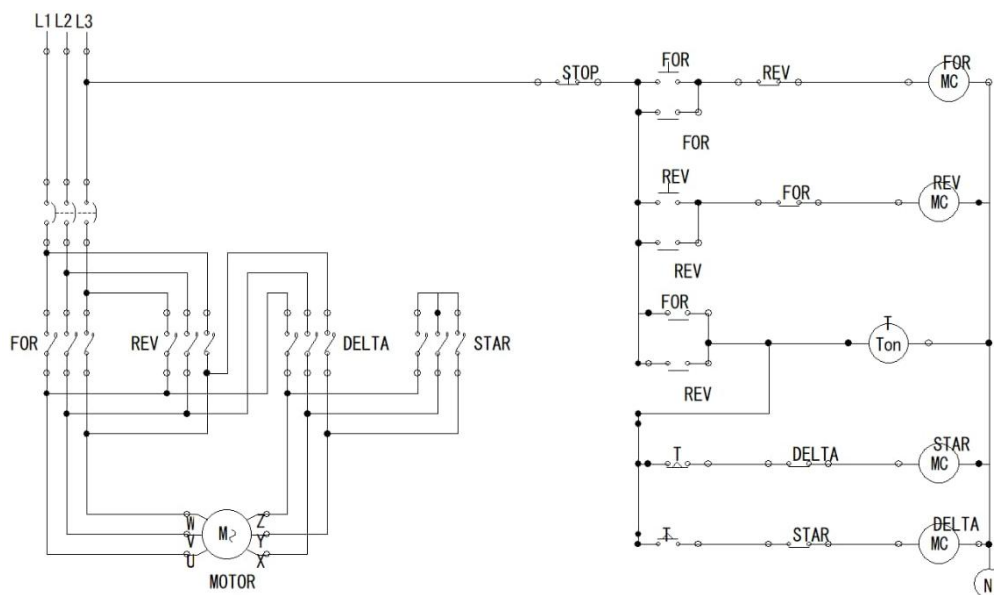


Fig: Manual Forward - Reverse with automatic Star - Delta Starter

Automatic forward – Reverse with Star – Delta Starter

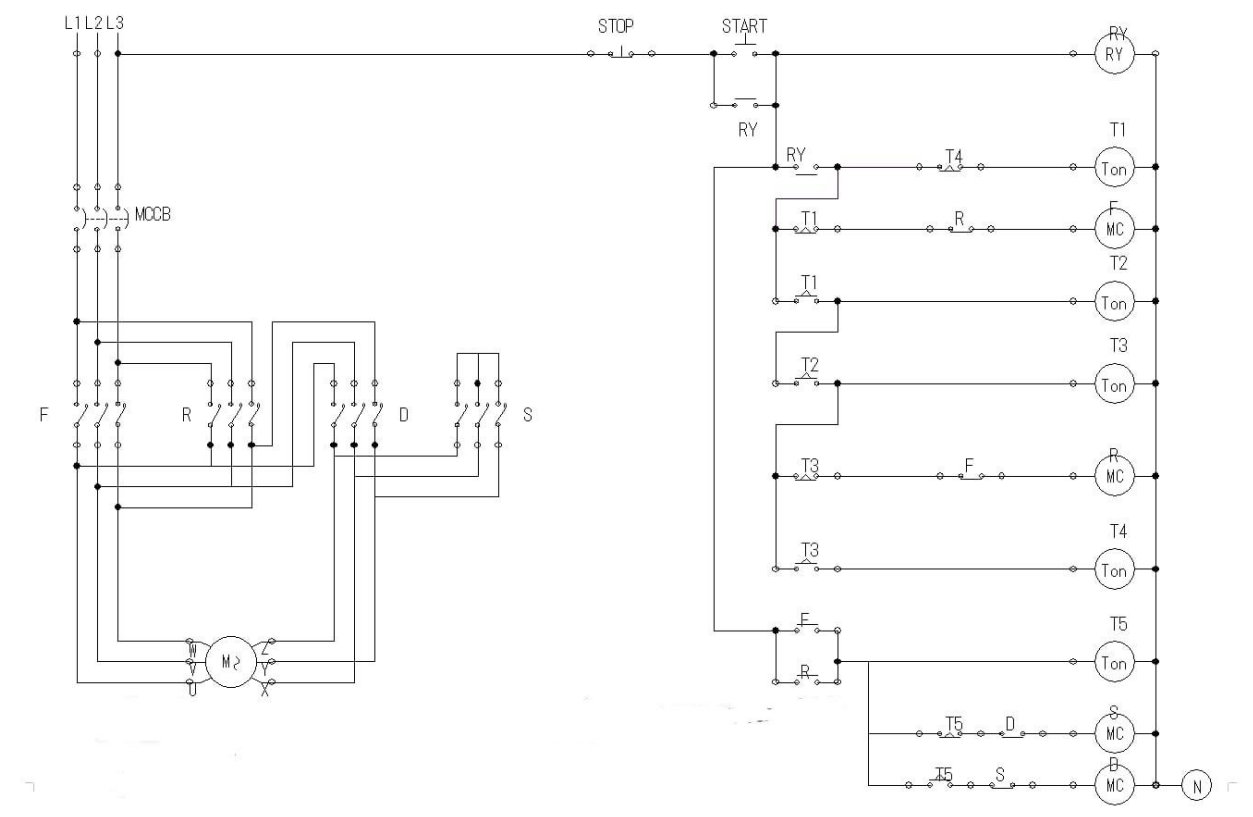


Fig: Automatic forward – Reverse with Star – Delta Starter



Self-Check 1.5-1

1. How is the direction of rotation of a three-phase induction motor reversed in a Forward-Reverse starter circuit?
2. What is the function of the Reverse Contactor (KM2) in the power circuit of the Manual Forward-Reverse starter?
3. What specific type of contacts from the contactors are used for latching and what type are used for electrical interlocking in the control circuit?
4. In the control circuit, what is the crucial safety purpose of the electrical interlocks between the two contactors?

5. What additional components are introduced in the Control Circuit to change the Manual Forward-Reverse Starter into an Automatic Forward-Reverse Starter?
6. Besides the electrical interlocks, what other type of interlock is preferably used in the control circuit of the automatic version to prevent simultaneous activation of the contactors?
7. What is the function of the Overload Relay in the Forward-Reverse starter circuit?



Answer Paper 1.5-1

1. The direction of rotation of a three-phase induction motor can be reversed by interchanging any two of the three supply lines connected to the motor terminals.
2. The Reverse Contactor (KM2) connects the power supply to the motor with two phases interchanged (e.g., L1-W, L2-V, L3-U) for reverse rotation.
3. Normally Open (NO) auxiliary contacts are used for latching, and Normally Closed (NC) auxiliary contacts are used for electrical interlocking.
4. The crucial safety purpose of the electrical interlocks is to prevent simultaneous energization of both contactors (forward and reverse), which would cause a short circuit.
5. The additional components introduced in the Control Circuit are the Forward Timer (K1T) and the Reverse Timer (K2T), which are ON-delay or cyclic timers.
6. Besides electrical interlocks, mechanical interlocks are preferably used in the control circuit of the automatic version.
7. The Overload Relay is placed in series with the motor and protects the motor from sustained overcurrent in either direction of rotation.

	Job Sheet 10
Qualification	Industrial Automation
Learning Unit	Constructing a Manual Forward-Reverse Circuit using Switch
Trainee Name	

PPE	Safety glasses (essential), Insulated gloves (when connecting power circuits), and appropriate work clothing.
Tools & Equipment	Three-phase Motor, Reversing Drum Switch (3-position, multi-pole switch specifically designed for reversing), Thermal Overload Relay (TOR), Three-phase Power Supply, Multimeter (DMM), Screwdriver set, Wire stripper/cutter, and connecting cables.
Notes	1. Phase Reversal: To reverse a three-phase motor, you must swap any two of the three power phases (e.g., swap L1 and L3) going to the motor. 2. Drum Switch: The specific reversing switch is designed to handle this phase swapping internally. 3. Overload Protection: The TOR is connected after the switch to protect the motor regardless of the direction of rotation. 4. LOTO: Strictly adhere to Lockout/Tagout procedures before wiring or component changes.
Procedure	1. Safety & Preparation: De-energize and apply LOTO to the power supply. Gather and verify motor, switch, and TOR ratings. 2. Power Circuit Wiring - Supply: Connect the three-phase power supply (L1, L2, L3) to the input terminals of the Reversing Drum Switch. 3. TOR Connection: Connect the output terminals of the Drum Switch to the input terminals of the Thermal Overload Relay (TOR). 4. Motor Connection: Connect the output terminals of the TOR to the terminals of the Motor. 5. Switch Functionality Check: Before powering, use a multimeter on the resistance setting to check the switch terminals. A) In the OFF (center) position, all paths should be open. B) In the Forward position, the path from L1 → T1, L2 → T2, and L3 → T3 should close (direct connection). C) In the Reverse position, the path should close with two phases swapped (e.g., L1 → T3, L2 → T2, L3 → T1). 6. Testing: Remove LOTO and apply power. A) Switch to the Forward position; the motor should start and run in one direction. B) Switch back

	to the OFF position and wait for the motor to stop. C) Switch to the Reverse position; the motor should start and run in the opposite direction. D) Never switch directly from Forward to Reverse without stopping. 7. Final Check: Document successful running in both Forward and Reverse directions and proper overload protection.
Trainee's Signature	
Assessor's Signature	
QA Signature	
Assessor's Comment	

	Job Sheet 11
Qualification	Industrial Automation
Learning Unit	Constructing an Automatic Forward-Reverse Circuit using Timer
Trainee Name	
PPE	Safety glasses (essential), Insulated gloves (when connecting power circuits), and appropriate work clothing.
Tools & Equipment	Two Motor Contactors (Forward and Reverse), Thermal Overload Relay (TOR), Control Timer (On-Delay or Off-Delay, depending on the logic chosen), Three-phase Motor, Control Power Supply (or transformer), Momentary Pushbuttons (Start/Stop), Multimeter (DMM), Screwdriver set, Wire stripper/cutter, and connecting wires.
Notes	1. Interlocking: Critical safety point: The Forward and Reverse contactors MUST be electrically and/or mechanically interlocked to prevent simultaneous closure (which would cause a dead short). 2. Delay: A short plugging delay (e.g., 0.5 to 1 second) must be included in the logic to ensure the motor comes to a stop or near-stop before the reverse contactor is energized.

	3. LOTO: Strictly adhere to Lockout/Tagout procedures before wiring or component changes.
Procedure	1. Safety & Preparation: De-energize and apply LOTO to all power sources. Gather and verify ratings of both contactors, the TOR, and the motor. 2. Power Circuit Wiring: Connect the three-phase supply through the TOR to the Main Contactors. The wiring for the Forward Contactor (MC-F) should be a direct phase connection (L1-T1, L2-T2, L3-T3). The wiring for the Reverse Contactor (MC-R) must be connected to the same motor terminals but with two phases swapped (e.g., L1-T3, L2-T2, L3-T1). 3. Control Circuit - Latching & Protection: Wire the Start/Stop latching circuit including the TOR NC contact (95-96) and the Stop Button in series with the control power. 4. Control Circuit - Forward Run: Pressing the Start button energizes the MC-F coil. This circuit must include the MC-R NC interlock and start the Timer. 5. Control Circuit - Automatic Reverse: When the Timer times out (e.g., 30 seconds), its contact must de-energize MC-F. After a short plugging delay (achieved via a second timer or an Off-Delay feature), the logic must then energize MC-R. 6. Control Circuit - Interlocking: Implement the electrical interlocks: Use a MC-R NC auxiliary contact in series with the MC-F coil, and an MC-F NC auxiliary contact in series with the MC-R coil. 7. Testing: Remove LOTO and energize the system. Press the Start button. A) The motor should immediately start in the Forward direction. B) After the preset time delay, the motor should stop briefly (plugging delay) and then start running in the Reverse direction. C) Press the Stop button; both contactors should open, and the motor should stop.

	8. Final Check: Confirm the correct automatic sequence (Forward→Delay→Reverse) and verify that the electrical interlocks successfully prevent simultaneous operation.
Trainee's Signature	
Assessor's Signature	
QA Signature	
Assessor's Comment	

Module 2: Implement PLC Installation and Wiring with Configuration



Contents of Module

Module Description

This unit covers the knowledge, skills and attitudes required to implement PLC installation and wiring with configuration. It specifically includes the tasks of preparing for works, setting up PLC hardware configurations with software tool and establishing communication between PLC And PC.

Minimum Time: 15 Hours



Learning Outcome

- 2.1. Prepare for works
- 2.2. Setup PLC hardware configurations with software tool
- 2.3. Establish communication between PLC and PC



Performance Criteria

- 4) Safe working practices are followed and Personal Protective Equipment (PPE) is worn as per workplace requirement.
- 5) Necessary tools and equipment are selected and prepared for Installation as job requirements.
- 6) Materials and PLC components are identified required for Installation and commissioning of PLC.

- 7) Typical PLC components and the control devices are installed as per job requirement.
- 8) Sensors and switches are connected to a particular input and output of PLC.
- 9) Cable connections between the PLC and the programming devices are connected as per work instruction.
- 10) Connection is checked as per required specification.
- 11) Protective devices are set as per the user manual.
- 12) Required software tool is installed.
- 13) Selected hardware is configured using PLC software tools.
- 14) Hardware devices are checked in accordance with user manual.
- 15) Address of PLC and PC are configured as per job requirement.
- 16) Communication between PLC and PC using communication protocols is established.
- 17) Communication between PLC & PC is verified.

Learning Outcome 2.1 – Prepare for Works



Content

- **System Overview and Documentation:** Understand the PLC architecture (CPU, I/O modules, power supply), interpret the system documentation, and verify the latest ladder logic program or configuration file for the installation.
- **Safety and Environmental Checks:** Review and implement all electrical safety protocols (LOTO), verify the environmental conditions (temperature, humidity, vibration) of the intended installation location, and check the panel for proper grounding.
- **Component and Tool Staging:** Inventory all required hardware (PLC modules, terminal blocks, wiring ducts), verify part numbers against the bill of materials, and organize all necessary crimping, stripping, and measuring tools.



Assessment Criteria

- Pre-Installation Checklist Completion
- Wiring Preparation Quality
- Panel Layout and Space Allocation



Necessary Equipment

- PLC Hardware Kit
- Wire Preparation Tools
- Timer
- Configuration and Diagnostic Tools
- Electrical Safety and Measurement Tools
- Cabinet Installation Components



Learning Activity 2.1-1

Learning Activity	Resources/ Instructions/ References
Prepare for Works	• Information Sheet: 2.1-1 • Self-Check: 2.1-1 • Answer Paper: 2.1-1 • Job Sheet 12



Information Sheet 2.1-1

Learning Objective: The learner will be able to verify all documentation, perform necessary safety and environmental checks, and stage all PLC hardware and tools to ensure a compliant and successful installation.

Programmable Logic Controller (PLC)

Introduction to PLC

- **PLC** → Programmable Logic Controller or Programmable Controller or Sequence Controller. It is called "**Programmable**" because the program can be edited, rewritten, and deleted at any time. It is called a "**Sequence Controller**" because any operation in an industrial machine can be controlled in a sequence.
- **PLC** is a microprocessor-based device that controls any machine or system by receiving various inputs and outputs.
- **Summary:** A **PLC** is essentially a small computer used in industrial automation.

Benefits of PLC

- Better Reliability
- More Flexible
- Low Cost
- Easy Communication
- Faster Response time
- Easy Troubleshooting
- Easy to Program

Brands of PLC

- Siemens (Germany)
- Rockwell Automation / Allen-Bradley (USA)
- Mitsubishi Electric (Japan)
- Schneider Electric (France)
- Omron (Japan)
- Delta Electronics (Taiwan)
- Honeywell (USA)
- Hitachi (Japan)
- Keyence (Japan)
- Phoenix Contact (Germany)
- Fuji Electric (Japan)

PLC Hardware Overview

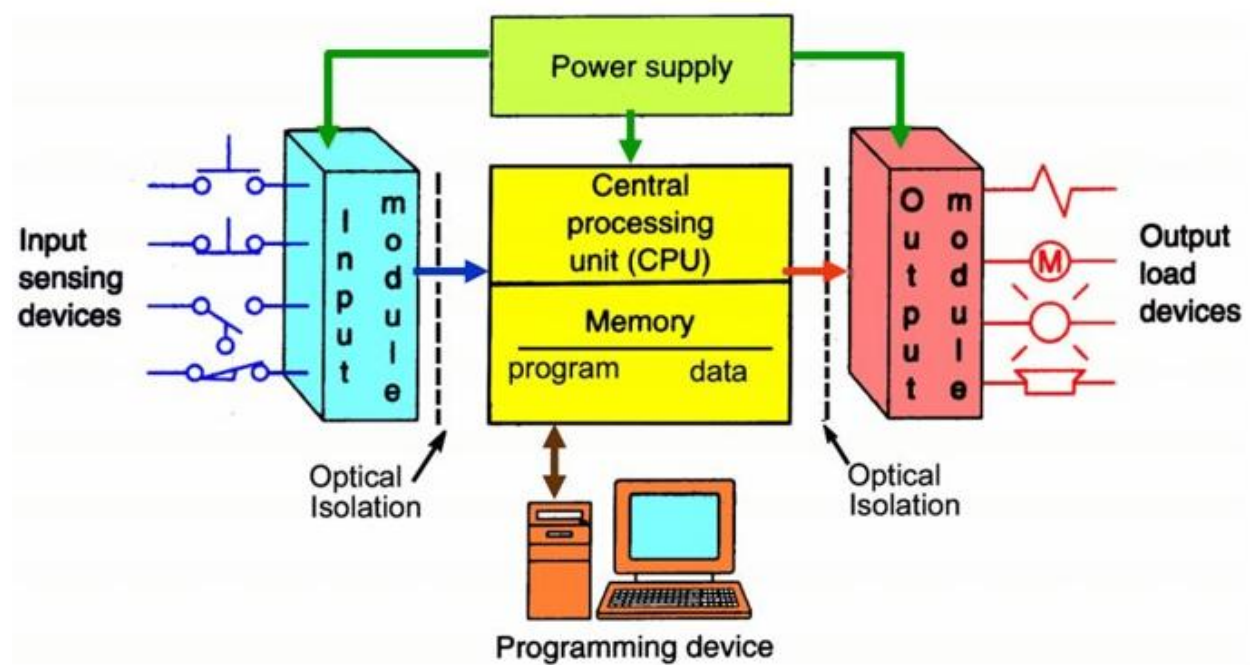


Fig: PLC System

A PLC (Programmable Logic Controller) hardware system is composed of several key components that work together to monitor and control industrial processes. Think of it as a specialized, rugged computer designed for the factory floor.

Central Processing Unit (CPU)

The **CPU** is the brain of the PLC. It's a microprocessor that executes the user-created program, which is stored in its memory. The CPU has two main modes:

- **Programming Mode:** The CPU accepts and stores the program downloaded from a computer.
- **Run Mode:** The CPU executes the program by continuously scanning and processing inputs and outputs. It takes data from input devices, processes it based on the program's logic, and sends commands to output devices.

Power Supply

The **power supply module** provides the necessary DC power to the PLC's internal components, including the CPU and I/O modules. It converts the incoming AC voltage (from the main power source) into a stable DC voltage that the electronics can use. It is crucial for ensuring the reliable operation of the entire system.

Input/Output (I/O) Modules

The **I/O modules** are the PLC's connection to the physical world. They act as the interface between the CPU and the field devices (sensors, switches, motors, etc.).

- **Input Modules:** These modules receive signals from input devices. They convert the electrical signals from sensors (e.g., a push button being pressed, a temperature sensor's reading) into a digital format that the CPU can understand.

- **Output Modules:** These modules take signals from the CPU and convert them into commands for output devices. They send electrical signals to activate things like motor starters, solenoid valves, or indicator lights.

Mounting Rack/Chassis

The **mounting rack**, also known as the **chassis** or **backplane**, is the physical structure that houses the PLC modules. . It provides a secure framework for the power supply, CPU, and I/O modules, and it includes a built-in bus that allows the modules to communicate with each other.

Programming Device

A **programming device** is a computer or a specialized handheld unit used to create, modify, and monitor the PLC program. It is connected to the PLC, usually through a USB, Ethernet, or serial cable. The software on the programming device allows the user to write the control logic and then download it to the PLC's memory.

Types of PLC

PLCs can be categorized in several ways, but the most common classification is based on their physical hardware design and I/O (Input/Output) capabilities.

Types of PLC according to Size

Compact PLC (Fixed I/O)

A Compact PLC, also known as a Fixed I/O PLC, is a single, self-contained unit. It houses the CPU, power supply, and a fixed number of inputs and outputs in one block.

Design: All components are integrated into a single chassis. The number of I/O points is predetermined by the manufacturer and cannot be changed or expanded.

Advantages

- **Cost-Effective:** They are generally less expensive than modular systems.
- **Simplicity:** Their all-in-one design simplifies wiring and installation.
- **Small Footprint:** They are ideal for applications where space is limited.

Disadvantages

- **Limited Scalability:** You cannot add more I/O modules, which can be a problem if your application requirements change or grow.
- **Difficult to Troubleshoot:** If one part of the unit fails (e.g., an input terminal), the entire PLC might need to be replaced.

Typical Applications: Small, standalone machines like packaging equipment, small conveyors, or simple control panels for a single process.

Modular PLC

A Modular PLC is a more flexible and scalable system. It consists of separate, individual modules that are plugged into a rack or chassis.

Design: The system is built using a rack or backplane into which you can insert different modules, such as a CPU module, power supply module, and various I/O modules (digital input, analog output, etc.).

Advantages

- **High Scalability:** You can easily add or remove I/O modules as needed, allowing the PLC to grow with your application. This is especially useful for complex or expanding systems.
- **Easy Maintenance:** If a module fails, you can simply replace the faulty module without having to replace the entire system, which reduces downtime and maintenance costs.
- **Flexibility:** You can choose from a wide range of specialized modules (e.g., communication modules, temperature control modules) to customize the system for specific tasks.

Disadvantages

- Higher Initial Cost: The individual modules and the rack make them more expensive upfront.
- Complex Wiring: The separate modules can lead to a more complex and larger wiring layout.

Typical Applications: Large-scale industrial processes, complex manufacturing lines, and automated systems that require a high number of I/O points and future expansion capabilities.

Types of PLC according to Output

The type of output a PLC module uses is crucial for connecting to and controlling field devices. The main types of outputs are:

Relay Output

- Description: The PLC's internal logic controls an electromechanical relay that opens or closes a physical contact. This allows the PLC to switch both AC and DC loads.
- Advantages: Provides electrical isolation between the PLC's internal circuitry and the load. Can handle a wide range of voltages and currents.
- Disadvantages: Slower switching speed and a limited number of on/off cycles due to mechanical wear. Not suitable for high-frequency switching.

Transistor Output (Solid-State DC)

- Description: The output signal is switched by a solid-state component (a transistor) with no moving parts. This is exclusively used for switching DC loads.
- Advantages: Extremely fast switching speed, making them ideal for high-speed applications like controlling stepper motors, solenoid valves, or pulse-width modulated (PWM) signals. They have a long operational life.
- Disadvantages: Can only handle DC voltage. Susceptible to damage from overcurrents or voltage spikes if not properly protected.

Triac Output (Solid-State AC)

- Description: The output signal is switched by a solid-state component called a Triac. This type of output is specifically designed for switching AC loads.
- Advantages: Fast switching speed and no mechanical wear.
- Disadvantages: Can only switch AC voltage. May not provide complete isolation, and some small "leakage" current may exist even when the output is off.

Analog Output

- Description: These modules produce a continuous, variable output signal, typically in the form of a voltage (e.g., 0-10V) or current (e.g., 4-20mA).
- Application: Used to control devices that require a variable signal, such as a motor's speed (via a Variable Frequency Drive - VFD), the position of a control valve, or the dimming of a light.

PLC Programming Language

There are five main PLC programming languages defined by the international standard **IEC 61131-3**. These languages are designed to suit different programming backgrounds and application types. They are divided into two main categories: graphical and textual.

Graphical Languages

Ladder Diagram (LD): This is the most popular and widely used PLC language. It's a graphical language that visually resembles the ladder diagrams of early relay logic circuits, with two vertical power "rails" and horizontal "rungs" connecting them. . It is intuitive for electricians and technicians familiar with electrical schematics and is excellent for simple, sequential, and Boolean (on/off) logic.

Function Block Diagram (FBD): FBD is a graphical language that uses "blocks" to represent functions or subroutines. These blocks are pre-defined functions, such as timers, counters, mathematical operations, or even custom user-defined functions. They are connected by lines that represent the flow of data. FBD is well-suited for applications that involve complex data flow, control loops (like PID), and mathematical operations.

Sequential Function Chart (SFC): SFC is a high-level graphical language used to structure a program into a sequence of steps, transitions, and actions. It is a powerful tool for designing complex processes that can be broken down into distinct stages. SFC makes it easy to visualize and debug the overall flow of a process, such as a startup or shutdown sequence.

Textual Languages

Structured Text (ST): ST is a high-level, text-based programming language that resembles traditional programming languages like Pascal or C. It's ideal for implementing complex algorithms, mathematical calculations, and data manipulation. ST is often used alongside other languages within a single program and is popular with programmers who have a background in traditional software development.

Instruction List (IL): IL is a low-level, assembly-like programming language. It uses mnemonic codes (like LD for Load, ST for Store, and AND) to perform operations one line at a time. It is less common today due to its complexity and lack of readability but is still used for applications that require very high execution speed or minimal memory usage.

PLC Programming Device and Software

A PLC programming device is typically a laptop or desktop computer that runs the PLC manufacturer's specific software. While hand-held devices were used in the past, a computer is now the standard for programming.

Programming Devices

The most common device for PLC programming is a **laptop**. It's preferred for its portability, allowing programmers to work directly on-site with the machinery. The computer must have sufficient processing power, RAM, and storage to handle the software and large project files.

- **Operating System:** Almost all PLC software runs on **Windows**. While some workarounds exist for other operating systems, Windows is the industry standard.
- **Connectivity:** The computer needs a way to physically connect to the PLC. This is usually done via a dedicated programming cable using a USB, Ethernet, or, for older PLCs, a serial (RS-232) port. Many modern PLCs use standard Ethernet for communication, which simplifies networking.

Programming Software

Each major PLC brand has its own proprietary software. You cannot use Rockwell's software to program a Siemens PLC, for example. The software is where you create, test, and debug the control program.

- **Rockwell Automation:** The primary software is **Studio 5000 Logix Designer**, used for their CompactLogix and ControlLogix platforms. Older software like **RSLogix 500** is used for legacy PLC models.
- **Siemens: TIA Portal (Totally Integrated Automation Portal)** is a comprehensive software suite that handles not only PLCs but also HMIs, drives, and other automation components.
- **Mitsubishi Electric: GX Works** is their main programming software, supporting their MELSEC PLC line.
- **Schneider Electric: Eco Struxure Machine Expert** is their software platform for a wide range of their PLCs and other devices.

Working Principle of PLC

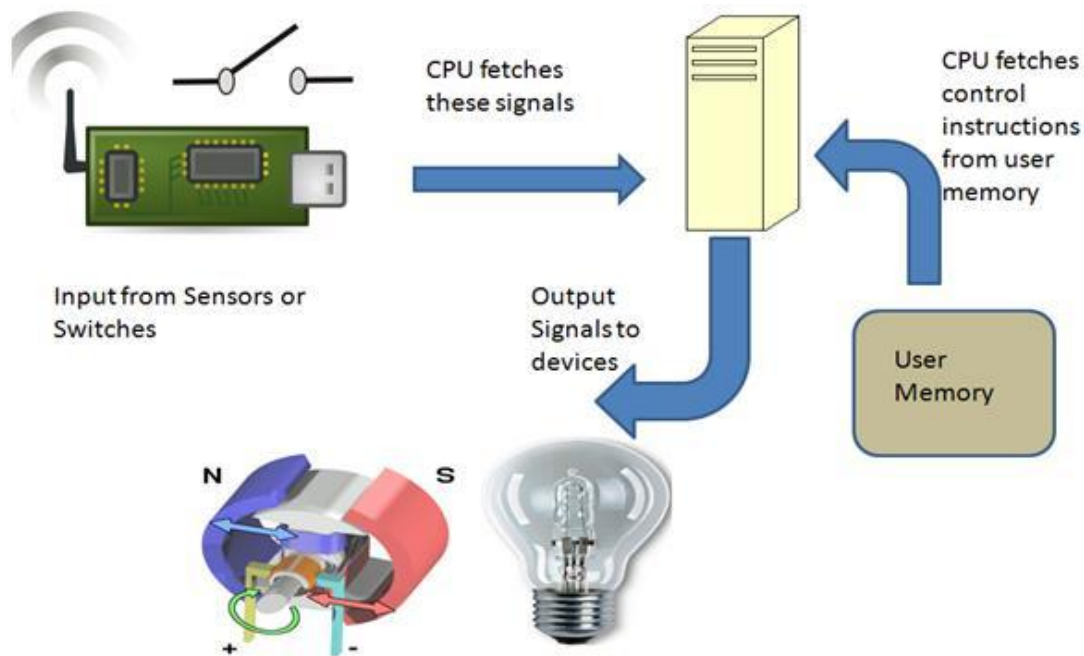


Fig: PLC Working PLC

A PLC operates by continuously executing a **scan cycle**, which is a high-speed, repetitive process that involves four main steps. This cycle is what allows the PLC to monitor and control a process in real-time.

The PLC Scan Cycle

The scan cycle runs in a continuous loop, starting over as soon as it finishes. A single cycle can be completed in just a few milliseconds for modern PLCs.

- **Input Scan:** The PLC first reads the status of all its **input devices** (e.g., switches, sensors, buttons) and stores this information in its internal memory, often called the **Input Image Table**. This creates a snapshot of the current state of the process.
- **Program Scan:** Next, the PLC executes the user-created program, which is stored in the CPU's memory. It processes the program's logic **rung by rung** (for Ladder Logic), using

the input status data that was stored in the previous step. The CPU performs logical and mathematical operations and determines what the new output states should be.

- **Output Scan:** After the program is executed, the PLC updates the state of its **output devices** (e.g., motors, lights, valves) based on the results from the program scan. The signals are sent to the output modules, which energize or de-energize the connected field devices.
- **Housekeeping:** The PLC performs internal diagnostics and communicates with other devices, such as a programming terminal or an HMI (Human-Machine Interface), before restarting the entire cycle. This step ensures that the PLC is running correctly and allows for monitoring and troubleshooting.

The entire process repeats continuously, ensuring that the PLC is always monitoring the inputs and responding to changes in the process in a deterministic and timely manner.

Siemens PLC Models

Siemens offers a comprehensive range of PLC models under its **SIMATIC** brand, catering to a wide spectrum of industrial applications from simple, compact tasks to large, complex, and high-performance systems. The most common and modern lines are the **S7-1200** and **S7-1500**, though older series like the **S7-300** and **S7-400** are still in use.

Siemens S7 200 PLC

The **Siemens SIMATIC S7-200** is a compact, micro-PLC that was popular for small-scale automation tasks. It's now considered a **legacy** or **obsolete** product and has been replaced by the more modern **S7-1200** series.

Key Features and Characteristics

- **Design:** The S7-200 was an all-in-one unit, integrating the CPU, power supply, and a fixed number of I/O points into a single, compact block. This made it a cost-effective and space-saving solution.

- **I/O:** It offered a variety of models with a different number of digital and analog I/O points, but its capacity was limited. For applications requiring more I/O, it could be expanded with separate expansion modules.
- **Programming Software:** It was programmed using a dedicated software called **STEP 7 Micro/WIN**. This software was designed specifically for the S7-200 series and used the familiar Ladder Logic (LAD) and Statement List (STL) languages.
- **Communication:** The S7-200 typically communicated via an RS-485 port using the PPI (Point-to-Point Interface) protocol.
- **Performance:** While it was suitable for simple control tasks, its processing speed and memory capacity were limited compared to modern PLCs.

Siemens S7 300 PLC

The **Siemens SIMATIC S7-300** is a mid-range, modular PLC. It was the workhorse of Siemens' automation portfolio for many years, used for a wide variety of medium to large-scale applications. Like the S7-200, it is also a **legacy** product and has been succeeded by the more advanced **S7-1500** series.

Key Features and Characteristics

- **Design:** The S7-300 is a modular system built on a **backplane rack**. The user can configure a system by selecting and plugging in various modules, including a power supply, CPU, digital I/O, analog I/O, and communication modules. This modularity made it highly flexible and scalable.
- **Performance:** It offered a broad range of CPU models with different processing speeds and memory capacities, allowing it to handle complex programs and a high number of I/O points.
- **Communication:** The S7-300 supported multiple communication protocols, most notably **PROFIBUS** and **PROFINET**, which enabled it to integrate with HMIs, SCADA systems, and other field devices.

- **Programming Software:** It was programmed using **STEP 7** software, which was a robust and widely used platform.

Siemens S7 400 PLC

The **Siemens SIMATIC S7-400** is a high-performance, rack-based PLC designed for large-scale, complex automation tasks and process control. It is considered the most powerful PLC in the legacy SIMATIC lineup, known for its speed and redundancy capabilities.

Key Features and Characteristics

- **Design:** The S7-400 is a modular system that is built on a central backplane or rack. Users can configure a powerful system by choosing from a wide range of modules, including different CPUs, power supplies, and various I/O and communication modules.
- **Performance:** It is known for its high-speed processing, large memory capacity, and robust design. This allows it to handle complex algorithms, vast amounts of data, and a very high number of I/O points.
- **Redundancy:** A key feature of the S7-400 is its support for **redundancy**. Two S7-400 PLCs can be configured to operate in a master/slave setup. If the master PLC fails, the slave takes over control seamlessly, ensuring continuous operation of critical processes. This is essential for industries where downtime is unacceptable, such as power generation, oil and gas, and chemical plants.
- **Communication:** The S7-400 supports various communication protocols, with a strong emphasis on **PROFIBUS** and **PROFINET** for large-scale networking.
- **Programming Software:** It is programmed using **STEP 7** software, which is a powerful and versatile platform.

Siemens S7 1200 PLC

The **Siemens SIMATIC S7-1200** is a compact, modular PLC designed for small to medium-sized automation tasks. It is considered the modern successor to the S7-200 series and is the standard for basic to mid-level applications.

Key Features and Characteristics

- **Design:** The S7-1200 is primarily a compact, all-in-one unit, with the CPU, power supply, and I/O integrated into a single chassis. However, its I/O can be expanded by adding additional modules.
- **Performance:** It offers a wide range of CPU models with different processing speeds and memory capacities. It is well-suited for a variety of tasks, from simple sequential control to more advanced applications.
- **Communication:** A key feature of the S7-1200 is its built-in **PROFINET** interface. This Ethernet-based communication protocol allows for easy integration with HMIs, other PLCs, and SCADA systems, and enables remote maintenance and diagnostics.
- **Technology Functions:** It includes powerful built-in functions for technology tasks, such as high-speed counters, pulse outputs for basic motion control, and PID (proportional-integral-derivative) control for process loops.
- **Programming Software:** The S7-1200 is programmed using **TIA Portal** (Totally Integrated Automation Portal), specifically the **STEP 7 Basic** software. This modern software environment is user-friendly and supports a variety of programming languages.



Fig: Siemens S7 1200 PLC

Siemens S7 1500 PLC

The **Siemens SIMATIC S7-1500** is a high-performance, modular PLC that is part of the Siemens **TIA Portal** (Totally Integrated Automation Portal) and represents the latest generation of Siemens controllers. It is designed to handle medium to large-scale, complex automation tasks, and it is the successor to the older S7-300 and S7-400 series.

Key Features and Characteristics

- **Design:** The S7-1500 is a modular, rack-based system. Its modules, including the CPU, power supply, and various I/O and communication modules, are a key feature that allows for flexibility and scalability.
- **Performance:** It offers a high processing speed and a fast backplane bus for rapid data exchange between modules, making it suitable for high-speed, data-intensive applications.

- **Integrated Technology:** The S7-1500 has integrated functions for motion control, process automation, and safety. This reduces the need for external hardware and simplifies programming.
- **Security:** Enhanced security is a core feature, including password protection, know-how protection for blocks, and integrated firewall functions to protect against unauthorized access.
- **Communication:** It has built-in **PROFINET** interfaces and supports a wide range of other communication protocols, making it easy to integrate with a variety of devices and systems.
- **Diagnostics:** The S7-1500 provides advanced diagnostics directly on the CPU display and in the programming software. This simplifies troubleshooting and helps reduce downtime.



Fig: Siemens S7 1500 PLC



Self-Check 2.1-1

1. What are the two main modes of operation for a PLC's Central Processing Unit (CPU)?
2. What is the function of the **Input/Output (I/O) Modules**, and what is their role in relation to the CPU and field devices?
3. What are the two primary categories used to classify PLC programming languages defined by the IEC 61131-3 standard?
4. According to the PLC Scan Cycle, what is the sequence of the first three main steps performed continuously by the PLC?
5. What key trade-offs (one advantage, one disadvantage) distinguish a **Compact PLC** from a **Modular PLC** based on their design?
6. What are the three main types of PLC outputs, and which type is suitable for exclusively switching AC loads?
7. What is the major feature of the high-performance **Siemens S7-400 PLC** that is essential for industries where continuous operation is critical?



Answer Paper 2.1-1

1. The two main modes of operation for a PLC's CPU are the Programming Mode (accepts and stores the program) and the Run Mode (executes the program by continuously scanning and processing inputs and outputs).
2. The I/O modules are the PLC's connection to the physical world. They act as the interface between the CPU and the field devices (sensors, switches, motors, etc.).
3. The two primary categories are Graphical Languages (e.g., Ladder Diagram, Function Block Diagram) and Textual Languages (e.g., Structured Text, Instruction List).

4. The sequence of the first three main steps in the PLC Scan Cycle is: Input Scan (reads status of all input devices), Program Scan (executes user-created logic), and Output Scan (updates the state of output devices).
5. A Compact PLC is Cost-Effective due to its all-in-one design but has Limited Scalability (fixed I/O). A Modular PLC offers High Scalability (can add/remove I/O) but has a Higher Initial Cost.
6. The three main types of PLC outputs are Relay Output, Transistor Output (Solid-State DC), and Triac Output (Solid-State AC). The Triac Output is specifically designed for switching AC loads.
7. A major feature of the Siemens S7-400 PLC is its support for Redundancy, where two PLCs can be configured in a master/slave setup to ensure continuous operation if one fails.

	Job Sheet 12
Qualification	Industrial Automation
Learning Unit	Prepare for PLC Hardware Configuration with Software Tool
Trainee Name	
PPE	Safety glasses (when handling PLC or wiring) and appropriate work clothing.
Tools & Equipment	Programmable Logic Controller (PLC) (e.g., Siemens S7, Allen-Bradley CompactLogix), PC/Laptop with PLC Programming Software (e.g., TIA Portal, Studio 5000), PLC Programming Cable (e.g., Ethernet, USB, Serial), Control Power Supply (matching PLC requirements), Screwdriver set, Wire stripper/cutter, and Multimeter (DMM).
Notes	1. Documentation: Always have the PLC Hardware Manual and Software Installation Guide available. 2. Communication: Ensure the PC's network settings (IP address, subnet mask) are compatible with the PLC's default or configured settings.

	3. Power Verification: Check the PLC's input power voltage before connecting it. 4. Safety: Strictly adhere to LOTO when connecting the PLC to power.
Procedure	1. Software Installation & License: Verify the correct PLC programming software version is installed on the PC. Confirm the license is active and accessible. 2. Hardware Inspection: Inspect the PLC module(s) for physical damage, correct mounting, and secure backplane connection (if modular). 3. Power Up & LOTO: Apply LOTO to the control power supply. Wire the control power to the PLC's power terminals. Remove LOTO and energize the PLC; verify the Power LED is green. 4. PC Communication Setup: Connect the programming cable (e.g., Ethernet or USB) between the PC and the PLC's communication port. On the PC, verify the necessary communication driver is recognized, or set the PC's IP address to be in the same subnet as the PLC. 5. New Project Creation: Open the PLC programming software. Create a New Project and provide a descriptive name (e.g., "PLC_Config_Test"). 6. Hardware Configuration: Within the new project, select the option for Hardware Configuration. Select the exact PLC model and firmware version being used from the hardware catalog. Configure the rack/slot arrangement if using a modular system. 7. Network/IP Address Configuration: Configure the PLC's communication port settings (e.g., assigning a unique IP address and subnet mask) within the software to match the network environment. 8. Verify Communication (GO ONLINE): Use the software's "Go Online" or "Ping/Test Connection" feature to establish a reliable communication link with the physical PLC. The software should successfully identify the connected hardware.

	9. Final Documentation: Confirm the PLC is in a STOP mode and ready for logic programming. Document the assigned IP address and firmware version.
Trainee's Signature	
Assessor's Signature	
QA Signature	
Assessor's Comment	

Learning Outcome 2.2 – Setup PLC hardware configurations with software tool



Content

- Addressing and I/O Mapping: Understand the relationship between the physical I/O (inputs/outputs) and their corresponding memory addresses (e.g., I:1/0, O:2/3) within the PLC configuration software.
- Module Configuration: Learn to correctly add, configure, and parameterize different I/O module types (e.g., discrete, analog, high-speed counter) in the software environment to match the installed hardware.
- Communication Settings: Establish and test the communication link between the PLC hardware (CPU) and the programming computer, including setting up IP addresses, subnet masks, or selecting the correct communication driver.



Assessment Criteria

- Accurate Hardware Representation
- Parameter Setting Compliance
- Successful Download and Connectivity



Necessary Equipment

- Programmable Logic Controller (PLC)
- Programming Computer/Laptop
- Communication Cable
- Technical Documentation
- Digital Multimeter (DMM)



Learning Activity 2.2-1

Learning Activity	Resources/ Instructions/ References
Setup PLC hardware configurations with software tool	• Information Sheet: 2.2-1 • Self-Check: 2.2-1 • Answer Paper: 2.2-1 • Job Sheet 13



Information Sheet 2.2-1

Learning Objective: The learner will be able to configure the PLC hardware modules and communication settings within the software tool to accurately match the physical system architecture and establish a working communication link.

Program Structure in Siemens PLC

The program structure in a Siemens PLC, particularly with the modern **TIA Portal** software, is organized hierarchically to make complex projects manageable and modular. This structure allows multiple programmers to work on different parts of a project simultaneously and simplifies debugging and maintenance.

Blocks

The fundamental building blocks of a Siemens PLC program are called **Blocks**. All program logic is contained within different types of blocks.

- **Organization Blocks (OBs):** These are the entry points for the program. The CPU calls these blocks automatically based on specific events. The most common is the **Main Organization Block (OB1)**, which the CPU calls repeatedly in its scan cycle. Other OBs can be configured to run on startup, on a time interrupt, or upon a hardware interrupt.
- **Function Blocks (FBs):** FBs are code modules that have a **memory associated with them (an instance data block)**. This means an FB can retain data from one scan to the next. FBs are ideal for writing reusable code for a specific component, like a motor or a valve, where you need to track its state, timers, and other data.
- **Functions (FCs):** Functions are code modules that **do not have a memory area** associated with them. They are designed to perform a specific task, such as a mathematical calculation or a data conversion, and they return a value. They are useful for creating reusable, stateless code.
- **Data Blocks (DBs):** These are memory areas used to store data for the program. They are not executable code but hold variables, parameters, and other data that the program uses. There are two types: **Global DBs**, which can be accessed from any block, and **Instance DBs**, which are automatically created to store the data for a specific Function Block.

Program and Device Structure

TIA Portal organizes the blocks within a project in a tree-like structure.

- **Project:** This is the top-level container that holds all the devices and programs.

- **Devices:** Within a project, you can have multiple devices, such as a PLC (e.g., S7-1500), an HMI, and a drive.
- **Program Blocks:** Under each PLC device, you have the "Program Blocks" folder, which contains all the OBs, FBs, FCs, and DBs.

This structured approach makes it easy to navigate, manage, and scale a project, from a simple, single-block program to a large, multi-controller automation system.

PLC Tags & Data Types

In a PLC, **tags** are symbolic names used to represent data locations in the controller's memory. Instead of using complex memory addresses, tags make programming easier to understand, read, and maintain. They are essentially human-readable labels for I/O points, variables, and data blocks.

Key Characteristics of PLC Tags

- **Symbolic Naming:** Tags use descriptive names (e.g., Motor_Start_PB, Conveyor_Speed, Fault_Status) rather than hard-to-read addresses (e.g., I:0/0.0, N7:10). This self-documenting approach simplifies troubleshooting and collaboration.
- **Data Types:** Each tag has a **data type** that defines the kind of information it can hold. Common data types include:
 - ✓ **BOOL (Boolean):** A single bit, representing a true/false or on/off state (e.g., Pump_On, Sensor_Active).
 - ✓ **INT (Integer):** A whole number (e.g., Part_Count).
 - ✓ **REAL (Float):** A number with a decimal point (e.g., Tank_Level).
 - ✓ **STRING:** A sequence of characters (e.g., Product_Name).
 - ✓ **TIMER/COUNTER:** Special data types for time and counting functions.

- **Scope:** Tags have a defined scope that determines where they can be accessed in the program.
- **Global Tags:** Accessible by all parts of the PLC program. These are often used for physical I/O points and important process variables.
- **Local Tags:** Limited to a specific program block, like a function or function block. This helps prevent naming conflicts and keeps data organized.

Data Type	Abbreviated Name	Size (Bytes)	Usage	Example Address
BOOL	1 bit	1 bit (1/8 byte)	For ON/OFF, True/False data only	MO.0, IO.1, Q4.3
BYTE	8 bits	1 byte	0–255 range data	MBO, IB4, QB3
WORD	16 bits	2 bytes	For small integer values	MW10, IW2, QW6
DWORD	32 bits	4 bytes	For large integer or floating-point values	MD4, ID20, QD12
REAL	Floating point	4 bytes	For Decimal or fractional values	MD8, DB10.DBD4
INT	Signed integer	2 bytes	From -32768 to +32767	MW20
DINT	32-bit Signed	4 bytes	From -2,147,483,648 to +2,147,483,647	MD100

Fig: Data Types in PLC



Self-Check 2.2-1

1. What is the role of the Organization Blocks (OBs), and what is the specific function of the Main Organization Block (OB1)?
2. What is the fundamental distinction between a Function Block (FB) and a Function (FC) concerning memory?
3. What are Data Blocks (DBs), and what is the difference between a Global DB and an Instance DB?

4. In the TIA Portal structure, what is the top-level container that holds all the devices and programs?
5. What are Tags in a PLC, and why are they preferred over complex memory addresses?
6. Name three common Data Types that a PLC tag can hold, and briefly state what kind of information each type represents.
7. What is the purpose of a tag's Scope, and what is the difference between Global Tags and Local Tags?



Answer Paper 2.2-1

1. Organization Blocks (OBs) are the entry points for the program, which the CPU calls automatically based on specific events. The Main Organization Block (OB1) is the one the CPU calls repeatedly in its scan cycle.
2. A Function Block (FB) is a code module that has a memory associated with it (an Instance Data Block), allowing it to retain data from one scan to the next. A Function (FC) is a code module that does not have a memory area associated with it, making it stateless.
3. Data Blocks (DBs) are memory areas used to store variables, parameters, and other non-executable data for the program. A Global DB can be accessed from any block, while an Instance DB is automatically created to store data for a specific Function Block.
4. The top-level container that holds all the devices and programs in the TIA Portal structure is the Project.
5. Tags are symbolic names used to represent data locations in the controller's memory. They are preferred because they use descriptive names (e.g., Motor_Start_PB) rather than hard-to-read addresses, making programming easier to understand, read, and maintain.
6. Three common Data Types are:

- **BOOL (Boolean):** Represents a single bit, or a true/false (on/off) state.
 - **INT (Integer):** Represents a whole number (e.g., Part_Count).
 - **REAL (Float):** Represents a number with a decimal point (e.g., Tank_Level).
7. A tag's Scope determines where it can be accessed in the program. Global Tags are accessible by all parts of the program, while Local Tags are limited to a specific program block (like an FC or FB).

	Job Sheet 13
Qualification	Industrial Automation
Learning Unit	Setup PLC Hardware Configuration with Software Tool
Trainee Name	
PPE	Safety glasses (essential) and appropriate work clothing.
Tools & Equipment	Programmable Logic Controller (PLC) rack with CPU and I/O modules, PC/Laptop with PLC Programming Software (e.g., Studio 5000, TIA Portal), Programming Cable (Ethernet/USB), and PLC Manuals/Datasheets.
Notes	1. Accuracy is Key: The software configuration must exactly match the physical PLC hardware (model number, firmware version, and slot assignment). 2. Address Verification: Pay close attention to the I/O addressing automatically assigned by the software; this determines how inputs and outputs are referenced in the program logic. 3. Backup: Save the hardware configuration file immediately after setup.
Procedure	1. Safety & Preparation: Ensure the PC is communicating with the PLC (as confirmed in Job Sheet 11). Ensure the PLC is in STOP mode. 2. Start Configuration: Open the existing PLC project file. Navigate to the Hardware Configuration or I/O Configuration area within the

	software (e.g., Device Configuration in TIA Portal or Controller Organizer in Studio 5000). 3. Insert CPU Module: Select the exact CPU model number and firmware version from the hardware catalog and place it into the correct slot (usually Slot 0 or the first slot). 4. Configure Communication: Select the CPU and configure its communication port(s). Set the IP Address, Subnet Mask, and Gateway (if applicable) to match the physical network settings and the configuration established in the previous step. 5. Insert I/O Modules: Starting from the next physical slot, drag and drop the exact Analog and/or Digital I/O Module models into the corresponding slots in the software configuration. Verify the I/O addressing (tags) assigned by the software. 6. Set I/O Parameters: For specific modules (especially Analog), configure parameters like Scaling, Resolution, Data Format, or Filter Time according to the application requirements. 7. Compile and Check: Compile the hardware configuration to check for errors or inconsistencies between modules. Resolve any errors identified by the software. 8. Download Configuration: With the PLC in STOP mode, download ONLY the Hardware Configuration (or the complete project) to the PLC CPU. 9. Verification: Go online with the PLC. Check the module status lights (e.g., OK/RUN LED) and confirm the software reports the correct hardware setup and module health. Switch the PLC to RUN mode if appropriate.
Trainee's Signature	
Assessor's Signature	
QA Signature	
Assessor's Comment	

Learning Outcome 2.3 – Establish Communication between PLC and PC



Content

- **Communication Protocols:** Understand the basics of common industrial communication protocols (e.g., Ethernet/TCP-IP, Serial/RS-232, USB) and how to select the correct one for the PLC/PC connection.
- **Network Configuration:** Learn the steps for configuring network parameters (IP address, subnet mask, gateway) on both the PC's network adapter and the PLC's communication port to ensure compatibility.
- **Driver and Software Setup:** Understand how to properly install and configure the necessary communication drivers (e.g., RSLinx, TIA Portal Access Point) within the PC's programming software to recognize the PLC.



Assessment Criteria

- Successful Connection Establishment
- Read/Write Verification
- Protocol and Parameter Accuracy



Necessary Equipment

- Programmable Logic Controller (PLC)
- Programming Computer/Laptop

- Communication Cable
- Technical Documentation
- Network Configuration Tools



Learning Activity 2.3-1

Learning Activity	Resources/ Instructions/ References
Establish Communication between PLC and PC	• Information Sheet: 2.3-1 • Self-Check: 2.3-1 • Answer Paper: 2.3-1 • Job Sheet 14



Information Sheet 2.3-1

Learning Objective: The learner will be able to configure network parameters and install necessary drivers to successfully establish a stable communication link between the Programmable Logic Controller (PLC) and the programming PC.

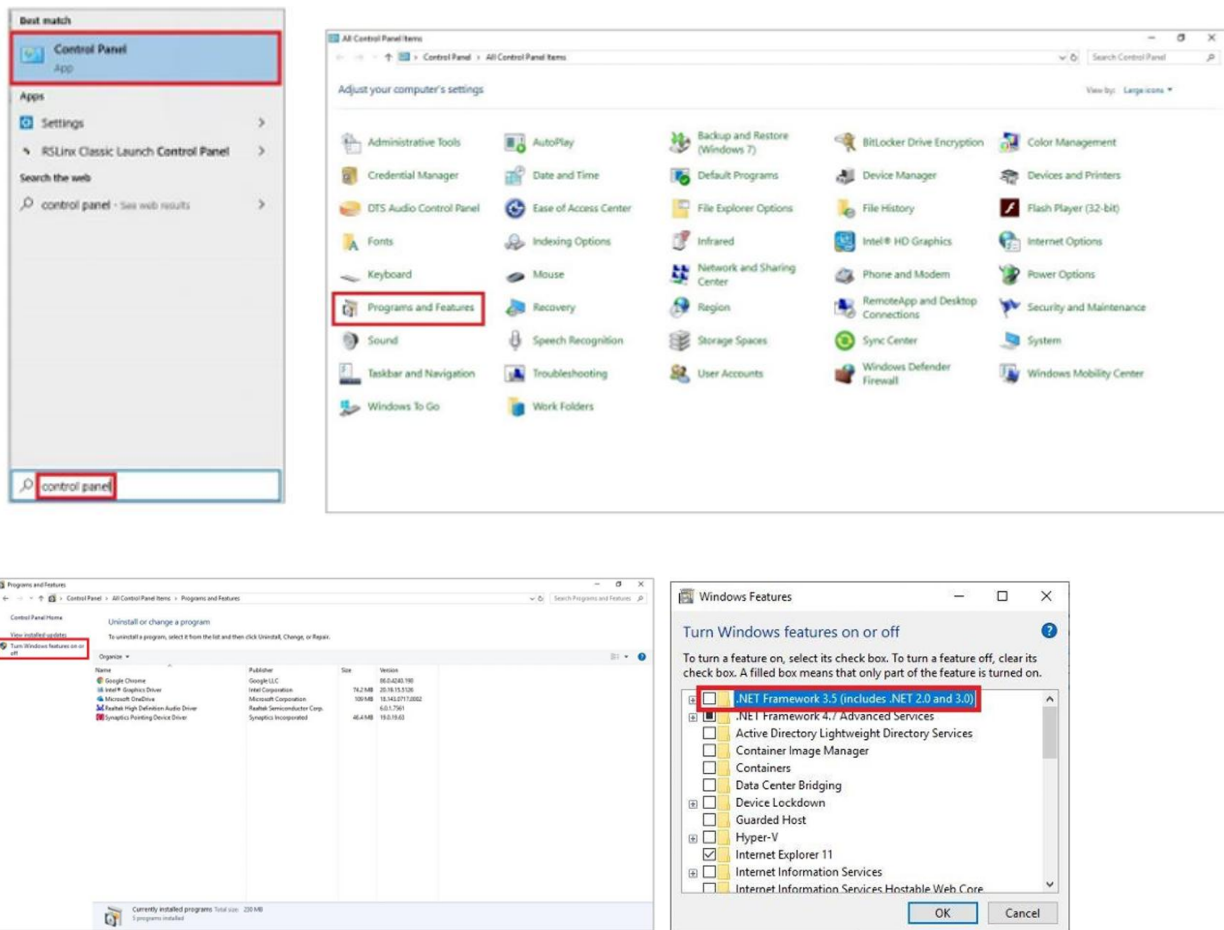
Programming of Siemens PLC

- ✓ Install software and drivers → Install TIA Portal and the communication cable driver.
- ✓ Connect the PLC with a supported communication cable → Profinet cable for communication.
- ✓ For output in PLC, use a coil.
- ✓ For input in PLC, use a NO/NC.
- ✓ For time delay in PLC, use a Timer.

Installing TIA Portal

Installing Prerequisite Software:

- Microsoft .NET Framework 3.5 is required and must be installed before TIA Portal V16 is installed.
- Microsoft .NET Framework 3.5 installation requires the computer to have an internet connection.
- Go to Control Panel → Programs and Features → Turn Windows features on or off.
- If the .NET Framework 3.5 checkbox (includes .NET 2.0 and 3.0) is empty, you must install .NET Framework 3.5. Click the .NET Framework 3.5 checkbox to start the installation.
- Click **Let Windows Update download the files for you.**
- Once .NET Framework 3.5 is complete, close the program.



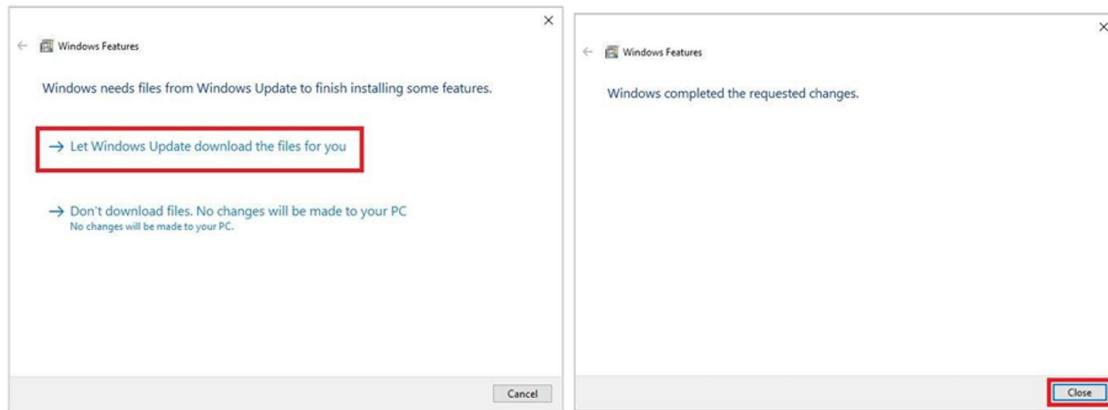
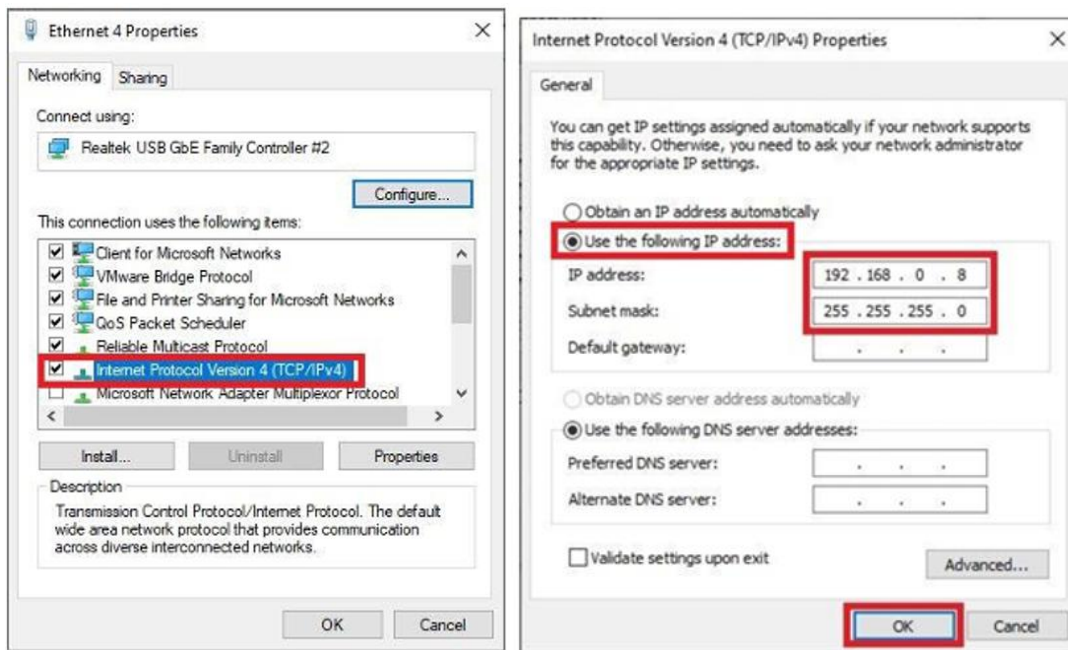
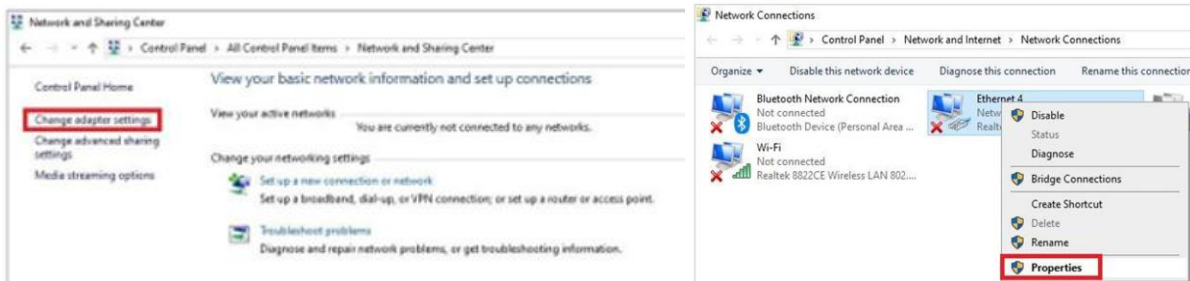
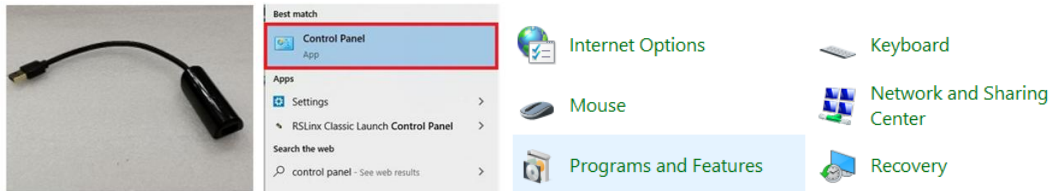


Fig: Installing Microsoft .NET Framework 3.5

Configure Network settings of Computer:

- A PC or Laptop should have a LAN port. The PC or Laptop is connected to the PLC with a LAN cable. If the laptop does not have an in-built network port, a USB network adapter can be used.
- Open **Control Panel** → Click **Network and Sharing Center**
- Change **Adapter Settings** → Right-click the network (Ethernet) port
- **Properties** → Double-click **Internet Protocol Version 4 (TCP/IPv4)**
- Use the following IP address:
- Enter IP address: **192.168.0.8**, subnet mask: **255.255.255.0**
- Click **OK**
- Back to Control Panel → Select "**Set Pa/ppe Interface (32 bit)**"
- Select the network name that has '.Auto' behind. Make sure the PC is connected to PLC. Then press OK. (Note: Different PCs will have different network names, please check and connect).



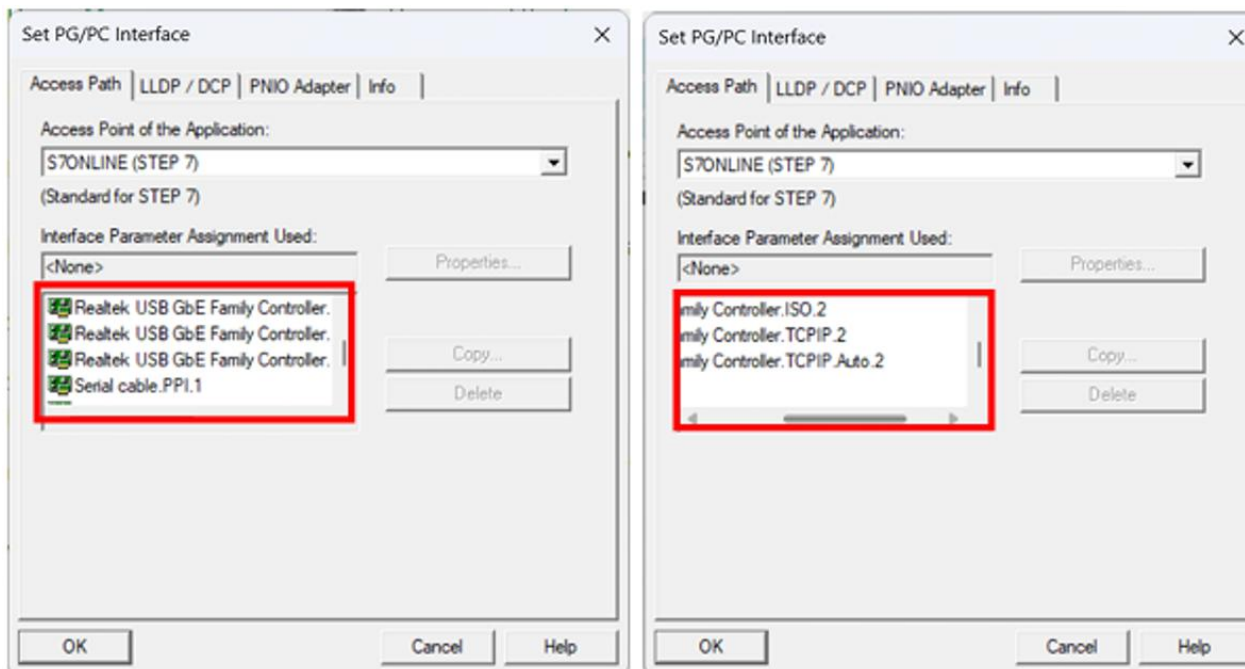
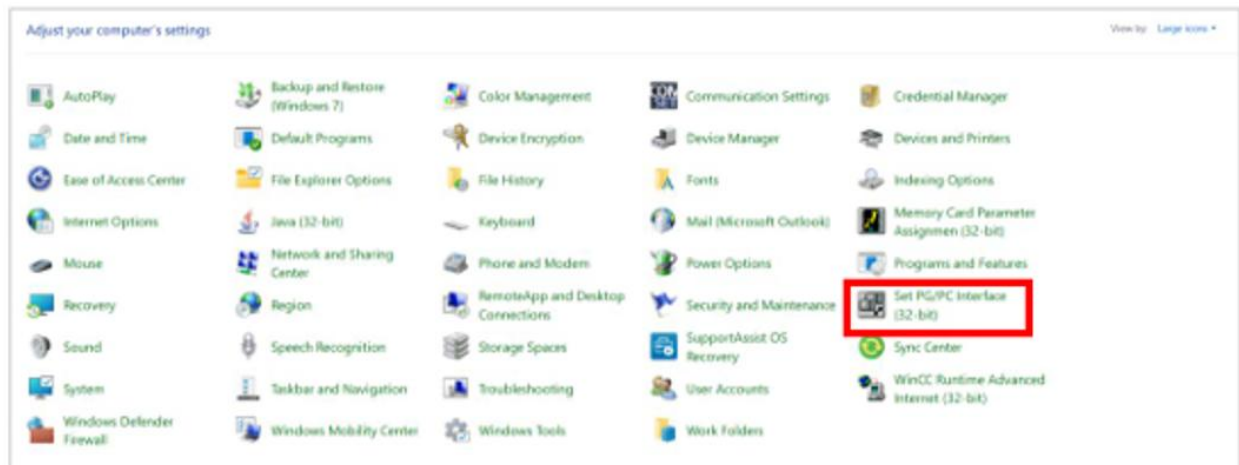


Fig: Configuring Network Setting of Computer

Before installing TIA Portal software:

- For Windows 10 and above, search for and install "**Turn Windows features on or off**" and select **.NET Framework 3.5** (which includes .NET 2.0 and 3.0).

- Turn off **Virus & Threat Protection Settings** and **Firewall & Network Protection Settings** (Microsoft Defender Firewall).
- If you have a problem installing **TIA Portal STEP 7** or **SIMATIC S7 PLC SIM** software, you may need to delete the following registry key:
 - Go to **Registry Editor**.
 - Navigate to: **Computer** → **HKEY_LOCAL_MACHINE** → **SYSTEM** → **CurrentControlSet** → **Control** → **Session Manager**

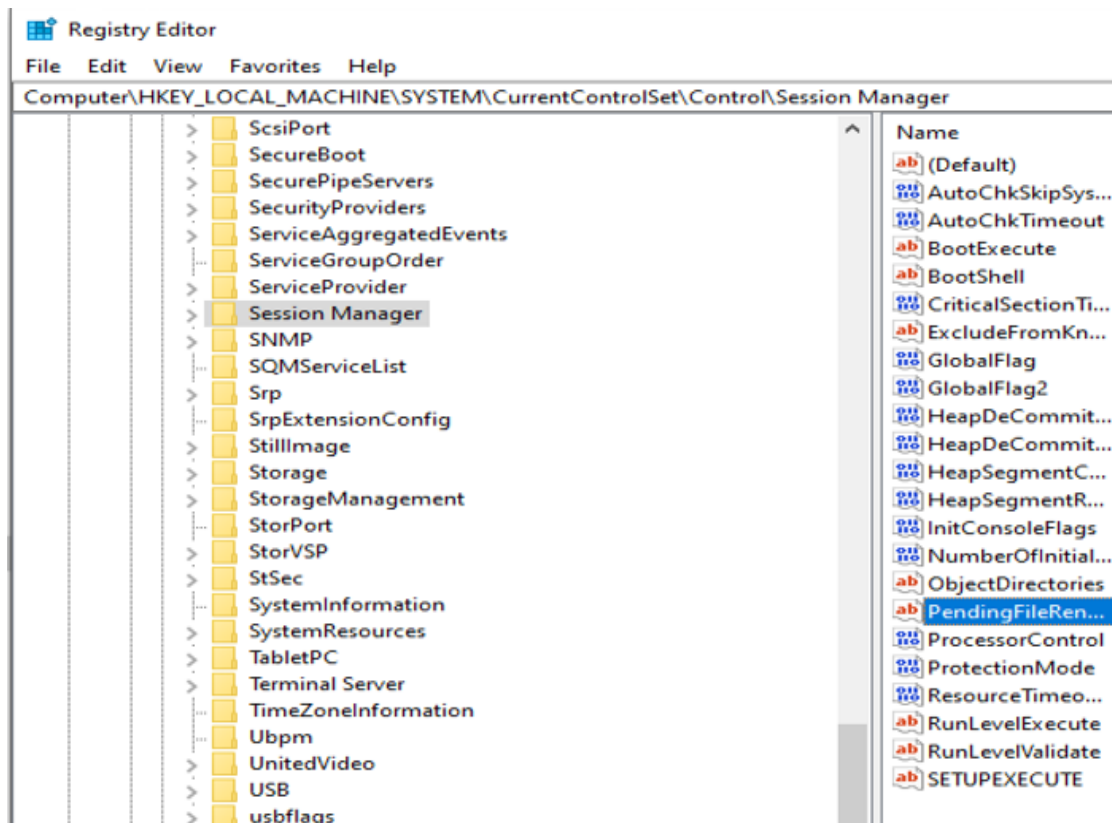
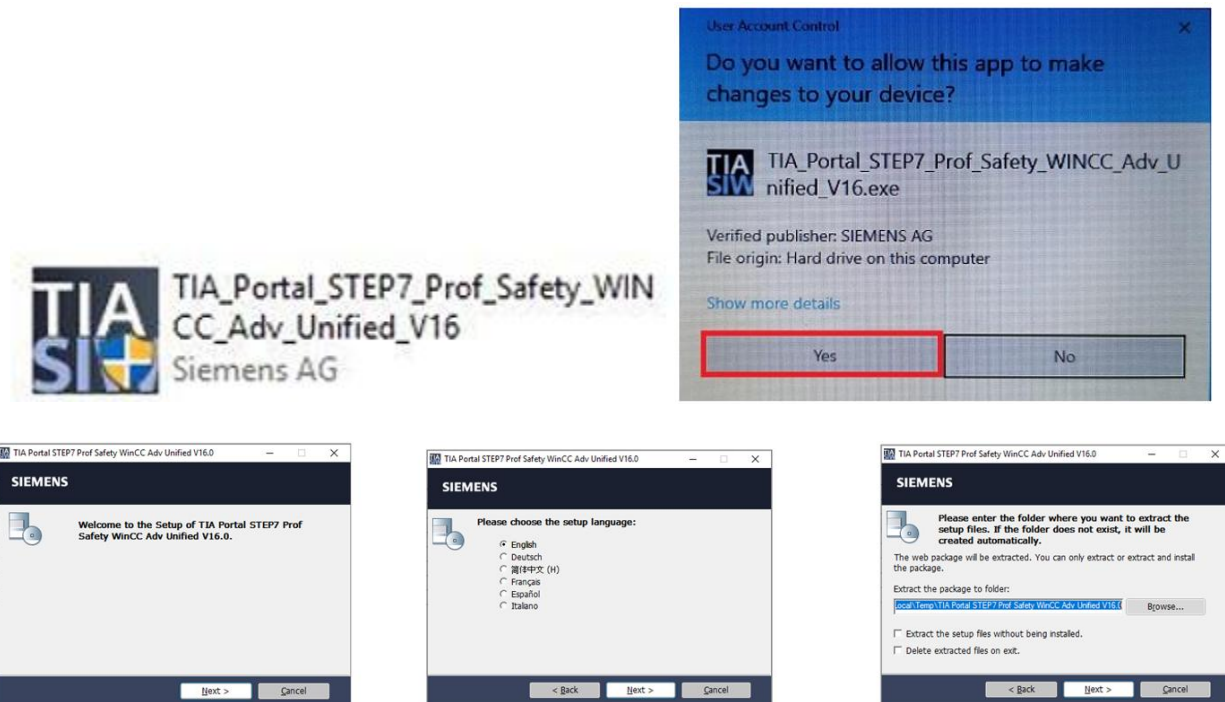


Fig: Deleting Registry Key Component

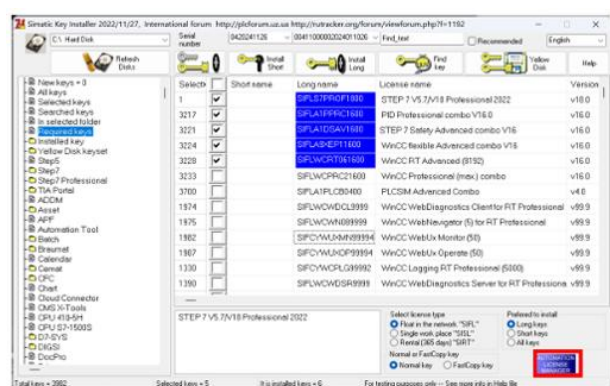
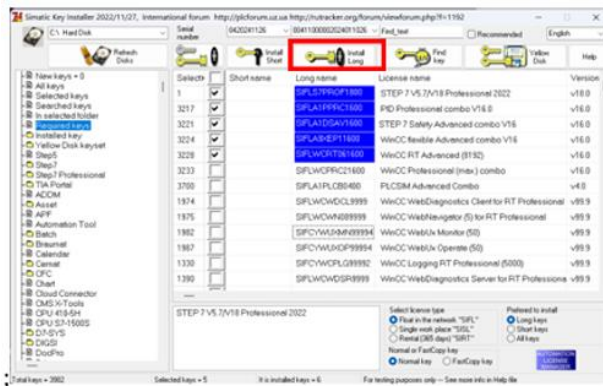
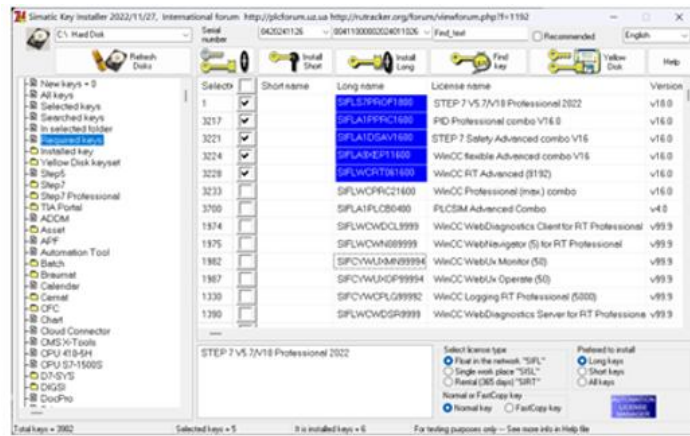
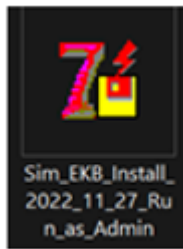
Installing TIA Portal V16 with License

- Memory: At least **8 GB** RAM.
- Storage: At least **30 GB**.
- System: Windows **10/11**.

- Double-click on **TIA_Portal_STEP7_Prof_Safety_WinCC_Adv_Unified_V16.exe** (or a similar executable file).
- Click **Next** → **Next** → **Next**.
- Wait until the extracting packages finish.
- Then click **Next** → **Yes** → **Next** → **Next** → **Next** → **Install** → **Restart**.
- After the installation is successfully completed, the software shortcut will automatically show up on the desktop. Start TIA Portal V16 to load a program.
- Right-click on **sim_EKB_Install_2022_11_27** and **Run as administrator**.
- Enable the checkbox.
- Click **Install** long.
- Double-click **AUTOMATION LICENSE MANAGER**.
- Select the license.
- Right-click the license, select **Check**.
- "License installed successfully. Click **OK**".







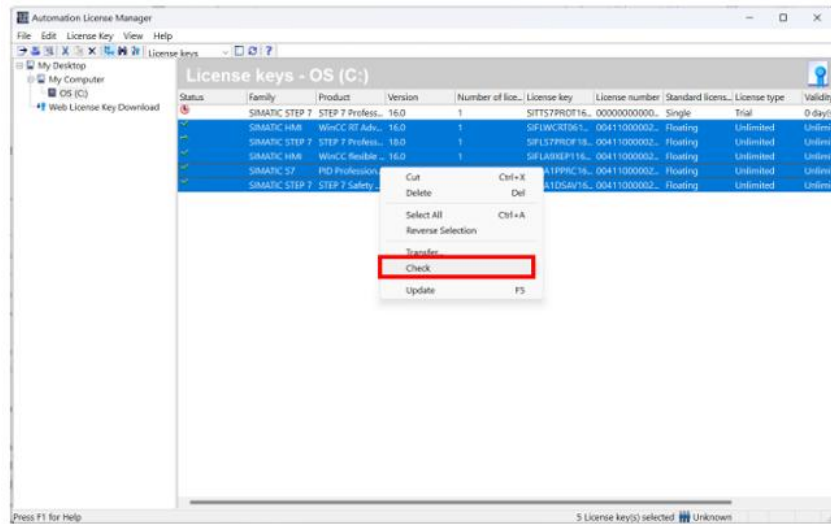
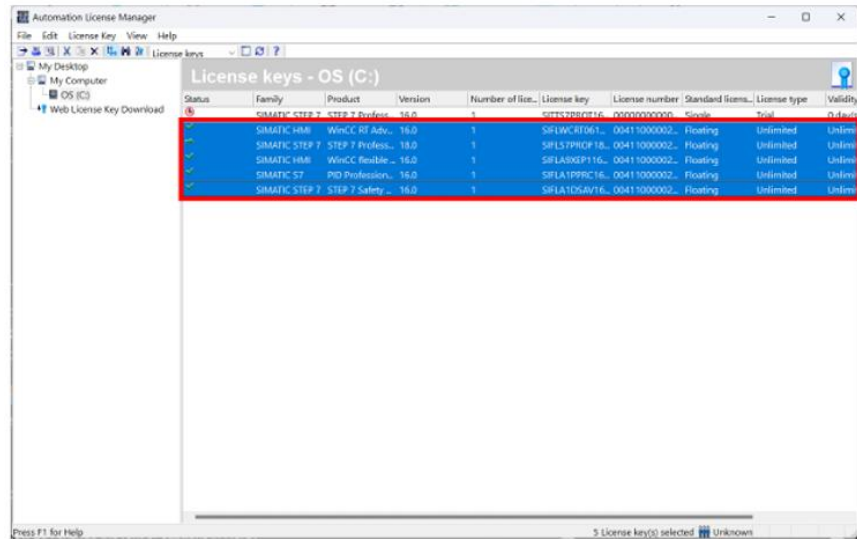


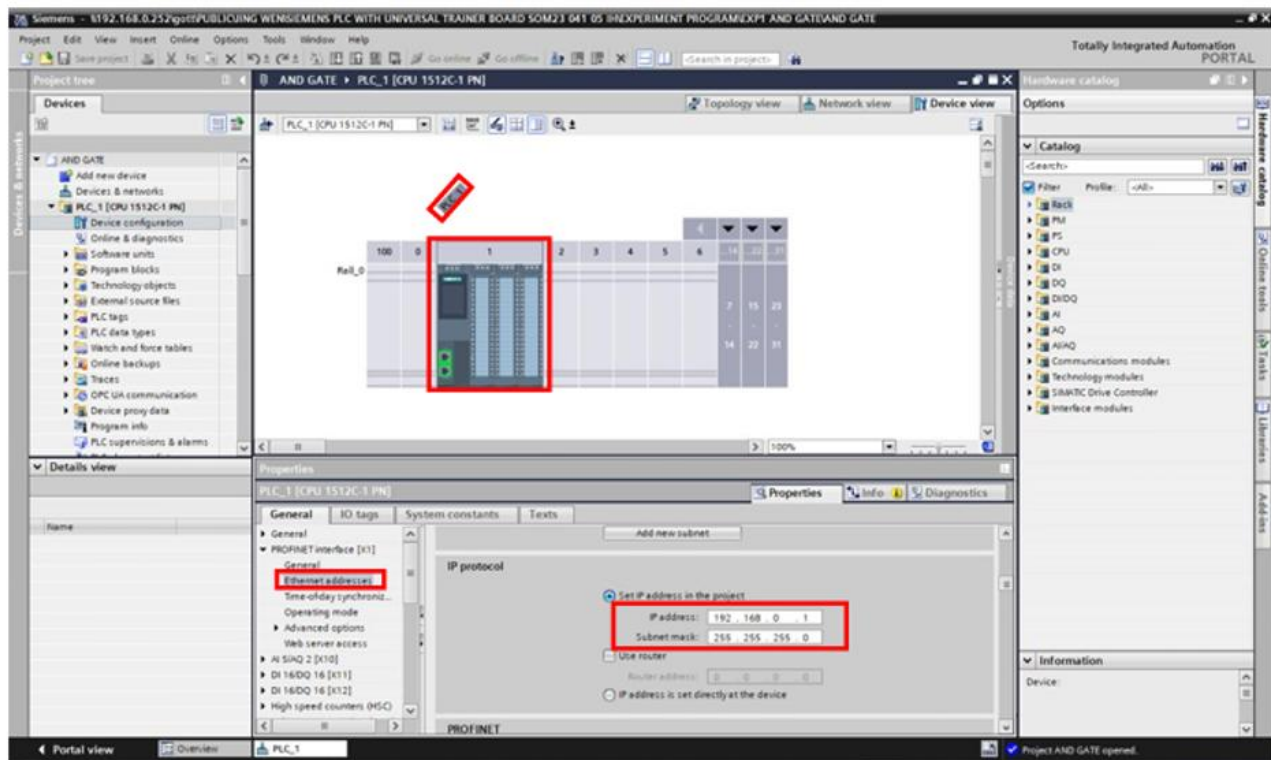
Fig: Installing TIA Portal V16 with License

Installing TIA Portal V18

- ✓ First, install the file from the **step 7 DVD 1 folder**
- ✓ Then, install the file from the **S7 PLC SIM folder**
- ✓ Then, check the file from Plc4me.Com Sim_EKB_Install_2022_11-27-3 by unzipping

Changing IP Address

- Click **PLC_1 (text)**, or **PLC Picture**
- **General -> PROFINET interface [X1] -> Ethernet addresses**
- Make **IP Address: 192.168.9.2** and **Subnet mask: 255.255.255.0**
- Then, scroll down the **General Tab** of the bottom pane until **Protection & security** is shown
- **Protection & security -> Connection mechanisms**
- **Permit access with PUT/GET communication from remote partner**



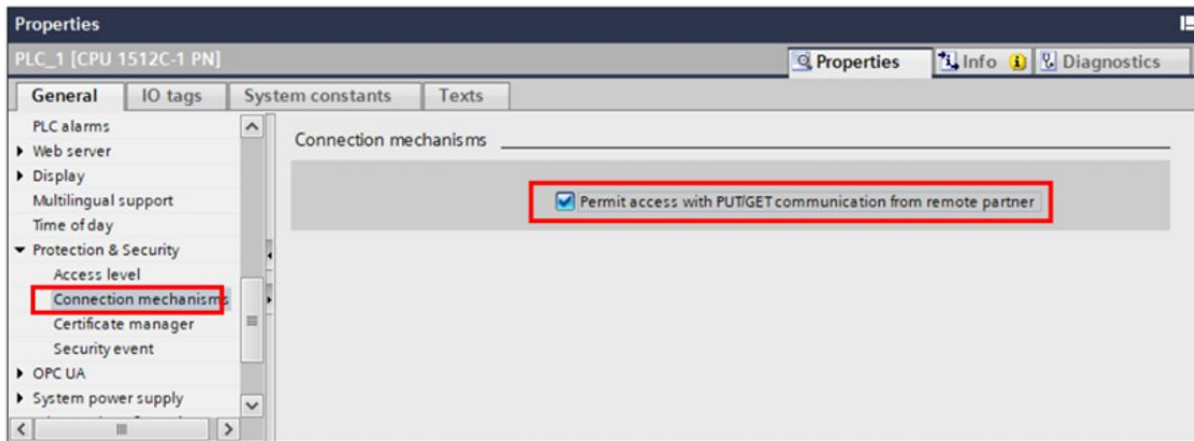
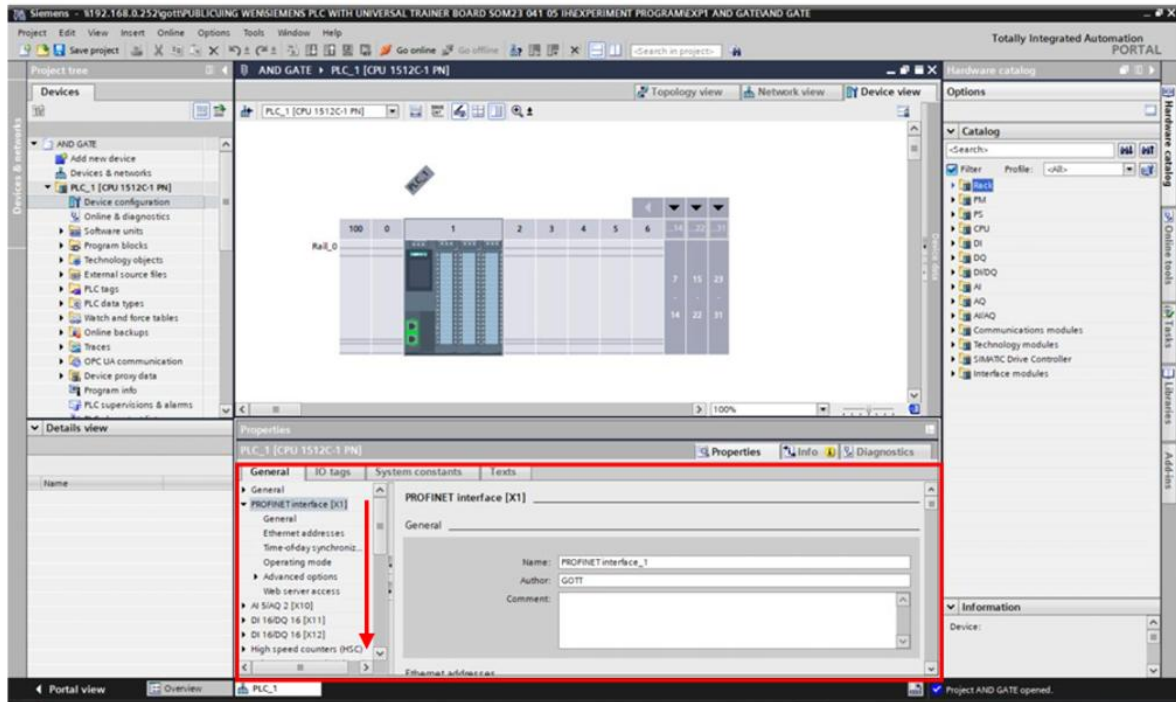
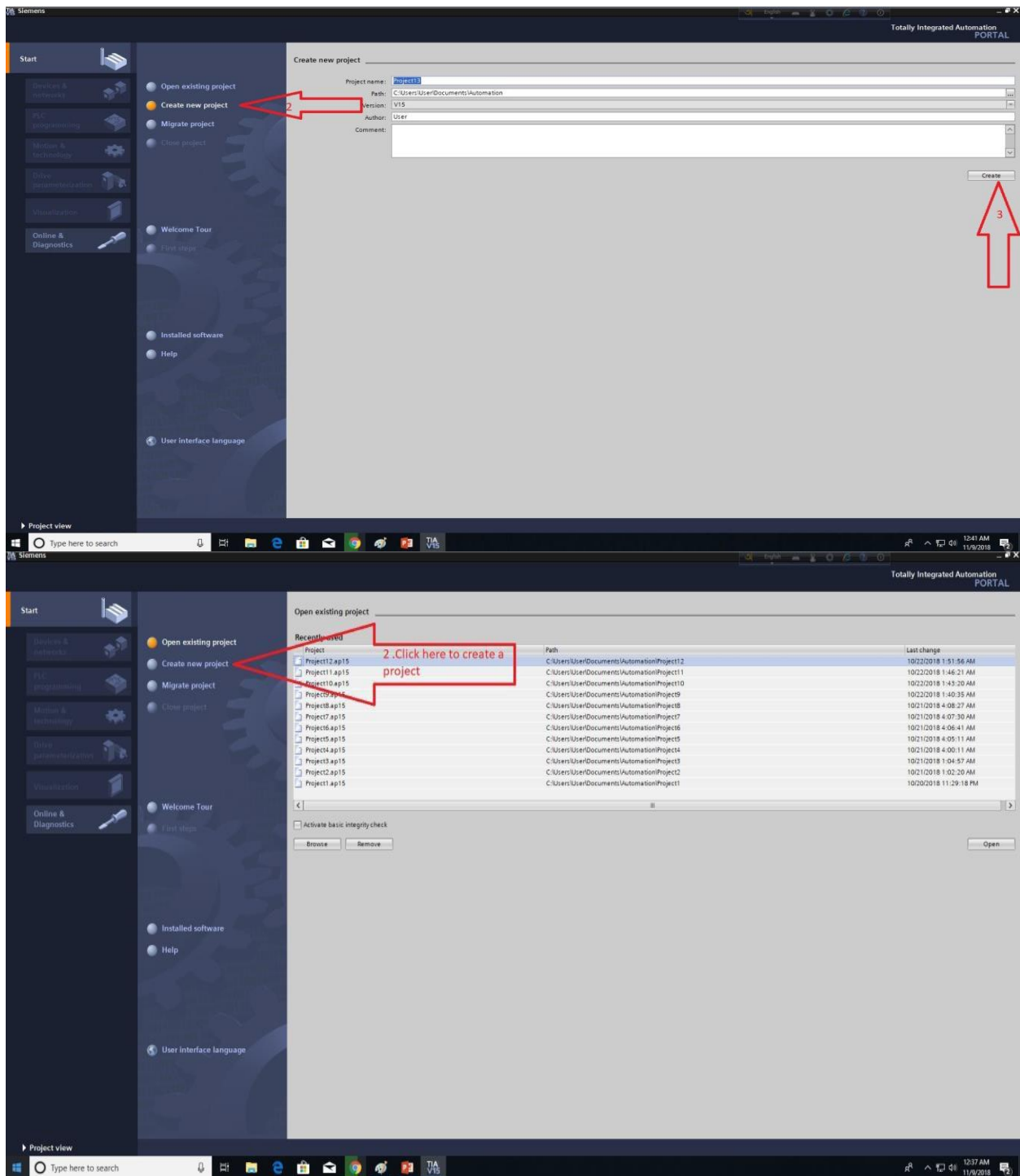
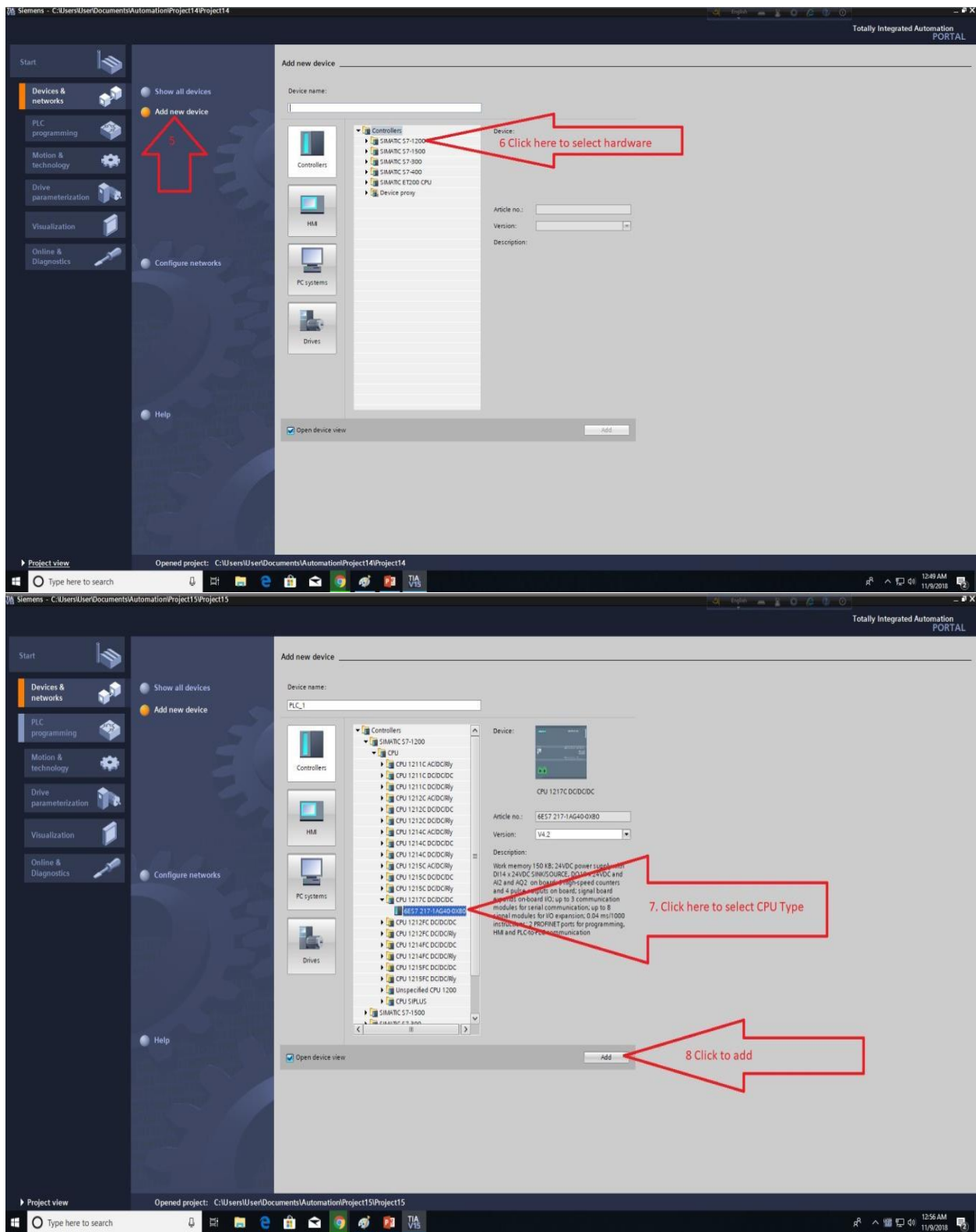


Fig: Changing IP Address & Permitting Connection Mechanism

Creating Project in TIA Portal Software

- ✓ Double click **TIA Portal V16 or V18** on the desktop
- ✓ **Create new Project -> Project name: Path, Version, Author, Comment: -> Create**
- ✓ **Configure a Device -> Add new device -> Controllers, HMI, PC systems**





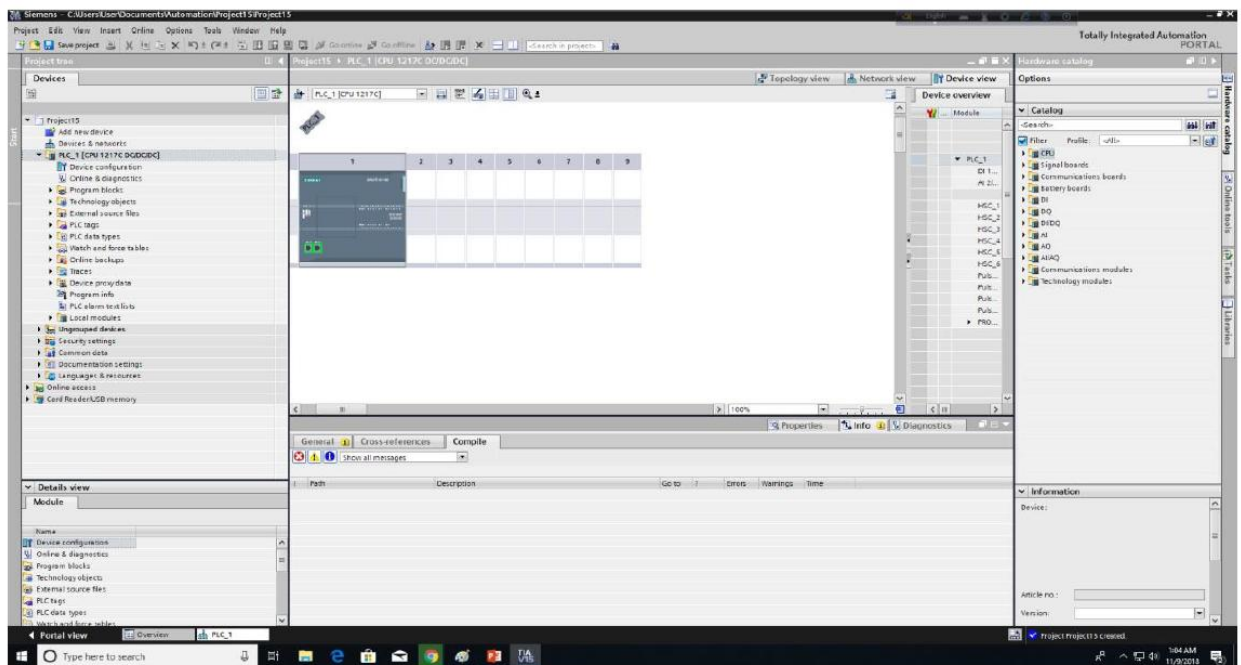
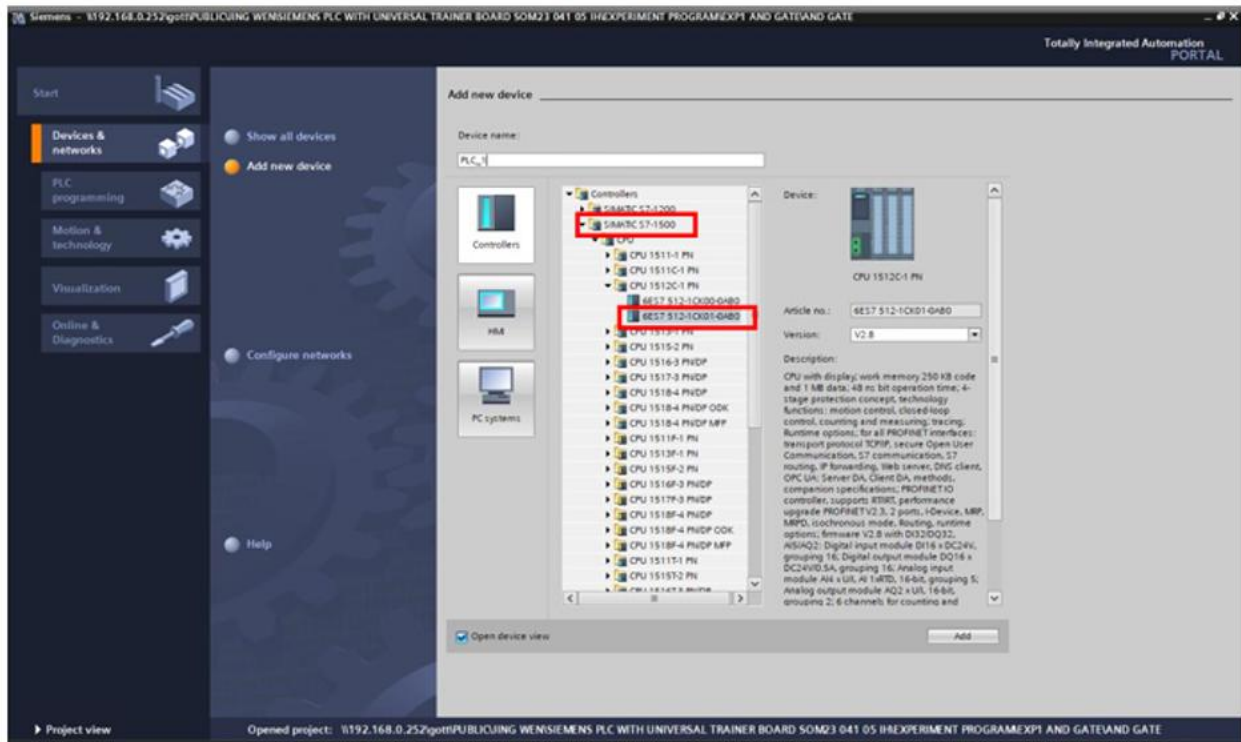


Fig: Creating New Project in TIA Portal Software



Self-Check 2.3-1

1. What two specific network settings must be matched between the PC and the PLC to successfully establish an Ethernet communication link?
2. What is the function of a USB or serial driver installed on the programming PC for direct communication with the PLC?
3. What is the required prerequisite software that must be installed on a computer before installing TIA Portal V16, and what specific Windows feature must be selected to install it?
4. What minimum specifications for RAM and storage are required for installing TIA Portal V16?
5. If communication between the PC and PLC fails, but the PLC is powered on, what common PC-related network issue could be the cause?
6. What basic PC command is used to quickly test if there is IP address connectivity (a basic network path) to the PLC before launching the programming software?
7. What is the key benefit of being able to go "online" with the PLC via the PC during commissioning and troubleshooting?



Answer Paper 2.3-1

1. Matching the IP address and subnet mask of the PC to the PLC's network settings.
2. It acts as a software interface that allows the PC's operating system to recognize and correctly exchange data with the PLC hardware.
3. The required prerequisite software is Microsoft .NET Framework 3.5. The specific Windows feature checkbox that must be selected to install it is .NET Framework 3.5 (includes .NET 2.0 and 3.0).

4. The minimum specifications required are at least 8 GB RAM for memory and at least 30 GB for storage.
5. The PC's firewall is blocking the communication port used by the PLC software.
6. The PING command.
7. It enables the programmer to monitor the logic, force I/O points, and debug the program in real-time.

	Job Sheet 14
Qualification	Industrial Automation
Learning Unit	Establish Communication between PLC and PC
Trainee Name	
PPE	Safety glasses (essential) and appropriate work clothing.
Tools & Equipment	Programmable Logic Controller (PLC), PC/Laptop with PLC Programming Software (and drivers installed), Programming Cable (e.g., standard Ethernet, custom USB/Serial), PLC Control Power Supply, Multimeter (DMM), and relevant network adapter/cable tester (if needed).
Notes	1. IP Compatibility: For Ethernet communication, the PC's IP address must be on the same subnet as the PLC's assigned IP address (e.g., PC: 192.168.1.10, PLC: 192.168.1.50). 2. Physical Link: Ensure the correct cable type is used (straight-through or crossover, depending on the devices). 3. Troubleshooting: If communication fails, check firewall settings and disable other unused network adapters on the PC.
Procedure	1. Safety & Preparation: Ensure the PLC is powered on and the Power LED is solid green. Verify the PC is running the correct programming software.

	2. Physical Connection: Connect the Programming Cable from the PC's communication port (usually Ethernet) to the corresponding port on the PLC CPU. Verify the Link/Activity LEDs on both the PC network adapter and the PLC port are lit or flashing. 3. PC Network Setup (Ethernet): Go to the PC's network settings. Manually set the PC's IP address and Subnet Mask to be compatible with the PLC's default or known settings. (e.g., if PLC is 192.168.0.x, set PC to 192.168.0.y). 4. Testing Connectivity (Ping): Open the PC's Command Prompt (CMD) and use the Ping command with the PLC's IP address (e.g., ping 192.168.0.10). A successful ping response confirms basic network connectivity. 5. Software Communication Setup: Open the PLC programming software. Navigate to the Communication Settings or Go Online feature. Select the correct communication driver/adaptor (e.g., Ethernet, USB). 6. Driver/Path Configuration: Configure the software's communication path (e.g., setting the target PLC IP address or auto-detecting active devices). 7. Establish Link (Discovery/Go Online): Use the software's Browse, Discover, or Go Online function to detect and connect to the PLC. The software should confirm a connection is established and display the PLC status (e.g., "Online, STOP Mode"). 8. Final Check: Confirm the successful link and that the software can read the PLC's operational mode and diagnostics. The system is now ready for program download.
Trainee's Signature	
Assessor's Signature	
QA Signature	
Assessor's Comment	

Module 3: Carry Out Ladder Diagram in PLC Programming



Contents of Module

Module Description

This unit of competency covers the knowledge, skills and attitudes required to carry out ladder diagram in PLC programming. It specifically includes the tasks of preparing for ladder diagram, performing PLC programming using ladder diagram and preparing PLC for operation.

Minimum Time: 35 Hours



Learning Outcome

- 3.1. Prepare for ladder diagram
- 3.2. Perform PLC programming using ladder diagram
- 3.3. Prepare PLC for operation



Performance Criteria

- 1. Safe work practices are followed and Personal Protective Equipment (PPE) are worn as required.
- 2. Necessary software and hardware are selected as per job requirements.
- 3. Table chart for sub-program, function, function block and data blocks are prepared.

4. Programming components and ladder logic symbols are identified required for ladder diagram of PLC.
5. Basic ladder logic symbols and components are identified according to instruction manual.
6. Ladder diagram is constructed by arranging symbols logically to represent the desired control sequence.
7. Input and output devices are mapped within the ladder diagram.
8. Ladder diagram is checked for logical consistency and observed through simulation.
9. Modifications and corrections are made to the ladder diagram based on testing results.
10. Programming devices are collected.
11. PLC program required by specific application is developed.
12. PLC Program is imported from memory card if required.
13. PLC Program is compiled with diagnosis.
14. Programs are transferred to PLC and set the PLC in Run Mode.
15. Optimization of software is done to ensure the program after the first test run.
16. Final circuit testing and optimization is done to ensure no errors occur by the entire system.

Learning Outcome 3.1 – Prepare for Ladder Diagram



Content

- **Ladder Logic Fundamentals:** Understand the basic structure and rules of ladder logic diagrams, including power rails, rungs, inputs (contacts), outputs (coils), and the scan cycle of the PLC.
- **Instruction Set Knowledge:** Learn the functionality and syntax of core PLC instructions required for basic control, such as XIC (Examine If Closed), XIO (Examine If Open), OTE (Output Energize), and basic timers/counters.

- Problem Decomposition: Practice translating control requirements (e.g., a simple start/stop circuit or a sequencing task) from a narrative description or flow chart into the structured graphical format of a ladder diagram.



Assessment Criteria

- Syntactical Correctness
- Functional Logic Accuracy
- Documentation and Tagging



Necessary Equipment

- Programming Software
- PLC Training Simulator (Optional)
- Technical Manuals/Guides
- Problem Descriptions/Scenarios
- Writing/Drafting Tools



Learning Activity 3.1-1

Learning Activity	Resources/ Instructions/ References
Prepare for Ladder Diagram	• Information Sheet: 3.1-1 • Self-Check: 3.1-1 • Answer Paper: 3.1-1 • Job Sheet 15



Information Sheet 3.1-1

Learning Objective: The learner will be able to analyze a control requirement and translate it into a structured ladder logic design using core instructions, ensuring the logic is ready for programming.

Carry Out Ladder Diagram in PLC Programming

Carrying out a **Ladder Diagram (LD)** in PLC programming involves creating a visual representation of a control system's logic. It's designed to mimic the rungs of a traditional ladder, with two vertical rails representing power and a series of horizontal rungs that contain the control logic.

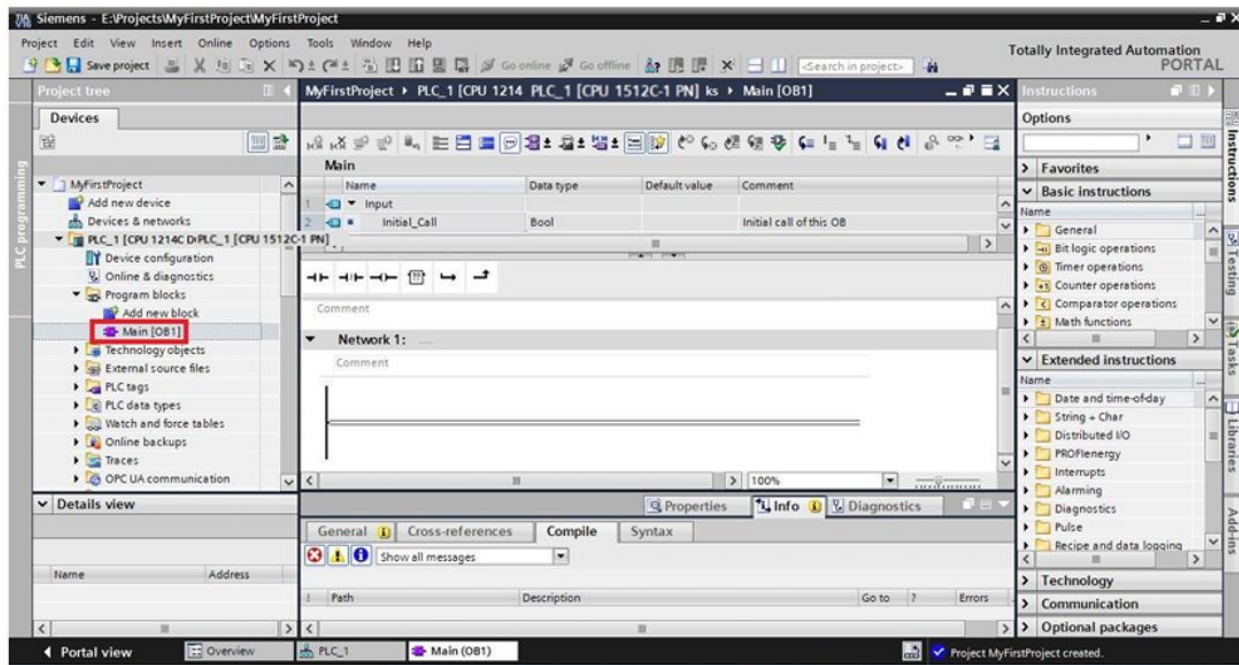
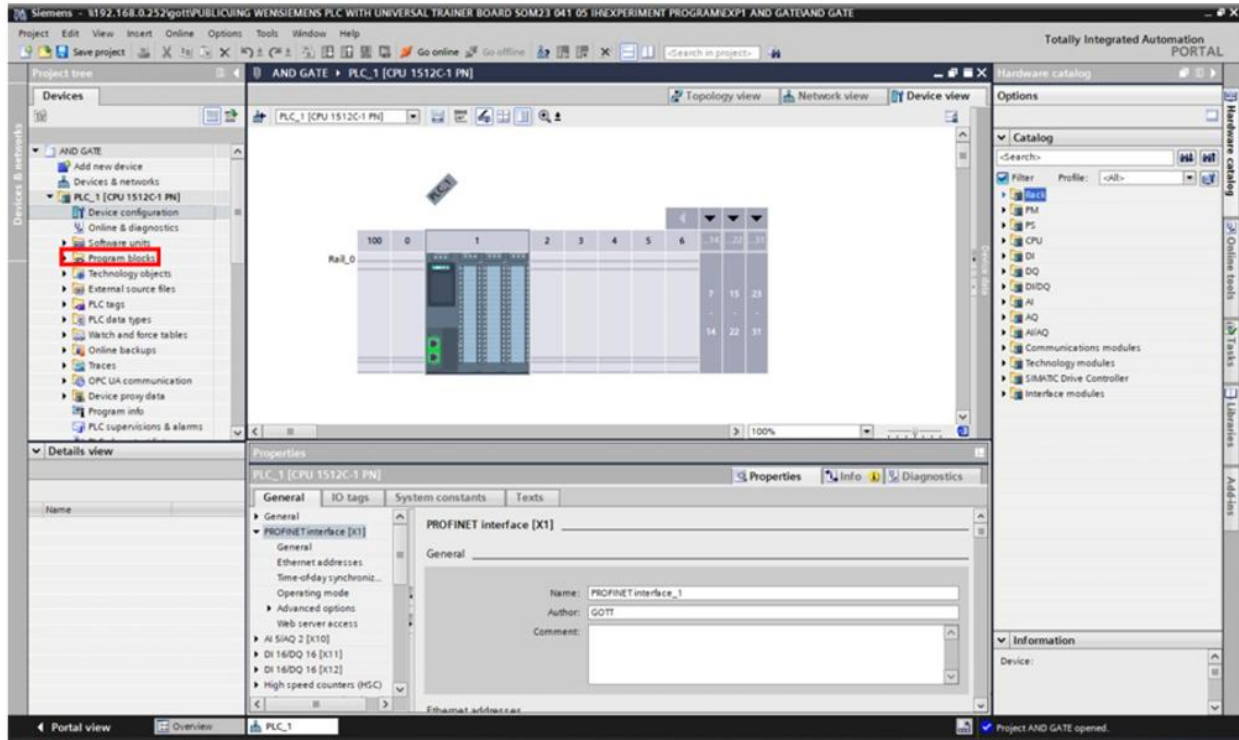
Basic Components

- **Rails:** The two vertical lines that represent the power source. The left rail is typically the positive or line voltage, and the right rail is the neutral or common.
- **Rungs:** The horizontal lines that extend between the rails. Each rung represents a logical instruction or a single control function.
- **Inputs:** Represented by **contacts**. These are conditions that must be met for the logic to be true. Common input types include push buttons, limit switches, and sensors.
 - **Normally Open (NO) Contact:** This contact is open by default and closes when the input is energized.
 - **Normally Closed (NC) Contact:** This contact is closed by default and opens when the input is energized.

- **Outputs:** Represented by **coils**. These are the actions or devices controlled by the logic. Common outputs include motors, lights, solenoids, and alarms.
 - **Output Coil:** This coil is energized when the logic on its rung is true.
 - **Latched/Unlatched Coils:** These coils are used to create memory or "latching" functions, where an output remains on even after the input is removed.

Prepare for Ladder Diagram in TIA Portal Software

- ✓ Open the software → Create new Project → Add Controller
- ✓ PLC_1 [CPU ...]
- ✓ Program blocks
- ✓ Main [OB1]
- ✓ Enter Tag → Rename Tag → Save Project
- ✓ Compile → Download to Device



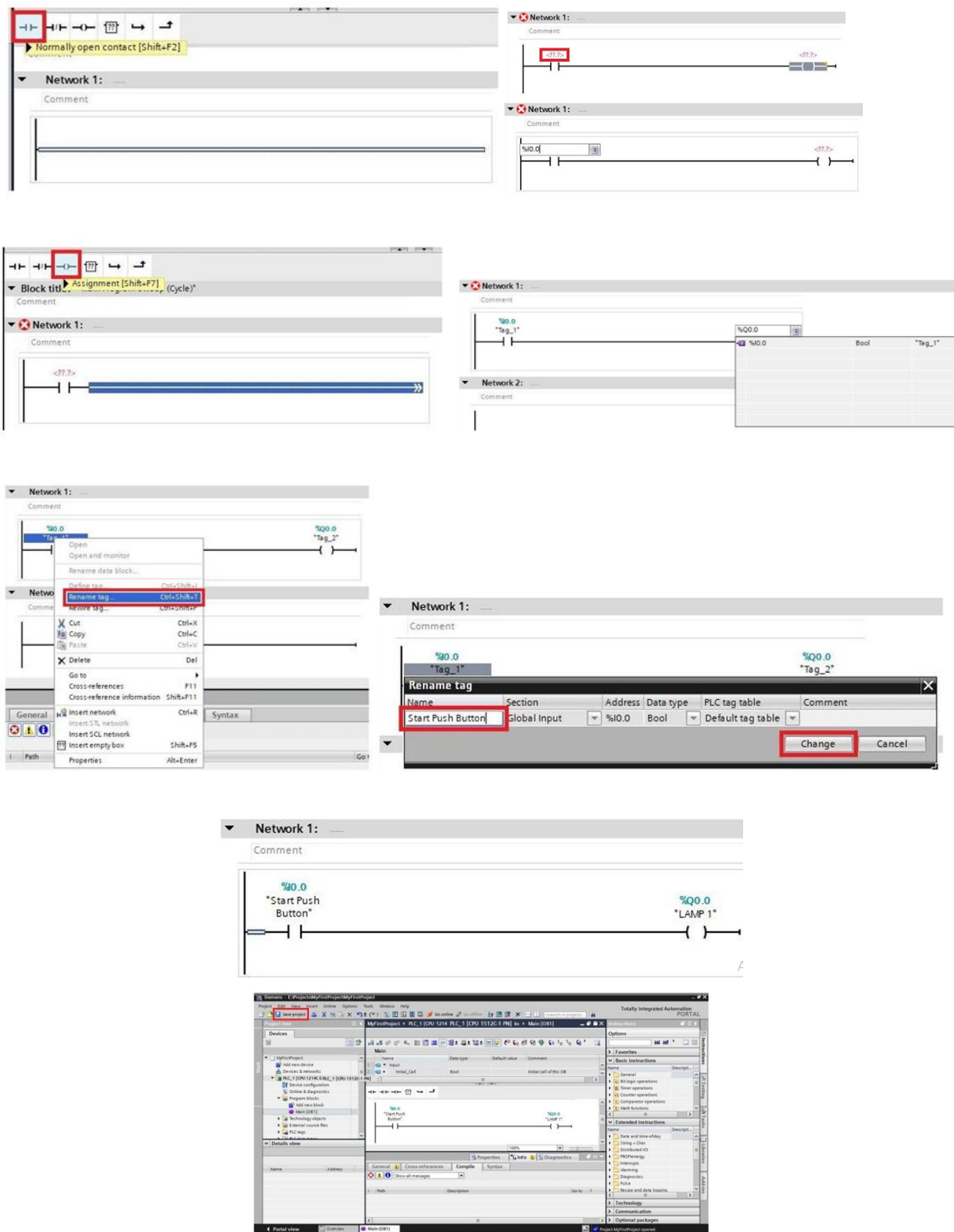


Fig: Ladder Diagram Preparation in TIA Portal



Self-Check 3.1-1

1. What is the purpose of the Rails in a Ladder Diagram, and what do the two vertical lines typically represent?
2. In the context of LD, what does each Rung represent?
3. What are the two basic types of Input contacts used in an LD, and how do they function by default?
4. What type of PLC component is used to represent Outputs, and when does this component become energized?
5. What is the function of Latched/Unlatched Coils in an LD?
6. List the first three steps a programmer must follow in the TIA Portal software after creating a new project to prepare for drawing the Ladder Diagram logic.
7. In the final steps of preparing the Ladder Diagram in TIA Portal, what two actions are performed after the tags have been entered, renamed, and the project is saved?



Answer Paper 3.1-1

1. The purpose of the Rails is to represent the power source. The left rail is typically the positive or line voltage, and the right rail is the neutral or common.
2. Each Rung represents a logical instruction or a single control function.
3. The two basic types are the Normally Open (NO) Contact, which is open by default and closes when energized, and the Normally Closed (NC) Contact, which is closed by default and opens when energized.
4. Outputs are represented by coils. The coil is energized when the logic on its rung is true.
5. Latched/Unlatched Coils are used to create memory or "latching" functions, where an output remains on even after the input is removed.
6. The first three steps are: Open the software → Create new Project → Add Controller.
7. The two actions are Compile and Download to Device.

	Job Sheet 15
Qualification	Industrial Automation
Learning Unit	Prepare for Ladder Diagram
Trainee Name	
PPE	Safety glasses (essential) and appropriate work clothing.
Tools & Equipment	PC/Laptop with PLC Programming Software, System Requirement Specification (SRS) or detailed Control Narrative, Input/Output (I/O) List with addresses, Process Flow Diagram/Timing Chart, and a Whiteboard or Paper for initial logic drafting.
Notes	1. Define Scope: Clearly understand the machine/process operation and safety requirements before writing any code. 2. Tag Naming: Use meaningful, consistent tag names that clearly describe the function (e.g., Motor_Start_PB, Conveyor_Run_Light). 3. I/O Mapping: Verify that all required physical inputs and outputs are correctly mapped to the PLC addresses configured in the hardware setup (Job Sheet 13).
Procedure	1. Review Documentation: Thoroughly read the Control Narrative or SRS to understand the required sequence, safety interlocks, and operating modes (Manual/Auto). 2. Finalize I/O List: Create a final, organized table (I/O Map) listing: Physical Device Name, PLC Tag Name, PLC Address, I/O Type (Digital Input, Analog Output, etc.), and a Brief Function Description. 3. Draft Control Logic (Flowchart/Narrative): Outline the sequence of operations. For complex steps, draft a simple flowchart or use a sequencing narrative to determine the necessary rungs and timing. 4. Identify Internal Memory: Determine the need for internal Memory Bits (M-bits), Timers (TON/TOF), and Counters (CTU/CTD) to handle internal logic (e.g., internal seal-in logic, time delays, cycle counting). 5. Open Software & Project: Open the PLC Programming Software and

	load the project containing the completed Hardware Configuration (Job Sheet 13). 6. Create Tag Database: In the software's Tag Editor or Symbol Table, enter all finalized Tag Names and assign them to the correct I/O Addresses and Internal Memory locations. 7. Create Program Blocks: Create the necessary Program Blocks, Routines, or Subroutines (e.g., Main Routine, Safety_Interlocks, Auto_Sequence) where the Ladder Diagram logic will be written, ensuring logical separation of code. 8. Draft Safety Rungs: Draft the initial safety and emergency stop rungs in the appropriate program block using the necessary NC contacts from E-Stops and Safety Relays. 9. Final Check: Ensure all required I/O points are accounted for in the Tag Database and that the logic framework (rungs and blocks) is structured and ready for code entry.
Trainee's Signature	
Assessor's Signature	
QA Signature	
Assessor's Comment	

Learning Outcome 3.2 – Perform PLC Programming using Ladder Diagram



Content

- **Programming Environment Proficiency:** Become proficient in navigating the PLC programming software, creating a new project, and understanding the compile and build process for the program file.
- **Core Instruction Implementation:** Learn to correctly implement fundamental ladder logic instructions (e.g., Timers, Counters, Move, Math) to solve common industrial control problems and sequences.
- **Program Debugging and Testing:** Develop skills in using online monitoring, forcing I/O, and troubleshooting tools within the software to test the running program and locate/fix logic errors.



Assessment Criteria

- Functional Program Output
- Code Efficiency and Readability.
- Online Program Modification



Necessary Equipment

- Programmable Logic Controller (PLC):
- Programming Computer/Laptop

- Control Scenario Hardware
- Communication Cable
- Reference Materials



Learning Activity 3.2-1

Learning Activity	Resources/ Instructions/ References
Perform PLC Programming using Ladder Diagram	• Information Sheet: 3.2-1 • Self-Check: 3.2-1 • Answer Paper: 3.2-1



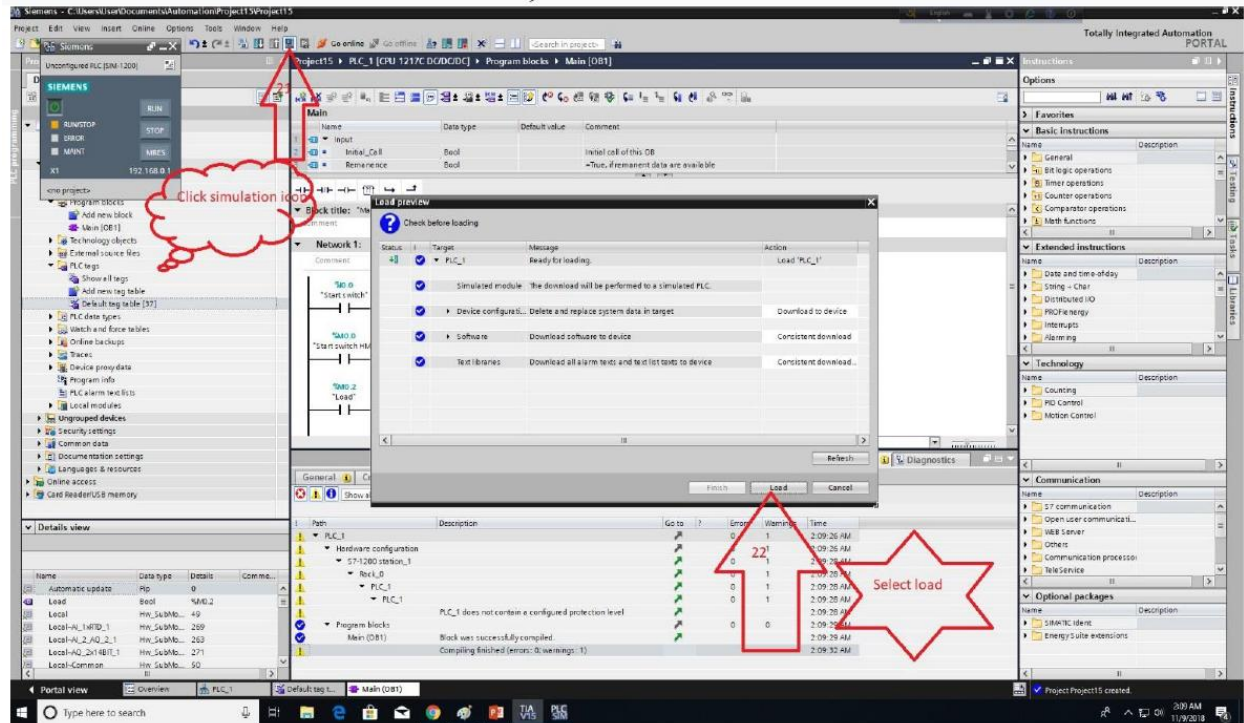
Information Sheet 3.2-1

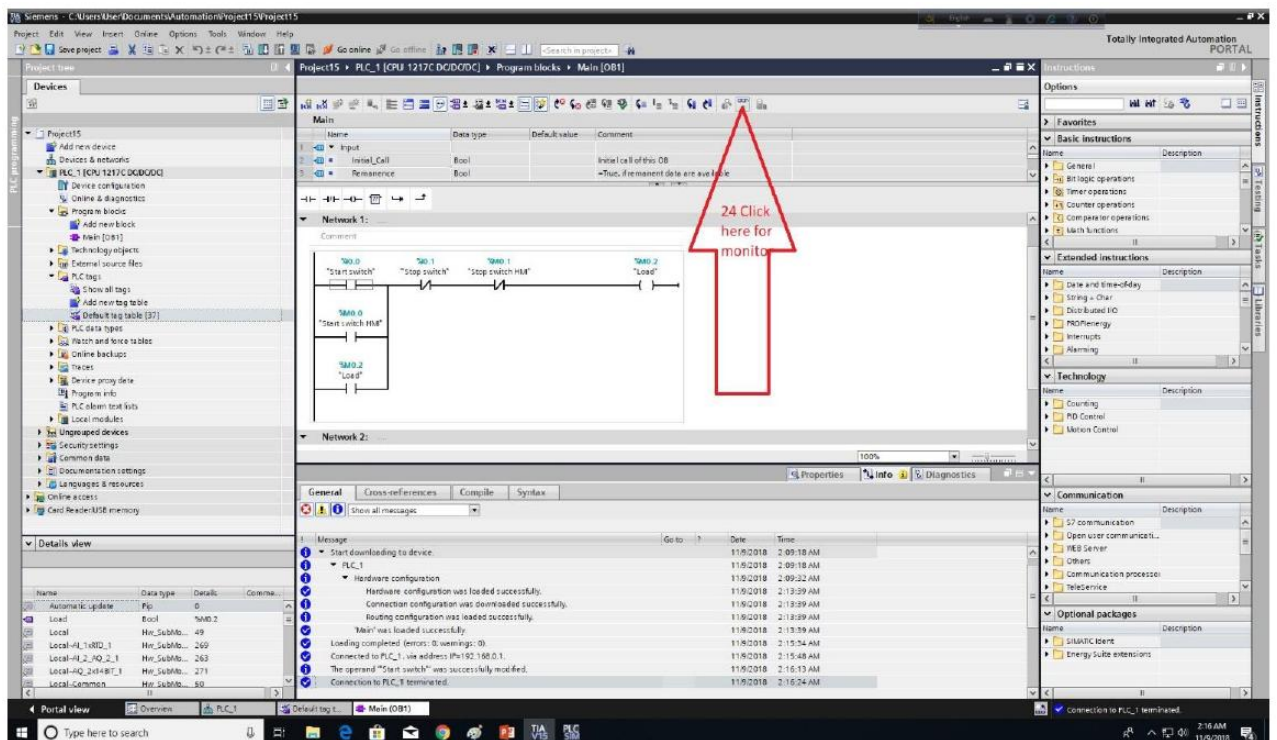
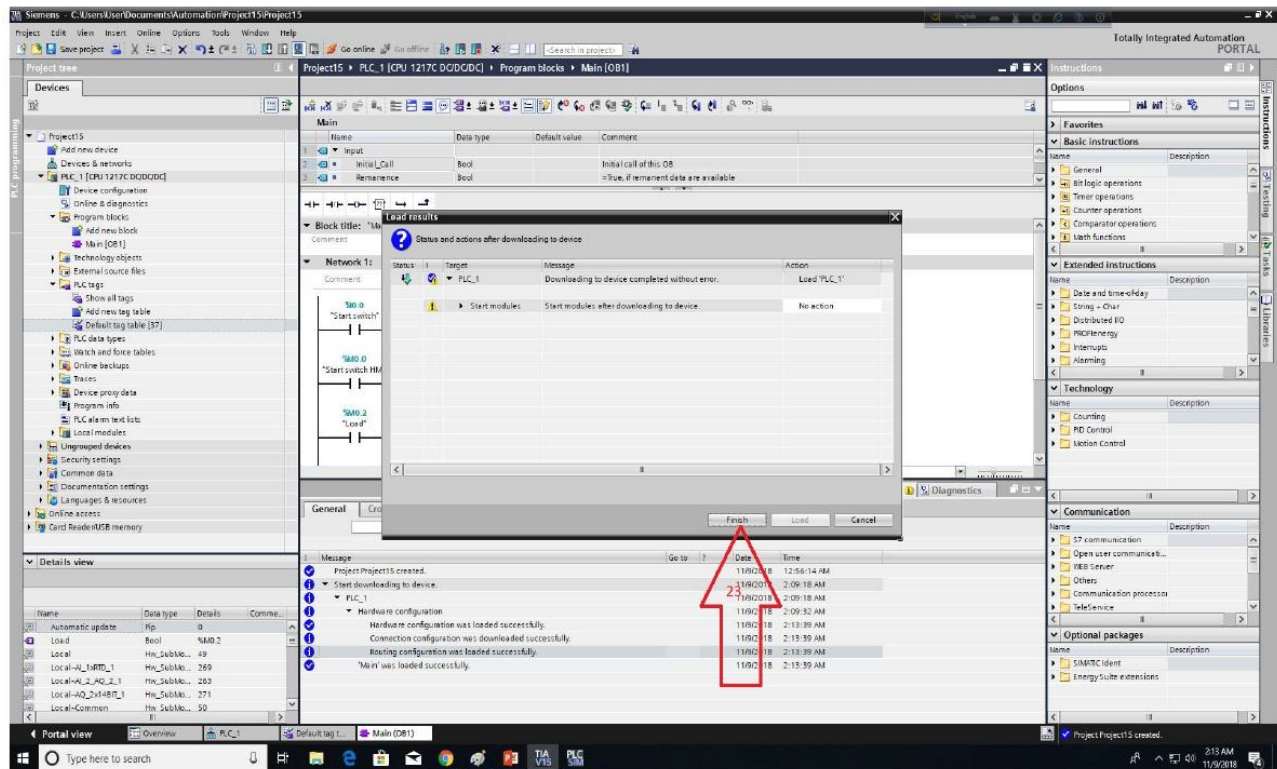
Learning Objective: The learner will be able to develop, enter, and execute a functional PLC program using Ladder Diagram logic to solve a specified industrial control problem.

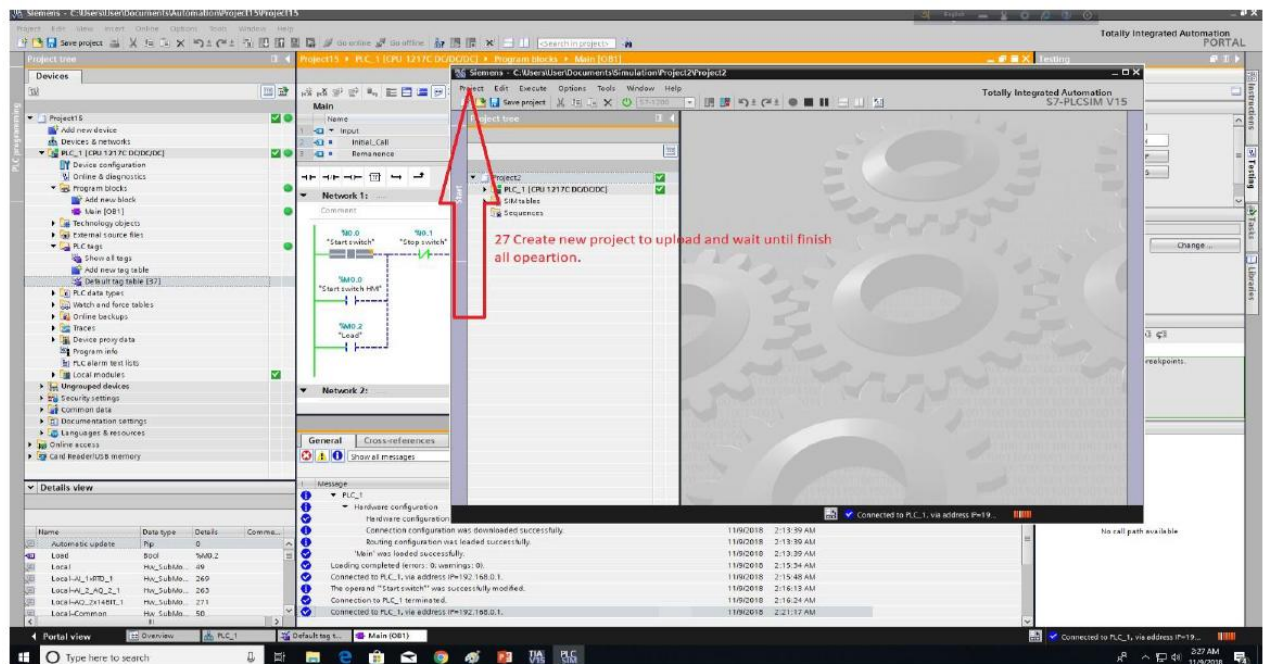
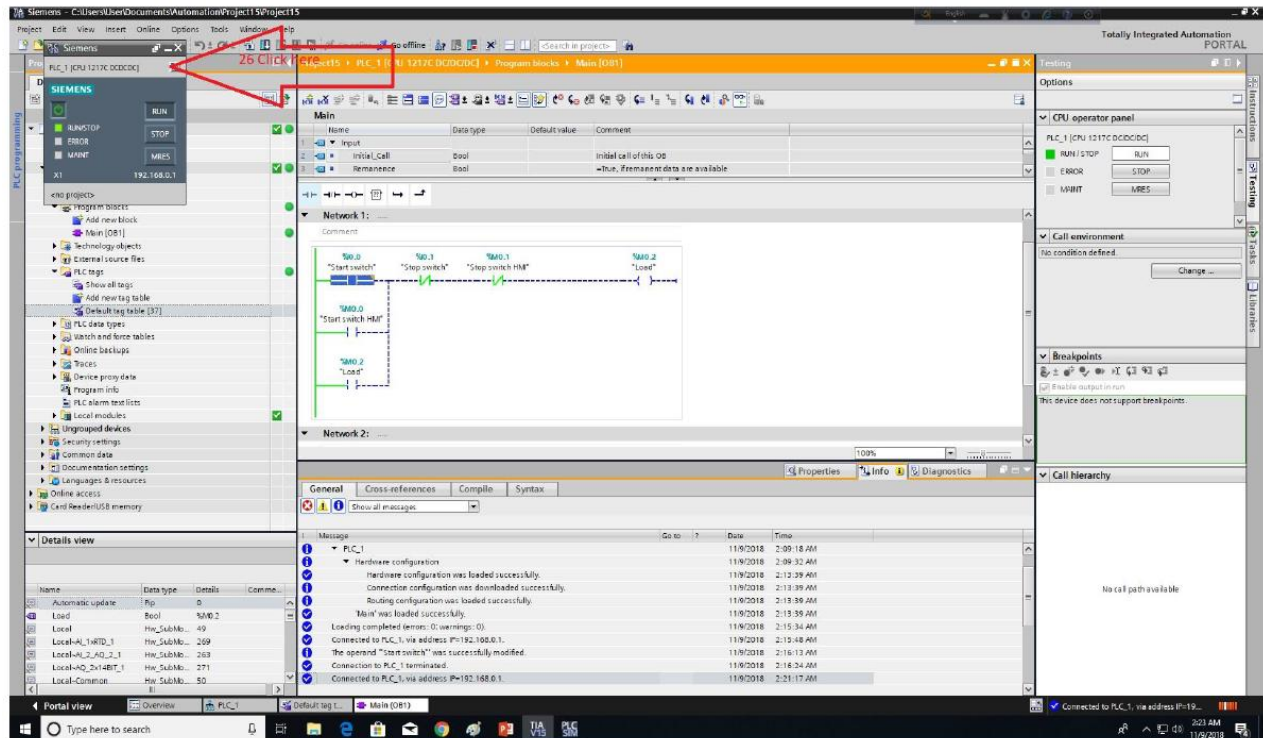
Program, Simulate and Run Ladder Diagram in TIA Portal Software and PLC

For Simulation:

1. Compile → Start Simulation → OK → OK → Load → Start modules → Finish
2. PLE SIM Siemens → switch to Project view
3. Create new Project → SIM table: 1
4. Insert an Input, output, memory







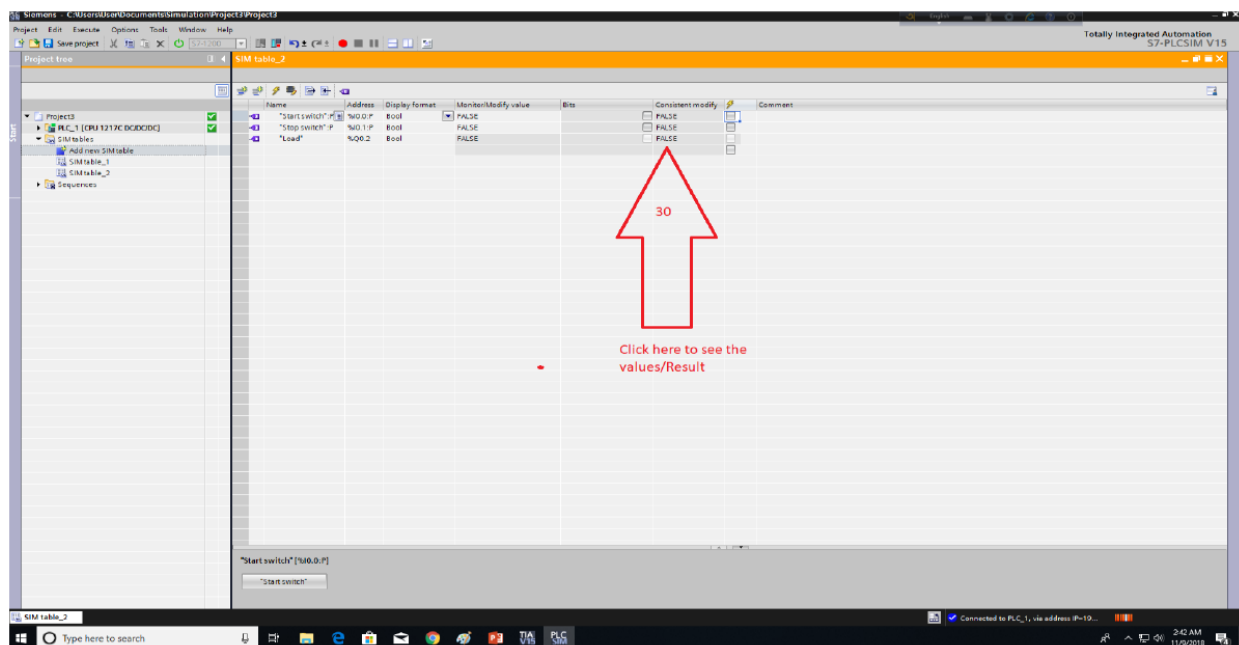
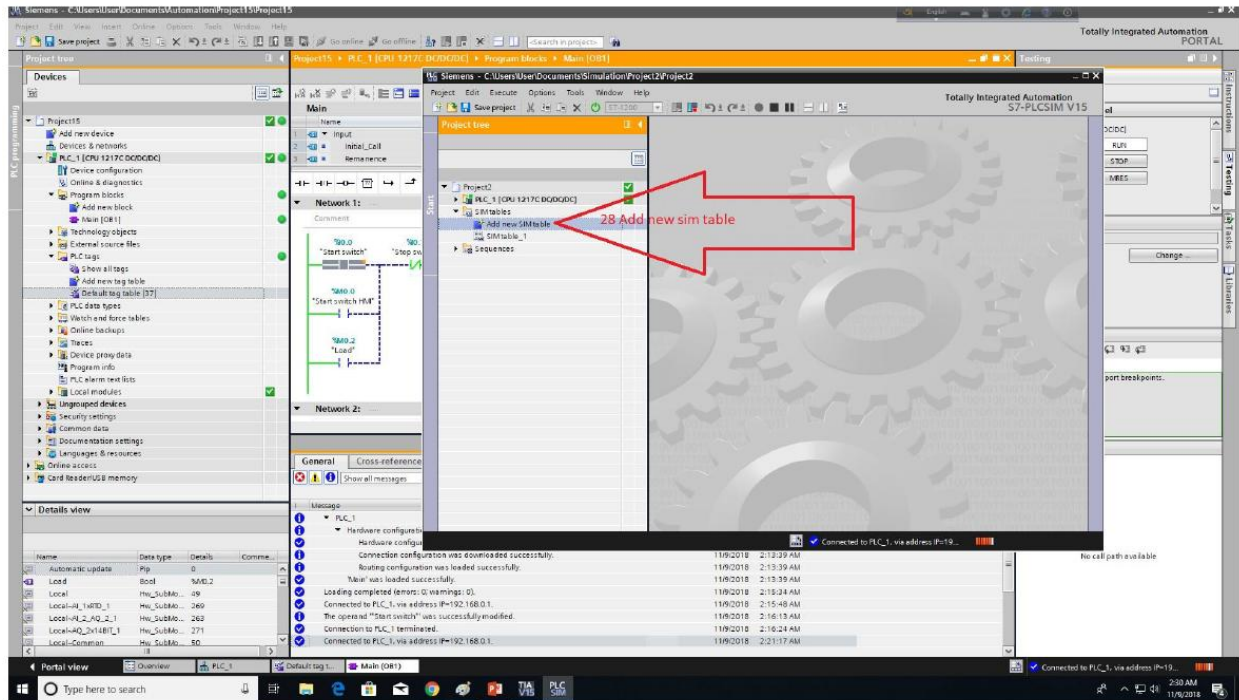


Fig: TIA Portal Simulation Process



Self-Check 3.2-1

1. What is the very first step a user must perform in TIA Portal before initiating the simulation process?
2. What is the second action a user performs in the TIA Portal software simulation process, immediately after the program has been compiled?
3. Following the initial steps of the TIA Portal simulation process, what are the three sequential commands a user must click to finalize the loading?
4. What must a user do with the "PLCSIM Siemens" application after it is started to prepare it for simulation?
5. What two actions are required when creating a new Project within the PLCSIM environment?
6. What three different components or data types must be inserted into the PLCSIM environment to facilitate the simulation?
7. What tool is necessary to execute the simulation process of the Ladder Diagram?



Answer Paper 3.2-1

1. The very first step a user must perform is Compile (the program).
2. The second action is to click Start Simulation.
3. The three sequential commands are: Load → Start modules → Finish.
4. The user must switch to Project view in the PLCSIM Siemens application.
5. The two actions required when creating a new Project in PLCSIM are Create new Project and setting the SIM table: 1.
6. The three components/data types that must be inserted are Input, output, and memory.
7. The tool necessary to execute the simulation process is the PLCSIM Siemens software.

Learning Outcome 3.3 – Prepare PLC for Operation



Content

- **Pre-Operational Checks:** Understand and perform crucial checks, including verifying power supply voltage and stability, ensuring proper grounding, and confirming all I/O wiring matches the schematic.
- **Mode Selection and Key Switch:** Learn to correctly select the operating mode of the PLC (e.g., RUN, PROGRAM, REMOTE) and understand the function and use of the CPU key switch for preventing unauthorized program changes.
- **Firmware and Program Verification:** Verify that the firmware version is compatible with the configuration software, and ensure the correct and tested program is successfully downloaded and residing in the PLC's memory.



Assessment Criteria

- Successful Transition to RUN Mode
- Program Integrity Check
- I/O Status Confirmation



Necessary Equipment

- Programmable Logic Controller (PLC) System
- Digital Multimeter (DMM)

- Programming Computer/Laptop
- Technical Documentation
- Safety Gear and Tools



Learning Activity 3.3-1

Learning Activity	Resources/ Instructions/ References
Prepare PLC for Operation	• Information Sheet: 3.3-1 • Self-Check: 3.3-1 • Answer Paper: 3.3-1 • Job Sheet 16 – Job Sheet 26



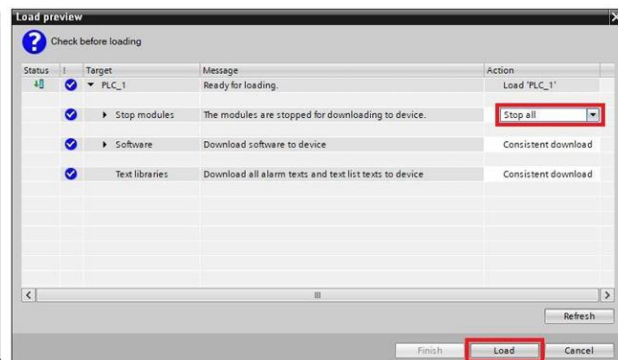
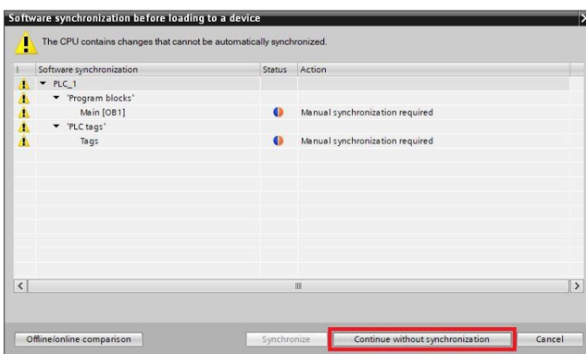
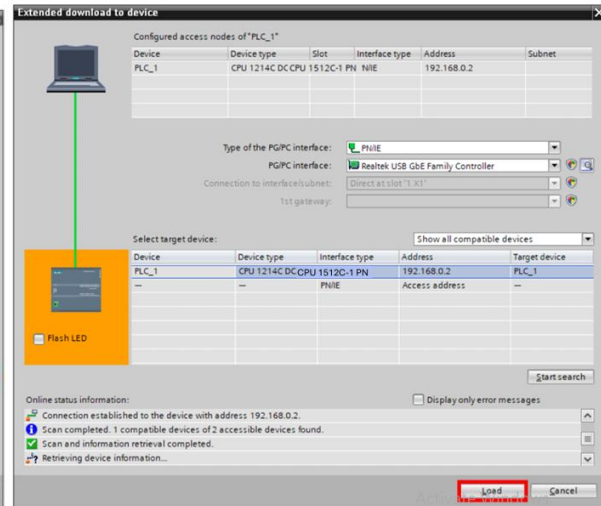
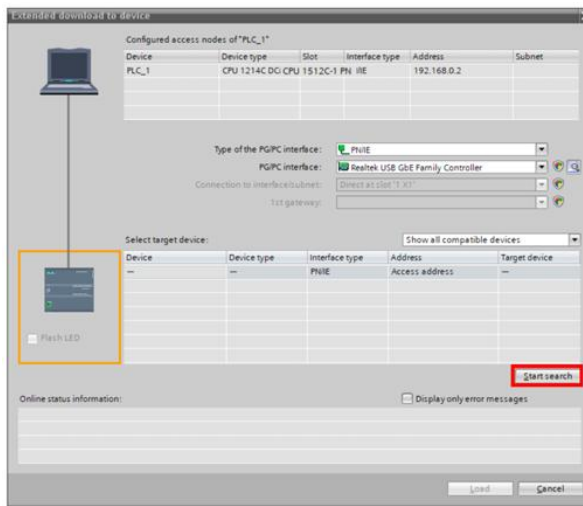
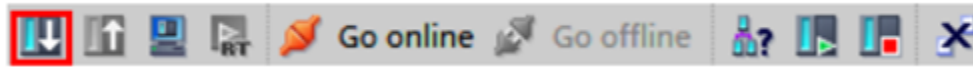
Information Sheet 3.3-1

Learning Objective: The learner will be able to safely verify the PLC status, confirm power and grounding, and select the correct operating mode to prepare the control system for functional run-time operation.

For Downloading:

1. Compile → Download to device → Load
2. Make sure to click the main **[OB1]** before downloading the program.

3. Compile → Select **PN/IE** as the PG/PC interface and select the interface. Click "Start search" button.
4. Select the Device → Load → Continue without synchronization.
5. Stop all → Load → Finish.
6. Loading completed (Error: 0, Warning: 0).
7. Start CPU of PLC.
8. Press Input and Output buttons of PLC to run the program.



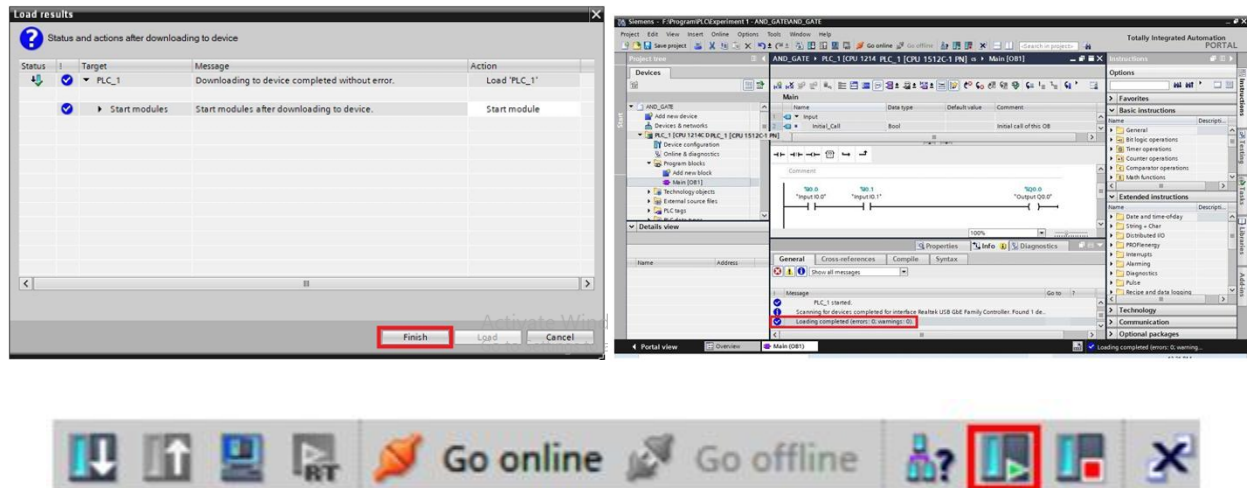


Fig: Download Program in TIA Portal

AND GATE

The AND gate is one of the three fundamental logic gates in digital electronics, performing the function of logical conjunction (similar to Boolean multiplication).

Logic and Principle: The AND gate produces a HIGH output (logic 1) only when all of its inputs are HIGH (logic 1). If *any* input is LOW (logic 0), the output will be LOW.



Ia0	Ia1	Output (Qc0)
0	0	0
0	1	0
1	0	0
1	1	1

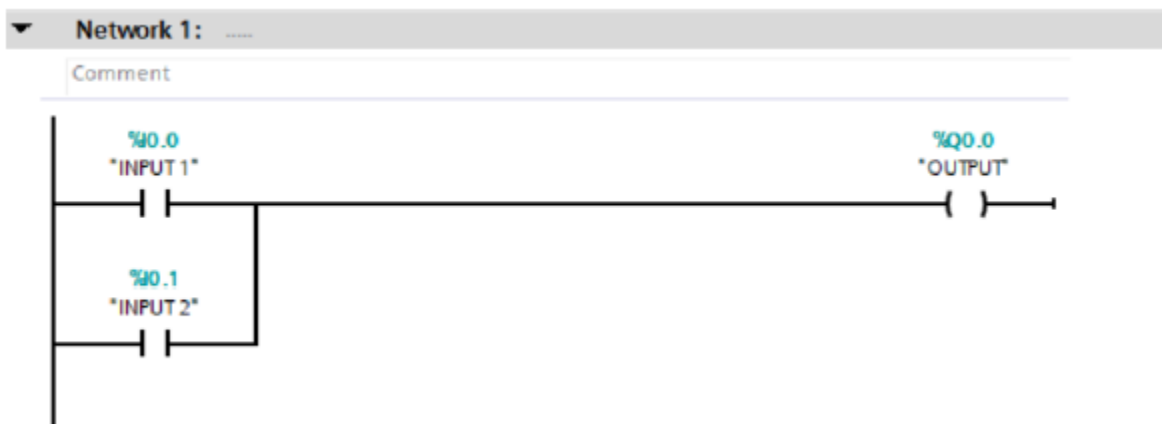
Key: 1 represent ON
0 represent OFF

Fig: AND GATE Program & Result

OR GATE

The OR gate is a fundamental digital logic gate that implements the logical disjunction, which is part of Boolean algebra. It is a circuit that has two or more inputs but only one output.

Logic and Principle: An OR Gate is a basic logic gate that performs a logical addition operation. The output is HIGH (1) if any one or both inputs are HIGH (1).



la0	la1	Output (Qc0)
0	0	0
0	1	1
1	0	1
1	1	1

Key: 1 represent ON
0 represent OFF

Fig: OR GATE Program & Result

NOT GATE

The NOT gate, also known as an inverter, is one of the basic logic gates in digital electronics. It performs logical negation or inversion on its input.

Logic and Principle: A NOT Gate, also called an Inverter, performs a logical negation operation. It produces an output that is the inverse of the input. If the input is HIGH (1), the output is LOW (0), and vice versa.



la0	Output (Qc0)
1	0
0	1

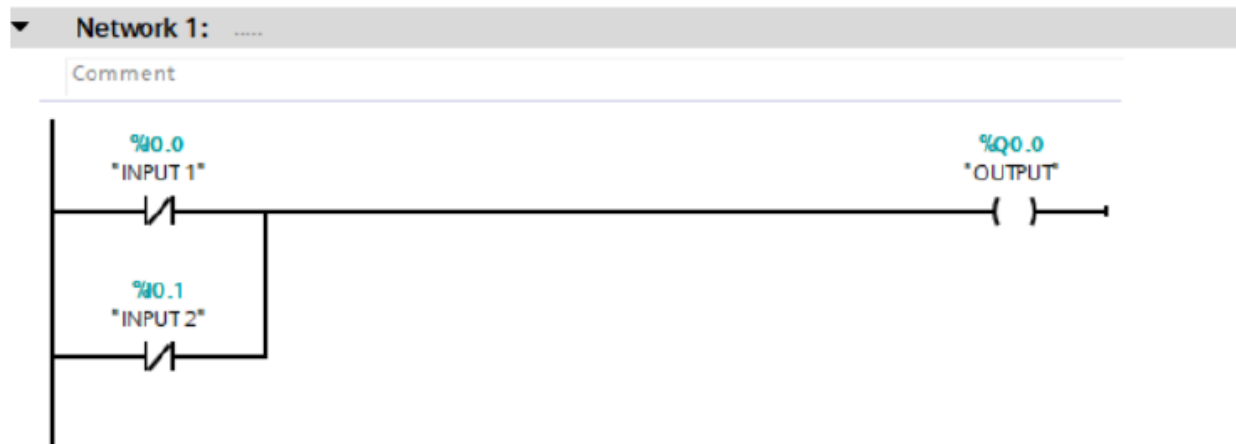
Key: 1 represent ON
0 represent OFF

Fig: NOT GATE Program & Result

NAND GATE

The NAND gate (short for NOT-AND) is a fundamental digital logic gate whose output is the complement (or inverse) of the logical AND operation.

Logic and Principle: A NAND Gate is a universal logic gate that performs the NOT AND operation. Its output is LOW (0) only when all inputs are HIGH (1); otherwise, the output is HIGH (1).



Ia0	Ia1	Output (Qc0)
0	0	1
0	1	1
1	0	1
1	1	0

Key: 1 represent ON
0 represent OFF

Fig: NAND GATE Program & Result

NOR GATE

The NOR gate (short for NOT-OR gate) is a fundamental digital logic gate that combines the operation of an OR gate and a NOT gate (inverter).

Logic and Principle: A NOR Gate is a universal logic gate that performs the NOT OR operation. Its output is HIGH (1) only when all inputs are LOW (0); otherwise, the output is LOW (0).

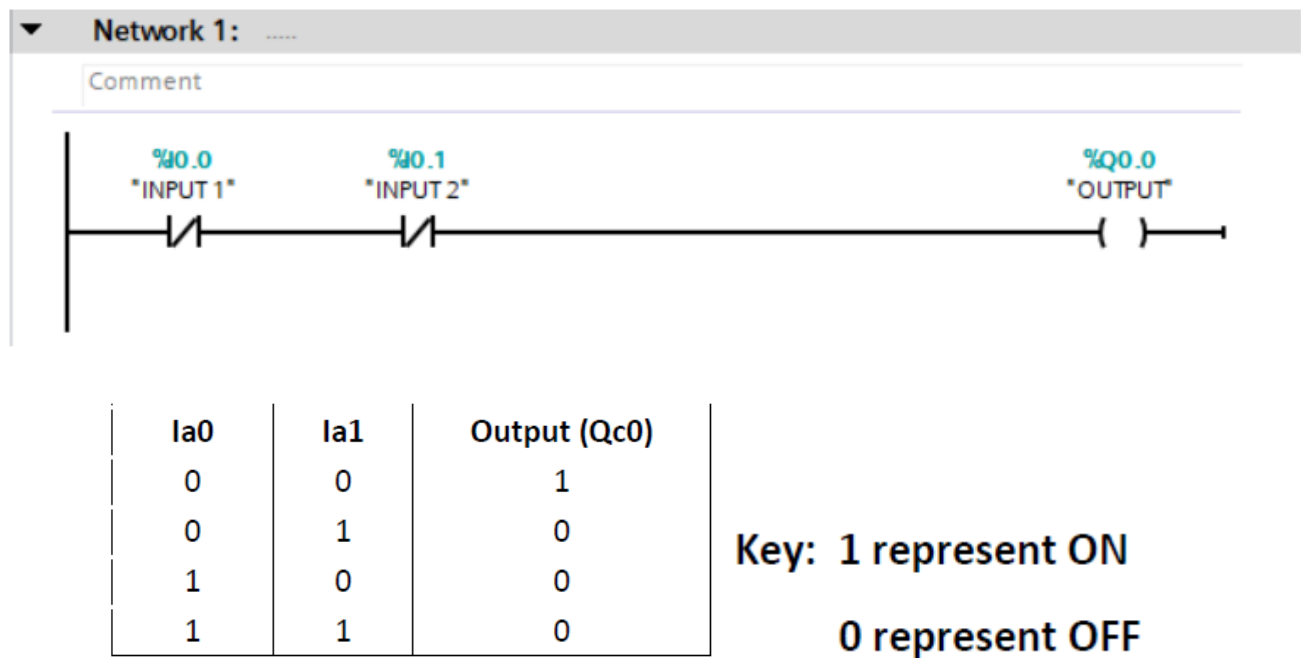
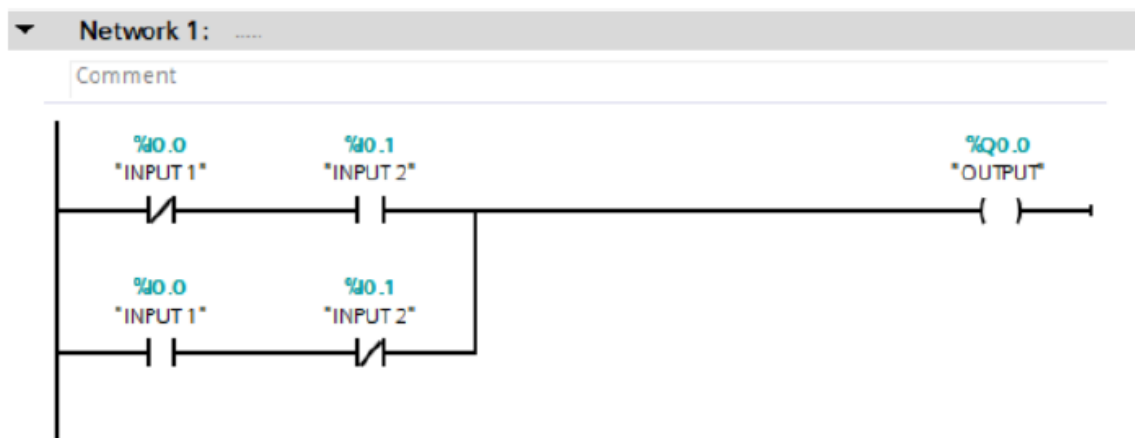


Fig: NOR GATE Program & Result

XOR GATE

The XOR gate (Exclusive-OR) is a fundamental digital logic gate that outputs a logic 1 (HIGH) if the two inputs are different, and a logic 0 (LOW) if the inputs are the same. It is often referred to as an "inequality detector" or an "odd-function" gate, as the output is HIGH when there is an odd number of HIGH inputs.



Ia0	Ia1	Output (Qc0)
0	0	0
0	1	1
1	0	1
1	1	0

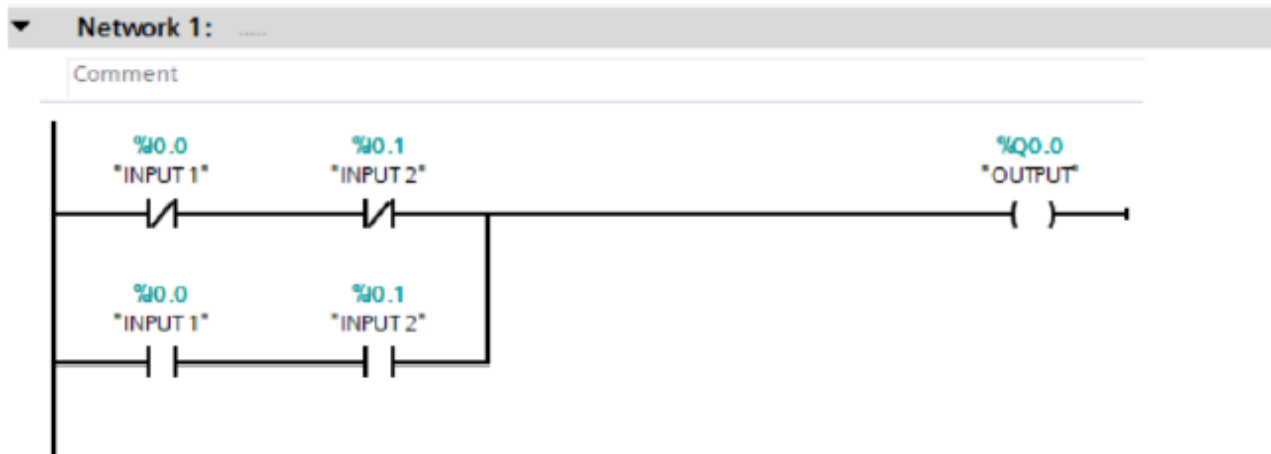
Key: 1 represent ON

0 represent OFF

Fig: XOR GATE Program & Result

XNOR GATE

The XNOR gate (Exclusive-NOR or Equivalence gate) is a digital logic gate that outputs a high signal (1 or True) only when its inputs are equal. If the inputs are different, the output is a low signal (0 or False).



Ia0	Ia1	Output (Qc0)
0	0	0
0	1	1
1	0	1
1	1	0

Key: 1 represent ON
0 represent OFF

Fig: XNOR GATE Program & Result

TIMER ON

A Timer ON (TON) instruction in a PLC (Programmable Logic Controller) is a fundamental function used to delay the activation of an output or an internal operation for a specific amount of time after its input condition becomes true.

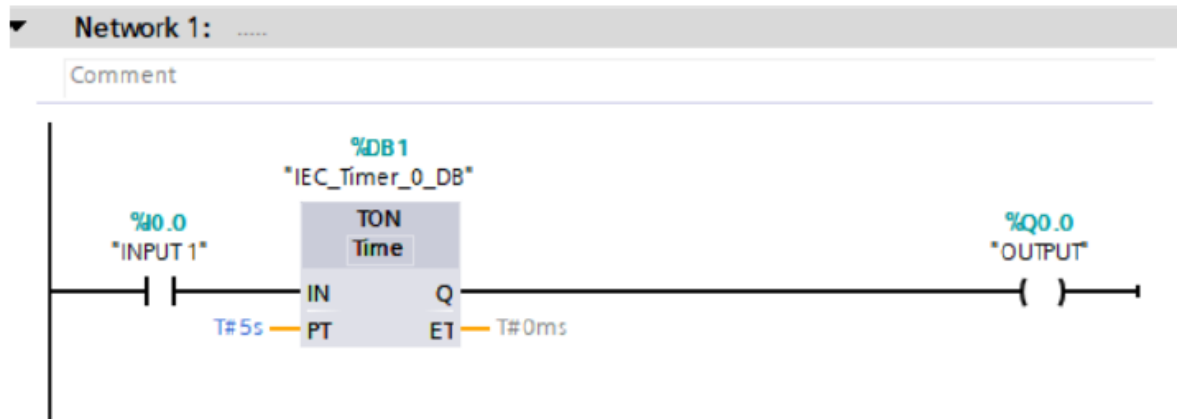


Fig: TIMER ON Ladder Diagram

Result

When PLC Input Ia0 is pressed, Output Qc0 turns on after 5 seconds.

SET & RESET

SET and RESET are non-retentive instructions in PLC (Programmable Logic Controller) programming used to control the state of an output coil or internal memory bit. They are typically used in pairs to create a latched or memory function.

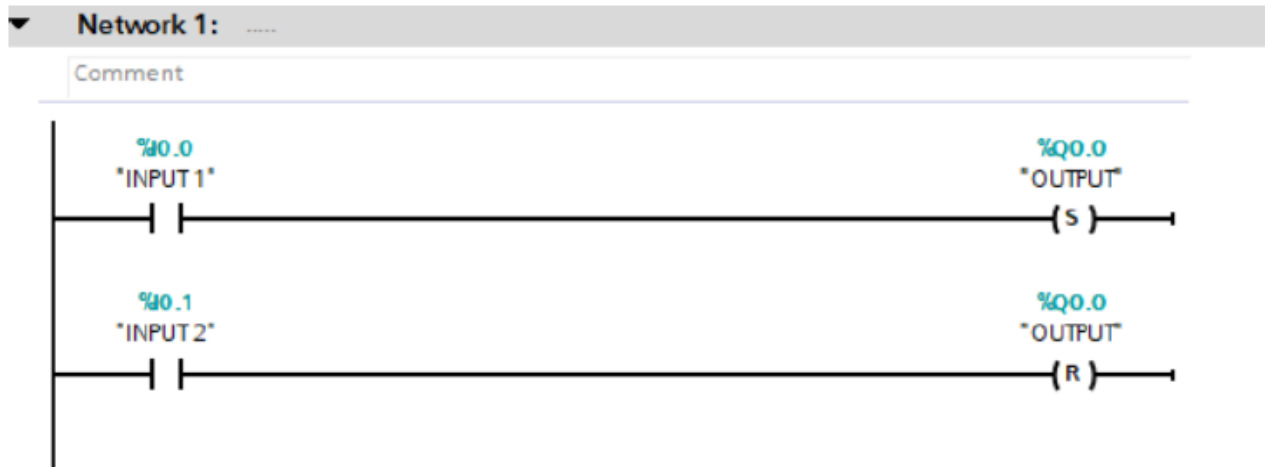


Fig: SET & RESET Ladder Diagram

Result

Output Qc0 is ON (SET) when Input Ia0 is ON.

Output Qc0 is OFF (RESET) when Input Ia1 is ON.

COUNTER UP

A Counter Up instruction in a PLC (Programmable Logic Controller) is used to count the number of times a specific event or condition occurs.

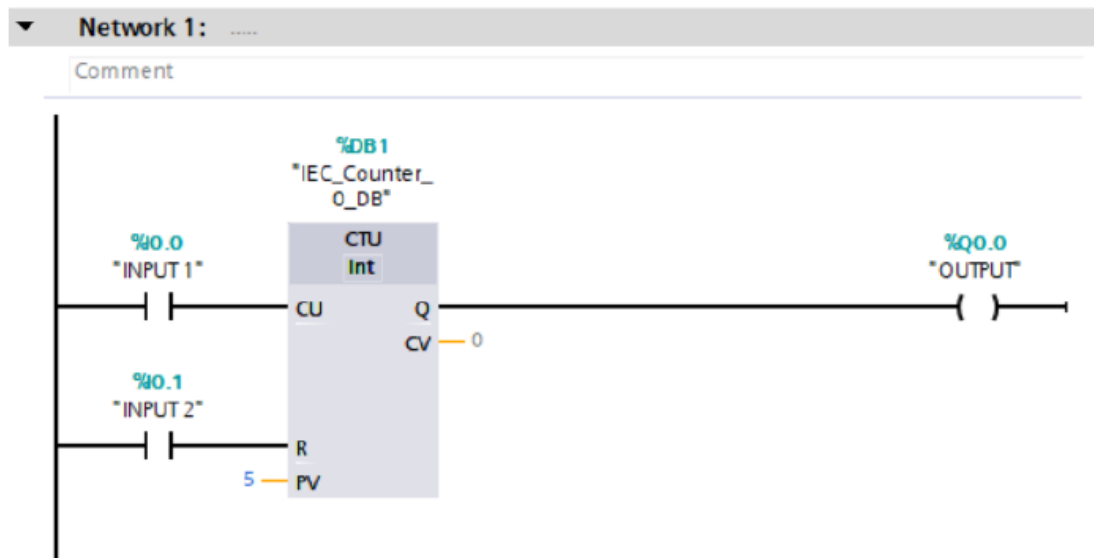


Fig: Counter Up Ladder Diagram

Result

After pressing INPUT Ia0 for 5 times, OUTPUT Qc0 turns on.

Pressing INPUT Ia1 resets the counter and OUTPUT Qc0 turns off.

COUNTER DOWN

A Counter Down instruction in a PLC (Programmable Logic Controller) is used to decrement its accumulated value from a starting number towards a target number, typically zero, each time a counting event occurs.

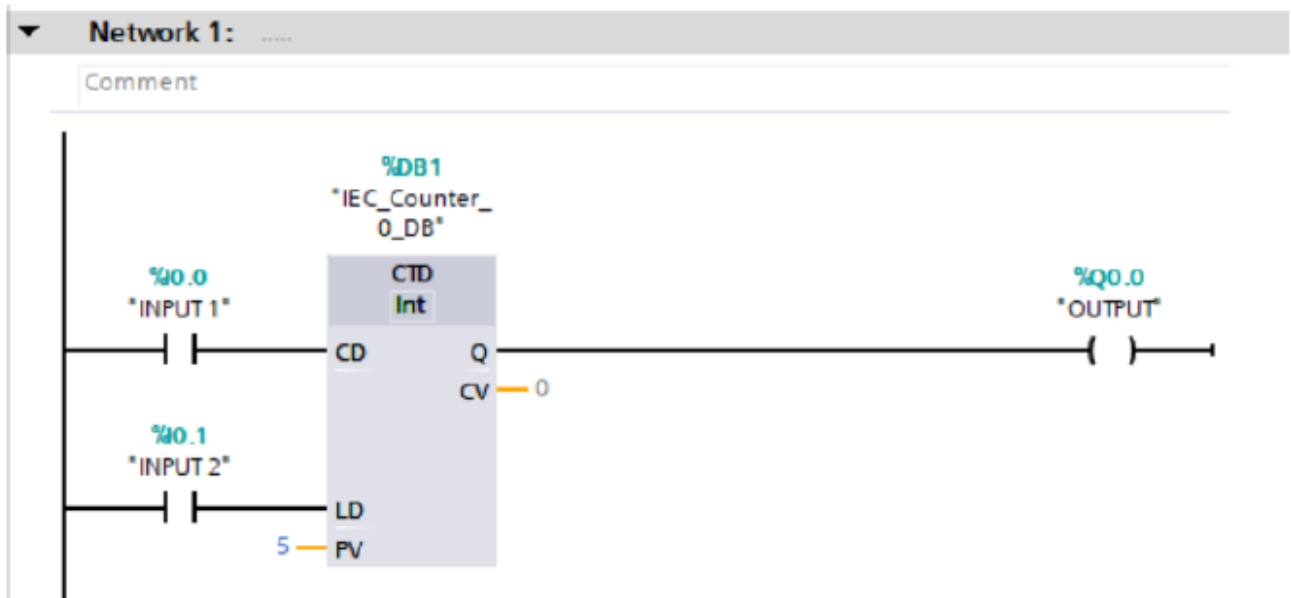


Fig: Counter Down Ladder Diagram

Result

After pressing INPUT Ia0 for 5 times, OUTPUT Qc0 turns on.

Pressing INPUT Ia1 resets the counter to 5, and OUTPUT Qc0 turns off.

COUNTER UP AND DOWN

The Count Up/Down instruction in a PLC (Programmable Logic Controller) is a single, versatile function block that combines the features of both the Count Up and Count Down instructions. It is designed to track a value that can increase or decrease based on two separate input signals.

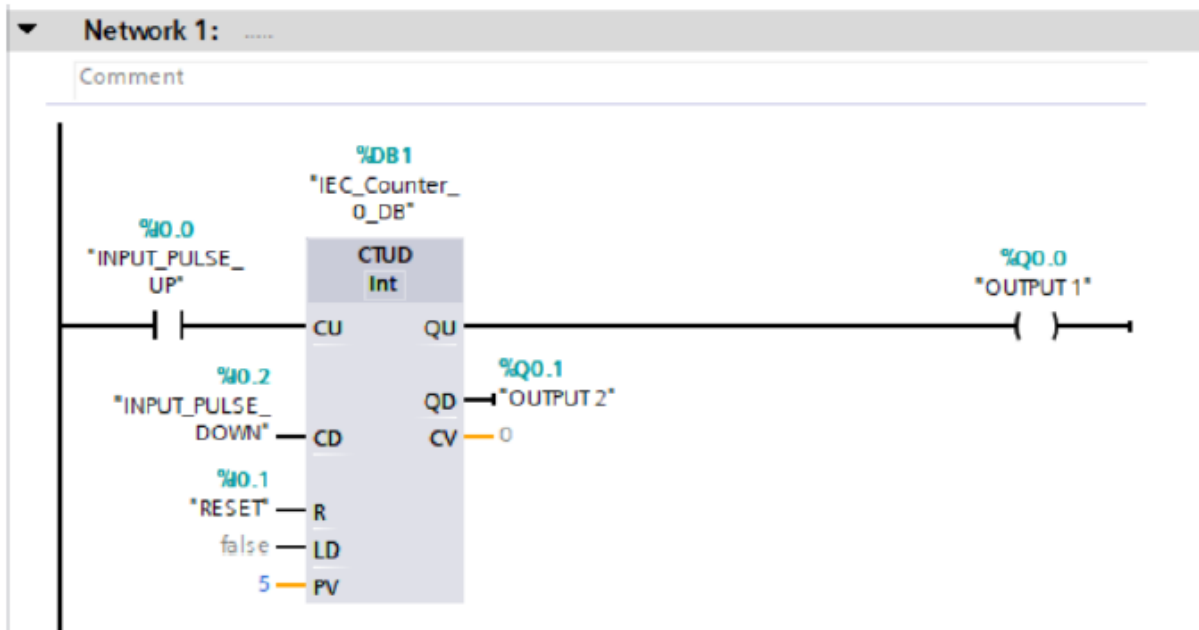


Fig: Counter Up and Down Ladder Diagram

Result

After pressing INPUT Ia0 for 5 times, OUTPUT Qc0 turns on.

Pressing INPUT Ia2 2 times decreases the counter to 3, and OUTPUT Qc0 turns off.

Pressing INPUT Ia1 resets the counter, and OUTPUT Qc0 remains off.



Self-Check 3.3-1

1. What is the single most critical safety verification that must be confirmed before switching a PLC from STOP to RUN mode?
2. What does the illumination of the PLC CPU's FAULT LED typically signify immediately after a program download and before attempting to run the logic?
3. Which operating mode is required for the PLC to allow a programmer to modify and download changes to the ladder logic program?
4. What specific feature in the programming software should a technician check to confirm that all physical I/O modules are communicating correctly after power-up?
5. If a programmer needs to modify a timer's preset value while the application logic is executing, which mode should the PLC CPU key switch be in?
6. What is the most important final step for a programmer to perform using the software after putting the PLC into RUN mode and before starting the physical machinery?
7. Which safety feature should a technician be prepared to use immediately upon initiating the machine's automated sequence to handle any unexpected movement or malfunction?



Answer Paper 3.3-1

1. All field devices and motor loads are free of personnel and physical obstructions.
2. A Major Fault (e.g., a critical hardware configuration mismatch or a serious program error).
3. The PROGRAM or STOP mode.
4. Review the 'Module Status' or 'Diagnostic Buffer' within the hardware configuration of the PLC software.
5. The RUN mode.
6. Going 'Online' with the programming software to monitor the logic status and I/O data in real-time.
7. The Emergency Stop (E-STOP) button and all hard-wired Stop buttons.

	Job Sheet 16
Qualification	Industrial Automation
Learning Unit	Perform AND GATE in PLC
Trainee Name	
PPE	Safety shoes, safety goggles, hand gloves
Tools & Equipment	PLC (with powered I/O terminals), PC/Laptop with PLC Programming Software, Programming Cable, Two Input Devices (e.g., Pushbuttons or Toggle Switches), One Output Indicator (e.g., Pilot Lamp/LED), Multimeter (DMM), and connecting wires.
Notes	1. AND Logic Definition: The output is TRUE (ON) only if all inputs are TRUE (ON). 2. Ladder Implementation: An AND gate is implemented by placing the input contacts in series on a single rung. 3. I/O Addresses: Use the I/O addresses configured in the hardware setup (e.g., I:0/0, I:0/1 for Inputs; O:0/0 for Output).
Procedure	1. Safety & Preparation: Ensure the PLC is powered on and communicating with the PC. Wire the two Input devices to two separate Digital Input terminals (e.g., I:0/0 and I:0/1). Wire the Output Indicator to a single Digital Output terminal (e.g., O:0/0). 2. Software Project Setup: Open the PLC project. Verify the correct Tag Names and Addresses for the inputs and output are established in the Tag Database. 3. Draft Ladder Diagram: Open a new or existing routine and insert a new rung. 4. Implement AND Logic: Place the first Normally Open (NO) contact (representing Input 1, e.g., I:0/0) on the rung. Place the second Normally Open (NO) contact (representing Input 2, e.g., I:0/1) in series immediately following the first contact. 5. Output Coil: Place the Output Coil (representing the Indicator, e.g., O:0/0) at the end of the rung.

	6. Compile and Download: Compile the logic to check for syntax errors. Download the program to the PLC. Switch the PLC to RUN mode. 7. Testing - Logic Verification: Perform the truth table test:
Trainee's Signature	
Assessor's Signature	
QA Signature	
Assessor's Comment	

	Job Sheet 17
Qualification	Industrial Automation
Learning Unit	Perform OR GATE in PLC
Trainee Name	
PPE	Safety shoes, safety goggles, hand gloves
Tools & Equipment	PLC (with powered I/O terminals), PC/Laptop with PLC Programming Software, Programming Cable, Two Input Devices (e.g., Pushbuttons or Toggle Switches), One Output Indicator (e.g., Pilot Lamp/LED), Multimeter (DMM), and connecting wires.
Notes	1. OR Logic Definition: The output is TRUE (ON) if at least one input is TRUE (ON). 2. Ladder Implementation: An OR gate is implemented by placing the input contacts in parallel (branches) on a single rung. 3. I/O Addresses: Use the I/O addresses configured in the hardware setup (e.g., I:0/0, I:0/1 for Inputs; O:0/0 for Output).
Procedure	1. Safety & Preparation: Ensure the PLC is powered on and communicating with the PC. Wire the two Input devices to two separate Digital Input terminals (e.g., I:0/0 and I:0/1). Wire the Output Indicator to a single Digital Output terminal (e.g., O:0/0).

	2. Software Project Setup: Open the PLC project. Verify the correct Tag Names and Addresses for the inputs and output are established in the Tag Database. 3. Draft Ladder Diagram: Open a new or existing routine and insert a new rung. 4. Implement OR Logic: Place the first Normally Open (NO) contact (representing Input 1, e.g., I:0/0) on the main rung path. Create a parallel branch beneath the first contact and place the second Normally Open (NO) contact (representing Input 2, e.g., I:0/1) within this branch. Join the branch back to the main rung. 5. Output Coil: Place the Output Coil (representing the Indicator, e.g., O:0/0) at the end of the rung. 6. Compile and Download: Compile the logic to check for syntax errors. Download the program to the PLC. Switch the PLC to RUN mode. 7. Testing - Logic Verification: Perform the truth table test:
Trainee's Signature	
Assessor's Signature	
QA Signature	
Assessor's Comment	

	Job Sheet 18
Qualification	Industrial Automation
Learning Unit	Perform NOT GATE in PLC
Trainee Name	
PPE	Safety shoes, safety goggles, hand gloves
Tools & Equipment	PLC (with powered I/O terminals), PC/Laptop with PLC Programming Software, Programming Cable, One Input Device (e.g., Pushbutton or

	Toggle Switch), One Output Indicator (e.g., Pilot Lamp/LED), Multimeter (DMM), and connecting wires.
Notes	1. NOT Logic Definition: The output is TRUE (ON) if the input is FALSE (OFF), and vice versa. It is an inverter. 2. Ladder Implementation: A NOT gate is implemented by using a Normally Closed (NC) contact in series with the output coil. 3. I/O Addresses: Use the I/O addresses configured in the hardware setup (e.g., I:0/0 for Input; O:0/0 for Output).
Procedure	1. Safety & Preparation: Ensure the PLC is powered on and communicating with the PC. Wire the Input device to a single Digital Input terminal (e.g., I:0/0). Wire the Output Indicator to a single Digital Output terminal (e.g., O:0/0). 2. Software Project Setup: Open the PLC project. Verify the correct Tag Names and Addresses for the input and output are established in the Tag Database. 3. Draft Ladder Diagram: Open a new or existing routine and insert a new rung. 4. Implement NOT Logic: Place a single Normally Closed (NC) contact (represented by a contact with a slash through it, using the address of the physical input, e.g., I:0/0) on the rung. This contact is TRUE when the input is OFF. 5. Output Coil: Place the Output Coil (representing the Indicator, e.g., O:0/0) at the end of the rung. 6. Compile and Download: Compile the logic to check for syntax errors. Download the program to the PLC. Switch the PLC to RUN mode. 7. Testing - Logic Verification: Perform the truth table test:
Trainee's Signature	
Assessor's Signature	
QA Signature	
Assessor's Comment	

	Job Sheet 19
Qualification	Industrial Automation
Learning Unit	Perform NAND GATE in PLC
Trainee Name	
PPE	Safety shoes, safety goggles, hand gloves
Tools & Equipment	PLC (with powered I/O terminals), PC/Laptop with PLC Programming Software, Programming Cable, Two Input Devices (e.g., Pushbuttons or Toggle Switches), One Output Indicator (e.g., Pilot Lamp/LED), Multimeter (DMM), and connecting wires.
Notes	1. NAND Logic Definition: The output is FALSE (OFF) only when all inputs are TRUE (ON). The output is ON for all other input combinations. 2. Ladder Implementation: A NAND gate is implemented using a standard AND gate structure (inputs in series) followed by a NOT element. This is achieved by using a Normally Closed (NC) auxiliary contact of a memory bit or internal coil that is energized by the AND logic. 3. I/O Addresses: Use the I/O addresses configured in the hardware setup (e.g., I:0/0, I:0/1 for Inputs; O:0/0 for Output).
Procedure	1. Safety & Preparation: Ensure the PLC is powered on and communicating with the PC. Wire the two Input devices to two separate Digital Input terminals (e.g., I:0/0 and I:0/1). Wire the Output Indicator to a single Digital Output terminal (e.g., O:0/0). 2. Software Project Setup: Open the PLC project. Verify Tag Names and Addresses for the inputs, output, and define one Internal Memory Bit (e.g., B3:0/0) to hold the result of the AND logic. 3. Draft Ladder Diagram - Rung 1 (AND Logic to Memory): Insert the first rung to implement the AND function internally. Place Input 1 (I:0/0 NO contact) in series with Input 2 (I:0/1 NO contact). Coil this rung to

	the Internal Memory Bit (B3:0/0). This bit is ON only when both inputs are ON. 4. Draft Ladder Diagram - Rung 2 (NOT Logic to Output): Insert a second rung to invert the result. Place a Normally Closed (NC) contact using the address of the Internal Memory Bit (B3:0/0). 5. Output Coil: Place the Output Coil (O:0/0) at the end of Rung 2. This logic is: If the AND condition (B3:0/0) is NOT true, the output is ON. 6. Compile and Download: Compile the logic. Download the program to the PLC. Switch the PLC to RUN mode. 7. Testing - Logic Verification: Perform the truth table test:
Trainee's Signature	
Assessor's Signature	
QA Signature	
Assessor's Comment	

	Job Sheet 20
Qualification	Industrial Automation
Learning Unit	Perform NOR GATE in PLC
Trainee Name	
PPE	Safety shoes, safety goggles, hand gloves
Tools & Equipment	PLC (with powered I/O terminals), PC/Laptop with PLC Programming Software, Programming Cable, Two Input Devices (e.g., Pushbuttons or Toggle Switches), One Output Indicator (e.g., Pilot Lamp/LED), Multimeter (DMM), and connecting wires.
Notes	1. NOR Logic Definition: The output is TRUE (ON) only when all inputs are FALSE (OFF). The output is OFF for any other input combination.

	2. Ladder Implementation: A NOR gate is implemented by using all input contacts as Normally Closed (NC) contacts wired in series. 3. I/O Addresses: Use the I/O addresses configured in the hardware setup (e.g., I:0/0, I:0/1 for Inputs; O:0/0 for Output).
Procedure	1. Safety & Preparation: Ensure the PLC is powered on and communicating with the PC. Wire the two Input devices to two separate Digital Input terminals (e.g., I:0/0 and I:0/1). Wire the Output Indicator to a single Digital Output terminal (e.g., O:0/0). 2. Software Project Setup: Open the PLC project. Verify Tag Names and Addresses for the inputs and output are established in the Tag Database. 3. Draft Ladder Diagram: Open a new or existing routine and insert a new rung. 4. Implement NOR Logic: Place the first Normally Closed (NC) contact (representing Input 1, e.g., I:0/0) on the rung. Place the second Normally Closed (NC) contact (representing Input 2, e.g., I:0/1) in series immediately following the first contact. 5. Output Coil: Place the Output Coil (O:0/0) at the end of the rung. This logic states that power flows only if Input 1 is NOT true AND Input 2 is NOT true. 6. Compile and Download: Compile the logic to check for syntax errors. Download the program to the PLC. Switch the PLC to RUN mode. 7. Testing - Logic Verification: Perform the truth table test:
Trainee's Signature	
Assessor's Signature	
QA Signature	
Assessor's Comment	

	Job Sheet 21

Qualification	Industrial Automation
Learning Unit	Perform XOR GATE in PLC
Trainee Name	
PPE	Safety shoes, safety goggles, hand gloves
Tools & Equipment	PLC (with powered I/O terminals), PC/Laptop with PLC Programming Software, Programming Cable, Two Input Devices (e.g., Pushbuttons), One Output Indicator (e.g., Pilot Lamp/LED), Multimeter (DMM), and connecting wires.
Notes	1. XOR Logic Definition: The output is TRUE (ON) only when the inputs are different (one ON and one OFF). If both are ON or both are OFF, the output is FALSE (OFF). 2. Ladder Implementation: XOR is implemented by combining two AND gates and one OR gate: (A AND NOT B) OR (NOT A AND B). 3. I/O Addresses: Use the I/O addresses configured in the hardware setup (e.g., I:0/0, I:0/1 for Inputs; O:0/0 for Output).
Procedure	1. Safety & Preparation: Ensure the PLC is powered on and communicating with the PC. Wire the two Input devices to two separate Digital Input terminals (e.g., I:0/0 for Input A and I:0/1 for Input B). Wire the Output Indicator to a single Digital Output terminal (e.g., O:0/0). 2. Software Project Setup: Open the PLC project. Verify Tag Names and Addresses for the inputs and output. 3. Draft Ladder Diagram - Rung 1 (A AND NOT B): Insert the first rung. Place an Input A NO contact (I:0/0) in series with an Input B NC contact (I:0/1). Coil this to the Output Coil (O:0/0) using a parallel branch structure (Step 5). 4. Draft Ladder Diagram - Rung 2 (NOT A AND B): Insert the second rung path in parallel with the first path. Place an Input A NC contact (I:0/0) in series with an Input B NO contact (I:0/1).

	5. Final Output (OR Function): The two logic paths from Steps 3 and 4 are combined to energize the single Output Coil (O:0/0). The final structure should be two parallel branches leading to the single output coil. 6. Compile and Download: Compile the logic. Download the program to the PLC. Switch the PLC to RUN mode. 7. Testing - Logic Verification: Perform the truth table test:
Trainee's Signature	
Assessor's Signature	
QA Signature	
Assessor's Comment	

	Job Sheet 22
Qualification	Industrial Automation
Learning Unit	Perform XNOR GATE in PLC
Trainee Name	
PPE	Safety shoes, safety goggles, hand gloves
Tools & Equipment	PLC (with powered I/O terminals), PC/Laptop with PLC Programming Software, Programming Cable, Two Input Devices (e.g., Pushbuttons), One Output Indicator (e.g., Pilot Lamp/LED), Multimeter (DMM), and connecting wires.
Notes	An XNOR Gate (Exclusive NOR) is a logic gate whose output is HIGH (1) when both inputs are the same (both 0 or both 1). In PLC programming, XNOR logic can be implemented using ladder logic or function blocks.
Procedure	1. Ensure all PPE is worn and the workspace is safe. 2. Power on the PLC and connect it to the PC/laptop using the programming cable.

	3. Open the PLC programming software and create a new program/project. 4. Identify two input addresses in the PLC corresponding to the pushbuttons (e.g., I0.0 and I0.1). 5. Identify one output address corresponding to the output indicator (e.g., Q0.0). 6. Program the XNOR logic in the ladder diagram: 7. Option 1: Use a function block or instruction if the PLC supports XNOR. 8. Option 2: Use normally closed contacts and normally open contacts to mimic XNOR logic manually. 9. Download the program to the PLC. 10. Connect the pushbuttons to the input terminals and the pilot lamp/LED to the output terminal. 11. Test all possible input combinations (00, 01, 10, 11). 12. Observe and record the output indicator behavior to verify the XNOR logic. 13. Adjust or debug the program if the output does not match the truth table. 14. After verification, power off the PLC and disconnect all wiring safely.
Trainee's Signature	
Assessor's Signature	
QA Signature	
Assessor's Comment	

	Job Sheet 23
Qualification	Industrial Automation

Learning Unit	Perform TIMER ON in PLC
Trainee Name	
PPE	Safety shoes, safety goggles, hand gloves
Tools & Equipment	PLC (with powered I/O terminals), PC/Laptop with PLC Programming Software, Programming Cable, Two Input Devices (e.g., Pushbuttons), One Output Indicator (e.g., Pilot Lamp/LED), Multimeter (DMM), and connecting wires.
Notes	A TIMER ON (TON) is a standard PLC instruction that delays turning on an output for a preset time after the input condition becomes TRUE.
Procedure	1. Ensure all PPE is worn and the workspace is safe. 2. Power on the PLC and connect it to the PC/laptop via programming cable. 3. Open the PLC programming software and create a new program/project. 4. Identify input device (pushbutton) for starting the timer (e.g., I0.0). 5. Identify output device (pilot lamp or LED) for the timer output (e.g., Q0.0). 6. Insert a TIMER ON (TON) instruction in the ladder diagram: 7. Assign Timer Address (e.g., T0). 8. Set the Preset Time (PT) according to the required delay (e.g., 5 seconds). 9. Connect the input pushbutton to the TON instruction and output indicator to the timer done bit (T0.DN). 10. Download the program to the PLC. 11. Press the input pushbutton and observe the output indicator: 12. It should turn ON only after the preset time delay. 13. Release the input and observe that the timer resets. 14. Record observations including delay time accuracy and output behavior.

	15. After testing, power off the PLC and disconnect all wiring safely.
Trainee's Signature	
Assessor's Signature	
QA Signature	
Assessor's Comment	

	Job Sheet 24
Qualification	Industrial Automation
Learning Unit	Perform SET & RESET in PLC
Trainee Name	
PPE	Safety shoes, safety goggles, hand gloves
Tools & Equipment	PLC (with powered I/O terminals), PC/Laptop with PLC Programming Software, Programming Cable, Two Input Devices (e.g., Pushbuttons), One Output Indicator (e.g., Pilot Lamp/LED), Multimeter (DMM), and connecting wires.
Notes	1. XNOR Logic Definition: The output is TRUE (ON) only when the inputs are the same (both ON or both OFF). If the inputs are different, the output is FALSE (OFF). 2. Ladder Implementation: XNOR is implemented by combining two AND gates and one OR gate: (A AND B) OR (NOT A AND NOT B). 3. I/O Addresses: Use the I/O addresses configured in the hardware setup (e.g., I:0/0 for Input A, I:0/1 for Input B; O:0/0 for Output).
Procedure	1. Safety & Preparation: Ensure the PLC is powered on and communicating with the PC. Wire the two Input devices to two separate Digital Input terminals (I:0/0 and I:0/1). Wire the Output Indicator to a single Digital Output terminal (O:0/0).

	2. Software Project Setup: Open the PLC project. Verify Tag Names and Addresses for the inputs and output. 3. Draft Ladder Diagram - Rung 1 (A AND B - Both ON): Insert the first rung path. Place an Input A NO contact (I:0/0) in series with an Input B NO contact (I:0/1). Coil this to the Output Coil (O:0/0) using a parallel branch structure (Step 5). 4. Draft Ladder Diagram - Rung 2 (NOT A AND NOT B - Both OFF): Insert the second rung path in parallel with the first path. Place an Input A NC contact (I:0/0) in series with an Input B NC contact (I:0/1). 5. Final Output (OR Function): The two logic paths from Steps 3 and 4 are combined to energize the single Output Coil (O:0/0). The final structure should be two parallel branches leading to the single output coil. 6. Compile and Download: Compile the logic. Download the program to the PLC. Switch the PLC to RUN mode. 7. Testing - Logic Verification: Perform the truth table test
Trainee's Signature	
Assessor's Signature	
QA Signature	
Assessor's Comment	

	Job Sheet 25
Qualification	Industrial Automation
Learning Unit	Perform COUNTER UP in PLC
Trainee Name	
PPE	Safety shoes, safety goggles, hand gloves
Tools & Equipment	PLC (with powered I/O terminals), PC/Laptop with PLC Programming Software, Programming Cable, One Momentary Input Device (for

	counting/CU), One Momentary Input Device (for reset/RES), One Output Indicator (to show done/DN status), Multimeter (DMM), and connecting wires.
Notes	1. CTU Function: The counter increments its Accumulated Value (ACC) by one on the false-to-true transition (rising edge) of the Count Up (CU) input. 2. Preset Value (PRE): This value must be set in the software and represents the target count. 3. Reset: A separate input is mandatory to reset the counter's ACC back to zero. 4. Tags: Define a unique Counter Tag (e.g., C5:0) with its PRE, ACC, and DN bits.
Procedure	1. Safety & Preparation: Ensure the PLC is powered on and communicating with the PC. Wire the counting input (CU) to an Input terminal (e.g., I:0/0). Wire the reset input (RES) to a separate Input terminal (e.g., I:0/1). Wire the output indicator to an Output terminal (e.g., O:0/0). 2. Software Project Setup: Open the PLC project. Verify Tag Names and Addresses. Define a Counter Tag (e.g., C5:0) and set a Preset Value (PRE) (e.g., 5). 3. Draft Ladder Diagram - Rung 1 (Count Up): Insert the first rung. Place an Input NO contact (I:0/0) on the rung. Place the CTU (Count Up) Instruction box on the output side of the rung. Assign the Counter Tag (C5:0) and the PRE (5) to the instruction. 4. Draft Ladder Diagram - Rung 2 (Reset): Insert a second rung. Place the Reset Input NO contact (I:0/1) on the rung. Place the RES (Reset) Instruction box on the output side, assigning the same Counter Tag (C5:0) to the instruction. 5. Draft Ladder Diagram - Rung 3 (Done Bit Output): Insert a third rung. Place a Normally Open (NO) contact using the counter's Done Bit (C5:0/DN). Place the Output Coil (O:0/0) at the end of the rung.

	6. Compile and Download: Compile the logic. Download the program to the PLC. Switch the PLC to RUN mode. 7. Testing - Counting: Momentarily actuate and release the Count Up Input (I:0/0) four times. Monitor the ACC value in the software (should be 4). Actuate it one more time (fifth count). The ACC should read 5, and the Done Bit (C5:0/DN) should activate, turning the Output Indicator (O:0/0) ON. 8. Testing - Reset: Momentarily actuate and release the Reset Input (I:0/1). The ACC value should return to 0, and the Output Indicator should turn OFF. 9. Final Check: Confirm the counter accurately increments on the rising edge of the input and correctly sets the DN bit at the PRE value.
Trainee's Signature	
Assessor's Signature	
QA Signature	
Assessor's Comment	

	Job Sheet 26
Qualification	Industrial Automation
Learning Unit	Perform COUNTER DOWN in PLC
Trainee Name	
PPE	Safety shoes, safety goggles, hand gloves
Tools & Equipment	PLC (with powered I/O terminals), PC/Laptop with PLC Programming Software, Programming Cable, One Momentary Input Device (for counting/CD), One Momentary Input Device (for preset/LOAD), One Output Indicator (to show done/DN status), Multimeter (DMM), and connecting wires.

Notes	1. CTD Function: The counter decrements its Accumulated Value (ACC) by one on the false-to-true transition (rising edge) of the Count Down (CD) input. 2. Preset Value (PRE) / Loading: The CTD instruction requires the ACC to be loaded to the PRE value before counting can begin effectively. 3. Done Bit: The Done Bit (DN) is set when the ACC reaches zero. 4. Tags: Define a unique Counter Tag (e.g., C5:1) with its PRE, ACC, and DN bits.
Procedure	1. Safety & Preparation: Ensure the PLC is powered on and communicating with the PC. Wire the counting input (CD) to an Input terminal (e.g., I:0/0). Wire the preset/load input (LOAD) to a separate Input terminal (e.g., I:0/1). Wire the output indicator to an Output terminal (e.g., O:0/0). 2. Software Project Setup: Open the PLC project. Verify Tag Names and Addresses. Define a Counter Tag (e.g., C5:1) and set a Preset Value (PRE) (e.g., 5). 3. Draft Ladder Diagram - Rung 1 (Load Preset): Insert the first rung. Place the Load Input NO contact (I:0/1) on the rung. Place the CTD (Count Down) Instruction box on the output side. Assign the Counter Tag (C5:1) and the PRE (5) to the instruction. (Note: Energizing the rung containing the CTD instruction often loads the ACC with the PRE value, though some PLCs use a dedicated RES instruction). 4. Draft Ladder Diagram - Rung 2 (Count Down): Insert a second rung. Place the Count Down Input NO contact (I:0/0) on the rung. Place the same CTD Instruction box (C5:1) on the output side of this rung. 5. Draft Ladder Diagram - Rung 3 (Done Bit Output): Insert a third rung. Place a Normally Open (NO) contact using the counter's Done Bit (C5:1/DN). Place the Output Coil (O:0/0) at the end of the rung. 6. Compile and Download: Compile the logic. Download the program to the PLC. Switch the PLC to RUN mode.

	7. Testing - Initialization: Momentarily actuate and release the Load/Preset Input (I:0/1). Monitor the ACC value in the software; it should be loaded to 5. The Output Indicator should be OFF. 8. Testing - Counting: Momentarily actuate and release the Count Down Input (I:0/0) four times. Monitor the ACC value (should be 1). Actuate it one more time (fifth count). The ACC should read 0, and the Done Bit (C5:1/DN) should activate, turning the Output Indicator (O:0/0) ON. 9. Final Check: Confirm the counter accurately decrements on the rising edge of the input and correctly sets the DN bit when the ACC reaches zero.
Trainee's Signature	
Assessor's Signature	
QA Signature	
Assessor's Comment	

Module 4: Integrate Industrial Sensors and Actuators



Contents of Module

Module Description

This unit covers the knowledge, skills and attitudes required to integrate industrial sensors and actuators. It specifically includes the tasks of identifying types of industrial sensors and classifications, identifying types of industrial actuators and classifications, selecting sensors based on application and material properties, and executing sensors and actuators for industrial application.

Minimum Time: 40 Hours



Learning Outcome

- 4.1. Identify types of industrial sensors and classifications
- 4.2. Identify types of industrial actuators and classifications
- 4.3. Select sensors based on application and material properties
- 4.4. Execute sensors and actuators for industrial application



Performance Criteria

1. Types of industrial sensors are interpreted.

2. Classifications of industrial sensors are identified and described.
3. Function and role of sensors are explained in relation to industrial applications.
4. Applications of industrial sensors are interpreted.
5. Types of actuators are interpreted.
6. Classifications of industrial actuators are identified and described.
7. Function and role of actuators are explained in relation to industrial applications.
8. Applications of industrial actuators are interpreted.
9. Requirements of the application are analyzed to determine appropriate sensor types.
10. Relevant material properties and surface characteristics are identified.
11. Sensor specifications are reviewed and matched with application needs.
12. Sensor technologies are selected based on material properties and operational conditions.
13. Installation and operating environment constraints are evaluated to ensure sensor compatibility and reliability.
14. Sensors and actuators are selected and collected according to system specifications.
15. Installation sites for sensors and actuators are prepared and inspected to ensure compatibility and safety.
16. Sensors and actuators are installed and wired following manufacturer guidelines.
17. PLC programming is carried out as per job requirement.
18. Functional testing is conducted to verify correct sensor detection and actuator response.
19. Faults or malfunctions are identified, diagnosed, and rectified according to troubleshooting procedures.

Learning Outcome 4.1 – Identify types of Industrial Sensors and Classifications



Content

- **Sensor Operating Principles:** Understand the fundamental physical principles (e.g., magnetic induction, photoelectric effect, capacitance) used by various industrial sensors to detect physical changes.
- **Classification by Output and Function:** Learn to classify sensors based on their output signal (digital/discrete vs. analog/continuous) and their function (position, proximity, level, temperature, pressure, etc.).
- **Key Industrial Sensor Types:** Identify the construction, application, and typical electrical characteristics of common industrial sensors, including Proximity Switches (Inductive, Capacitive), Photoelectric Sensors, and Limit Switches.



Assessment Criteria

- Accurate Identification
- Classification Accuracy
- Application Matching



Necessary Equipment

- Variety of Sensor Samples
- Sensor Documentation
- Digital Multimeter (DMM)
- Power Supply
- Test Objects/Targets



Learning Activity 4.1-1

Learning Activity	Resources/ Instructions/ References
Identify types of Industrial Sensors and Classifications	• Information Sheet: 4.1-1 • Self-Check: 4.1-1 • Answer Paper: 4.1-1 • Job Sheet 27 – Job Sheet 32



Information Sheet 4.1-1

Learning Objective: The learner will be able to identify the operating principles and key characteristics of various common industrial sensor types and accurately classify them based on their function, output, and detection method.

Integrate Industrial Sensors and Actuators

Integrating industrial sensors and actuators is a fundamental aspect of industrial automation and robotics, allowing machines to perceive their environment and take action. This process creates a "sense-think-act" loop where sensors gather data, a control system (the "think" part) processes it, and actuators perform the required physical tasks. The integration involves three main components: sensors, actuators, and the control system that connects them.

Sensors

Sensors are fundamental components that act as the eyes and ears of automated systems, enabling them to perceive and interact with the physical world. They convert physical quantities like temperature, pressure, or light into electrical signals that a control system can process.



Fig: Various Types of Sensors

Role of Sensors in Automation, Process Control, and Data Acquisition

Sensors play a crucial role in modern systems, acting as the bridge between the physical and digital worlds. Their primary functions can be broken down into three main areas:

- ✓ **Automation:** In automation, sensors provide real-time feedback that allows systems to operate autonomously. A simple example is a motion sensor that detects a person's presence and automatically turns on a light. In industrial settings, sensors on a conveyor belt can detect a part's arrival, signaling a robotic arm to pick it up. Without this continuous feedback, automated

processes would be blind and unable to react to changing conditions, making them inefficient and unsafe.

- ✓ **Process Control:** This involves using sensor data to maintain a variable at a specific setpoint. A classic example is a thermostat. A temperature sensor measures the room's temperature and sends this data to a controller. If the temperature falls below the setpoint, the controller activates the furnace. Once the temperature reaches the desired level, the sensor signals the controller to turn the furnace off. This constant feedback loop ensures the process remains stable and within desired parameters, which is essential in manufacturing, chemical processing, and power generation.
- ✓ **Data Acquisition:** Sensors are a primary source of data for monitoring, analysis, and decision-making. They collect information about environmental conditions, machine status, or product quality, which is then logged and stored. This data is invaluable for tasks like **predictive maintenance**, where analyzing vibration sensor data can predict when a machine part might fail, allowing for proactive repairs and preventing costly downtime. The rise of the **Internet of Things (IoT)** has further amplified this role, as billions of sensors now stream data from a wide range of devices, enabling smarter systems and better-informed decisions.

Principles of Industrial Sensor

The fundamental principle of an industrial sensor is **transduction**, the conversion of a physical property into a usable electrical signal. Sensors act as a bridge between the physical world and a control system, allowing for the automation of processes. They measure a specific physical quantity and provide a corresponding output, which can be an analog voltage or current, or a digital signal.

How Industrial Sensors Work

All sensors, regardless of their type, follow a core process to function:

- ✓ **Sensing:** A sensor's internal component, often called the sensing element, is designed to react to a specific stimulus, such as heat, pressure, light, or proximity.
- ✓ **Transduction:** This physical interaction is then converted into an electrical signal. For example, a pressure sensor might use a diaphragm that deforms under pressure, causing a change in resistance in an attached **strain gauge**. That change in resistance is the electrical output.
- ✓ **Signal Conditioning:** The initial electrical signal from the transducer is often weak and noisy. The sensor's electronics will amplify, filter, and sometimes convert this signal (e.g., from an analog to a digital format) to make it readable and stable for the control system.
- ✓ **Output:** The final, processed signal is sent to a control device, like a Programmable Logic Controller (PLC) or a computer, which uses this data to make decisions. The output can be as simple as an on/off signal (digital) or a proportional signal (analog) that corresponds to the magnitude of the measured physical quantity.

Common Principles and Sensor Types

The specific principle used by a sensor determines what it can measure and how it's applied.

Mechanical Principles

- ✓ **Resistive:** The sensor's resistance changes in response to a physical change. A **strain gauge** works on this principle, where the resistance changes as the material is stretched or compressed, allowing it to measure force or pressure.
- ✓ **Capacitive:** These sensors measure changes in capacitance. A **capacitive proximity sensor**, for instance, detects objects by measuring the change in capacitance when an object enters its electric field, making it suitable for both metallic and non-metallic targets.
- ✓ **Piezoelectric:** This principle uses certain materials that generate a voltage when they are mechanically stressed or compressed. **Accelerometers** and pressure sensors often use this effect to measure motion or force.

Electromagnetic Principles

- ✓ **Inductive:** These sensors use a coil to generate a magnetic field. When a conductive object (like metal) enters this field, it causes a change in the field that the sensor detects. **Inductive proximity sensors** are a common example, used to detect the presence of metal parts on a conveyor line.
- ✓ **Hall Effect:** These sensors respond to changes in a magnetic field. They're often used to detect the position of a magnet, making them useful in speed measurement and rotary encoders.

Optical and Thermal Principles

- ✓ **Photoelectric:** These sensors use a light source (often infrared) and a receiver to detect objects based on how they interact with the light beam (blocking it, reflecting it, etc.).
- ✓ **Thermoelectric:** This principle, used by **thermocouples**, relies on the Seebeck effect, where a voltage is produced when two dissimilar metals are joined and their junction is subjected to a temperature difference. This voltage is proportional to the temperature.

Classifications of Industrial Sensors

Industrial sensors can be classified in several ways, with the most common methods based on their **function, power requirement, and output signal type.**

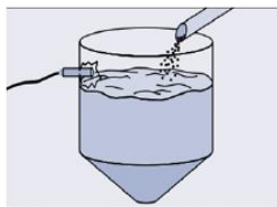
By Measured Quantity (Function)

This is the most straightforward classification, categorizing sensors by the physical quantity they are designed to measure.

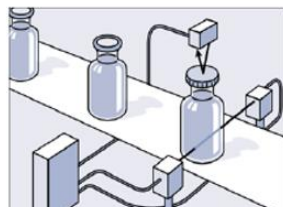
- **Proximity Sensors:** Detect the presence or absence of an object without physical contact. Examples include inductive, capacitive, and photoelectric sensors.

Inductive 	<4-40 mm	Any close-range detection of ferrous material	Iron Steel Aluminum Copper etc. 
Capacitive 	<3-60 mm	Close-range detection of non-ferrous material	Liquids Wood Granulates Plastic Glass etc. 
Photoelectric 	<1mm- 60 mm	Long-range, small or large target detection	Silicon Plastic Paper Metal etc. 

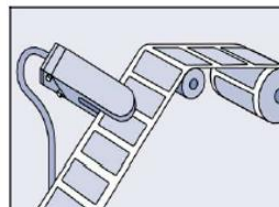
Fig: Proximity Sensors Comparison



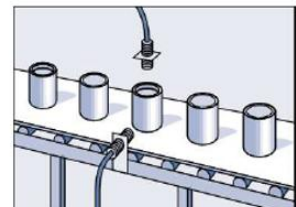
Application
Controlling Fill level of solids in a bin



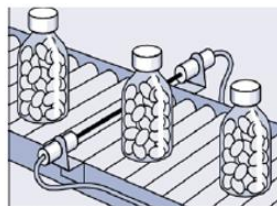
Application
Detecting Caps on Bottles



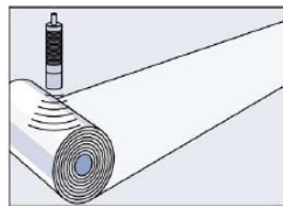
Application
Detecting Presence of Can and Lid



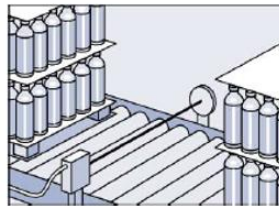
Application
Detecting Labels with Transparent Background



Application
Verifying Objects in Clear Bottles



Application
Diameter Sensing and Strip Speed Control



Application
Flow of Pallets Carrying Bottles



Application
Bottle Counting

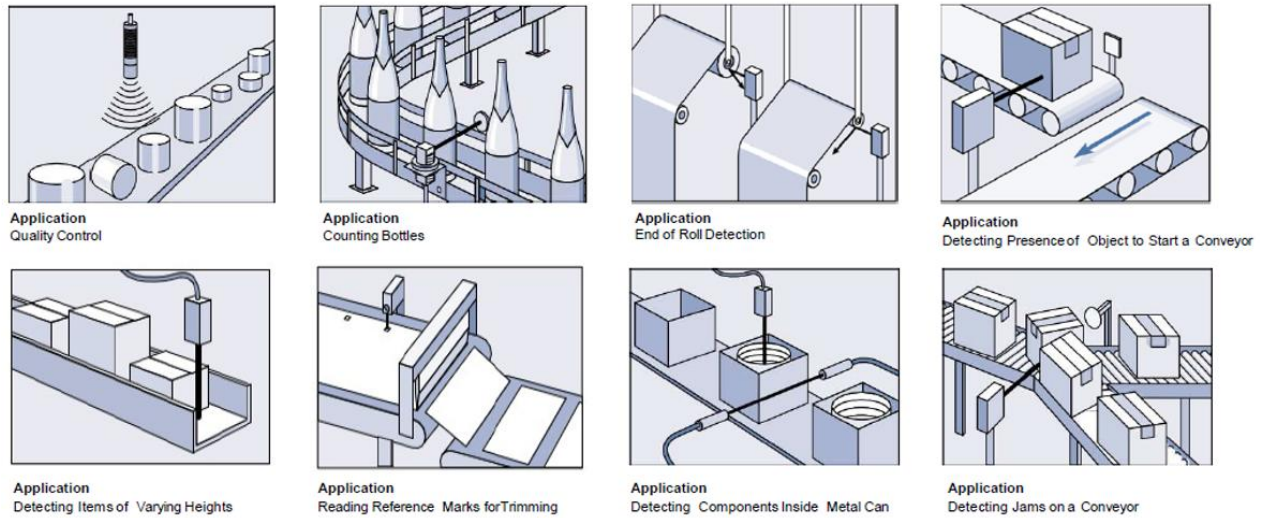


Fig: Applications of Proximity Sensors

- **Temperature Sensors:** Measure heat or cold. Common types are thermocouples and Resistance Temperature Detectors (RTDs).

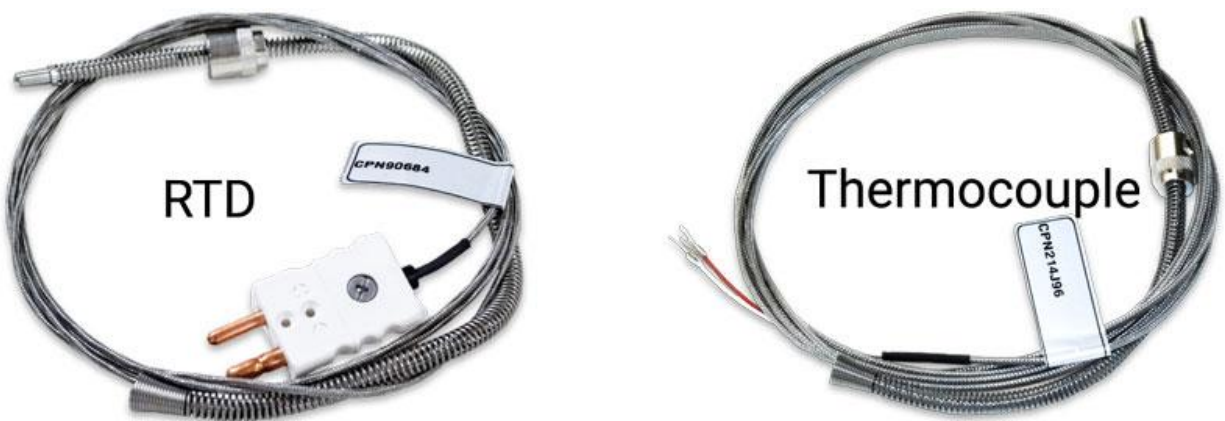


Fig: RTD & Thermocouple

- **Pressure Sensors:** Measure the force exerted by a gas or liquid. They are critical for monitoring hydraulic and pneumatic systems.



Fig: Different Types of Pressure Sensors

- **Position Sensors:** Determine the position of a machine part or object. This includes linear, rotary, and angular position sensors.
- **Flow Sensors:** Measure the rate of fluid or gas moving through a system, crucial in chemical and water treatment plants.
- **Vision Sensors:** Use cameras and image processing to perform tasks like quality control and part inspection.

By Power Requirement

This classification divides sensors based on whether they require an external power source to operate.

- **Passive Sensors:** Do not require an external power source. They generate their own electrical signal from the measured stimulus. A **thermocouple**, for example, produces a voltage proportional to a temperature difference.
- **Active Sensors:** Require an external power source, often called an "excitation signal." This power is used to energize the sensor's internal components, which then measure how the physical quantity affects the signal. A **resistive strain gauge** is an active sensor that needs an applied voltage to measure changes in resistance due to force.

By Output Signal

Sensors are also classified by the type of electrical signal they produce.

- **Analog Sensors:** Provide a continuous output signal, such as a voltage or current, that is directly proportional to the measured physical quantity. For example, an analog temperature sensor might output a voltage that continuously increases as the temperature rises.
- **Digital Sensors:** Provide a discrete, digital output signal. This can be a simple "on/off" signal (binary) or a coded digital value (e.g., a series of bits representing a temperature). Digital sensors are often less susceptible to noise than analog sensors.

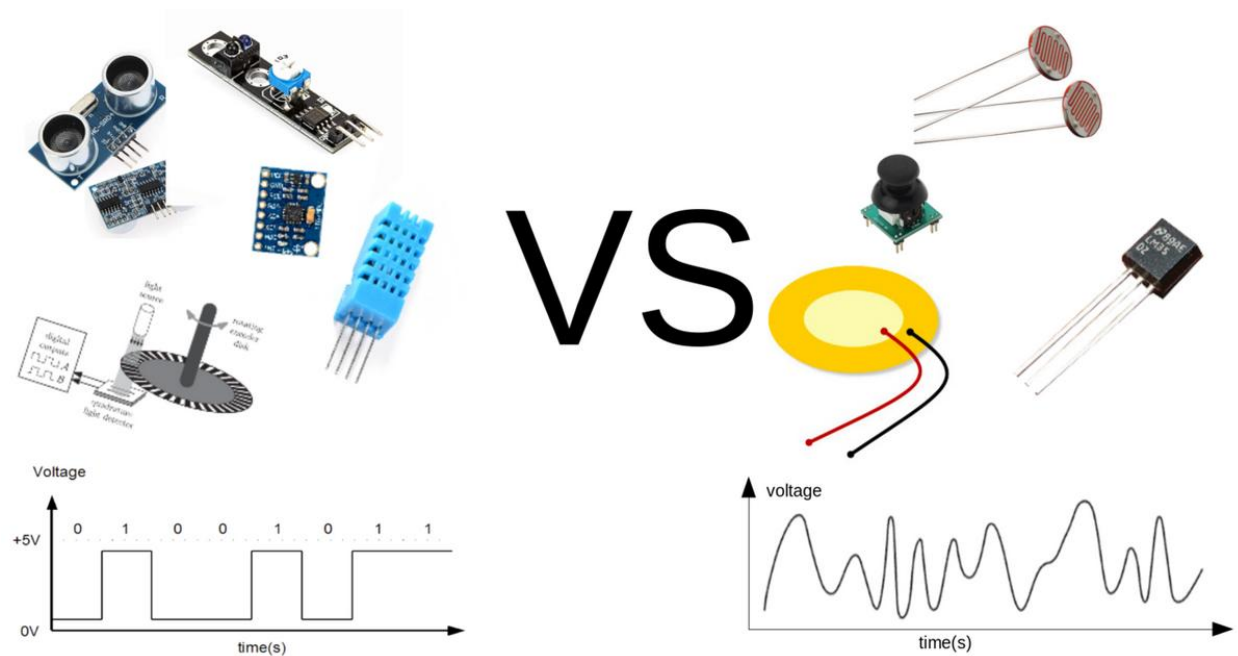


Fig: Digital Vs Analog Sensors

By Sensing Principle

This classification focuses on the physical principle the sensor uses to convert the measured quantity into a signal.

- **Resistive:** Changes in electrical resistance are used to measure a quantity.
- **Capacitive:** Changes in capacitance are measured.
- **Inductive:** Changes in a magnetic field are detected.
- **Piezoelectric:** A voltage is generated in response to mechanical stress.



Self-Check 4.1-1

1. Which type of non-contact sensor specifically uses a high-frequency electromagnetic field to detect the presence of a target object?
2. How is a sensor classified if its output value is continuous and directly proportional to the physical quantity being measured (e.g., 4-20 mA for level)?
3. In which photoelectric sensing mode are the light emitter and the light receiver mounted as two separate components across the detection area?
4. Which proximity sensor, capable of detecting both metallic and non-metallic substances, is typically used to measure the level of powdered materials like grain or cement?
5. For a digital sensor classified as 'Normally Closed (NC)', what is its electrical output state when the target is NOT present?
6. Which type of field device provides feedback that requires the PLC to use scaling logic to convert a voltage or current into engineering units (e.g., degrees Celsius)?
7. What is the main advantage of using a Photoelectric sensor over an Inductive sensor?



Answer Paper 4.1-1

1. The Inductive proximity sensor.
2. An Analog sensor.
3. The Through-beam mode.
4. A Capacitive proximity sensor.
5. The output is ON (closed).

6. An Analog Transmitter (e.g., pressure, level, or temperature).
7. The ability to achieve much longer sensing distances and detect non-metallic targets.

	Job Sheet 27
Qualification	Industrial Automation
Learning Unit	Identify Inductive Proximity Sensor
Trainee Name	
PPE	Safety shoes, safety goggles, hand gloves, anti-static wrist strap.
Tools & Equipment	Inductive proximity sensor, Connecting wires, 24V DC power supply, Multimeter, Metal target object, Mounting stand or fixture
Notes	An inductive proximity sensor detects metallic objects without physical contact. It operates based on the principle of electromagnetic induction, generating an electromagnetic field to sense the presence of conductive materials.
Procedure	1. Ensure all necessary PPE is worn before starting the task. 2. Collect the inductive proximity sensor, power supply, connecting wires, and metal target. 3. Connect the sensor to the 24V DC power supply according to the wiring diagram (brown to +V, blue to 0V, black as output). 4. Use a multimeter to check the output signal when a metallic target is brought near the sensing face. 5. Observe the LED indicator on the sensor (if available) to verify activation. 6. Measure the sensing distance and record your observation. 7. Disconnect the setup after testing is complete. 8. Return all tools and materials to their designated places.
Trainee's Signature	
Assessor's Signature	

QA Signature	
Assessor's Comment	

	Job Sheet 28
Qualification	Industrial Automation
Learning Unit	Identify Capacitive Proximity Sensor
Trainee Name	
PPE	Safety shoes, safety goggles, hand gloves, anti-static wrist strap.
Tools & Equipment	Capacitive proximity sensor, Connecting wires 24V DC power supply, Multimeter, Metallic and non-metallic target objects (e.g., plastic, wood, water, glass, metal), Mounting stand or fixture
Notes	A capacitive proximity sensor detects both metallic and non-metallic materials without physical contact. It operates based on the change in capacitance between the sensor and the target object. When an object enters the sensor's electric field, the capacitance changes, triggering the sensor output.
Procedure	1. Ensure all PPE is properly worn before starting the activity. 2. Collect the capacitive proximity sensor, power supply, wires, and target objects. 3. Connect the sensor to the 24V DC power supply (brown to +V, blue to 0V, black as output). 4. Verify proper power connection and ensure no loose wiring. 5. Bring different target materials (metal, plastic, wood, etc.) close to the sensor's sensing face. 6. Observe the LED indicator or check the output signal using a multimeter. 7. Note the sensing distance and sensitivity difference for each type of material.

	8. Adjust the sensitivity knob (if available) and observe changes in detection performance. 9. After testing, disconnect the setup safely and return all tools and components.
Trainee's Signature	
Assessor's Signature	
QA Signature	
Assessor's Comment	

	Job Sheet 29
Qualification	Industrial Automation
Learning Unit	Identify Magneto-Resistive Proximity Sensor
Trainee Name	
PPE	Safety shoes, safety goggles, hand gloves, anti-static wrist strap.
Tools & Equipment	• Magneto-resistive proximity sensor • Connecting wires • 24V DC power supply • Multimeter • Permanent magnet (target) • Mounting stand or fixture
Notes	A magneto-resistive proximity sensor detects the presence of magnetic fields generated by a permanent magnet or ferromagnetic object. It operates based on the magneto-resistive effect, where the electrical resistance of the sensor element changes when exposed to a magnetic field. These sensors are widely used in position sensing, rotational speed detection, and automation systems.
Procedure	1. Ensure all PPE is properly worn before beginning the task.

	2. Gather the magneto-resistive proximity sensor, power supply, magnet, and connecting wires. 3. Connect the sensor to the 24V DC power supply (brown to +V, blue to 0V, black as output). 4. Check all wiring connections for correctness and tightness. 5. Bring a permanent magnet slowly near the sensing face of the sensor. 6. Observe the LED indicator or use a multimeter to monitor the output signal change. 7. Gradually move the magnet away and note the sensing distance at which the output changes. 8. Repeat the test with magnets of different strengths or orientations if available. 9. Disconnect all connections safely after testing and store equipment properly.
Trainee's Signature	
Assessor's Signature	
QA Signature	
Assessor's Comment	

	Job Sheet 30
Qualification	Industrial Automation
Learning Unit	Identify Retro-Reflective Sensor
Trainee Name	
PPE	Safety shoes, safety goggles, hand gloves, anti-static wrist strap.
Tools & Equipment	• Retro-reflective photoelectric sensor • Reflector • Connecting wires

	• 24V DC power supply • Multimeter • Mounting stand or fixture • Target object (for testing interruption of beam)
Notes	A retro-reflective sensor is a type of photoelectric sensor that uses a single housing for both the emitter and receiver. The emitted light beam reflects back from a reflector, and the sensor detects any interruption of the beam caused by an object. It is widely used for object detection, counting, and positioning in industrial automation.
Procedure	1. Ensure all PPE is properly worn before starting the task. 2. Collect the retro-reflective sensor, reflector, power supply, and necessary wiring. 3. Mount the sensor and reflector so that the sensor's light beam directly faces the reflector. 4. Connect the sensor to the 24V DC power supply (brown to +V, blue to 0V, black as output). 5. Check proper alignment between sensor and reflector—adjust if needed for maximum signal strength. 6. Observe the indicator LED to verify that the beam is correctly received. 7. Place an object between the sensor and reflector to interrupt the beam. 8. Use a multimeter to monitor output signal changes when the beam is blocked and unblocked. 9. Record your observations of detection distance and response time. 10. After testing, disconnect all connections safely and return equipment to proper storage.
Trainee's Signature	
Assessor's Signature	

QA Signature	
Assessor's Comment	

	Job Sheet 31
Qualification	Industrial Automation
Learning Unit	Identify Fiber Optic Sensor
Trainee Name	
PPE	Safety shoes, safety goggles, hand gloves, anti-static wrist strap.
Tools & Equipment	• Fiber optic sensor amplifier unit • Fiber optic cable (transmitter and receiver) • 24V DC power supply • Connecting wires • Multimeter • Target objects (metallic and non-metallic) • Mounting stand or fixture
Notes	A fiber optic sensor uses light transmission through optical fibers to detect the presence, position, or movement of an object. The sensing head contains optical fibers that guide light from the emitter to the target and back to the receiver. These sensors are ideal for precise detection in small spaces, high-temperature areas, or environments with strong electromagnetic interference.
Procedure	1. Ensure all PPE is properly worn before beginning the experiment. 2. Collect the fiber optic sensor amplifier, fiber optic cable, power supply, and target objects. 3. Insert the fiber optic cables into the amplifier unit according to the manufacturer's instructions.

	4. Connect the amplifier to the 24V DC power supply (brown to +V, blue to 0V, black as output). 5. Verify that the power indicator on the amplifier turns on. 6. Adjust the sensitivity or gain control (if available) on the amplifier. 7. Place a target object in front of the fiber optic sensing head and observe the indicator LED response. 8. Use a multimeter to check output signal changes during detection. 9. Test with different target materials and distances, recording detection range and accuracy. 10. After testing, disconnect all equipment safely and store components properly.
Trainee's Signature	
Assessor's Signature	
QA Signature	
Assessor's Comment	

	Job Sheet 32
Qualification	Industrial Automation
Learning Unit	Identify Diffuse Sensor
Trainee Name	
PPE	Safety shoes, safety goggles, hand gloves, anti-static wrist strap.
Tools & Equipment	• Diffuse photoelectric sensor • Connecting wires • 24V DC power supply • Multimeter

	• Target objects (metallic and non-metallic surfaces with varying colors) • Mounting stand or fixture
Notes	A diffuse sensor is a type of photoelectric sensor that emits light toward a target. When the light hits the object, it reflects directly back to the sensor's receiver, which detects the presence of the object. Unlike retro-reflective or through-beam sensors, the object itself acts as the reflector. These sensors are ideal for short-range detection and are commonly used in automation for detecting items on conveyors or assembly lines.
Procedure	1. Ensure all PPE is properly worn before starting the experiment. 2. Collect the diffuse sensor, power supply, connecting wires, and target objects. 3. Mount the sensor securely on a stand with its sensing face directed toward the test area. 4. Connect the sensor to the 24V DC power supply (brown to +V, blue to 0V, black as output). 5. Verify proper power connection and ensure the indicator LED is functioning. 6. Place a target object within the sensor's sensing range. 7. Observe the indicator LED and/or use a multimeter to check for output signal changes. 8. Move the object closer and farther from the sensor to find the effective sensing distance. 9. Test with objects of different colors, materials, and surface finishes to note sensitivity variations. 10. Adjust the sensitivity knob (if available) for optimal performance. 11. Record all observations and detection results. 12. After completing the test, disconnect the setup and return all tools to their proper place.

Trainee's Signature	
Assessor's Signature	
QA Signature	
Assessor's Comment	

Learning Outcome 4.2 – Select Sensors based on Application and Material Properties



Content

- **Material Property Analysis:** Understand how the physical and chemical properties of target materials (e.g., metallic vs. non-metallic, liquid vs. solid, color, transparency, temperature) dictate sensor selection.
- **Sensor Selection Criteria:** Learn the technical specifications and decision factors, including sensing distance, response time, repeatability, environmental rating (IP rating), and cost, necessary to select the correct sensor.
- **Application Matching Techniques:** Study practical case studies to match sensor types (e.g., Inductive, Capacitive, Photoelectric, Ultrasonic) to specific tasks like position control, object counting, level detection, or part presence checking.



Assessment Criteria

- Correct Sensor Justification
- Parameter Verification
- Output Compatibility Check



Necessary Equipment

- Sensor Specification Catalogues/Datasheets
- Application Scenarios and Samples
- Target Material Samples
- Digital Multimeter (DMM) and Power Supply
- Selection Flowcharts/Decision Trees



Learning Activity 4.2-1

Learning Activity	Resources/ Instructions/ References
Select Sensors based on Application and Material Properties	• Information Sheet: 4.2-1 • Self-Check: 4.2-1 • Answer Paper: 4.2-1



Information Sheet 4.2-1

Learning Objective: The learner will be able to analyze a target material's properties and application requirements to correctly select the most suitable industrial sensor based on its specifications, operating principle, and output type.

Selection Criteria of Industrial Sensor

Selecting an industrial sensor requires a careful evaluation of the application's specific needs, the sensor's performance characteristics, and the operating environment. The wrong sensor can lead to inaccurate data, system failures, and unnecessary costs.

Application-Specific Criteria

The first step is to define the application's requirements.

- **Measured Quantity:** What physical property needs to be measured? (e.g., temperature, pressure, proximity, level, flow, etc.) The sensor must be designed for that specific purpose.
- **Measurement Range:** What are the minimum and maximum values of the quantity to be measured? The sensor's **dynamic range** must be sufficient to cover this span.
- **Target Characteristics:** What is the nature of the object or medium being sensed? Is it metallic, non-metallic, solid, liquid, or gas? This is crucial for selecting the right sensing technology, such as an inductive sensor for metal or a capacitive sensor for non-metallic materials.
- **Sensing Distance:** How far must the sensor be from the object to get a reliable reading? Proximity sensors, for example, have a specific operating range that must be considered.
- **Response Time:** How quickly must the sensor detect a change and provide an output? For high-speed applications, a fast **response time** is essential to ensure the control system can react in time.

Performance and Technical Criteria

These criteria relate to the sensor's internal capabilities and quality.

- **Accuracy and Precision:** **Accuracy** is how close a measurement is to the true value, while **precision** (or repeatability) is the ability to get the same measurement repeatedly under the same conditions. Depending on the application, one may be more critical than the other.
- **Resolution:** This is the smallest change in the measured quantity that the sensor can detect. A high-resolution sensor is necessary for applications requiring very subtle measurements.
- **Output Signal:** The output must be compatible with the control system. This involves choosing between an **analog** output (e.g., 4-20mA or 0-10V) for continuous measurements or a **digital** output (e.g., on/off) for simple presence detection.
- **Power Requirements:** The sensor must be compatible with the available power source. Some sensors require a specific voltage or current to function correctly.
- **Connectivity:** How will the sensor communicate with the control system? Options include hardwired connections, wireless protocols (Wi-Fi, Bluetooth), or industrial communication standards like IO-Link or EtherCAT.

Environmental and Physical Criteria

The sensor must be robust enough to operate reliably in its environment.

- **Operating Conditions:** What are the environmental conditions in which the sensor will be used? Factors like temperature, humidity, dust, dirt, and vibrations can affect performance. The sensor's **IP (Ingress Protection) rating** is a key indicator of its ability to withstand dust and moisture.
- **Physical Form Factor:** The size and shape of the sensor must fit within the available space. A wide range of housing styles (cylindrical, block, etc.) are available to suit different mounting needs.
- **Durability:** The sensor should be able to withstand physical shocks and vibrations common in industrial environments.
- **Cost and Maintenance:** While cost is a factor, it should be weighed against the sensor's long-term **reliability** and **lifespan**. A more expensive, durable sensor may offer a lower total cost of ownership than a cheap one that requires frequent replacement.

Inductive Analog Sensor

An **inductive analog sensor** is a type of non-contact sensor that uses an electromagnetic field to measure the distance to a metallic object and provides a continuous, proportional output signal. Unlike digital or "switching" inductive sensors that simply provide an on/off signal when a metal object is present, an analog version gives a variable output (e.g., a voltage or current) that directly corresponds to the object's proximity.



Fig: Inductive Analog Sensor

Working Principle

The working principle is based on electromagnetic induction and the concept of eddy currents.

1. **Electromagnetic Field Generation:** The sensor contains an internal coil and an oscillator circuit that generates a high-frequency alternating electromagnetic field from its sensing face.
2. **Eddy Current Induction:** When a metallic object enters this field, the magnetic field induces tiny circulating electrical currents, known as **eddy currents**, within the object.
3. **Energy Loss and Signal Change:** These eddy currents create their own magnetic field, which opposes the sensor's original field. This interaction causes a change in the impedance (the opposition to current flow) of the sensor's coil, which in turn reduces the amplitude of the oscillator's signal.

4. **Proportional Output:** The sensor's internal circuitry measures this change in signal amplitude. Because the strength of the eddy currents and the resulting signal loss are **proportional to the distance** of the metallic object, the sensor can provide a continuous output signal (e.g., a 0-10V or 4-20mA signal) that changes smoothly as the object moves closer or farther away.

Advantages & Applications

Analog inductive sensors are particularly useful in applications where simple presence/absence detection isn't enough, and precise distance measurement is required. Their robust, solid-state design allows them to operate reliably in harsh industrial environments with dust, dirt, and moisture.

Some common applications include:

- **Positioning and Alignment:** Precisely measuring the position of a robotic arm or a machine part for accurate assembly and quality control.
- **Dimensional Measurement:** Checking for slight variations in the thickness or height of metallic parts during manufacturing.
- **Monitoring and Control:** Regulating the distance between a tool and a workpiece in a machining process to ensure consistent results.

Inductive Proximity Sensor

An **inductive proximity sensor** is a non-contact, solid-state electronic device that detects the presence of metal objects. It operates by generating a high-frequency electromagnetic field and detecting changes in that field caused by the presence of a metal target.

Working Principle

1. **Oscillator Circuit:** An inductive sensor contains a coil of wire connected to an oscillator circuit. This circuit generates a continuous, alternating electromagnetic field that radiates from the sensor's face.
2. **Eddy Currents:** When a metal object enters this field, the alternating magnetic field induces tiny electrical currents, called **eddy currents**, in the object.
3. **Load on the Oscillator:** These eddy currents create their own magnetic field, which opposes the sensor's primary field. This opposition causes a loss of energy and a drop in the amplitude of the oscillator's signal.
4. **Signal Detection:** The sensor's internal circuitry, which includes a Schmitt trigger, continuously monitors the amplitude of the oscillation. When the amplitude drops below a predetermined threshold, the sensor's output is switched on, signaling the presence of a metal object.



Fig: Inductive Proximity Sensor

Advantages & Applications

- **Detection:** Inductive sensors can only detect **metallic objects**, including ferrous metals (like steel and iron) and non-ferrous metals (like aluminum and copper), though the sensing distance is shorter for non-ferrous materials.
- **Durability:** Since they are non-contact devices with no moving parts, they have a long operational life and are highly resistant to harsh industrial environments with dust, dirt, and moisture.

- **Switching Output:** Most inductive proximity sensors are "switching" or "digital" sensors, providing a simple on/off signal when an object is detected within their range. This makes them ideal for simple presence detection.

Common applications include:

- **Counting Parts:** Counting metal parts moving on a conveyor belt in a manufacturing line.
- **Positioning:** Verifying that a metal component is in the correct position for an assembly task.
- **Machine Control:** Acting as limit switches to detect the end of a stroke on a pneumatic or hydraulic cylinder.
- **Speed Detection:** Monitoring the rotation of a gear to calculate its speed.

Capacitive Proximity Sensor

A **capacitive proximity sensor** is a non-contact sensor that detects the presence or absence of both metallic and non-metallic objects. It works by using an electrostatic field rather than a magnetic one, which gives it a distinct advantage over inductive sensors for certain applications.

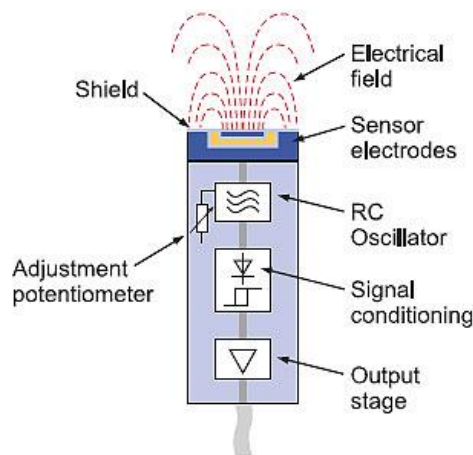


Fig: Capacitive Proximity Sensor

Working Principle

The operation of a capacitive sensor is based on the principle of **capacitance**. A sensor contains a high-frequency oscillator with two conductive plates that act as an open capacitor.

1. **Electrostatic Field:** The oscillator creates an electrostatic field that radiates from the sensor's sensing face.
2. **Capacitance Change:** The sensor's capacitance is determined by the properties of the material (typically air) in its electrostatic field. When an object, metallic or non-metallic, enters this field, it acts as a new dielectric material. This changes the overall capacitance of the circuit.
3. **Threshold Detection:** The sensor's internal circuitry continuously monitors this capacitance. When the change reaches a certain threshold, the sensor's output is triggered, signaling the presence of an object. The sensitivity of the sensor can often be adjusted to detect objects at different distances or with varying material properties.

Advantages & Applications

Capacitive proximity sensors are known for their versatility and are widely used in industrial automation.

- **Versatile Detection:** Unlike inductive sensors, capacitive sensors can detect a wide range of materials, including plastics, wood, paper, glass, liquids, and powders, in addition to metals.
- **Level Sensing:** They are often used for **liquid level detection** and are capable of sensing a liquid through a non-metallic tank wall.
- **High Sensitivity:** The sensors can detect lightweight or small objects that might be missed by mechanical limit switches.
- **Non-Contact Operation:** Because they are non-contact devices, they have a long operational life and are not susceptible to wear and tear.

Common applications include:

- **Bottle and Container Counting:** Detecting the presence of non-metallic bottles on a conveyor belt.
- **Liquid Level Control:** Monitoring the fill level in a tank and signaling when to start or stop a pump.
- **Powder and Granule Detection:** Sensing the level of materials like grains, sand, or plastic pellets in a hopper.

Magneto–Resistive Proximity Sensor

A **magneto-resistive proximity sensor** is a type of magnetic sensor that detects the presence of a permanent magnet by measuring changes in electrical resistance. It operates on the **magneto-resistive effect**, where the electrical resistance of a material changes when it is exposed to an external magnetic field.



Fig: Magneto–Resistive Proximity Sensor

Working Principle

1. **Magneto-resistive Element:** The sensor contains a sensing element made from a special ferromagnetic material, such as nickel-iron (Permalloy). The resistance of this material is very sensitive to the direction and strength of an applied magnetic field.
2. **External Magnet:** A separate, permanent magnet is attached to the target object being detected.

3. **Resistance Change:** As the magnet on the target object moves closer to the sensor, its magnetic field influences the sensor's internal magneto-resistive element. This causes a change in the element's electrical resistance.
4. **Signal Output:** The change in resistance is measured by internal circuitry, typically a **Wheatstone bridge**, which converts the resistance change into a voltage signal. This signal is then processed to provide a digital (on/off) or analog (proportional to distance) output, indicating the presence or position of the magnet.

Advantages & Applications

Magneto-resistive sensors offer significant advantages over other types of proximity sensors, particularly in applications requiring a long sensing range and a small form factor.

- **Long Sensing Range:** They are highly sensitive to even weak magnetic fields, allowing them to detect a magnet from a much greater distance (up to 70mm) than inductive or Hall effect sensors.
- **Detection Through Non-Metallic Materials:** Since magnetic fields can penetrate non-ferrous materials, these sensors can reliably detect a magnet through plastic, wood, aluminum, or stainless steel walls, which is a major benefit for level detection and other similar applications.
- **High Sensitivity:** Magneto-resistive sensors are more sensitive than Hall effect sensors, which allows for more accurate and repeatable measurements.
- **No Mechanical Wear:** As non-contact sensors with no moving parts, they are robust, durable, and maintenance-free.

Common applications include:

- **Cylinder Position Detection:** Detecting the position of a piston carrying a magnet inside a pneumatic or hydraulic cylinder from the outside.
- **Level Sensing:** Monitoring the level of a liquid in a non-metallic tank using a floating magnet.
- **Door and Gate Security:** Detecting the open or closed status of a door or gate.

- **Rotary Position Sensing:** Counting revolutions or determining the angular position of a rotating shaft with a magnet attached.

Retro-Reflective Sensor

A **retro-reflective sensor** is a type of photoelectric sensor that uses the interruption of a reflected light beam to detect objects. Both the light emitter and the receiver are housed together in a single unit. To function, it requires a separate reflector to be mounted on the opposite side of the detection path.



Fig: Retro-Reflective Sensor

Working Principle

1. **Light Emission:** The sensor's emitter sends out a concentrated beam of light, typically infrared or visible red light.
2. **Retroreflection:** The light beam travels across the detection zone and hits a special **retro-reflector** mounted opposite the sensor. Unlike a normal mirror, a retro-reflector (often using "corner cubes" or similar structures) reflects the light directly back along its original path, regardless of the angle of incidence. This ensures the light returns directly to the sensor's receiver.

3. **Beam Interruption:** When an object passes through the light beam, it interrupts the path between the sensor and the reflector. The receiver in the sensor no longer receives the light, causing its output to switch on, thereby signaling the presence of an object.
4. **Polarized Version:** A common issue with standard retro-reflective sensors is that a shiny object might reflect the light back to the sensor, causing a false detection. To prevent this, **polarized retro-reflective sensors** use a polarization filter on both the emitter and receiver. The reflector rotates the light's polarization by 90 degrees, ensuring that only light from the intended reflector is detected. Light reflected directly from a shiny object does not have this rotation, so it is filtered out by the receiver.

Advantages & Applications

- **Simple Wiring:** Since the emitter and receiver are in a single housing, only one side of the detection path needs to be wired for power and signal.
- **Longer Range:** Retro-reflective sensors have a longer sensing range than diffuse sensors because the light beam is highly concentrated and consistently returns to the receiver.
- **Object Detection:** They can reliably detect most opaque objects, regardless of their color, reflectivity, or surface texture. Polarized versions are also excellent for detecting shiny objects.
- **Transparent Object Detection:** Some specialized retro-reflective sensors are designed with a very sensitive receiver to detect small changes in light, making them suitable for sensing transparent objects like glass or plastic bottles.

Fiber Optic Sensor

A fiber optic sensor uses a fiber optic cable as the sensing element to measure physical quantities. Unlike traditional electronic sensors that use electrical signals, these sensors use the properties of light to detect changes in the environment.



Fig 5.11 Fiber Optic Sensor

Working Principle

At the core of a fiber optic sensor is the principle of **total internal reflection**, which is also the basis for fiber optic communication. Light travels down the core of a very thin glass or plastic fiber. The core is surrounded by a cladding material with a lower refractive index. When light hits the boundary between the core and the cladding at a specific angle, it is reflected back into the core, allowing it to travel over long distances with minimal loss.

A fiber optic sensor detects a physical parameter by measuring how that parameter alters the properties of the light propagating through the fiber. A light source (like a laser or LED) transmits light into the fiber, and a detector measures the light at the other end.

Types and Principles

Fiber optic sensors are broadly categorized into two main types based on where the sensing takes place:

- **Extrinsic Sensors:** In this type, the optical fiber acts as a **light guide**, simply transmitting light to and from an external sensing element. The physical measurement happens outside

the fiber. The external element, which could be a tiny mirror or a diaphragm, changes the light in response to a stimulus (like pressure or displacement), and the fiber carries this modulated light back to a detector.

- **Intrinsic Sensors:** In this type, the optical fiber itself is the **sensing element**. A physical perturbation, such as temperature or strain, directly changes the characteristics of the light traveling within the fiber. This change is then measured at the detector.

Based on how the light is modulated, intrinsic sensors can be further classified by principle:

- **Intensity-Based:** Measures changes in the light's intensity. For example, bending the fiber can cause light to leak out of the core, reducing the intensity of the light reaching the detector.
- **Wavelength-Based:** Measures changes in the light's wavelength. A common example is a **Fiber Bragg Grating (FBG)** sensor, where a section of the fiber has a periodic change in its refractive index. When strain or temperature changes, the spacing of the grating shifts, causing a corresponding change in the reflected wavelength.
- **Phase-Based:** Measures changes in the light's phase. These are often used for highly sensitive measurements of acoustic waves or vibrations.

Advantages

Fiber optic sensors offer several key advantages over traditional electronic sensors:

- **Immunity to EMI:** They are immune to electromagnetic and radio frequency interference because they don't use electrical signals. This makes them ideal for use in harsh electrical environments, such as power plants or near high-voltage lines.
- **High Temperature and Pressure Resistance:** They can be used in extreme temperatures and pressures where conventional electronic sensors would fail.
- **Safety:** They are intrinsically safe in explosive or flammable environments as they do not generate sparks or conduct electricity.
- **Small Size and Lightweight:** Their small form factor allows them to be used in tight spaces, and their light weight is an advantage in applications like aerospace.

Diffuse Sensor

A **diffuse sensor**, also known as a diffuse-reflective sensor, is a type of photoelectric sensor that uses the reflection of a light beam off a target object to detect its presence. Unlike other photoelectric sensors, it does not require a separate receiver or a reflector.

Working Principle

The diffuse sensor operates on a very simple principle where the target object acts as the reflector.

1. **Emitter and Receiver in One:** The sensor's housing contains both a light emitter (typically an LED or a laser) and a receiver (a photodiode or phototransistor).
2. **Light Emission:** The emitter sends out a continuous beam of light.
3. **Diffuse Reflection:** When an object enters the sensor's range, the light beam strikes its surface. This light is then **diffusely reflected**, meaning it scatters in all directions, as opposed to a single, focused reflection like a mirror.
4. **Signal Detection:** A small portion of this scattered light returns to the sensor's receiver. If the intensity of the returning light is above a pre-set threshold, the sensor's output is triggered, indicating the presence of an object.

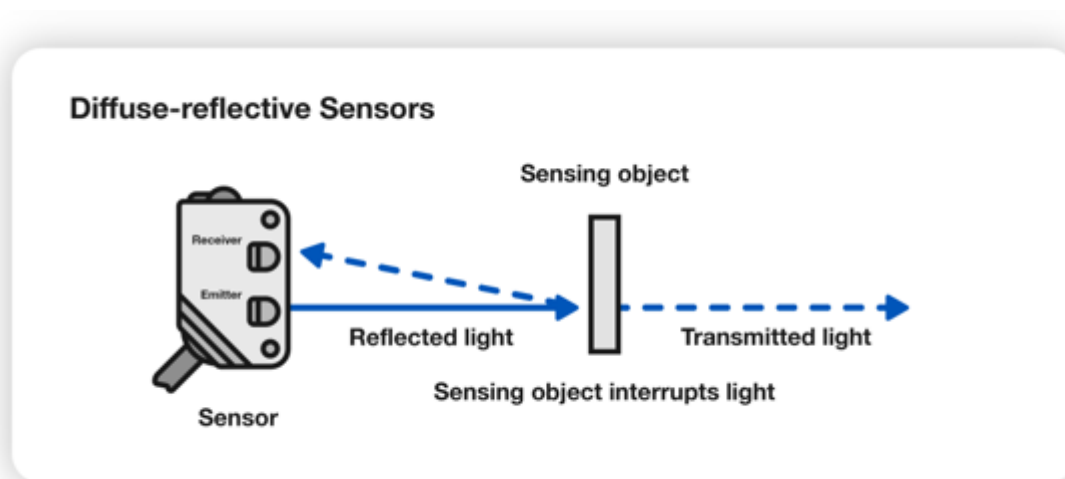


Fig: Diffuse Sensor

The sensing range of a diffuse sensor is highly dependent on the object's surface properties, color, and texture. A white or shiny object will reflect more light and be detected at a greater distance than a dark or matte object.

Advantages & Applications

- **Easy Installation:** Since the emitter and receiver are in a single unit, there is only one device to mount and wire, making installation quick and simple.
- **Versatility:** Diffuse sensors can detect a wide range of materials, including opaque objects of varying colors and textures.
- **Background Suppression:** Advanced diffuse sensors may include **background suppression** technology, which allows them to ignore objects or surfaces behind the target object, making detection more reliable. This is particularly useful in applications where a reflective background could cause false readings.

Common applications include:

- **Object Counting:** Counting products on a conveyor belt.
- **Presence Detection:** Confirming that a part is in the correct position for a robotic arm to pick up.
- **Level Sensing:** Detecting the level of opaque materials in a hopper.

Thermocouple

A **thermocouple** is a sensor used to measure temperature. It consists of two dissimilar metals joined together at one end. When this junction is heated or cooled, it generates a voltage that is proportional to the temperature difference between the hot junction and a reference junction (usually the connection point to the measuring device). This phenomenon is known as the **Seebeck effect**.

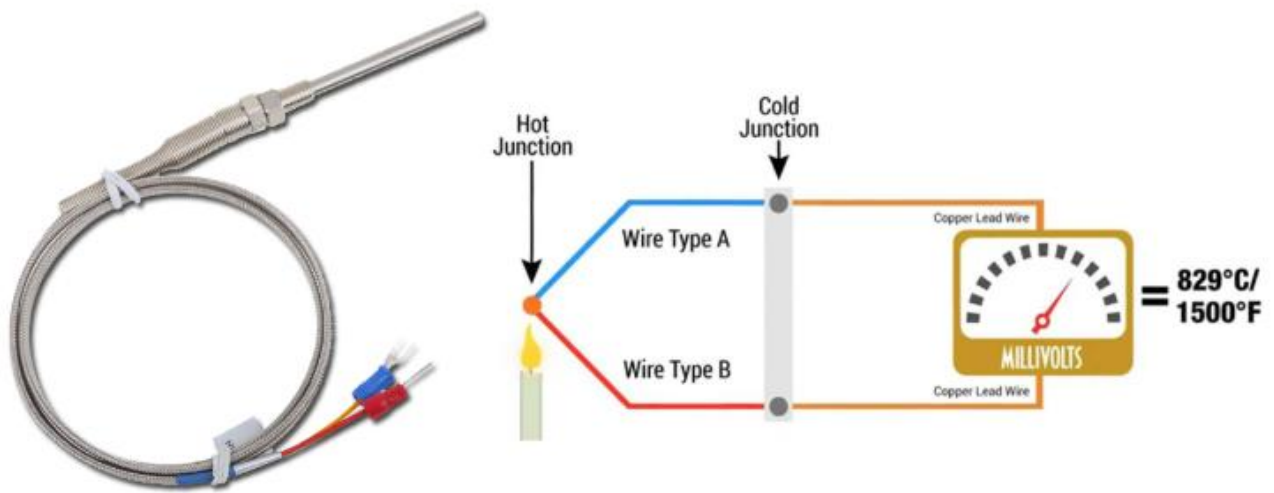


Fig: Thermocouple & Working Principle

Working Principle

1. **Seebeck Effect:** When two different metals are joined to form a circuit and their junctions are held at different temperatures, a net voltage is produced. The magnitude of this voltage depends on the types of metals used and the temperature difference between the two junctions.
2. **Junctions:** A basic thermocouple setup has two junctions:
 - **Hot Junction (Measuring Junction):** This is the point where the two dissimilar metals are welded together and is placed at the location where the temperature is to be measured.
 - **Cold Junction (Reference Junction):** This is the point where the thermocouple wires connect to the measurement instrument. To accurately determine the temperature at the hot junction, the temperature of this cold junction must be known and compensated for by the instrument's circuitry.
3. **Voltage Measurement:** The voltage generated by the thermocouple is very small (in the millivolt range). A voltmeter or a specialized temperature controller measures this voltage.

4. **Temperature Conversion:** The measured voltage is then converted into a temperature reading using a **thermocouple reference table** or a mathematical formula specific to the metal types.

Types & Applications

Thermocouples are classified into different **types** (e.g., J, K, T, E, N, R, S, B) based on the metal combinations used. Each type has a unique temperature range, sensitivity, and operating environment.

- **Type K (Chromel-Alumel):** This is the most common type due to its wide temperature range (-200 to 1,350°C) and low cost. It is widely used in industrial applications, kilns, and furnaces.
- **Type T (Copper-Constantan):** Ideal for low-temperature measurements (-200 to 350°C), making it suitable for cryogenics and food processing.
- **Type S (Platinum-Rhodium):** Used for extremely high-temperature applications (up to 1,600°C) and in calibration standards due to its high stability.

Common applications of thermocouples include:

- **Industrial Process Control:** Monitoring and controlling temperatures in manufacturing, chemical, and refining processes.
- **HVAC Systems:** Measuring temperatures in heating, ventilation, and air conditioning systems.
- **Ovens and Furnaces:** Regulating temperatures in high-temperature environments.

Resistive Temperature Detector (RTD)

A **Resistive Temperature Detector (RTD)** is a sensor that measures temperature by correlating the change in its electrical resistance with a change in temperature. It is a highly accurate and stable temperature sensor, widely used in industrial and scientific applications.

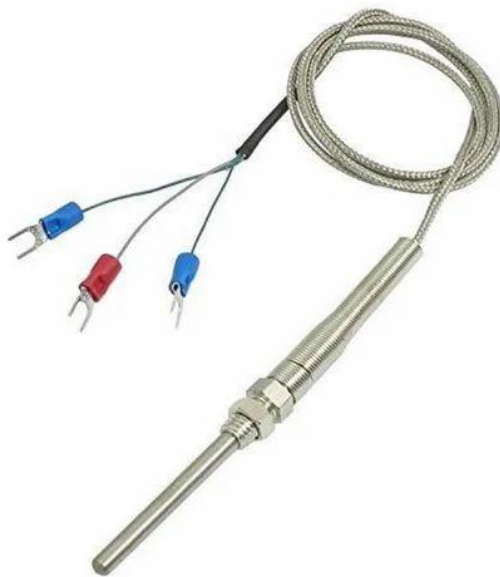


Fig: RTD

Working Principle

The working principle of an RTD is based on the **positive temperature coefficient** of certain metals. This means that as the temperature of the metal increases, its electrical resistance also increases in a predictable and linear manner.

1. **Sensing Element:** The core of an RTD is a resistive element, usually made from a pure metal like **platinum (Pt)**, nickel, or copper, wound into a coil or deposited as a thin film. Platinum is the most common choice due to its chemical inertness, high melting point, and a highly linear and repeatable resistance-to-temperature relationship.
2. **Resistance Change:** When the RTD is exposed to a temperature change, the atoms within the metal lattice vibrate more vigorously, which impedes the flow of electrons and causes an increase in resistance.
3. **Measurement Circuit:** To measure this resistance change accurately, the RTD is typically connected to a **Wheatstone bridge** circuit. This circuit measures the resistance of the RTD element by passing a small, known current through it and measuring the resulting voltage drop.

4. **Temperature Conversion:** The measured resistance value is then converted into a temperature reading using a standard curve or an equation, such as the **Callendar-Van Dusen equation**, which precisely defines the relationship between resistance and temperature for a specific RTD material (e.g., Pt100).

Types & Key Features

RTDs are classified by the material and their resistance at 0°C. The most common is the **Pt100 RTD**, which has a resistance of 100 ohms at 0°C.

- **Accuracy and Repeatability:** RTDs are known for their high accuracy and long-term stability. They offer more precise measurements than thermocouples.
- **Linearity:** The relationship between temperature and resistance is highly linear, which simplifies the signal processing and conversion to a temperature value.
- **Operating Range:** While generally having a narrower temperature range than thermocouples, they are suitable for a wide variety of applications, typically from -200°C to 850°C.
- **Wiring Configurations:** RTDs can be connected in 2-wire, 3-wire, or 4-wire configurations. The 3-wire and 4-wire setups are used to compensate for the resistance of the lead wires, which can otherwise introduce measurement errors, especially over long distances.

Comparison between RTD and Thermocouple

When comparing RTDs and thermocouples, the choice depends on the specific requirements of the application, as each sensor type has distinct advantages and disadvantages. The primary differences lie in their operating principles, accuracy, temperature range, and cost.

Operating Principles

- **RTD (Resistive Temperature Detector):** An RTD is a **passive sensor** that measures temperature based on the principle that the electrical resistance of a pure metal, like platinum, changes predictably with temperature. An external current is required to measure this resistance change.
- **Thermocouple:** A thermocouple is an **active sensor** that generates a voltage based on the **Seebeck effect**, where a voltage is produced at the junction of two dissimilar metals when a temperature difference exists. No external power is required for the thermocouple itself to produce a signal, but cold-junction compensation is necessary for accurate readings.

Feature	RTD (Resistance Temperature Detector)	Thermocouple
Accuracy	Generally more accurate and repeatable. Typical accuracy is around $\pm 0.1^{\circ}\text{C}$.	Generally less accurate . Typical accuracy is around $\pm 1^{\circ}\text{C}$ for most types.
Temperature Range	Limited range, typically from -200°C to 600°C .	Wide range, from -200°C to over 2300°C , depending on the type.
Stability	Excellent long-term stability with minimal drift over time.	Prone to drift over time due to chemical changes and environmental exposure.
Linearity	Highly linear output, making signal conversion and processing simpler.	Non-linear output, which requires more complex compensation or look-up tables.
Response Time	Slower due to a larger sensing element and thermal mass.	Faster response time, especially for exposed-tip models.
Cost	More expensive due to the use of platinum and more complex construction.	Less expensive and a good choice for budget-conscious projects.
Durability	More fragile and susceptible to shock and vibration.	Rugged and can withstand harsh, high-vibration environments.

Fig: Performance Comparison between RTD & Thermocouple



Self-Check 4.2-1

1. Which type of sensor is the most appropriate and reliable choice for non-contact detection of a small, fast-moving aluminum block at a very short range?

2. Which sensor technology is best suited for the non-contact detection of the high level of water inside a thick-walled non-metallic (plastic) tank?
3. For reliably detecting a large opaque object, like a shipping box, over an extremely long distance (e.g., 10 meters), which photoelectric sensing mode is the best choice?
4. To continuously monitor the level of grain in a storage hopper, requiring a real-time signal proportional to the height, what type of sensor output is necessary?
5. Which photoelectric sensing mode is most likely to fail due to variability when attempting to detect a highly reflective, polished metal surface?
6. Which sensor technology is generally the most suitable choice for applications operating in environments consistently filled with heavy dust and airborne particles?
7. What specialized component or method is required for a Retro-reflective sensor to reliably detect the presence of a challenging target like a clear glass bottle?



Answer Paper 4.2-1

1. Inductive Proximity Sensor.
2. Capacitive Proximity Sensor.
3. Photoelectric Through-Beam Sensor (due to its longest sensing range).
4. Analog Output (e.g., 4–20mA or 0–10V).
5. Photoelectric Diffuse-Reflective Sensor.
6. Ultrasonic Sensor (as sound waves are less affected by dust than light).
7. A polarization filter and reflector (to reject the light reflected directly off the shiny or transparent surface).

Learning Outcome 4.3 – Identify types of Industrial Actuators and Classifications



Content

- **Actuator Operating Principles:** Understand the fundamental energy sources and conversion methods used by industrial actuators, focusing on electrical (motors, solenoids), pneumatic (air pressure), and hydraulic (fluid pressure) systems.
- **Classification by Motion and Type:** Learn to classify actuators based on the type of motion they produce (linear vs. rotary) and their core technology (e.g., solenoids, cylinders, valves, electric motors).
- **Control and Feedback Mechanisms:** Identify how actuators are controlled (e.g., ON/OFF, proportional, servo) and the role of feedback devices (e.g., encoders, potentiometers, limit switches) in achieving precise positioning.



Assessment Criteria

- Accurate Identification and Description
- Classification Accuracy
- Application Suitability



Necessary Equipment

- Variety of Actuator Samples
- Actuator Documentation
- Control Manifolds/Valves
- Power Supply and Regulator
- Measuring Tools



Learning Activity 4.3-1

Learning Activity	Resources/ Instructions/ References
Identify types of Industrial Actuators and Classifications	• Information Sheet: 4.3-1 • Self-Check: 4.3-1 • Answer Paper: 4.3-1



Information Sheet 4.3-1

Learning Objective: The learner will be able to identify the operating principles, primary power sources, and type of motion for various common industrial actuators and classify them according to their function and technology.

Actuators

An actuator is a device that converts a control signal into a physical output, such as motion or force. It's an essential component in any automated system, acting as the "muscle" that performs a task based on instructions from a controller.

Role of Actuators in Automation, Process Control, and Data Acquisition

Actuators are the "muscles" of an automated system, converting a control signal into a physical action. They are the final components in a control loop, executing the commands sent by a controller based on information from sensors.

✓ **Automation:** In automation, actuators are responsible for performing tasks that were once done manually. They provide controlled movement, force, and position, enabling machines to operate

without continuous human intervention. For example, a robotic arm uses electric actuators to move precisely, and a solenoid valve uses an electromagnetic actuator to open and close, allowing a filling machine to dispense a liquid.

- ✓ **Process Control:** Actuators are critical for maintaining a process at a desired setpoint. A classic example is a temperature control system where a sensor detects the temperature and sends data to a controller. The controller then commands an **actuator** to open or close a valve, adjusting the flow of a cooling or heating fluid to maintain the temperature within a specified range. This closed-loop feedback system is essential in industries like chemical manufacturing, food processing, and power generation.
- ✓ **Data Acquisition:** While actuators don't directly collect data like sensors do, their status can be a crucial part of a data acquisition system. Modern "smart" actuators can provide feedback on their position, speed, or force. This data can be logged to monitor a process's performance, diagnose potential failures, and ensure that the actuator is performing its task correctly. For instance, a data acquisition system might record the position of an actuator to verify that a valve has fully opened or closed, which is vital for process safety and quality control.

A Brief History of Actuator Development

The history of actuators is closely tied to the history of automation and the Industrial Revolution.

- ✓ **Early Mechanical Actuators (Pre-19th Century):** Early forms of actuators were simple mechanical devices. Waterwheels and windmills, for instance, were a primitive form of actuator that converted the energy of water or wind into a rotary motion to grind grain or pump water. The steam engine, with its piston and cylinder, was a more sophisticated early actuator that converted thermal energy into linear motion, laying the groundwork for later fluid power systems.
- ✓ **The Rise of Fluid Power (19th and Early 20th Centuries):** The development of compressed air and hydraulics marked a major turning point. Pneumatic actuators, which use compressed air to generate linear or rotary motion, emerged in the 19th century and became widespread in industrial applications after World War II. They were simple, reliable, and powerful. Hydraulic

actuators, which use an incompressible fluid to generate immense force, also became a staple in heavy-duty machinery.

- ✓ **The Electrical and Electronic Revolution (Mid-20th Century):** The introduction of electric motors led to the development of the **electric actuator**. Unlike their fluid counterparts, electric actuators offered precise control over position, speed, and torque. The 1970s and 1980s saw the widespread adoption of microprocessors and PLCs, allowing for the creation of smart actuators with integrated electronics for advanced control and feedback. This period marked the beginning of actuators' seamless integration with digital control systems.
- ✓ **Modern and "Smart" Actuators (21st Century):** Today's actuators are highly advanced, intelligent devices. The development of **electromechanical actuators** that combine the power of electric motors with sophisticated mechanical drive systems has made them indispensable in robotics and automation. The advent of the **Internet of Things (IoT)** and industrial networking has led to "smart actuators" that can communicate wirelessly, perform self-diagnostics, and adapt to changing conditions in real time, making them a crucial part of the modern interconnected factory.

Principle of Actuator Operation

An actuator is a mechanical device that converts energy from a source into mechanical motion. It operates on the core principle of energy conversion. An actuator takes an input of electrical, hydraulic (fluid), or pneumatic (air) energy and translates it into a controlled output of physical motion, which can be either **linear** (straight-line) or **rotary** (rotational).

Here's a breakdown of the principle of operation for the three main types of actuators:

Electric Actuators

Electric actuators use an electric motor to generate motion. The motor's rotational force is typically converted into linear motion via a mechanical system such as a lead screw, ball screw, or gear system. A control signal, often an electrical current, tells the motor when and how to move. These actuators are known for their precision, quiet operation, and energy efficiency.



Fig: Electric Valve Actuator

Hydraulic Actuators

Hydraulic actuators utilize the pressure of an incompressible fluid (usually oil) to create motion. When pressurized fluid is pumped into a cylinder, it pushes a piston, generating a powerful linear force. For rotary motion, hydraulic fluid can drive a hydraulic motor. Because hydraulic fluid is nearly incompressible, these actuators can generate very high forces and are used for heavy-duty applications.

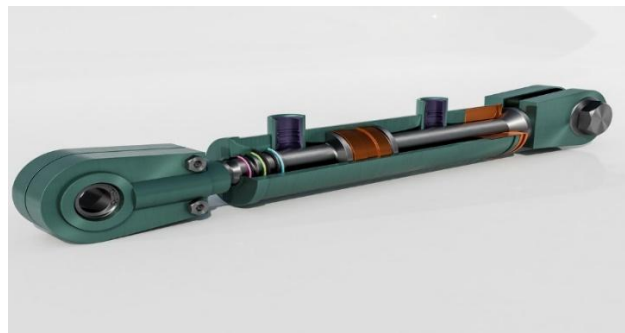


Fig: Hydraulic Actuator

Pneumatic Actuators

Pneumatic actuators operate using compressed air. Similar to hydraulic actuators, compressed air is directed into a cylinder to move a piston, or to a rotary vane to produce a turning motion. They are often chosen for applications requiring fast, rapid movements and are popular in industrial settings where a supply of compressed air is readily available.

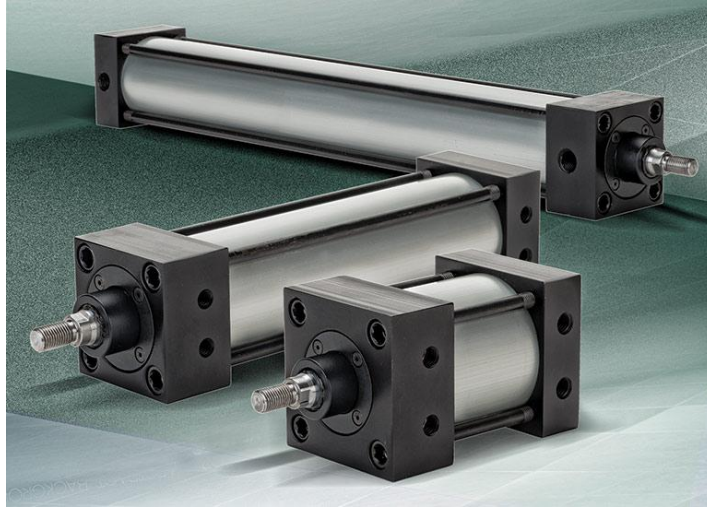


Fig 5.18 Pneumatic Actuator

The choice of actuator type depends on the specific requirements of an application, including the amount of force needed, the desired speed, and the precision required.

Classification of Industrial Actuator: By Power Source

Industrial actuators are classified by their power source into three primary categories: electric, hydraulic, and pneumatic. There are also less common types that use other power source

Electric Actuators

These actuators use electrical energy to generate motion. They can be powered by AC or DC motors and are commonly found in applications that require precise control, such as robotics and automation systems.

- **Key Characteristics:**
 - **Power Source:** Electricity.
 - **Advantages:** High precision, low maintenance, quiet operation, and easy to integrate with digital control systems.

- **Disadvantages:** Can be limited in force output compared to hydraulic systems and may be more prone to overheating under heavy, continuous loads.

Hydraulic Actuators

Hydraulic actuators convert the energy of pressurized fluid (typically oil) into mechanical motion. This makes them ideal for heavy-duty applications.

- **Key Characteristics:**

- **Power Source:** Pressurized fluid.
- **Advantages:** Can generate immense force and torque, are very durable, and are capable of holding a high load in place without additional energy input.
- **Disadvantages:** Requires a more complex system of pumps and reservoirs, can be prone to leaks, and are generally messier and more difficult to maintain than other types.

Pneumatic Actuators

Pneumatic actuators use compressed air to generate force. They are known for their simplicity and fast response times.

- **Key Characteristics:**

- **Power Source:** Compressed air.
- **Advantages:** Simple design, cost-effective, operate at high speeds, and are generally safe to use in hazardous environments as they do not involve electricity or flammable fluids.
- **Disadvantages:** The compressed air they rely on can be noisy and less precise than electric or hydraulic systems. They also have a lower force capacity compared to hydraulic actuators.

Other Actuator Types

In addition to the main three, other actuators are used for specialized applications:

- **Thermal Actuators:** These use thermal energy to produce motion, often relying on materials that expand or contract with temperature changes.
- **Mechanical Actuators:** These convert rotary motion into linear motion using a physical mechanism like a lead screw, gears, or cams.
- **Piezoelectric Actuators:** These use piezoelectric materials that change shape in response to an electrical field, making them suitable for micro-scale and high-precision positioning.

Classification of Industrial Actuator: By Motion Type

Industrial actuators are classified by the type of motion they produce into two main categories: **linear actuators** and **rotary actuators**. This classification is independent of the actuator's power source (e.g., electric, hydraulic, or pneumatic).

Linear Actuators

Linear actuators produce a straight-line, or back-and-forth, motion. They're designed for applications that require pushing, pulling, lifting, lowering, or clamping. The motion can be either extending or retracting.



Fig: Linear Actuator

- **Working Principle:** Linear actuators often convert a rotary input from a motor into linear movement using a mechanical system like a lead screw, ball screw, or rack and pinion.
- **Common Applications:**
 - Opening and closing valves and gates
 - Positioning components in assembly lines
 - Lifting and tilting machinery components
 - Operating hospital beds and patient lifts

Rotary Actuators

Rotary actuators produce rotational or circular motion. They are used for applications that require turning, twisting, or rotating an object around a fixed axis. The motion can be either a full 360-degree rotation or a limited angle.

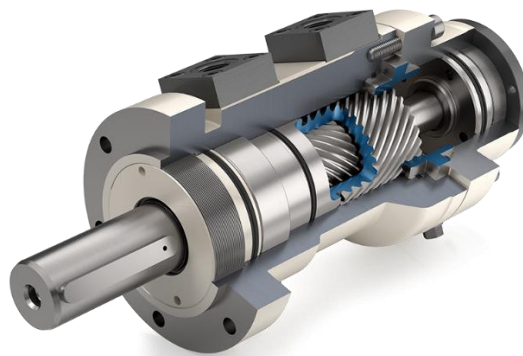


Fig: Rotary Actuator

- **Working Principle:** Rotary actuators are essentially motors or cylinders that are designed to produce a torque (rotational force) at their output shaft.
- **Common Applications:**
 - Operating ball valves and butterfly valves
 - Controlling robotic arms

- Rotating conveyor belts
- Adjusting the angle of solar panels



Self-Check 4.3-1

1. Which electrical actuator converts electrical energy directly into a mechanical rotary motion to drive a load?
2. An actuator system that generates high force or torque using pressurized liquid (typically oil) is categorized as what type of system?
3. In a pneumatic system, what is the primary function classification of a solenoid valve?
4. What is the key advantage of using a pneumatic cylinder as an actuator compared to a simple electric solenoid?
5. Why is a Proportional Control Valve classified as an actuator in a control system?
6. What is the primary role of a Variable Frequency Drive (VFD) when controlling an AC motor?
7. Why are actuators often referred to as the final control elements in a closed-loop system?



Answer Paper 4.3-1

1. The AC Induction Motor.
2. A Hydraulic system.
3. A Directional Control Valve.
4. The ability to achieve adjustable, much longer linear stroke distances (unlike a limited-stroke solenoid pusher).
5. It is commanded by the PLC to modulate (smoothly change) the flow rate of the fluid based on an analog input signal.

6. To adjust the motor's speed and torque by changing the frequency and voltage of the power supplied to the motor.
7. Because they are the last device in the control loop that converts the PLC's electrical output command into a physical action on the process.

Learning Outcome 4.4 – Execute Sensors and Actuators for Industrial Application



Content

- I/O Wiring and Interfacing: Learn the correct electrical and electronic methods for interfacing various sensor outputs (e.g., PNP/NPN, analog current/voltage) and actuator inputs (e.g., solenoid coils, motor contactors) to the PLC or control system.
- Control Loop Implementation: Understand how to integrate sensors (inputs) and actuators (outputs) into a basic control loop, focusing on ON/OFF control logic and sequencing for tasks like counting or filling.
- Calibration and Testing: Practice calibrating analog sensors (e.g., scaling 4-20mA to engineering units) and performing functional testing on actuators to verify correct operation and movement speed/force.



Assessment Criteria

- Functional System Operation
- Wiring and Connection Quality
- Parameter Tuning and Adjustment



Necessary Equipment

- PLC Control System
- Industrial Sensors
- Industrial Actuators
- Digital Multimeter (DMM)
- Connecting Wires and Tools



Learning Activity 4.4-1

Learning Activity	Resources/ Instructions/ References
Execute Sensors and Actuators for Industrial Application	• Information Sheet: 4.4-1 • Self-Check: 4.4-1 • Answer Paper: 4.4-1 • Job Sheet 33



Information Sheet 4.4-1

Learning Objective: The learner will be able to correctly interface and program PLC I/O with industrial sensors and actuators to reliably execute basic control loops and sequences for a given application.

Sensor Execution: Placement, and Signal Conditioning

Placement Strategy

Optimal sensor placement is crucial for obtaining representative and accurate data.

- **Accessibility:** Easy access for calibration, maintenance, and replacement.
- **Process Interaction:** Position the sensor where it is directly exposed to the variable being measured, minimizing lag or interference. For example, a flow sensor must be placed in a straight pipe run to avoid turbulence.
- **Interference Mitigation:** Locate sensors away from strong electromagnetic fields, heat sources, and heavy vibration that could introduce noise or cause damage.

Signal Conditioning

The raw electrical output from a sensor often needs processing before it is usable by a controller. This is signal conditioning.

- **Amplification:** Boosting a weak signal (e.g., from a thermocouple) to a usable level.
- **Filtering:** Removing unwanted noise or high-frequency interference.
- **Linearization:** Correcting non-linear sensor responses (e.g., a resistance temperature detector, RTD) to provide a linear output proportional to the physical variable.
- **Conversion:** Converting an analog signal to a digital one (A/D Conversion) for use in digital control systems.

Actuator Execution: Sizing, and Interface

Sizing and Power Requirements

Proper sizing is essential for actuator longevity and process efficiency. An undersized actuator may fail prematurely or lack the necessary force/torque/speed, leading to poor process control. An oversized actuator wastes energy and increases cost.

- **Motors:** Calculated based on the required torque, speed, and inertia of the load. Account for duty cycle and service factor.
- **Valves:** Sized using the flow coefficient (C_v) and the maximum required pressure drop across the valve.
- **Pneumatics/Hydraulics:** Sizing cylinders involves calculating the required force and selecting the appropriate piston diameter and operating pressure.

Control and Interfacing

Actuators require a robust interface with the control system.

- **Control Signals:** Typically 4–20 mA or 0–10 V for proportional control (e.g., adjusting the position of a control valve) or digital ON/OFF signals for discrete actions (e.g., starting a motor).
- **Motor Drives:** Variable Frequency Drives (VFDs) or Servo Drives are used to control the speed, torque, and position of electric motors with high precision.
- **Power Circuitry:** Includes motor starters, relays, and fuses/breakers to handle the high current requirements and provide protection.

Summary of Execution Success Factors

Successful deployment of sensors and actuators in industrial applications depends on a holistic approach encompassing:

1. **Correct Specification:** Matching component capabilities (range, accuracy, speed) to process requirements.

2. **Robust Installation:** Ensuring proper placement, environmental protection (IP rating), and noise mitigation (shielding).
3. **Seamless Integration:** Ensuring electrical and communication compatibility with the central control system (PLC/DCS).
4. **Effective Maintenance:** Implementing a strategy for calibration and condition monitoring to ensure long-term reliability and precision.



Self-Check 4.4-1

1. When wiring a PNP (Sourcing) type proximity sensor to a PLC digital input module, to which terminal must the PLC input common terminal be wired?
2. In ladder logic, to what memory address must the Output Coil instruction be addressed to energize a physical motor contactor coil?
3. When implementing a PID control loop, the PLC's analog output signal (e.g., 4–20mA) is typically used to control which type of actuator?
4. A Normally Closed (NC) limit switch detects a component's home position. Which PLC instruction should be used in the logic to make the HOME tag TRUE when the switch is physically actuated (pressed)?
5. If a pressure transmitter with a range of 0–10 bar corresponds to a raw PLC input count of 0–16384, what pressure value should a raw count of 8192 be scaled to?
6. To verify that a pneumatic cylinder has fully completed its extension stroke before the sequence advances, the PLC must read an input from which type of device?
7. In a closed-loop temperature control system, what is the pair of components that represents the final PLC Output and the essential process Input?



Answer Paper 4.4-1

1. The PLC input common terminal must be wired to 0 VDC Negative (since the PNP sensor sources 24 VDC positive).
2. The Digital Output terminal connected to the coil of the motor contactor.
3. A Variable Frequency Drive (VFD) controlling motor speed (or a proportional control valve).
4. An Examine if Open (XIO) contact addressed to the limit switch input.
5. 5 bar (since 8192 is half of the maximum raw count 16384).
6. A limit switch or proximity sensor mounted at the end of the stroke.
7. The Heating Element Contactor Output and the Temperature Transmitter Input.

	Job Sheet 33
Qualification	Industrial Automation
Learning Unit	Operate Three-Phase Motor using Magnetic Contactor and Proximity Sensor
Trainee Name	
PPE	Safety shoes, safety goggles, hand gloves, anti-static wrist strap
Tools & Equipment	• Three-phase induction motor • Magnetic contactor (MC) • Overload relay • Proximity sensor (inductive or capacitive type) • Control transformer (for 24V or 230V control circuit) • Push buttons (Start/Stop) • Indicator lamp

	• Connecting wires and terminal blocks • Multimeter • Electrical control panel or trainer board • Circuit diagram
Notes	A magnetic contactor is an electromagnetic switch used to control the operation of a three-phase motor. In this task, a proximity sensor is used as an automatic input device to control motor operation without direct physical contact. The proximity sensor sends a signal to energize the contactor coil, which starts the motor. When the sensor no longer detects the object, the contactor de-energizes, and the motor stops.
Procedure	1. Ensure all PPE is properly worn and that the work area is safe and clean. 2. Collect all required tools and equipment. 3. Study the wiring diagram of the control circuit before starting the connection. 4. Connect the three-phase motor to the power circuit through the magnetic contactor and overload relay. 5. Prepare the control circuit: 6. Connect the Start and Stop push buttons for manual operation. 7. Integrate the proximity sensor output into the control line of the contactor coil. 8. Connect the sensor's power supply (as per its rated voltage, e.g., 24V DC). 9. Verify all connections using a multimeter for continuity and correct wiring. 10. Turn on the power supply and test the manual operation using Start/Stop buttons. 11. Place a metallic target near the proximity sensor to simulate automatic operation.

	12. Observe that the motor starts when the target is detected and stops when it moves away. 13. Record all test observations, including sensor distance, motor response, and safety checks. 14. After testing, turn off the power, disconnect all connections safely, and store the tools properly.
Trainee's Signature	
Assessor's Signature	
QA Signature	
Assessor's Comment	

Module 5: Perform Process Visualization (HMI)



Contents of Module

Module Description

This unit of competency covers the knowledge, skills and attitudes required to perform process visualization (HMI). It specifically includes the tasks of configuring human machine interface (HMI) panel integration, performing process design in HMI, carrying out interface between PLC and HMI and visualizing the process in HMI.

Minimum Time: 20 Hours



Learning Outcome

- 1.1. Configure human machine interface (HMI) panel integration
- 1.2. Perform process design in HMI
- 1.3. Carry out interface between PLC and HMI
- 1.4. Visualize the process in HMI



Performance Criteria

1. Concept and functions of Human Machine Interface (HMI) are interpreted and understood

according to system requirements.

2. Different HMI communication protocols are established and configured.
3. Various HMI screens are created, selected, and programmed with soft buttons.
4. Basic objects and elements are created and configured.
5. Graphic objects are imported from the software library and integrated.
6. Analogue data tags are configured to enable real-time monitoring.
7. Process requirements and specifications are reviewed and interpreted.
8. Relevant process control parameters are identified into the HMI design.
9. Appropriate interactive elements are designed and configured to control and monitor the process.
10. Alarm and notification systems are integrated into the HMI.
11. Process design is simulated and tested within the HMI.
12. Interface performance is monitored.
13. The process flow and operational parameters are interpreted and analyzed for visualization purposes.
14. Appropriate graphical elements and indicators are selected and configured to represent process variables accurately.
15. Process data is integrated and displayed in real-time on HMI screens using charts, gauges, and trend graphs.
16. Interactive components and alarms are incorporated to facilitate process control and monitoring.
17. The HMI visualization is tested and validated to confirm accuracy and responsiveness.

Learning Outcome 5.1 – Configure Human Machine Interface (HMI) Panel Integration



Content

- **HMI Software and Project Setup:** Understand the HMI software environment (e.g., FactoryTalk View, WinCC), learn to create a new project, and correctly select the target panel model and communication driver.
- **Tag Database and Communication Link:** Learn to establish communication with the PLC, import or create the HMI tag database, and link the HMI tags to the corresponding PLC memory addresses (e.g., registers, I/O bits).
- **Screen Design and Object Configuration:** Master the creation of basic screens, navigation buttons, data displays, and input objects (e.g., numeric entry fields, pushbuttons) and configure their properties based on PLC tags.



Assessment Criteria

- Stable PLC-HMI Communication
- Accurate Data Visualization and Control
- Intuitive User Navigation



Necessary Equipment

- Human Machine Interface (HMI) Panel
- Programming Computer/Laptop
- Programmable Logic Controller (PLC)
- Communication Cable/Network
- Technical Documentation



Learning Activity 5.1-1

Learning Activity	Resources/ Instructions/ References
Configure Human Machine Interface (HMI) Panel Integration	• Information Sheet: 5.1-1 • Self-Check: 5.1-1 • Answer Paper: 5.1-1 • Job Sheet 34



Information Sheet 5.1-1

Learning Objective: The learner will be able to create a new HMI project in the configuration software, select the correct panel and communication driver, and establish a working communication link with the target PLC.

Perform Process Visualization

Process visualization is the graphical representation of a process to provide a clear, end-to-end overview. It helps in understanding the steps, identifying bottlenecks, and optimizing workflows. This method is used across various fields, including business, manufacturing, and engineering. Common tools for process visualization include flowcharts, value stream maps, and swimlane diagrams.

Human Machine Interface (HMI)

A **Human Machine Interface (HMI)** is a dashboard or screen that connects a human operator to a machine, system, or industrial process. It serves as a communication bridge, translating complex data into an intuitive visual format. HMI is a key component of process visualization in industrial and manufacturing settings, enabling operators to:

- **Monitor in Real-Time:** HMIs display real-time data from sensors and controllers in an easy-to-understand format, such as graphs, charts, and diagrams. For example, an operator can see the temperature of a furnace or the speed of a conveyor belt instantly.
- **Control Processes:** Operators can interact with the system directly through the HMI to adjust parameters, start/stop machinery, or perform other control functions.
- **Track Performance:** HMIs can track key performance indicators (KPIs) like production rate, downtime, and energy usage, presenting this data in a centralized, visual dashboard.
- **Manage Alarms and Alerts:** When a problem or anomaly occurs, the HMI can provide clear visual and audible alarms to alert the operator, helping them to respond quickly and efficiently.

Essentially, HMI is the practical application of process visualization in a dynamic, industrial environment, allowing for enhanced transparency and data-driven decision-making.

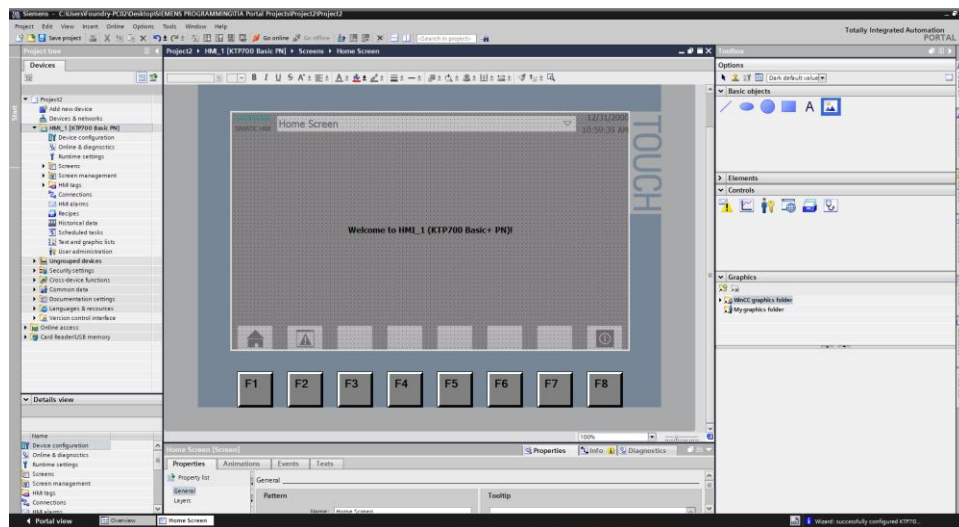


Fig: HMI Screen

Basic Objects of HMI

The basic objects of a Human Machine Interface (HMI) are the graphical elements used to create the visual and interactive display. They are the building blocks of an HMI screen and allow an operator to monitor and control a process. These objects can be broadly categorized by their function-

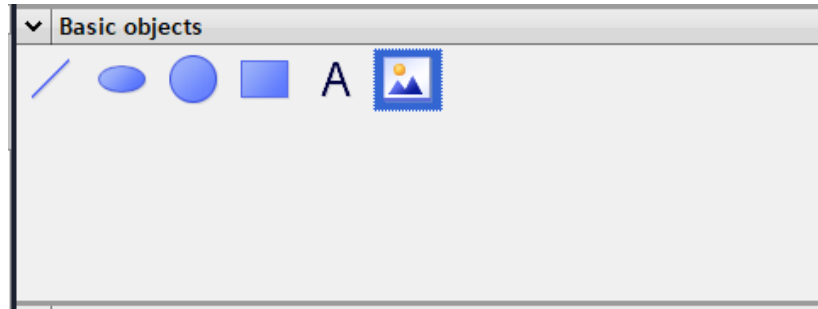


Fig: Basic Objects of HMI

Display and Data Objects

These objects are used to visualize real-time data from the process. They provide operators with a clear understanding of the system's status.

- **Text Fields:** Display static or dynamic text, such as labels for equipment or numerical values for a sensor reading.
- **Gauges and Indicators:** Visually represent a specific value, such as temperature or pressure, using a dial or a linear bar. A gauge provides an analog-style representation, while a bar graph is a simple, effective way to show continuous change.
- **Trend Charts:** Plot data over time, allowing operators to analyze historical trends and identify patterns or anomalies.
- **Symbol Libraries:** A collection of pre-designed symbols and icons (e.g., pumps, valves, motors) that represent physical equipment on the HMI screen.

Control and Input Objects

These objects enable the operator to interact with and control the process.

- **Pushbuttons and Switches:** Allow the operator to send commands to the system, such as starting or stopping a motor. Buttons are momentary, while switches have a persistent on/off state.
- **Data Entry Fields:** Provide a space for the operator to input numerical values or text, such as a new setpoint for a process variable.
- **Sliders and Knobs:** Used to adjust a value within a specific range, providing a more intuitive interface for continuous control.

Navigation and Alert Objects

These objects are designed to improve user experience and safety.

- **Navigation Buttons:** Allow the operator to switch between different screens or views within the HMI application.
- **Alarm/Event Displays:** A dedicated area that shows active alarms and historical events. These objects are crucial for alerting operators to faults or abnormal conditions.
- **Containers and Frames:** Graphical elements that group related objects together to create a more organized and logical layout.

Each of these objects is tied to a "tag" or "variable" from the programmable logic controller (PLC), which is the device controlling the machinery. This link is what allows the HMI to display real-time data and send commands to the equipment.

Elements of HMI

A Human Machine Interface (HMI) is a system that allows operators to interact with industrial machines and processes. The "elements" of an HMI can be broken down into both the physical hardware components and the graphical design elements of the software that makes up the user interface.

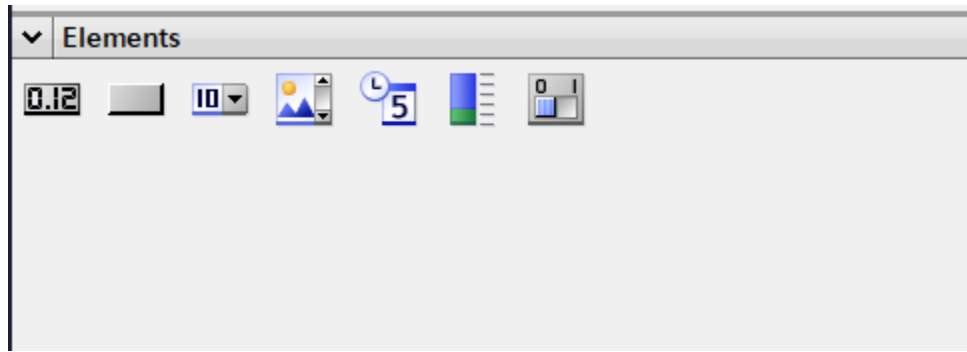


Fig: Elements of HMI

Hardware Elements

These are the physical components that an HMI is built with.

- **Display Screen:** This is the most visible part of the HMI. It can range from a simple, small LCD display to a large, high-resolution multi-touch panel. The display is responsible for showing all the visual information to the operator, such as real-time data, alarms, and process diagrams.
- **Input Devices:** This is how the operator gives commands to the system. The most common input device in modern HMIs is a **touchscreen**, which combines the display and input in one unit. Other input devices can include:
 - Physical buttons and switches
 - Keypads
 - Keyboards and mice
- **Processing Unit:** This is the "brain" of the HMI. It's the computer that runs the HMI software, processes the data from the connected devices (like a PLC), and manages the display and input.
- **Communication Ports:** These are the physical connections that allow the HMI to communicate with other devices on the factory floor, such as PLCs, sensors, and other HMIs. Common communication protocols include Ethernet, Modbus, and Profibus.

Software and Graphical Elements

These are the building blocks used to design and program the HMI screen and its functionality.

- **User Interface (UI):** This is the visual layout that the operator sees and interacts with. A well-designed UI is intuitive and easy to navigate. Key principles of good UI design for HMIs include:
 - **Simplicity:** Avoid clutter and only show essential information to the operator.
 - **Consistency:** Use consistent colors, symbols, and navigation across all screens.
 - **Clear Feedback:** Provide immediate and clear visual or auditory feedback when an action is performed, such as a button press or an alarm.
- **Graphical Objects:** These are the visual components that represent the process. They were discussed in the previous response, but it's worth highlighting their importance again as fundamental elements. They include:
 - **Symbols and Icons:** Standardized icons for pumps, motors, valves, tanks, etc. that give the operator a clear picture of the process.
 - **Gauges and Indicators:** Graphical representations of numerical data, like a speedometer for speed or a bar graph for level.
 - **Trend Charts:** Historical data plots that allow operators to see how a process variable has changed over time.
 - **Navigation Buttons:** Buttons that allow the operator to move between different screens (e.g., from a plant overview to a detailed view of a specific machine).
- **Data and Logic:** This is the underlying programming that connects the graphical elements to the physical process.
 - **Tags/Variables:** Every piece of data displayed on the HMI (e.g., motor speed, tank level) is linked to a specific "tag" or "variable" in the PLC.
 - **Alarms and Notifications:** Logic that triggers a visual or audible alert when a variable exceeds a safe limit. This is a critical safety element.
 - **Recipes and Batching:** For processes that require specific settings, the HMI can store and manage "recipes" which are sets of parameters that can be loaded with the press of a button.

HMI Communication Protocols

HMI communication protocols are the standardized sets of rules that allow an HMI to exchange data with other devices in an industrial control system, primarily with a PLC (Programmable Logic Controller). This exchange is crucial for displaying real-time process data, sending commands from the operator, and managing alarms.

Key communication protocols include:

Modbus

Modbus is one of the oldest and most widely used protocols, developed in 1979. It's known for its simplicity and reliability.

- **Function:** It operates on a master-slave architecture, where the HMI acts as the master requesting data from slave devices like PLCs and sensors.
- **Variants:**
 - **Modbus RTU/ASCII:** Uses serial communication over physical connections like RS-232 or RS-485. It's slower but simple and reliable for point-to-point connections.
 - **Modbus TCP/IP:** Uses standard Ethernet, allowing for faster data transfer and the ability to communicate with multiple devices simultaneously over a network.

Ethernet/IP

Ethernet/IP (Ethernet Industrial Protocol) is an open standard that uses the standard Ethernet physical layer but is optimized for industrial automation.

- **Function:** It allows for high-speed, real-time data exchange, making it suitable for complex, data-intensive applications like robotics or high-speed manufacturing lines.
- **Advantage:** It leverages existing IT infrastructure, making it easier to integrate into plant-wide networks.

Profibus and Profinet

Profibus (Process Field Bus) is a well-established fieldbus protocol, especially popular in Europe, that uses a decentralized bus system to reduce wiring complexity. **Profinet** is its successor, an Industrial Ethernet protocol that offers faster and more flexible communication.

- **Function:** Both protocols are designed for real-time data exchange between controllers, HMIs, and field devices.
- **Advantage:** Profinet's use of Ethernet provides higher speeds and better integration with enterprise-level systems.

OPC UA

OPC UA (Open Platform Communications Unified Architecture) is a modern, platform-independent, and highly secure communication protocol.

- **Function:** Unlike older, device-specific protocols, OPC UA is designed for seamless data exchange between different vendors' hardware and software, from the factory floor to the enterprise level.
- **Advantage:** Its interoperability and built-in security features, such as encryption and authentication, make it ideal for modern, connected industrial systems (IIoT).



Self-Check 5.1-1

1. What is the primary function of the Human Machine Interface (HMI) panel in an automated system for the operator?
2. What crucial initial configuration step is required on the HMI to enable communication with the PLC over an Ethernet network?

3. To create an HMI push button that starts a motor, the button's Write Address must be linked to which type of PLC memory tag?
4. Which PLC data type is required to accurately store and display a continuously changing, scaled analog value (e.g., 10.55 bar) on the HMI?
5. What is the key benefit of implementing a hierarchical screen structure (e.g., Home screen with subprocess navigation) on the HMI?
6. An HMI security feature that restricts screen access based on the operator's role (e.g., Maintenance vs. Operator) is achieved by linking the screen to what parameter?
7. What is the essential purpose of the HMI's data logging and trending features?



Answer Paper 5.1-1

1. To serve as the operator's central point for monitoring machine status, controlling process variables, and viewing alarms.
2. Setting a unique IP address and ensuring the subnet mask matches the PLC's network settings.
3. A Boolean tag (bit) that the PLC logic monitors to receive the Start command.
4. Floating Point (FLOAT or REAL), as it can store decimal places.
5. It improves operator efficiency and reduces error by providing an intuitive and organized flow for process access.
6. The operator's User Login Level or Group ID.
7. Storing historical process data (e.g., temperature, pressure, flow) to identify performance issues and troubleshoot over time.

	Job Sheet 34
Qualification	Industrial Automation
Learning Unit	Configure Human Machine Interface (HMI) Panel Integration
Trainee Name	
PPE	Safety shoes, safety goggles, hand gloves
Tools & Equipment	• HMI panel (touchscreen or display unit) • PLC (with powered I/O terminals) • PC/Laptop with HMI configuration software • Programming cable for PLC and HMI • Input devices (sensors, pushbuttons) • Output devices (motors, lamps, actuators) • Multimeter (DMM) • Connecting wires • Network cables (if HMI uses Ethernet communication)
Notes	A Human Machine Interface (HMI) provides a user-friendly graphical interface to monitor, control, and interact with PLC-controlled industrial processes. Integration with a PLC allows real-time data visualization, setpoint adjustment, and control of machines and devices.
Procedure	1. Ensure all PPE is properly worn and the work area is safe. 2. Power on the PLC and HMI panel. 3. Connect the HMI panel to the PLC using the appropriate communication method (e.g., RS-232, RS-485, Ethernet). 4. Open the HMI configuration software on the PC/Laptop. 5. Create a new project and select the PLC model and communication protocol. 6. Define tags/addresses corresponding to PLC inputs, outputs, and internal registers. 7. Design the HMI screens:

	8. Include buttons, switches, and sliders for control. 9. Include indicators, gauges, and alarms for monitoring. 10. Configure screen navigation (main screen, sub-menus, alarms). 11. Download the HMI project to the panel. 12. Test integration by manipulating PLC inputs and observing HMI output. 13. Test control commands from the HMI and verify proper operation of connected outputs (e.g., motor start/stop, lamp ON/OFF). 14. Record observations, verify communication, and troubleshoot if necessary. 15. After testing, safely disconnect the HMI and PLC if required, and save the project.
Trainee's Signature	
Assessor's Signature	
QA Signature	
Assessor's Comment	

Learning Outcome 5.2 – Perform Process Design in HMI



Content

- **Process Flow Visualization:** Learn to translate a P&ID (Piping and Instrumentation Diagram) or process flow chart into a clear, graphical representation on the HMI screen using static and dynamic objects (e.g., pipes, tanks, pumps, valves).
- **Dynamic Data Linking:** Master the configuration of dynamic HMI objects (e.g., analog gauges, trends, color-changing symbols) to accurately reflect the real-time status and values of the linked PLC tags.

- Navigation and Screen Hierarchy: Design an intuitive screen structure with efficient navigation paths (e.g., main menu, detailed equipment views, alarm pages) that allows the operator rapid access to all parts of the process.



Assessment Criteria

- Graphical Accuracy and Clarity
- Effective Dynamic Feedback
- Usability and Consistency



Necessary Equipment

- HMI Configuration Software
- Target HMI Panel and PLC
- Process Documentation
- Color and Style Guide



Learning Activity 5.2-1

Learning Activity	Resources/ Instructions/ References
Perform Process Design in HMI	• Information Sheet: 5.2-1 • Self-Check: 5.2-1 • Answer Paper: 5.2-1 • Job Sheet 35



Information Sheet 5.2-1

Learning Objective: The learner will be able to design and implement a graphical representation of an industrial process on an HMI, accurately linking dynamic objects to PLC data for effective visualization and control.

Process Design in HMI

Process design in an HMI is the practice of creating a user-friendly and effective graphical interface that allows an operator to monitor and control an industrial process. It's not just about making a screen look nice, but about organizing information and controls in a logical way that supports an operator's tasks and reduces the risk of error.

Key Principles of HMI Process Design

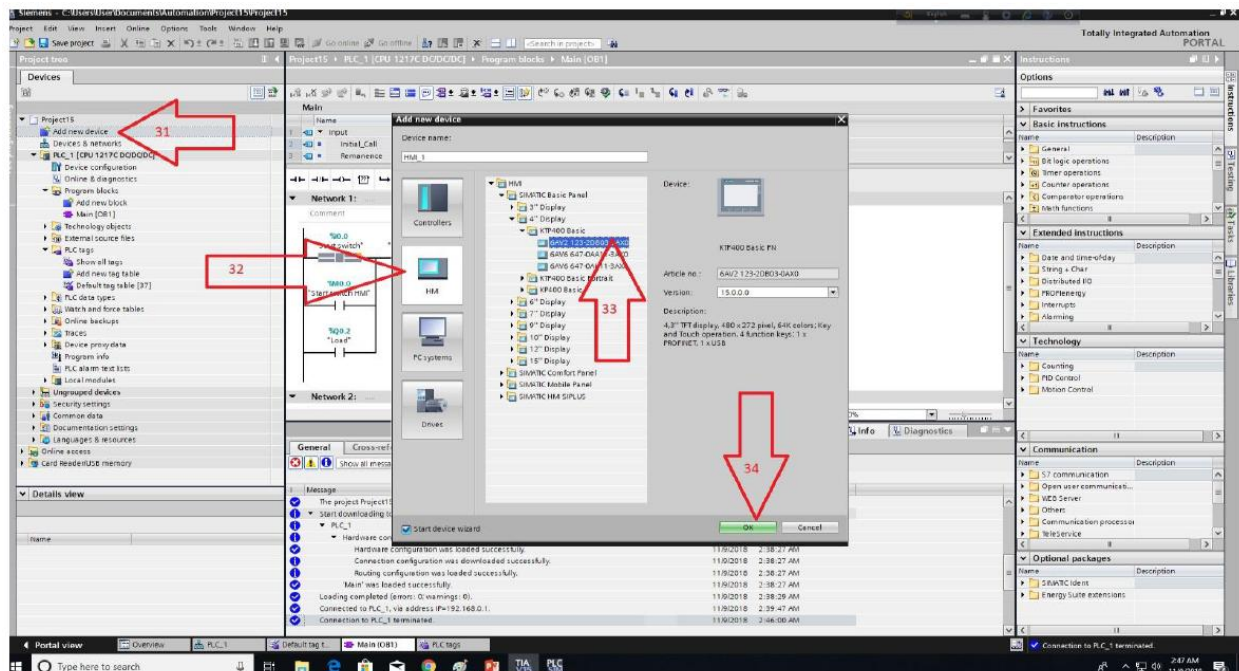
The design of an HMI should follow these core principles to ensure it's effective for the end-user:

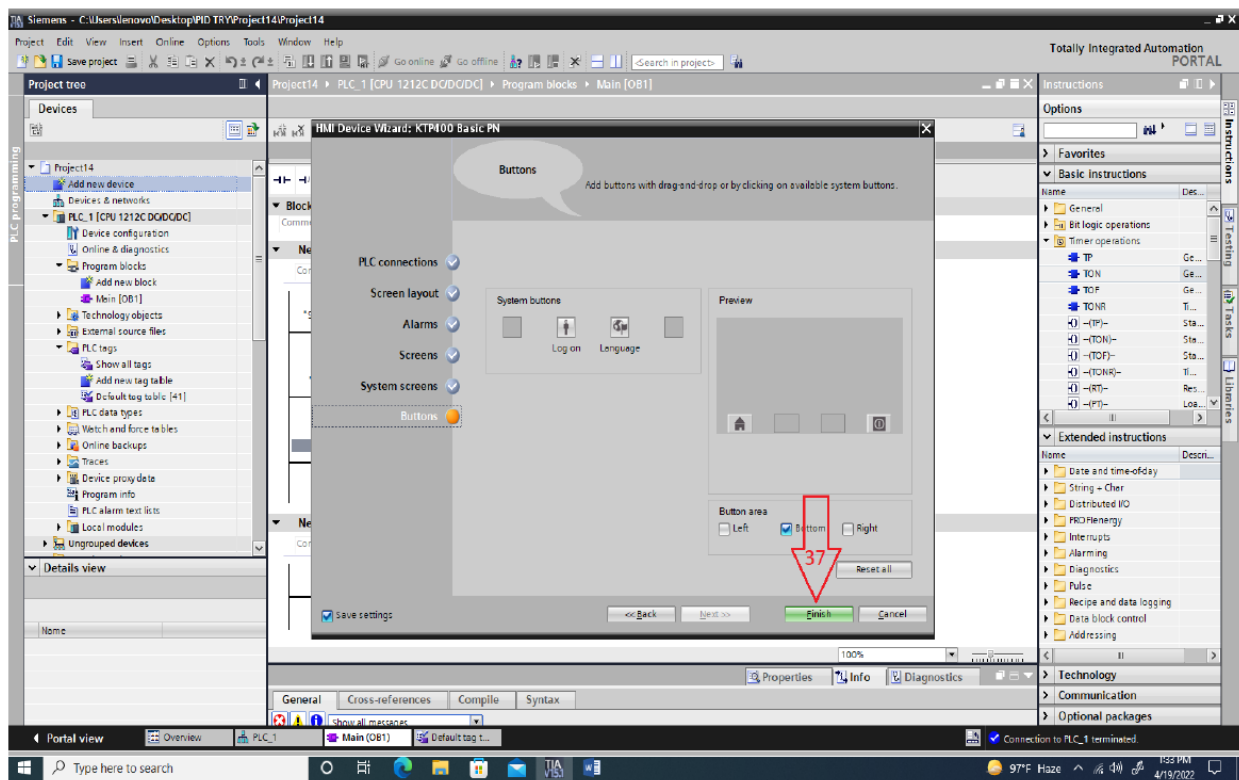
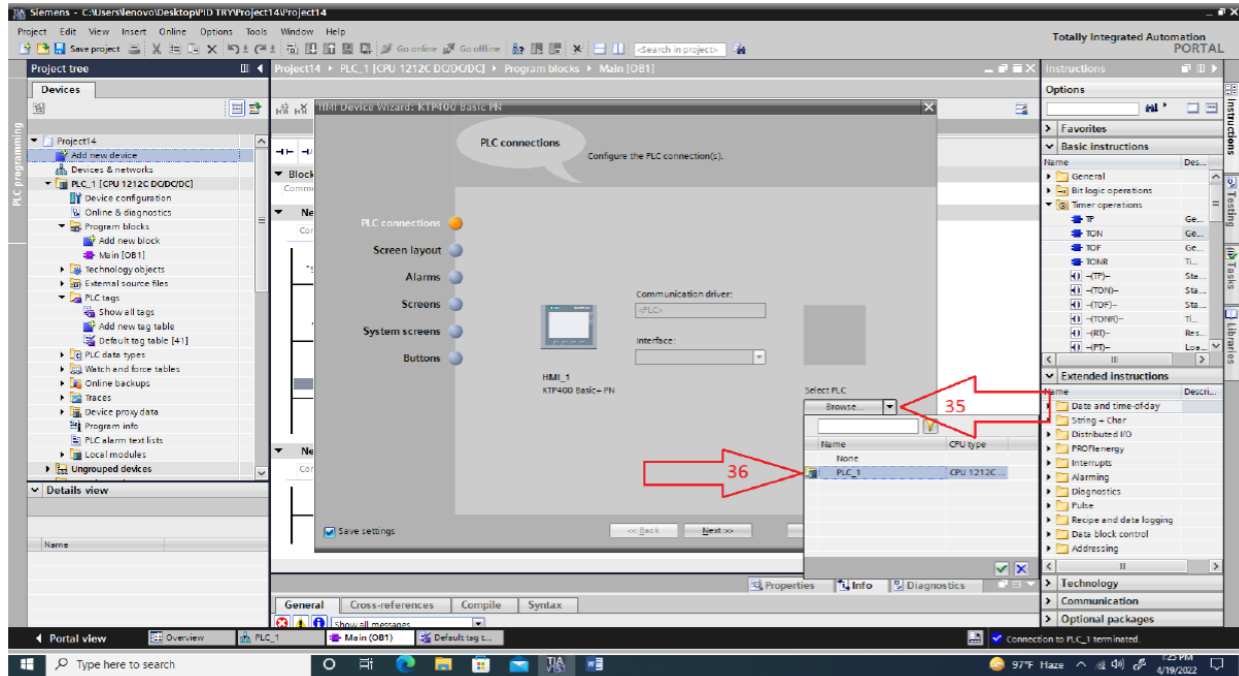
- **User-Centered Design:** The HMI is for the operator, so its design must be based on their needs, tasks, and environment. This involves talking to operators to understand their workflow and what information they need most.
- **Situational Awareness:** The primary goal is to provide the operator with a clear, at-a-glance understanding of the process's status. A well-designed HMI helps the operator

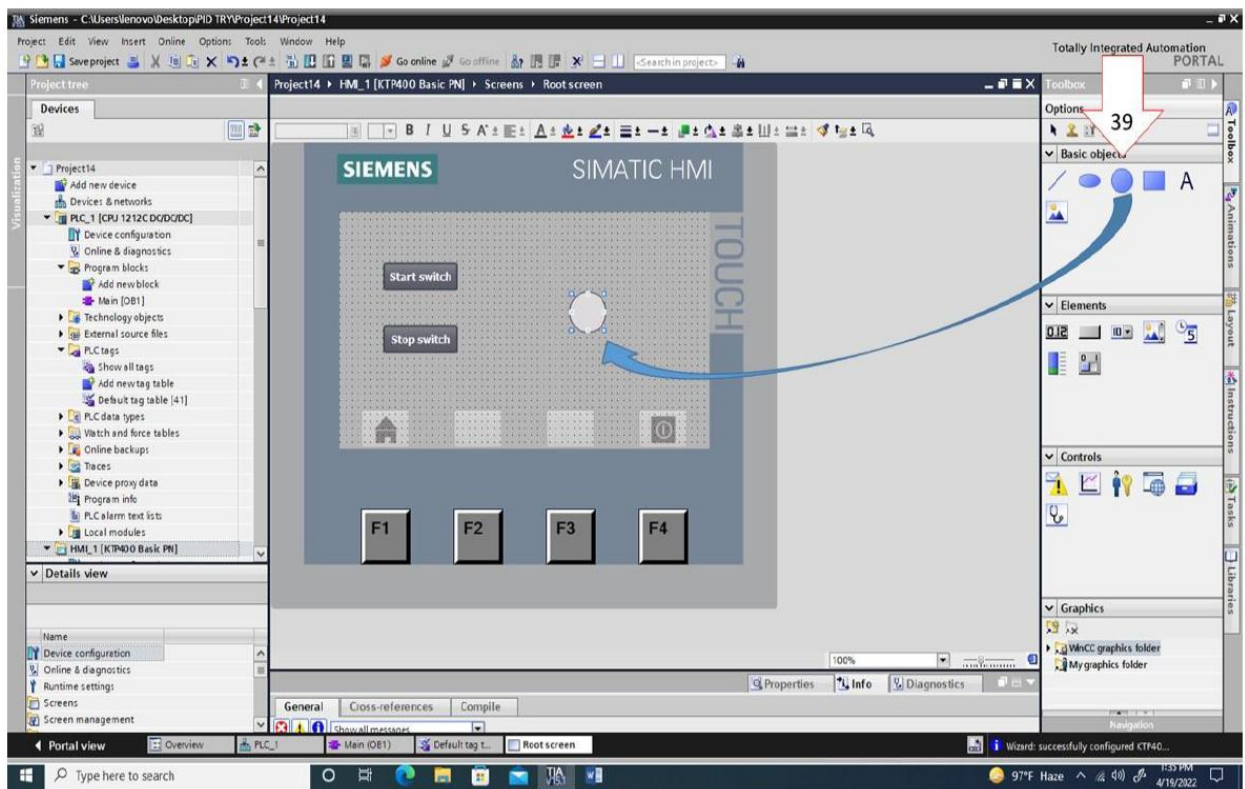
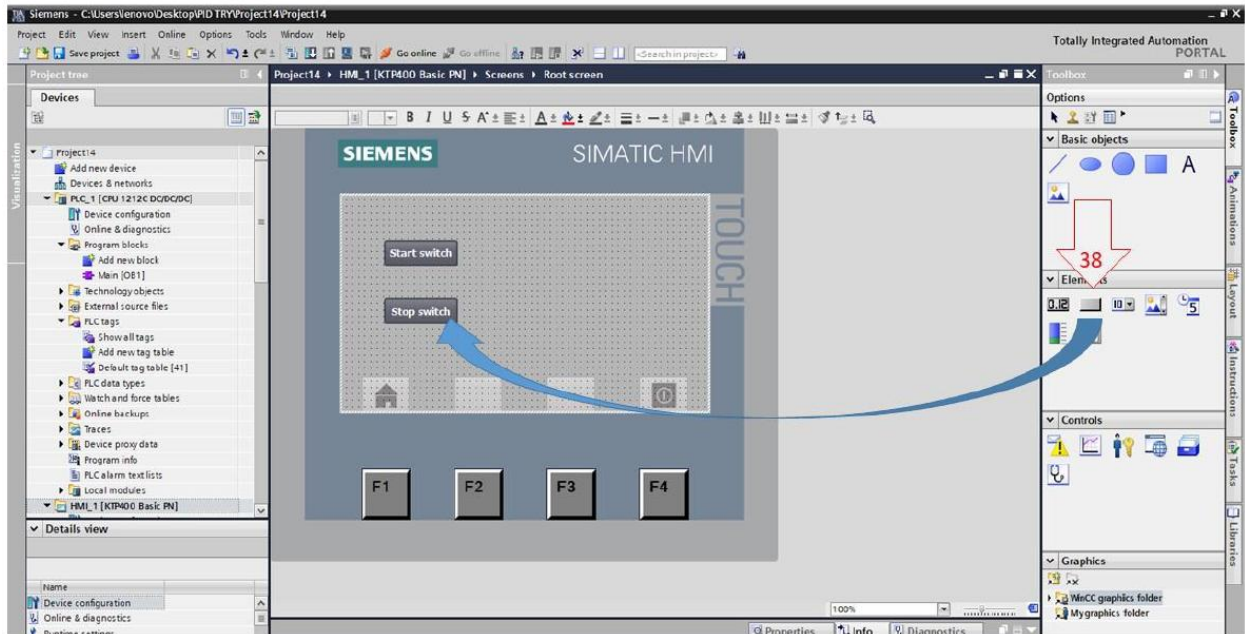
quickly identify what's happening, what the information means, and what might happen next.

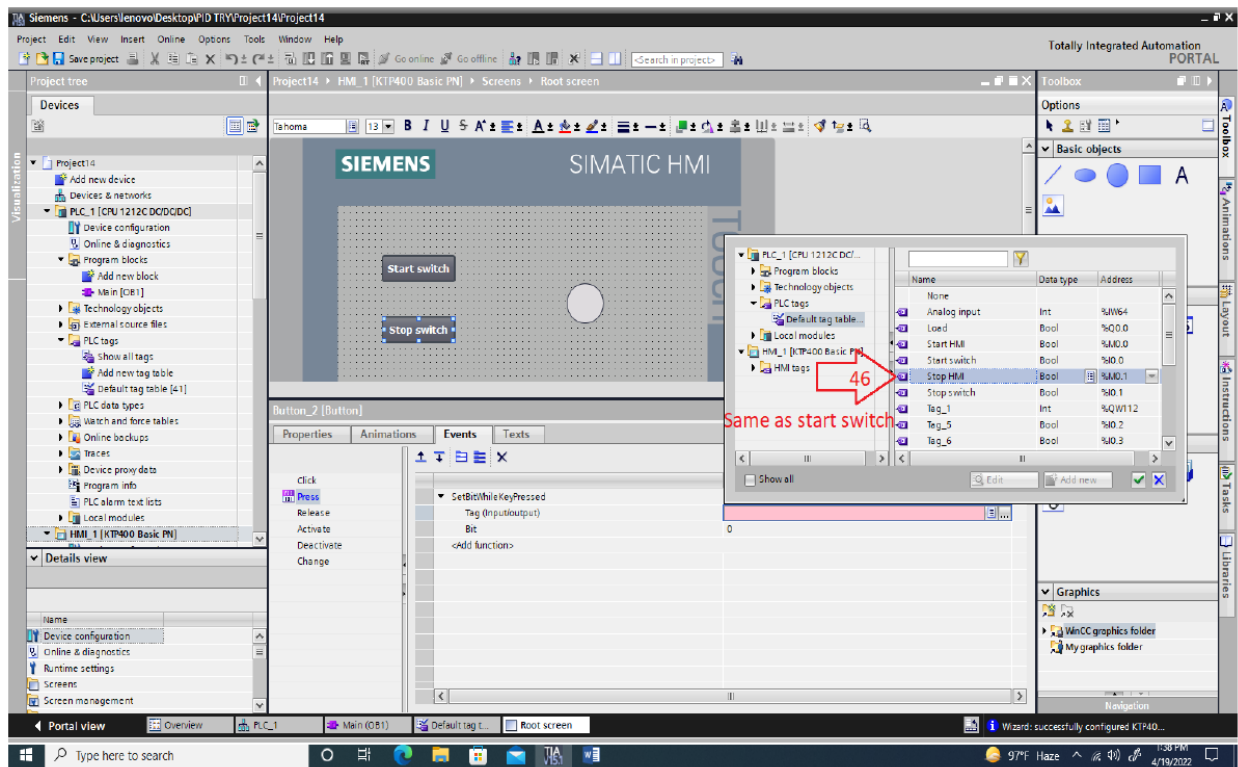
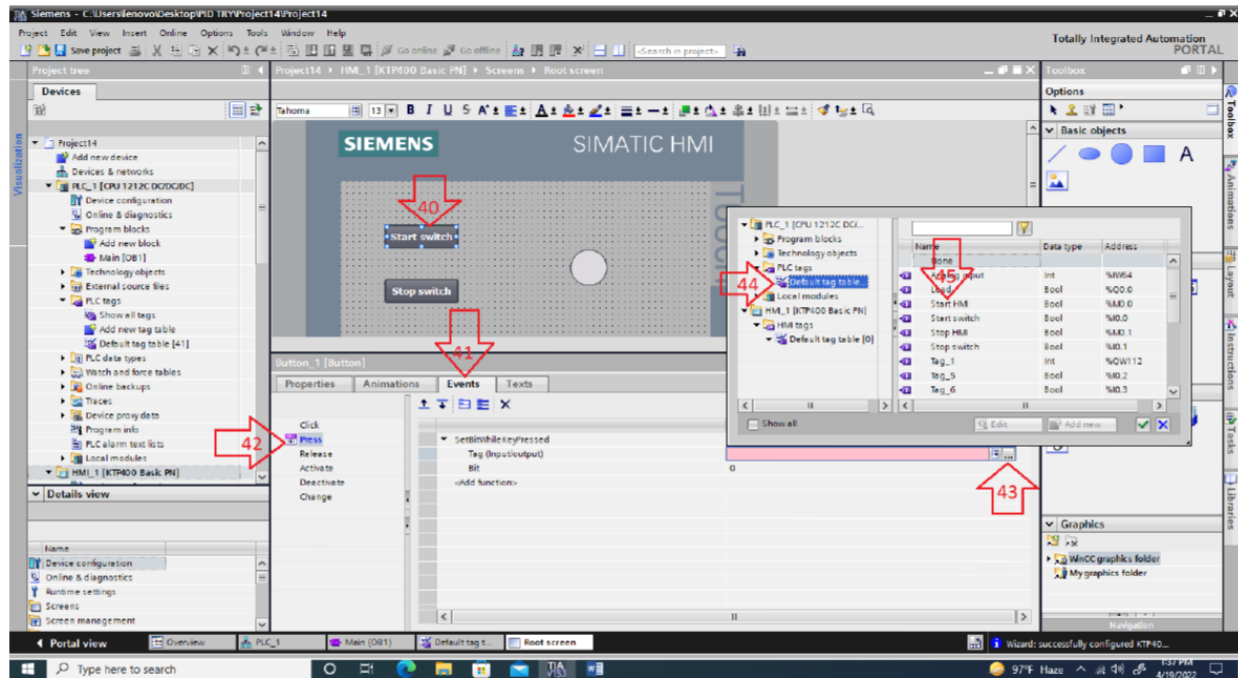
- **Consistency:** Consistent use of colors, symbols, layouts, and navigation across all screens is crucial. This helps operators build a "mental model" of the system, which reduces training time and the potential for errors.
- **Simplicity and Clarity:** Screens should be uncluttered and easy to read. Avoid showing unnecessary data. Use simple, familiar symbols and a neutral background color (like a light gray) to make important information, like alarms, stand out.
- **Effective Use of Color:** Color should be used purposefully and consistently to convey meaning. For example, use red for alarms, yellow for warnings, and green for a "running" or "safe" state. Never rely solely on color to indicate a status, as some people are colorblind; use text labels or shapes as well.

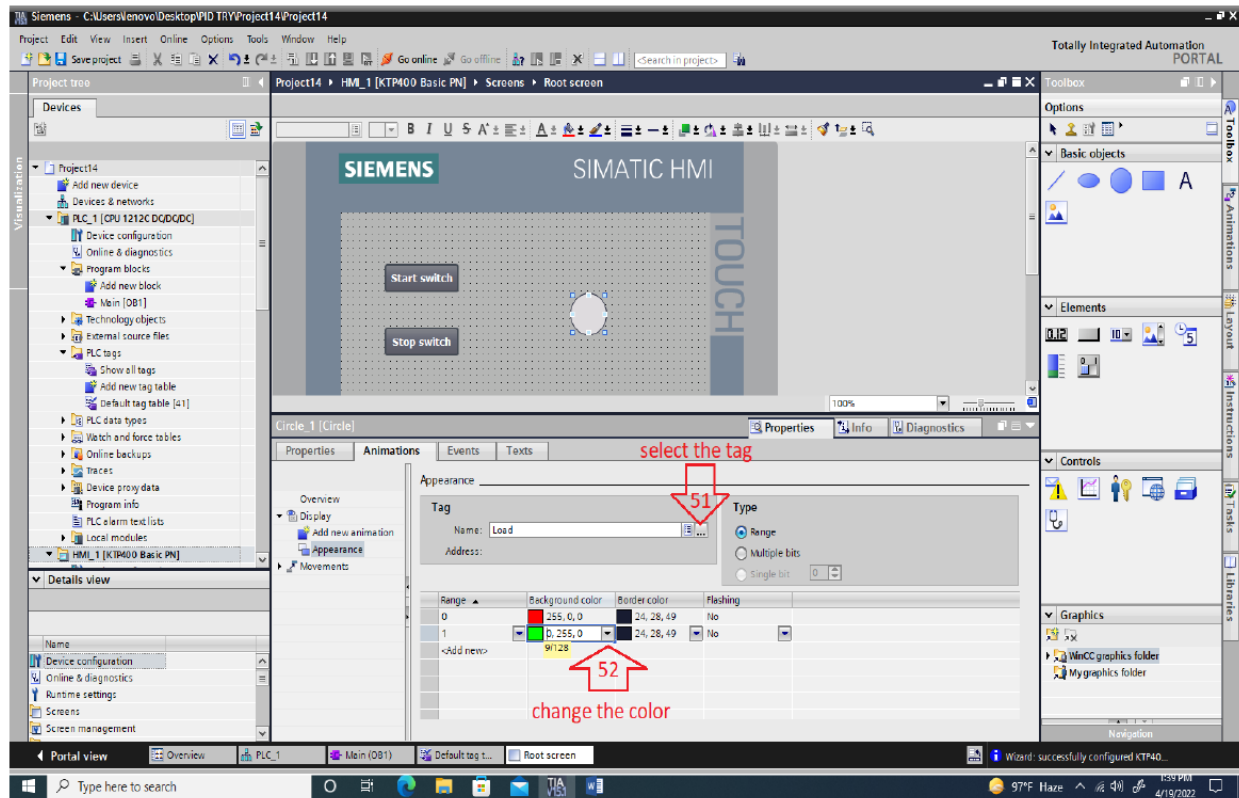
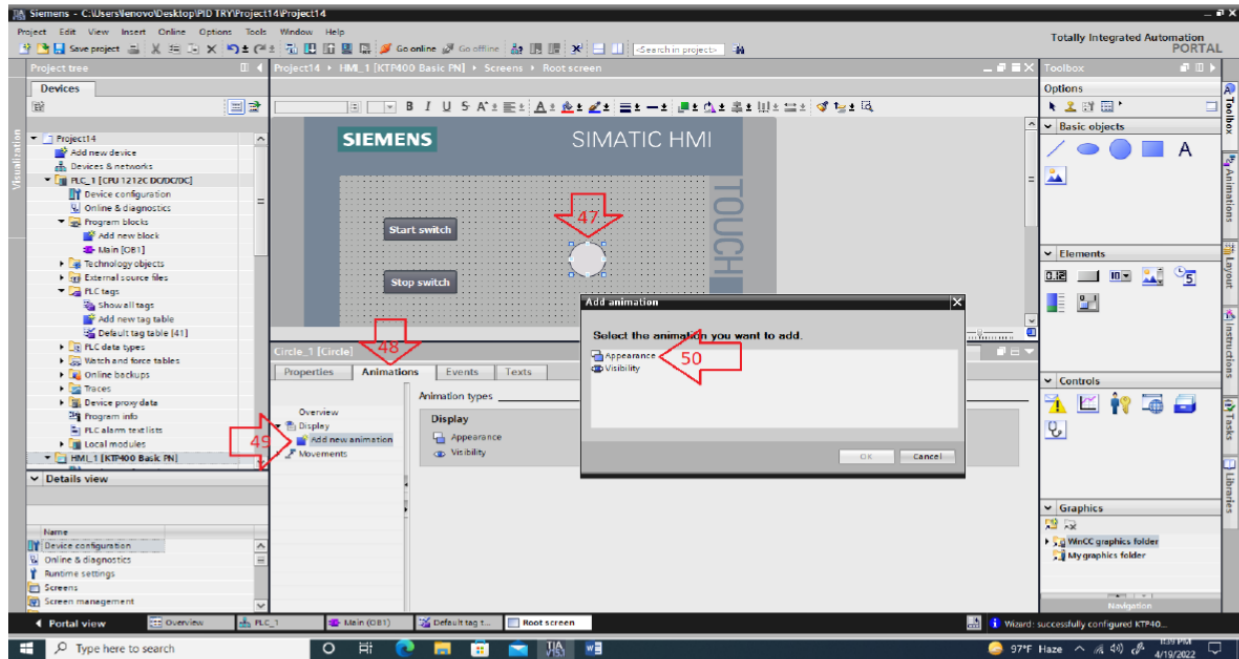
Designing an HMI Screen

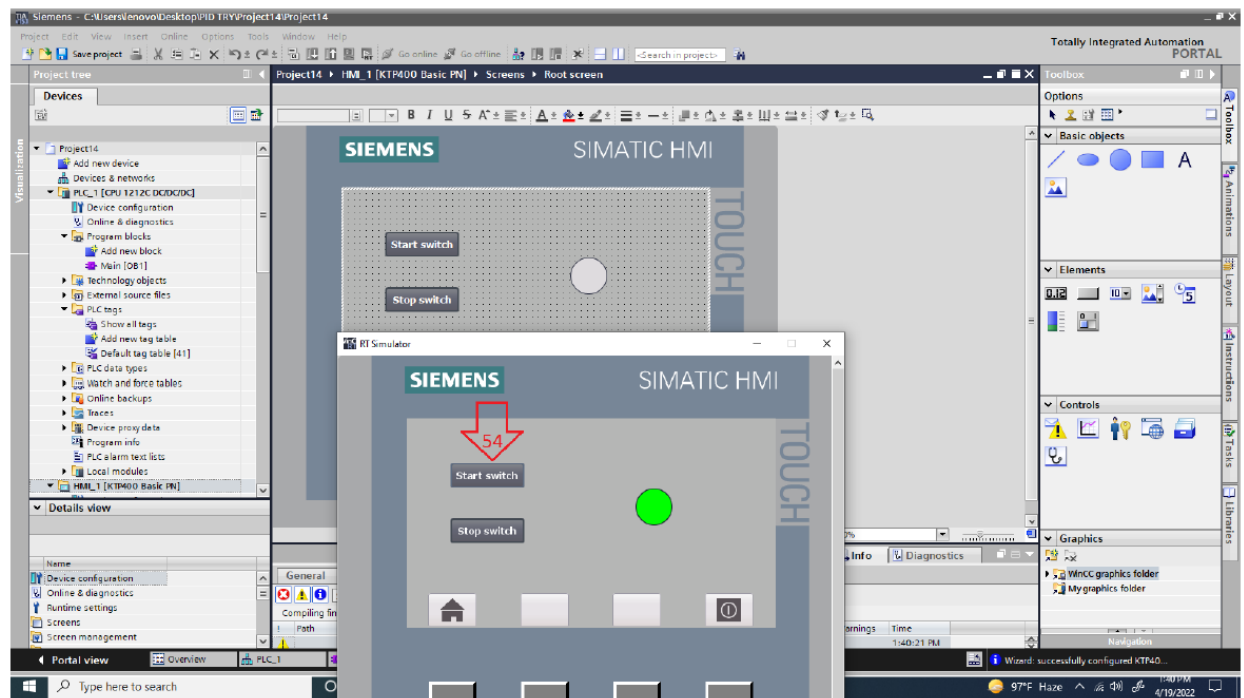
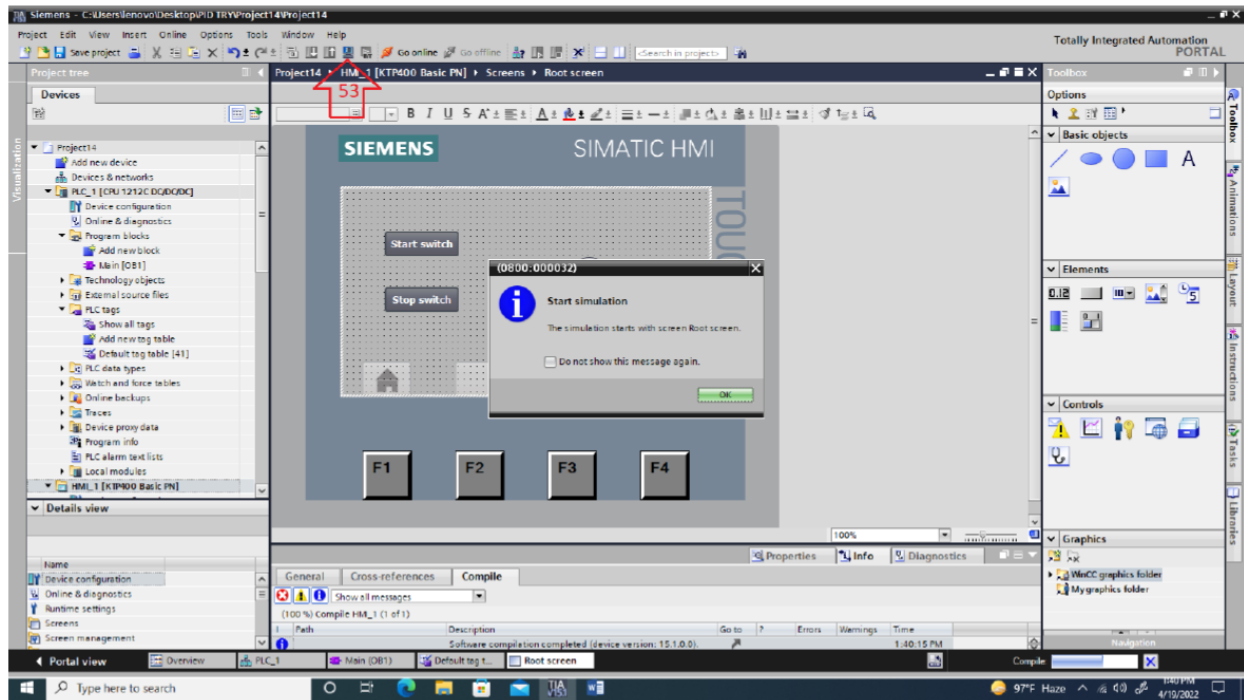












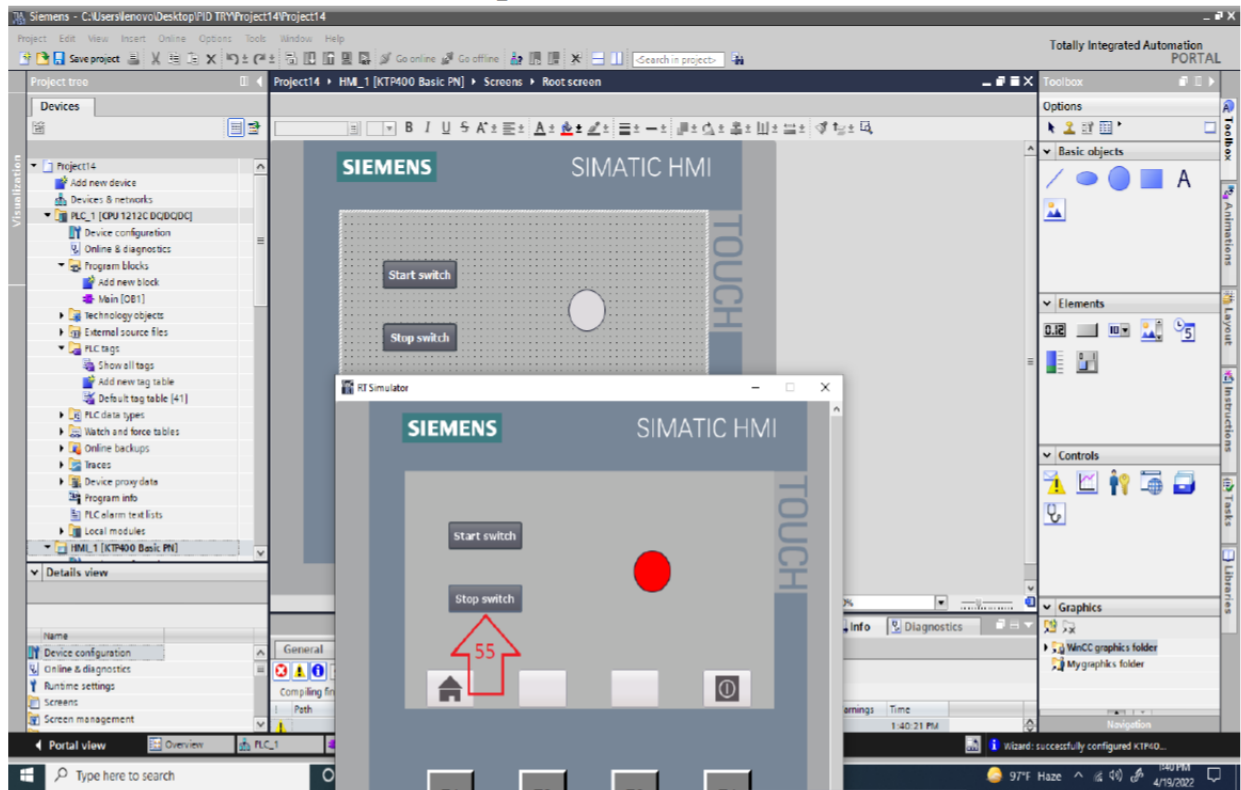


Fig: HMI Designing Processes

The process of designing an HMI screen typically involves these steps:

1. **Define the Hierarchy:** Start by creating a tiered navigation structure. A common approach is a "shallow" design with a high-level **overview** screen at the top, which can then lead to more detailed screens for specific **areas**, **sub-stations**, and individual **components**. This prevents information overload by allowing operators to drill down only when necessary.
2. **Sketch a Storyboard:** Before using design software, create a storyboard or a simple text-based outline for each screen. This helps you plan the layout, identify what data needs to be displayed, and where controls should be placed.
3. **Choose the Right Visuals:** Use graphical objects that are intuitive and represent the physical equipment. Instead of raw data tables, use **gauges**, **trend charts**, and **schematic diagrams** to visually represent the process. For example, instead of a number, a gauge can show at a glance if a value is in a normal or high range.

4. **Place Controls Logically:** Group related controls and information together. For example, put all the controls for a specific pump (start/stop button, speed setting, etc.) in a logical cluster. Critical buttons like an emergency stop should be highly visible, distinct, and protected from accidental activation.
5. **Test and Refine:** Once a design is implemented, it's essential to test it with the operators who will be using it. This feedback is invaluable for identifying awkward situations or areas where the design could be improved. The best HMI designs are often the result of an iterative process with continuous feedback.



Self-Check 5.2-1

1. What is the primary goal of the situational awareness design principle in HMI development?
2. When designing an HMI trend chart for a process variable (e.g., pressure), what essential information should be displayed alongside the real-time data for context?
3. Which poor design practice must be avoided to prevent the operational issue known as Alarm Flooding?
4. According to modern HMI standards, what is the recommended color scheme for displaying equipment that is running under normal conditions?
5. To enable an operator to change a running value (like a recipe parameter) in the PLC, which HMI object type must be configured with Write Access?
6. Which HMI visualization object provides the fastest, most intuitive indication of a liquid level relative to the vessel's maximum capacity?
7. What is the main purpose of having a dedicated System Overview screen at the highest level of the HMI navigation hierarchy?



Answer Paper 5.2-1

1. To ensure the operator can instantly grasp the current status of the process, its deviations from normal, and the time history of key variables.
2. A clear representation of the Set Point and Alarm Limit values.
3. Assigning an alarm for every single digital input that changes state (which results in an overload of non-critical messages).
4. A subdued color, such as a medium grey or dim green, to keep the overall display muted so that alarm colors stand out.
5. A Numerical Input/Output Object linked to a Write Access PLC memory register.
6. A Level Gauge or Bar Graph that fills up from the bottom.
7. To show a comprehensive, top-level status of all critical areas in the process and provide navigation links to detailed screens.

	Job Sheet 35
Qualification	Industrial Automation
Learning Unit	Perform Process Design in HMI
Trainee Name	
PPE	Safety shoes, safety goggles, hand gloves
Tools & Equipment	• HMI panel (touchscreen or display unit) • PLC (with powered I/O terminals) • PC/Laptop with HMI configuration software • Programming cables for HMI and PLC • Input devices (sensors, pushbuttons) • Output devices (motors, lamps, actuators) • Multimeter (DMM)

	• Connecting wires • Network cables (if communication uses Ethernet/RS-485)
Notes	Process design in HMI involves creating visual and interactive screens to monitor and control industrial processes. This includes designing operator screens, control elements, indicators, alarms, and trends to reflect real-time process behavior. Effective HMI process design improves operator efficiency, process safety, and automation reliability.
Procedure	1. Ensure all PPE is properly worn and the workspace is safe. 2. Power on the PLC and HMI panel, and connect them using the appropriate communication interface. 3. Open the HMI configuration software on the PC/Laptop. 4. Create a new project and select the correct PLC model and communication protocol. 5. Define tags for all process variables corresponding to PLC inputs, outputs, and internal registers. 6. Design process screens: ○ Add control elements: buttons, sliders, switches. ○ Add indicators: lamps, gauges, meters, or numeric displays. ○ Add trends for real-time process data visualization. ○ Configure alarms for critical process conditions. 7. Organize screen navigation, ensuring operators can easily access main, sub, and alarm screens. 8. Configure interlocks and safety indicators if applicable. 9. Download the process design project to the HMI panel. 10. Test all interactive elements: ○ Verify that control actions update the PLC correctly. ○ Check that indicators reflect accurate real-time process values. ○ Ensure alarms trigger properly when conditions are met.

	11. Make adjustments to the process design based on testing and operator feedback. 12. Save the project and back up the HMI configuration. 13. After testing, disconnect equipment safely and store tools and HMI panel appropriately.
Trainee's Signature	
Assessor's Signature	
QA Signature	
Assessor's Comment	

Learning Outcome 5.3 – Carry Out Interface between PLC and HMI



Content

- **Communication Driver Setup:** Learn the process for configuring the correct communication driver (e.g., Ethernet/IP, Modbus TCP) on both the PLC and the HMI to enable reliable data exchange between the two devices.
- **Tag Mapping and Linking:** Understand how to map HMI graphic objects and data entry fields to the precise PLC memory addresses (tags), ensuring that data is read and written correctly.
- **Troubleshooting Connectivity Issues:** Identify and resolve common interface problems, such as IP address conflicts, communication timeouts, incorrect protocol settings, and unmapped or mismatched data types.



Assessment Criteria

- Stable Two-Way Communication
- Correct Tag Data Integrity
- Fault Isolation and Resolution



Necessary Equipment

- Programmable Logic Controller (PLC)
- Human Machine Interface (HMI) Panel
- Communication Cable/Network
- Programming Software Suite
- Technical Documentation



Learning Activity 5.3-1

Learning Activity	Resources/ Instructions/ References
Carry Out Interface between PLC and HMI	• Information Sheet: 5.3-1 • Self-Check: 5.3-1 • Answer Paper: 5.3-1 • Job Sheet 36



Information Sheet 5.3-1

Learning Objective: The learner will be able to configure communication drivers and accurately map data tags to successfully establish and verify a stable two-way interface for data exchange between a PLC and an HMI panel.

Interface between PLC and HMI

The interface between a **Programmable Logic Controller (PLC)** and a **Human Machine Interface (HMI)** is a two-way communication link that allows an HMI to read data from and write data to the PLC. The PLC, acting as the "brain," processes logic and controls the physical equipment, while the HMI, serving as the "face," provides a visual and interactive display for the operator. This interface is made possible through a combination of hardware and software elements.

Hardware Interface

The physical connection between a PLC and an HMI is established through communication ports and cables. These can be:

- **Serial Connections (RS-232, RS-485):** These are older, slower methods that are still used for simple, point-to-point connections. They are reliable for short distances and less data-intensive applications.
- **Ethernet:** This is the most common and preferred method in modern industrial systems. Ethernet allows for high-speed data transfer over long distances and can connect multiple devices to the same network, which is essential for larger systems. Many HMIs and PLCs come with built-in Ethernet ports.

Software Interface and Data Mapping

The software interface is what truly enables the communication between the two devices. It's where the "language" for data exchange is established.

- **Communication Protocols:** Both the HMI and PLC must be configured to use the same communication protocol, which is the set of rules that governs the data exchange. Common protocols include:
 - **Modbus:** A simple, widely-used protocol for serial or Ethernet communication.
 - **Ethernet/IP:** An open standard that is very popular for high-speed applications.
 - **Profinet:** A real-time Ethernet protocol commonly used with Siemens equipment.
 - **OPC UA:** A platform-independent protocol that provides secure and reliable data exchange between different brands of devices.
- **Tag or Variable Mapping:** This is the crucial step of linking a specific graphical object on the HMI screen to a data point (or "**tag**") in the PLC's memory. For example, a "Start" button on the HMI is mapped to a "Motor_Start" tag in the PLC's program. When the operator presses the button, the HMI writes a "1" to that tag in the PLC, which then triggers the PLC's logic to start the motor.
- **Polling:** The HMI constantly polls (requests data from) the PLC to get the latest values for all the tags it needs to display, like temperature, pressure, or motor speed. This ensures the information on the HMI is always in sync with the live process.



Self-Check 5.3-1

1. What is the most common and standard physical medium used for high-speed communication between a modern industrial PLC and an HMI?
2. What is the primary function of the protocol (e.g., EtherNet/IP, Modbus TCP) that must be matched between the PLC and the HMI?
3. What critical interface step is required for an HMI text display object to successfully monitor the value of a PLC timer's Accumulated Time?

4. Which two specific network settings must be coordinated between the PLC and the HMI for them to reside on the same local network segment?
5. If an HMI uses a Numeric Input Object to allow an operator to enter a floating-point value (e.g., 95.5 °C) into the PLC, what must the linked PLC memory tag's data type be?
6. What is the term for the process where the HMI continuously requests or retrieves the current data values from the PLC's memory tags?
7. If a technician successfully uses the PING command to test connectivity to the PLC, but the HMI still displays "No Communication," what is the most likely cause?



Answer Paper 5.3-1

1. Twisted-Pair Ethernet Cable (RJ45).
2. It defines the language, rules, and data structure for how the PLC and HMI exchange information.
3. Link the HMI object's Read Address directly to the PLC's timer Accumulated Value tag address.
4. The IP Address and Subnet Mask settings.
5. Floating Point (REAL), which supports decimal numbers.
6. Tag Polling or Data Refresh Rate.
7. The HMI is configured to use the wrong PLC Communication Protocol or Port Setting.

	Job Sheet 36
Qualification	Industrial Automation
Learning Unit	Carry Out Interface between PLC and HMI

Trainee Name	
PPE	Safety shoes, safety goggles, hand gloves
Tools & Equipment	• PLC (with powered I/O terminals) • HMI panel (touchscreen or display unit) • PC/Laptop with HMI configuration software • Programming cables for PLC and HMI • Input devices (sensors, pushbuttons) • Output devices (motors, lamps, actuators) • Multimeter (DMM) • Connecting wires • Network cables (if communication uses Ethernet/RS-485)
Notes	PLC-HMI interfacing allows real-time communication between the programmable logic controller and the Human Machine Interface. This enables operators to monitor process parameters, control outputs, view trends, and respond to alarms. Proper interfacing ensures reliable data exchange, accurate control, and operator safety.
Procedure	1. Ensure all PPE is properly worn and the workspace is safe. 2. Power on the PLC and HMI panel, and establish physical connections using the correct communication interface (e.g., RS-232, RS-485, Ethernet). 3. Open the HMI configuration software on the PC/Laptop. 4. Create a new HMI project and select the PLC model and communication protocol. 5. Define PLC tags for all inputs, outputs, and internal registers required for monitoring and control. 6. Map these PLC tags to HMI objects, such as buttons, switches, indicators, gauges, and numeric displays. 7. Configure screen navigation including main, sub, and alarm screens. 8. Download the HMI project to the HMI panel. 9. Test communication:

	10. Manipulate PLC inputs and verify corresponding changes on the HMI. 11. Operate control elements from HMI and verify correct response from PLC outputs. 12. Check for data accuracy, response time, and stability. 13. Troubleshoot any communication or mapping issues, adjusting tags or settings as needed. 14. Record observations, including successful data exchange and any communication errors. 15. After testing, power off the system safely and store all tools and equipment.
Trainee's Signature	
Assessor's Signature	
QA Signature	
Assessor's Comment	

Learning Outcome 5.4 – Visualize the Process in HMI



Content

- Contact States (Inputs): Normally Open (NO) contacts must be ON (closed) for current to pass. Normally Closed (NC) contacts must be OFF (open) for current to pass.
- Coil Activation (Outputs): If current reaches the output coil (()), the coil energizes (turns ON).
- State Change (Feedback): An energized coil causes all of its associated contacts throughout the diagram to change state: NO contacts close, and NC contacts open, influencing the logic of other rungs.



Assessment Criteria

- Ability to Map Diagram to Logic Gates
- Predicting Output State Based on Inputs
- Understanding Latching/Sealing Circuit Function



Necessary Equipment

- Relay
- Magnetic Contactor
- Timer
- Switch

- Load
- Auxiliary Device



Learning Activity 5.4-1

Learning Activity	Resources/ Instructions/ References
Visualize the Process in HMI	• Information Sheet: 5.4-1 • Self-Check: 5.4-1 • Answer Paper: 5.4-1



Information Sheet 5.4-1

Learning Objective: The learner will be able to design and implement a graphical representation of an industrial process on an HMI, accurately linking dynamic objects to PLC data for effective visualization and control.

Visualizing Process in HMI

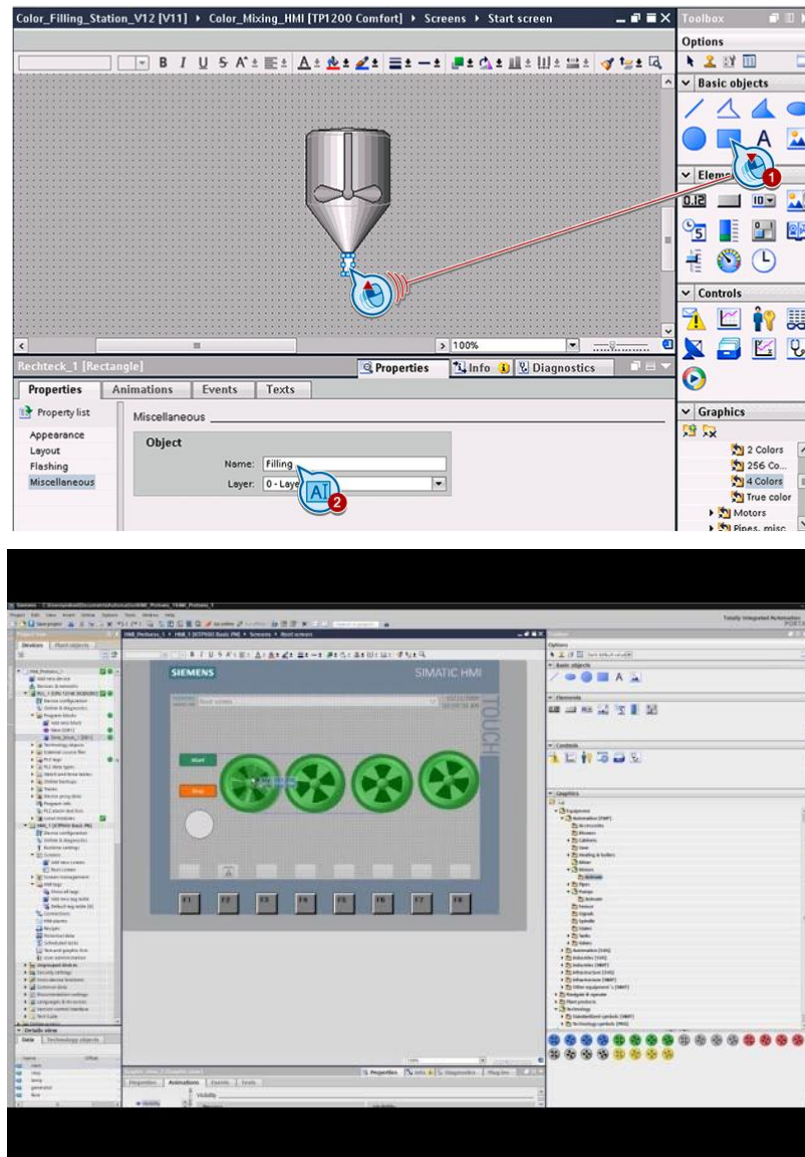


Fig: Visualizing Process in HMI



Self-Check 5.4-1

1. Which HMI visualization technique should be strictly reserved for indicating a critical or fault condition?

2. What is the main benefit of designing HMI numeric input fields to be larger than standard text elements on a touchscreen control screen?
3. What visual element is used on an HMI to clearly show the relationship between a tank's current level measurement and its high level set point (target)?
4. To effectively manage screen space and group related controls (e.g., Start/Stop) for a specific device, what single, dedicated area is often used?
5. What is the primary purpose of using animation (e.g., color changes or motion) on HMI process graphics?
6. Why is it considered a best practice to use muted, low-saturation colors (e.g., gray or light blue) for the HMI screen background?
7. What three critical pieces of information must an HMI's Alarm Summary Display provide for every alarm condition?



Answer Paper 5.4-1

1. Using high-saturation, flashing, or inverse colors (e.g., flashing red) for the equipment graphic and status text.
2. It improves usability by making the target easier for the operator to press with a finger or stylus on a touchscreen.
3. A Trend Chart with a setpoint line or a Vertical Gauge with a marker.
4. A Group Box, Faceplate, or Pop-up Window.
5. To clearly communicate the Status (ON/OFF, Running/Stopped) and Direction (Flow) of equipment in a rapid, intuitive manner.
6. To ensure that high-saturation colors (e.g., bright red for an alarm) have maximum visual contrast and draw the operator's immediate attention.
7. The Alarm Priority, Status (Active/Inactive, Acknowledged/Unacknowledged), and the Time Stamp.

Module 6: Operate Pneumatic and Hydraulic System Using PLC



Contents of Module

Module Description

This unit of competency covers the knowledge, skills and attitudes required to operate pneumatic and hydraulic control system using PLC. It specifically includes the tasks of identifying pneumatic and hydraulic system components, installing and configuring PLC, developing PLC programs for pneumatic control system, developing PLC programs for hydraulic control system and testing, and running PLC controlled pneumatic and hydraulic systems.

Minimum Time: 30 Hours



Learning Outcome

- 6.1. Identify Pneumatic and Hydraulic System Components
- 6.2. Install and Configure PLC
- 6.3. Develop PLC Program for Pneumatic Control System
- 6.4. Develop PLC Program for Hydraulic Control System
- 6.5. Test and run PLC- Controlled Pneumatic and Hydraulic Systems



Performance Criteria

1. Pneumatic system and Hydraulic system are interpreted and described.
2. Components for pneumatic and hydraulic control system are recognized and classified.
3. The operating principles of pneumatic and hydraulic components are interpreted.
4. Safety features associated with pneumatic and hydraulic systems are identified and explained.
5. Installation site and equipment for PLC integration with pneumatic and hydraulic systems are inspected and prepared.
6. PLC hardware components are installed and connected.
7. Wiring between PLC and pneumatic and hydraulic components are carried out.
8. PLC software is installed and configured to control pneumatic and hydraulic system operations.
9. Valve sequencing is performed using PLC.
10. A two-step control system is executed to regulate and maintain pressure within specified limits.
11. Three-step control system is executed to provide enhanced pressure control as per system requirements.
12. Valve sequencing is performed using PLC according to system requirements.
13. Two-step control system is executed to regulate pressure within specified parameters.
14. Three-step control system is executed to provide advanced pressure control.
15. Control circuit for controlling pneumatic and hydraulic system is tested.
16. Operation of the systems is conducted according to testing protocols.
17. Faults and irregularities during operation are identified, diagnosed, and resolved.
18. System responses to control commands are monitored and recorded.
19. Test results and fault resolution actions are documented.

Learning Outcome 6.1 – Identify Pneumatic and Hydraulic System Components



Content

- **Fluid Power Fundamentals:** Understand the basic principles of pneumatics (compressed air) and hydraulics (pressurized liquid), including the concepts of pressure, flow, and the differences in their industrial applications.
- **Key System Components:** Identify the function and symbolism of core components, including the power source (e.g., compressor/pump, reservoir), actuators (cylinders/motors), and control elements (valves).
- **Valve Types and Function:** Learn to differentiate between various control valves, such as Directional Control Valves (DCV) (e.g., 3/2, 5/2-way), Flow Control Valves, and Pressure Control Valves, and recognize their schematic symbols.



Assessment Criteria

- Component Recognition
- Symbol Interpretation
- Classification by Function



Necessary Equipment

- Pneumatic Trainer Kit
- Hydraulic Component Samples (or Models)
- Schematic Symbols Chart
- Technical Documentation
- Measuring Tools



Learning Activity 6.1-1

Learning Activity	Resources/ Instructions/ References
Identify Pneumatic and Hydraulic System Components	• Information Sheet: 6.1-1 • Self-Check: 6.1-1 • Answer Paper: 6.1-1 • Job Sheet 37



Information Sheet 6.1-1

Learning Objective: The learner will be able to identify and explain the function of the primary components used in pneumatic and hydraulic systems, including actuators, power sources, and control valves, using standard ISO schematic symbols.

Operate Pneumatic and Hydraulic Control System using PLC

Operating a pneumatic or hydraulic control system with a Programmable Logic Controller (PLC) involves using the PLC as the central brain to automate the process. In both systems, sensors provide input signals to the PLC, which then processes this information based on a pre-programmed logic. The PLC's output signals are sent to solenoid valves, which are the electrical-to-fluid interface. These valves control the flow of the working fluid—compressed air for pneumatic systems or hydraulic oil for hydraulic systems—to actuators like cylinders or motors.

This integration allows for precise control over the sequence and timing of operations, enhances system flexibility by simplifying logic changes, and provides diagnostic capabilities that help with troubleshooting and maintenance. The fundamental difference lies in the working fluid and the power they can deliver: pneumatics are fast and clean, while hydraulics are powerful and precise, making the PLC's role crucial in managing the unique characteristics of each system for various industrial applications.

Pneumatic System

A **pneumatic system** is a power system that uses compressed air or another gas to perform work. The process starts with a compressor that takes in atmospheric air, which is then filtered, dried, and pressurized. This high-pressure air is stored in a receiver or tank before being distributed through a network of pipes and hoses to various components. At the heart of the system are **actuators** (such as cylinders or motors) that convert the energy from the compressed air into mechanical motion, either linear or rotary. The flow of air to these actuators is precisely controlled by **valves**, which are the directional control elements. Pneumatic systems are valued in many industries for their cleanliness, safety (as air is not flammable), and fast response times, making them ideal for applications ranging from factory automation and robotics to dental drills and air brakes.

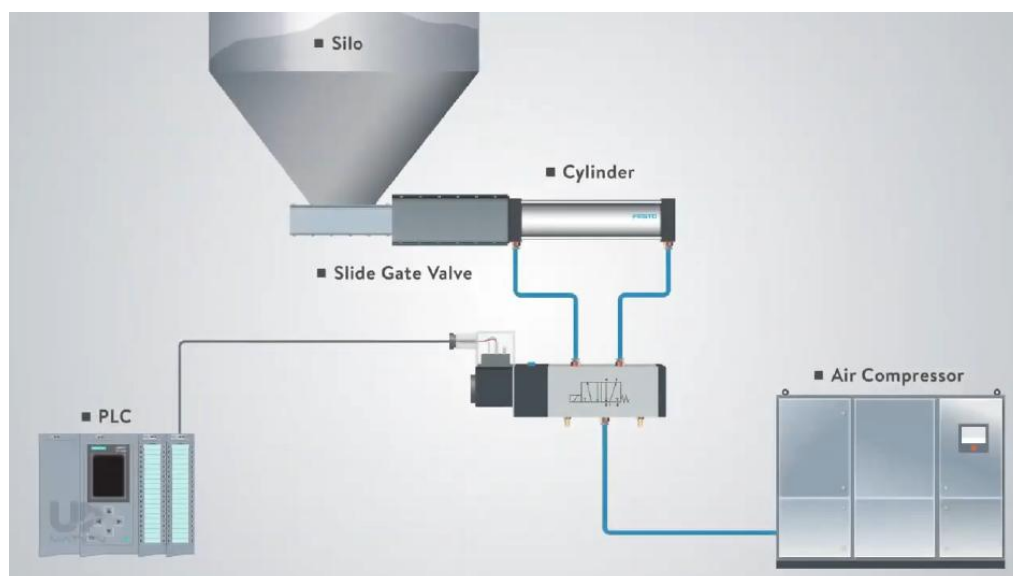


Fig: Pneumatic Control System

Working Principle of Pneumatic Systems

The working principle of pneumatic systems is based on the use of **compressed air** to transmit and control energy, ultimately converting it into mechanical motion. This process involves a series of interconnected components that work in a coordinated sequence. The system begins with an **air compressor**, which draws in atmospheric air and increases its pressure and temperature. This high-pressure air is then typically stored in a receiver tank to ensure a continuous and stable supply. Before being used, the air is usually passed through an **air preparation unit**, often consisting of a filter, regulator, and lubricator (FRL) that cleans the air, adjusts its pressure to the required level, and adds a fine mist of oil to lubricate downstream components.

This "conditioned" air is then directed to **valves**—the control elements of the system—that manipulate its flow, pressure, and direction. The valves are the interface that allows an operator or a programmable logic controller (PLC) to direct the compressed air to **actuators**, which are the final output devices. Common actuators include pneumatic cylinders, which produce linear motion (pushing or pulling a load), and air motors, which create rotary motion. The energy of the compressed air exerts a force on a piston within a cylinder or a vane within a motor, causing it to move and perform a specific task, such as clamping, lifting, or rotating. Once the work is done, the air is exhausted from the system, often vented directly to the atmosphere.

Applications of Pneumatic Systems

Pneumatic systems are widely used in various industries due to their safety, cleanliness, and efficiency. They are found in applications ranging from heavy-duty industrial machinery to precision medical equipment.

Industrial Automation and Manufacturing

In manufacturing, pneumatic systems are used for a wide range of tasks, including the operation of automated assembly lines. Their speed and power make them ideal for tasks like **lifting**,

clamping, punching, and stamping. Pneumatic grippers are a common application, used by robotic arms to pick and place items on a production line. **Pneumatic presses and cylinders** are essential for tasks like forming and molding plastics and metals.

Food and Beverage Industry

The cleanliness of pneumatic systems, as they don't use oil that could contaminate products, makes them a preferred choice in the food and beverage industry. Applications include **bottling and capping machines, packaging equipment, and sorting systems**. Pneumatic systems are also used to control valves and actuators in liquid-filling machines, ensuring precise and hygienic operation.

Medical and Dental Fields

Pneumatic technology is crucial in the medical sector. **Dental drills and tools** are a prime example, using high-speed air turbines for their operation. In hospitals, pneumatic systems power **surgical tools, hospital beds, and patient lifts**. Their clean and reliable operation is critical for patient safety and precise control.

Construction and Transportation

In construction, **pneumatic tools** like jackhammers, nail guns, and concrete vibrators are powered by portable air compressors. The transportation sector relies on pneumatic systems for a variety of functions, including **air brakes in trucks and buses** and the **suspension systems** that provide a smoother ride.

Aerospace Industry

Pneumatic systems are used in aircraft for a variety of tasks where hydraulic power might be too heavy or complex. This includes **landing gear actuation, cargo door operation, and de-icing systems**. They are also used to power air-driven gyroscopes and attitude indicators in cockpits.

Advantages of Pneumatic Systems

Pneumatic systems offer numerous advantages that make them a popular choice for a wide range of industrial and commercial applications. These benefits often outweigh their limitations, especially in environments where safety and cleanliness are paramount.

Safety

Pneumatic systems are inherently safer than other power sources, such as hydraulics or electricity. Compressed air is non-flammable and non-toxic, so leaks do not pose a fire hazard or create a messy, slippery environment. This makes them ideal for use in hazardous areas where flammable materials or explosive gases are present. Additionally, pneumatic tools and actuators are designed to be spark-proof and can be operated without the risk of electric shock.

Cleanliness and Environmentally Friendly

Since the working fluid is compressed air, there is no risk of messy oil leaks or contamination of products. This is a critical advantage in industries with strict hygiene standards, such as food and beverage processing, pharmaceuticals, and medical manufacturing. Furthermore, any air that is exhausted from the system simply returns to the atmosphere without causing environmental pollution.

Simplicity and Reliability

Pneumatic systems are known for their straightforward design, which typically includes a compressor, valves, and actuators. They have fewer moving parts compared to other systems, which reduces the potential for mechanical failure and simplifies maintenance. The components

are also very durable and can withstand tough industrial environments, leading to long operating lives and high reliability.

Cost-Effectiveness

While the initial cost of a compressor can be significant, the overall cost of a pneumatic system is often lower than that of a hydraulic or electrical system. The components are generally made from inexpensive materials like aluminum and plastic, and the working medium (air) is free and readily available. Additionally, the low maintenance requirements and durability of the components contribute to a lower long-term operating cost.

Speed and Versatility

Pneumatic systems are capable of providing very fast and responsive motion, making them well-suited for high-speed automated tasks like clamping, sorting, and packaging. The system's pressure and speed can be easily adjusted to suit different applications, offering a high degree of versatility.

Overload Protection

Because air is a compressible gas, it acts as a cushion that can absorb sudden shocks and prevent damage from overloads. This compressibility provides a built-in safety mechanism that protects both the equipment and the load from excessive force.

Components of Pneumatic Systems

A pneumatic system consists of several key components that work together to convert compressed air into mechanical work. It begins with the **air compressor**, which takes in atmospheric air and pressurizes it. This compressed air is then typically stored in an **air receiver** or tank to ensure a steady supply. Before the air can be used, it goes through an **air preparation unit**, often a combined filter, regulator, and lubricator (**FRL**), to remove contaminants and moisture, set the pressure to the desired level, and add lubrication if needed. The conditioned air then travels through **valves**, which control the direction.

Pneumatic Generation Devices

Pneumatic generation devices are tools or instruments that utilize compressed air as their power source. They encompass a wide range of applications, from industrial machinery to everyday household appliances.

- **Air Compressor:**

The heart of any pneumatic system, the air compressor draws in atmospheric air and compresses it to a higher pressure. Compression can be achieved through various methods, such as rotary screw, reciprocating piston, or rotary vane.



Fig: Air Compressor

- **Air Receiver/Storage Tank:**

Stores compressed air, smoothing out pressure fluctuations and providing a reserve supply.



Fig: Storage Tank

- **Air Treatment Units:**

These units prepare the compressed air for use by removing impurities like moisture, oil, and particulates. Common components include air dryers, filters, and lubricators.



Fig: Air Treatment Plant

Pneumatic Control Devices

Pneumatic Control Devices are components that use compressed air to regulate and control the flow and pressure of air within a pneumatic system. They are essential for precise operation and automation in various industrial and mechanical applications.

- **Solenoid Valves**

These valves use an electromagnetic coil to open or close a passage for compressed air. They are commonly used for on/off control or to direct air flow to different parts of a system.



Fig: Solenoid Valve

- **Directional Control Valves**

These valves control the direction of air flow, allowing it to move in different paths within the system. They can be used to extend or retract pneumatic cylinders, control rotary actuators, or switch between different functions.

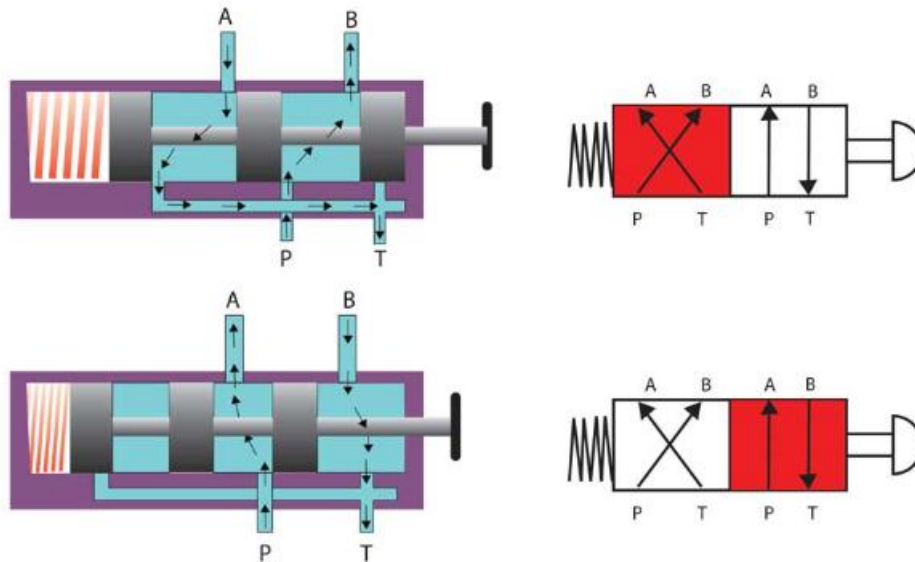


Fig: Direction Control Valves

- **Pressure Regulators**

These devices reduce and maintain a constant downstream pressure, regardless of upstream pressure fluctuations. They ensure consistent operation of pneumatic devices even when the supply pressure varies.



Fig: Pressure Regulator

- **Flow Control Valves**



Fig: Pneumatic Flow Control Valve

These valves restrict the flow of air, controlling the speed and rate of movement of pneumatic actuators. They are used to fine-tune the operation of devices and prevent excessive speeds or forces.

- **Mufflers and Silencers**

These devices reduce the noise generated by the exhaust of compressed air from pneumatic devices. They are important for creating a quieter and more comfortable working environment.

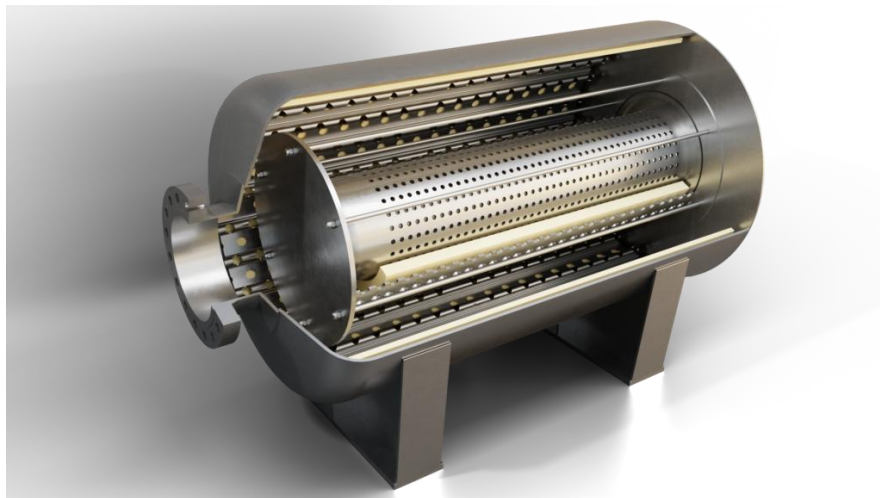


Fig: Industrial Silencers

Pneumatic Actuating Devices

Pneumatic actuating devices are mechanical components that convert the energy of compressed air into linear or rotary motion. They are essential for a wide range of industrial and mechanical applications, providing precise and powerful movement.

Pneumatic Cylinders

- ✓ These devices convert compressed air pressure into linear motion.
- ✓ They consist of a cylindrical chamber with a piston that moves back and forth within the chamber.
- ✓ When compressed air is introduced into one side of the cylinder, it forces the piston to move, extending or retracting a connected rod.

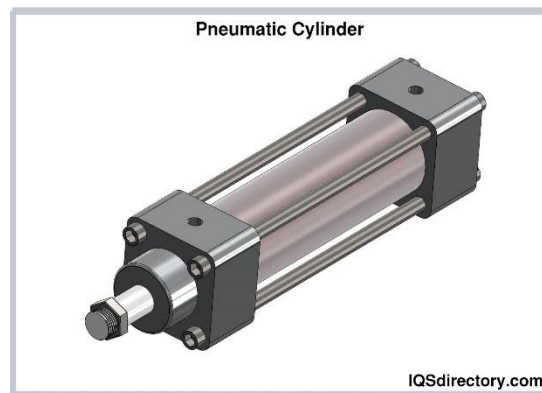


Fig: Pneumatic Cylinder

Pneumatic Motors

- ✓ These devices convert compressed air energy into rotary motion.
- ✓ They are similar in principle to internal combustion engines, using the expansion of compressed air to rotate a shaft.
- ✓ Pneumatic motors are available in various configurations, including vane motors, gear motors, and axial piston motors.

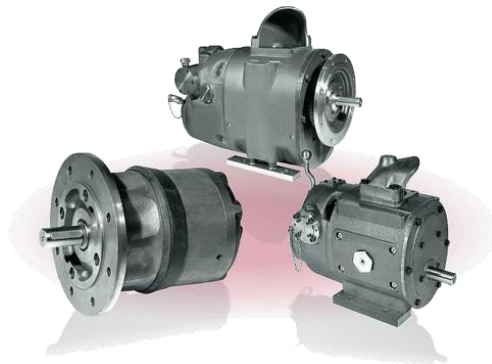


Fig: Pneumatic Motor

Hydraulic System

A hydraulic system uses an incompressible fluid, like oil, to transmit force and motion from one point to another. It operates based on **Pascal's Principle**, which states that a pressure change at any point in a confined incompressible fluid is transmitted throughout the fluid such that the same change occurs everywhere. In a typical setup, a small force applied to a small piston creates pressure in the fluid, which is then transmitted to a larger piston, generating a much larger force. This ability to multiply force makes hydraulic systems highly effective for heavy-duty applications such as in car brakes, construction equipment, and elevators. The system consists of a pump, which moves the fluid, and various valves, which control the flow and pressure, along with cylinders and pistons that convert the fluid pressure into mechanical work.

Working Principle of Hydraulic Systems

A hydraulic system operates by using a **pressurized, incompressible fluid** (like oil) to transmit force and motion from a small area to a larger one. Its fundamental working principle is **Pascal's Law**. Pascal's Law states that a pressure change at any point in a confined incompressible fluid is transmitted throughout the fluid such that the same change occurs everywhere. This is the key to how a hydraulic system can multiply force.

In a basic hydraulic system, a small piston (with area A_1) is connected to a larger piston (with area A_2) by a fluid-filled conduit. When a small force (F_1) is applied to the small piston, it creates a pressure (P_1) in the fluid, calculated as: $P_1 = A_1 F_1$.

According to Pascal's Law, this pressure (P_1) is transmitted equally to the larger piston (P_2), meaning $P_1 = P_2$. The force (F_2) exerted on the larger piston can then be calculated using the same formula: $F_2 = P_2 \times A_2$.

Since $P_1 = P_2$, we can combine these equations to see the force multiplication effect: $A_1 F_1 = A_2 F_2$. This shows that the output force (F_2) is greater than the input force (F_1) by a factor equal to the ratio of the areas of the two pistons (A_1/A_2). This is the **mechanical advantage** of the system.

For example, if the area of the large piston is 10 times that of the small piston, a 10-pound force applied to the small piston will generate a 100-pound force on the large piston.

Applications of Hydraulic Systems

Hydraulic systems are used in a wide range of industries and everyday life due to their ability to generate immense force and maintain precise control.

- **Construction:** Heavy machinery like excavators, bulldozers, cranes, and backhoes rely on hydraulics for lifting, digging, and moving heavy materials.
- **Automotive:** Hydraulic brakes in cars use fluid to amplify the force from the brake pedal, and hydraulic jacks are used to lift vehicles for maintenance.
- **Aerospace:** Landing gear, wing flaps, and flight control surfaces on aircraft are often operated by hydraulic systems for their reliability and power-to-weight ratio.
- **Manufacturing:** Hydraulic presses, molding machines, and robotic arms in factories use hydraulic power for tasks requiring high force and precision.

Advantages of Hydraulic Systems

Hydraulic systems offer several benefits over mechanical, pneumatic, or electrical systems:

- **High Power Density:** They can transmit a large amount of power using relatively small components.
- **Precision and Control:** The incompressibility of the fluid allows for very accurate and smooth control of motion and force.
- **Overload Protection:** Pressure relief valves can be incorporated to protect the system from damage if the load exceeds a certain limit.
- **Smooth Operation:** The fluid medium reduces friction and wear, leading to smoother operation and longer component life.
- **Versatility:** Hydraulic lines can be routed easily, offering flexibility in machine design.

Components of Hydraulic Systems

A complete hydraulic system consists of several key components that work together to generate, control, and use fluid power.

Hydraulic Generation Devices

These devices are responsible for creating the flow of pressurized hydraulic fluid. The main component is the **hydraulic pump**. It draws fluid from a reservoir and pushes it through the system, converting mechanical energy from a motor (electric or internal combustion) into hydraulic energy. There are various types, including gear, vane, and piston pumps, each suited for different pressure and flow requirements.

Hydraulic Control Devices

These components regulate the flow, pressure, and direction of the hydraulic fluid. **Hydraulic valves** are the primary control devices. They can be manually, electrically, or pneumatically operated. Common types of valves include:

- **Directional Control Valves:** These valves direct the fluid to the correct actuator to control the direction of movement.
- **Pressure Control Valves:** These valves maintain, reduce, or relieve pressure within the system to ensure safety and proper operation.
- **Flow Control Valves:** These valves regulate the rate of fluid flow to control the speed of the actuators.

Hydraulic Actuating Devices

Hydraulic actuators convert the fluid's pressure and flow back into mechanical motion to perform a task. They are the "muscle" of the system.

- **Hydraulic Cylinders:** These are the most common type of linear actuator. A pressurized fluid acts on a piston inside a cylinder, causing it to extend or retract. They are used for pushing, pulling, lifting, and clamping.

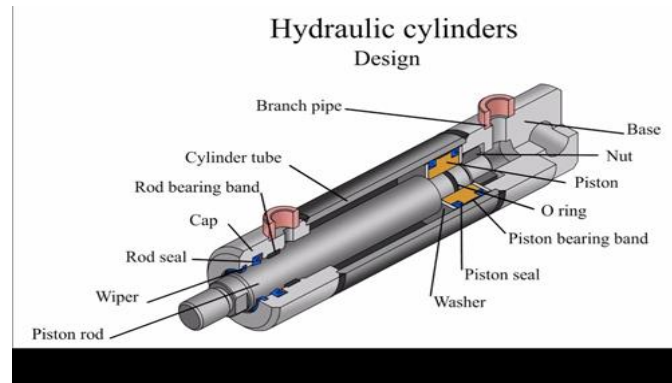


Fig: Hydraulic Cylinder

- **Hydraulic Motors:** These are rotary actuators that use hydraulic pressure to produce continuous rotational motion (torque). They are used to turn shafts, wheels, and other rotating components.



Fig: Hydraulic Motor



Self-Check 6.1-1

1. What is the primary purpose of a Regulator in a fluid power system?
2. In IEC 61131-3 notation, what do the 5 and 2 represent in a 5/2 Directional Control Valve?
3. What specific component in a pneumatic system is designed to remove solid contaminants and condensed water from the compressed air?
4. Why is a Pump considered essential in a typical hydraulic system, but not in a local pneumatic system?
5. What is the functional difference in the power source for motion between a Single-Acting Cylinder and a Double-Acting Cylinder?
6. Besides storing the fluid, what other two critical functions does the Reservoir perform in a hydraulic system?
7. What is the main safety function of a Pressure Relief Valve in a hydraulic system?



Answer Paper 6.1-1

1. The primary purpose of a Regulator is to limit and maintain the system's working pressure at a constant, lower value than the supply pressure.
2. The 5 represents the number of connection ports, and the 2 represents the number of operating positions the valve can shift into (e.g., Extend and Retract).
3. The Filter (part of the FRL unit) physically removes solid particles (rust, scale) and condensed water from the compressed air.

4. A hydraulic system requires a Pump to actively pressurize the liquid, whereas a pneumatic system utilizes compressed air supplied by a central Compressor (often separate from the local system).
5. A Double-Acting Cylinder uses fluid power for both extension and retraction strokes, while a Single-Acting Cylinder uses fluid power for only one stroke and a spring or external force for the other.
6. The Reservoir allows for heat dissipation from the fluid and provides a settling area for contaminants to fall out of suspension.
7. Its main safety function is to divert excess fluid back to the reservoir when the system pressure exceeds a predetermined maximum limit, thus protecting components from over-pressurization.

	Job Sheet 37
Qualification	Industrial Automation
Learning Unit	Identify Pneumatic and Hydraulic System Components
Trainee Name	
PPE	Safety glasses, gloves, steel-toe boots, ear protection
Tools & Equipment	Spanners, Allen keys, pressure gauge, flow meter, hose cutter, component ID chart
Notes	Ensure all components are depressurized before handling. Verify system tags.
Procedure	1. Wear appropriate PPE 2. Collect required tools and equipment 3. Inspect the pneumatic and hydraulic panels 4. Identify components such as compressors, actuators, valves, cylinders, filters, regulators, and reservoirs 5. Record and label each component correctly 6. Report any damage or wear to supervisor

Trainee's Signature	
Assessor's Signature	
QA Signature	
Assessor's Comment	

Learning Outcome 6.2 – Install and Configure PLC



Content

- I/O Mapping for Fluid Power: Understand how to map PLC inputs (e.g., limit switches, pressure sensors) and outputs (e.g., solenoid valve coils, pump contactors) to the pneumatic and hydraulic system schematics.
- Interfacing Solenoid Valves: Learn the electrical wiring and power requirements for interfacing PLC digital outputs with industrial solenoid coils on directional control valves (DCVs) in both pneumatic and hydraulic systems.
- PLC Sequence Programming: Develop and implement ladder logic programs (including timing and counting instructions) to achieve required fluid power sequences, such as automatic cylinder cycling or pump control with safety interlocks.



Assessment Criteria

- Correct I/O Wiring and Power
- Functional Sequence Execution
- Safety Interlock Verification



Necessary Equipment

- Programmable Logic Controller (PLC)
- Fluid Power Trainer System

- Connecting Cables and Wires
- Programming Computer and Software
- Digital Multimeter (DMM)



Learning Activity 6.2-1

Learning Activity	Resources/ Instructions/ References
Install and Configure PLC	• Information Sheet: 6.2-1 • Self-Check: 6.2-1 • Answer Paper: 6.2-1 • Job Sheet 38



Information Sheet 6.2-1

Learning Objective: The learner will be able to safely install and correctly wire PLC I/O modules to sensors and solenoid valves and perform the necessary hardware and software configuration to prepare the PLC to control a fluid power system.

PLC Program, Test, and Run for Pneumatic and Hydraulic Control Systems

To program, test, and run a PLC for pneumatic and hydraulic control systems, you must follow a structured process that involves hardware, software, and safety protocols. The core of this work is **ladder logic programming**, which is a graphical programming language that mimics the relay logic of older electrical control systems.

PLC Selection and Installation (The Hardware)

A. System Planning and Selection

- **I/O Requirement:** Count the total number of Digital Inputs (DI) (e.g., limit switches, pressure switches), Digital Outputs (DO) (e.g., solenoid valve coils), and any Analog I/O (e.g., proportional valve commands, pressure transducers). Choose a PLC model with sufficient I/O capacity, allowing for 20-30% future expansion.
- **Processing Speed:** Select a PLC with a fast scan time suitable for the dynamic response required by the hydraulic or pneumatic actuators.
- **Network:** Determine required communication protocols (e.g., Ethernet/IP, Profibus) for HMI or SCADA integration.

B. Panel Installation

- **Mounting:** Install the PLC and its modules on a standard DIN rail within a protective control panel. Ensure adequate spacing for cooling and wiring access.
- **Power Supply:** Use a dedicated, appropriately sized 24 VDC power supply for the PLC and I/O field devices. Use a separate power source, if necessary, for high-power hydraulic or pneumatic valves (e.g., 120 VAC or 24 VDC from a power bus).
- **Grounding and Shielding:** Properly ground the PLC chassis and power supply. Use shielded cables for analog signals and high-speed communication lines to mitigate electrical noise (EMI/RFI) common in industrial environments.

C. Wiring I/O

- Inputs (Sensors): Wire proximity sensors, limit switches (position feedback), and pressure/level switches to the PLC's DI terminals. Use the PLC's internal common (24 VDC or 0 VDC) according to the sensor's NPN (sinking) or PNP (sourcing) type.
- Outputs (Actuators): Wire the coils of the solenoid directional control valves (pneumatic/hydraulic) to the PLC's DO terminals. Ensure the output module's voltage and current rating can safely drive the valve coils. For high-current valves, use an interposing relay between the PLC output and the valve coil.



Self-Check 6.2-1

1. What type of PLC output module is required to energize a 24VDC solenoid coil on a directional control valve?
2. Which specific type of PLC input module is necessary to correctly read an analog position sensor that provides a continuous 4-20mA current signal?
3. When controlling a pneumatic cylinder, what is the primary function of adding a Timer On-Delay (TON) instruction after commanding the actuator to extend?
4. If a Normally Open (NO) pressure switch on an FRL unit closes to indicate "pressure READY", which PLC instruction confirms this TRUE READY state?
5. What is the technical term for the process of converting a PLC's raw integer count from an analog input (e.g., 0 - 16384) into engineering units (e.g., 0-500PSI) for use in logic?
6. When controlling a hydraulic pump motor via a Variable Frequency Drive (VFD), what parameter of the motor is the PLC's analog output signal used to adjust?
7. What is the crucial field check that must be performed when installing a cylinder end-of-stroke sensor to ensure it functions reliably?



Answer Paper 6.2-1

1. A Digital Output Module (Sourcing or Sinking Type) is required to provide the ON/OFF voltage or current needed to switch the solenoid coil.
2. A Current-Sensing Analog Input Module is specifically required to correctly measure and interpret the continuous 4-20mA current range from the sensor.
3. The TON instruction provides a safety margin to ensure the actuator has a minimum amount of time to physically reach its end-of-stroke before the PLC proceeds to the next sequence step.
4. An Examine if Closed (XIC) instruction is used. Since the NO switch closes, the PLC input is TRUE, making the XIC instruction TRUE and confirming the READY state.
5. The process is called Signal Scaling, which maps the raw PLC data range to the sensor's physical engineering units.
6. The analog signal is used to control the VFD's Voltage and Frequency, which in turn adjusts the flow rate of the pump.
7. The sensor must be physically positioned and checked to reliably activate turn ON when the cylinder is in the desired end position and deactivate turn OFF when it begins to move away.

	Job Sheet 38
Qualification	Industrial Automation
Learning Unit	Install and Configure PLC for Pneumatic and Hydraulic System
Trainee Name	
PPE	Safety glasses, insulated gloves, safety boots, ear protection
Tools & Equipment	Laptop with PLC programming software, PLC unit, I/O modules, multimeter, screwdrivers, wiring tools, pneumatic/hydraulic test bench

Notes	Ensure all power sources are isolated before beginning work. Double-check all wiring connections before powering up the PLC.
Procedure	1. Wear all necessary PPE. 2. Collect and inspect required tools and equipment. 3. Install the PLC unit near the control panel. 4. Connect input/output devices to the PLC (e.g., sensors, solenoids). 5. Use the laptop to load or write the control program. 6. Download the program to the PLC. 7. Test the system using simulation or step-by-step real-time execution. 8. Verify correct operation of pneumatic and hydraulic components via PLC control. 9. Document the setup and program. 10. Shut down and store equipment safely.
Trainee's Signature	
Assessor's Signature	
QA Signature	
Assessor's Comment	

Learning Outcome 6.3 – Develop PLC Program for Pneumatic and Hydraulic Control Systems



Content

- Sequential Control Logic: Learn to design and implement step-by-step sequential control programs for fluid power systems using SET/RESET instructions or the Shift Register/Step Ladder method to ensure proper component operation order.
- Safety Interlocks and Emergency Stops: Incorporate robust electrical and programming interlocks to prevent simultaneous activation of opposing solenoids and design the Emergency Stop (E-Stop) logic for immediate, safe system shutdown.
- Timing and Counter Control: Integrate PLC Timer and Counter instructions (e.g., TON/TOF, CTU/CTD) to manage dwell times for pneumatic/hydraulic cylinders and control the number of cycles for repetitive tasks.



Assessment Criteria

- Faultless Sequence Execution
- Interlock Functionality
- Code Efficiency and Documentation



Necessary Equipment

- Programmable Logic Controller (PLC)

- Fluid Power Trainer System
- Programming Computer and Software
- Sequence Control Diagram
- Digital Multimeter (DMM)



Learning Activity 6.3-1

Learning Activity	Resources/ Instructions/ References
Develop PLC Program for Pneumatic and Hydraulic Control Systems	• Information Sheet: 6.3-1 • Self-Check: 6.3-1 • Answer Paper: 6.3-1 • Job Sheet 39 – Job Sheet 44



Information Sheet 6.3-1

Learning Objective: The learner will be able to design and implement sequential ladder logic programs using safety interlocks, timers, and counters to control and automate the operation of pneumatic and hydraulic cylinder and valve circuits.

Double Cylinder Operation for A+ B+: A- B- with TONR

For the double-cylinder sequence **A+ B+ A- B-** with a **TONR (ON-Delay Retentive Timer)**, the PLC ladder logic program must be carefully designed to ensure the correct sequence of cylinder movements and to incorporate the timing function.

System Components

- **Cylinders:** Two double-acting cylinders, Cylinder A and Cylinder B.
- **Solenoid Valves:** Four solenoid outputs to control the two cylinders.
 - **A+** (solenoid to extend cylinder A)
 - **A-** (solenoid to retract cylinder A)
 - **B+** (solenoid to extend cylinder B)
 - **B-** (solenoid to retract cylinder B)
- **Sensors (Inputs):** Four sensors to detect the position of the cylinders.
 - **A0** (sensor for Cylinder A retracted)
 - **A1** (sensor for Cylinder A extended)
 - **B0** (sensor for Cylinder B retracted)
 - **B1** (sensor for Cylinder B extended)
- **Control Inputs:**
 - **Start Button**
 - **Stop Button**
- **Timer:** A retentive ON-Delay timer (TONR). This timer holds its accumulated value even after a power loss, which is important for certain applications.

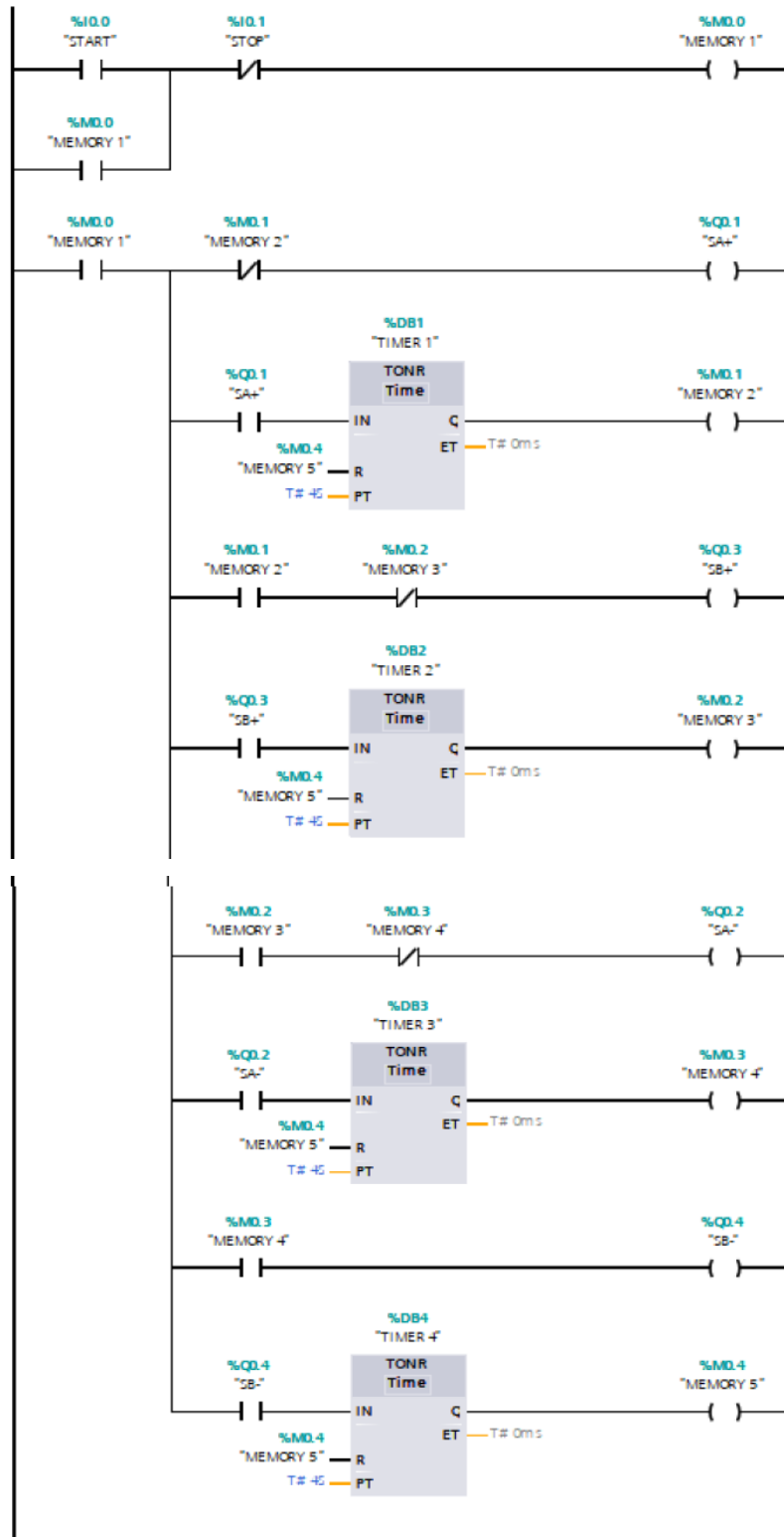


Fig: Ladder Diagram for A+ B+: A- B- with TONR operation

Double Cylinder Operation for A+ B+: B- A- with TONR

To control a double-cylinder operation with the sequence **A+ B+ B- A-** using a **TONR (Retentive ON-Delay Timer)**, you need to program a PLC with ladder logic. The retentive timer is crucial for introducing a delay between the second and third steps of the sequence.

System Components

- **Cylinders:** Two double-acting cylinders, Cylinder A and Cylinder B.
- **Solenoid Outputs:** Four solenoids to control the cylinders:
 - **A+** (to extend cylinder A)
 - **A-** (to retract cylinder A)
 - **B+** (to extend cylinder B)
 - **B-** (to retract cylinder B)
- **Sensors (Inputs):** Four position sensors:
 - **A0** (Cylinder A retracted)
 - **A1** (Cylinder A extended)
 - **B0** (Cylinder B retracted)
 - **B1** (Cylinder B extended)
- **Control Inputs:** A **Start** pushbutton to initiate the cycle and a **Stop** button for emergency stops.

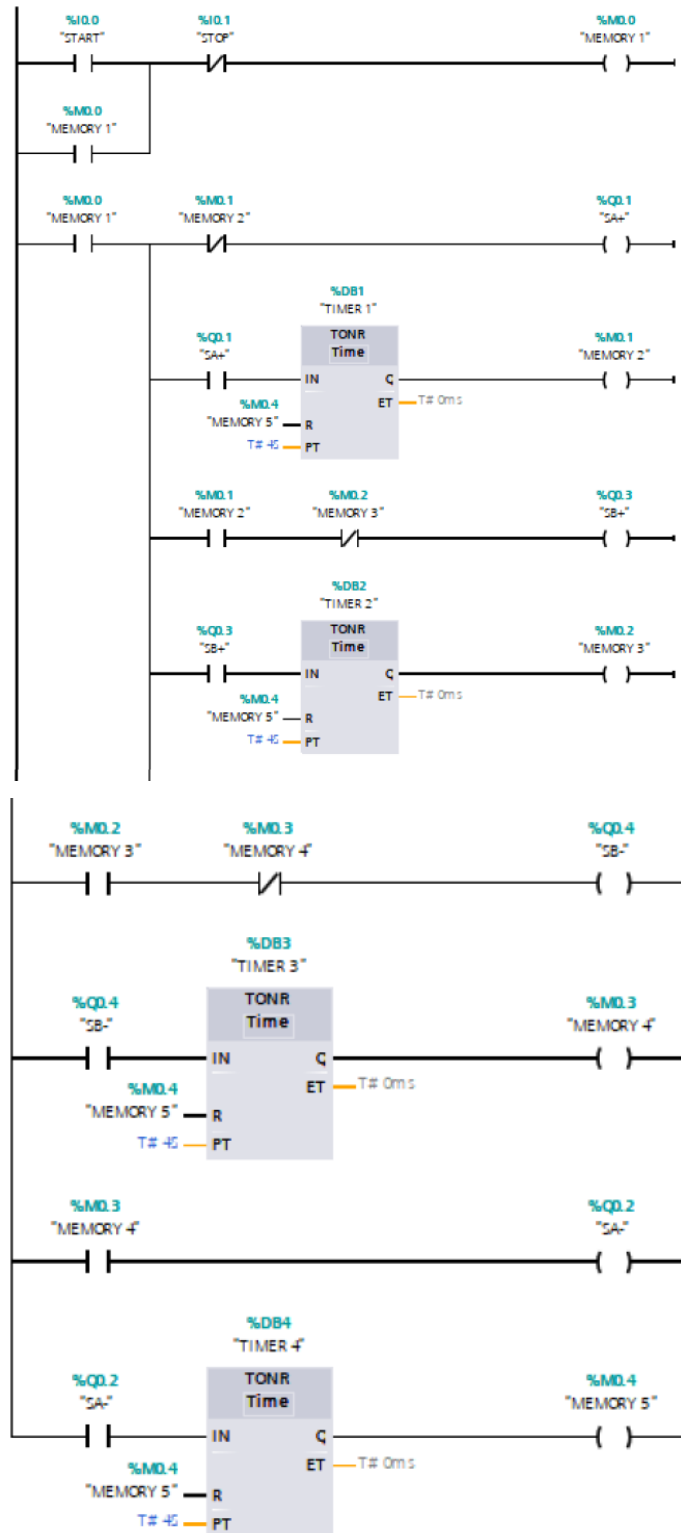


Fig: Ladder Diagram for A+ B+: B- A- with TONR operation

Double Cylinder Operation for A+ A-: B+ B- with TONR

To program a double-cylinder operation with the sequence **A+ A- B+ B-** using a PLC, you will need ladder logic that includes a **TONR (Retentive ON-Delay Timer)**. This timer will introduce a delay between the first and second cylinder operations.

System Components

- **Cylinders:** Two double-acting cylinders, Cylinder A and Cylinder B.
- **Solenoid Outputs:** Four solenoid outputs to control the cylinders:
 - **A+** (to extend cylinder A)
 - **A-** (to retract cylinder A)
 - **B+** (to extend cylinder B)
 - **B-** (to retract cylinder B)
- **Sensors (Inputs):** Four position sensors:
 - **A0** (Cylinder A retracted)
 - **A1** (Cylinder A extended)
 - **B0** (Cylinder B retracted)
 - **B1** (Cylinder B extended)
- **Control Inputs:** A **Start** pushbutton to initiate the cycle and a **Stop** button for emergency halts.

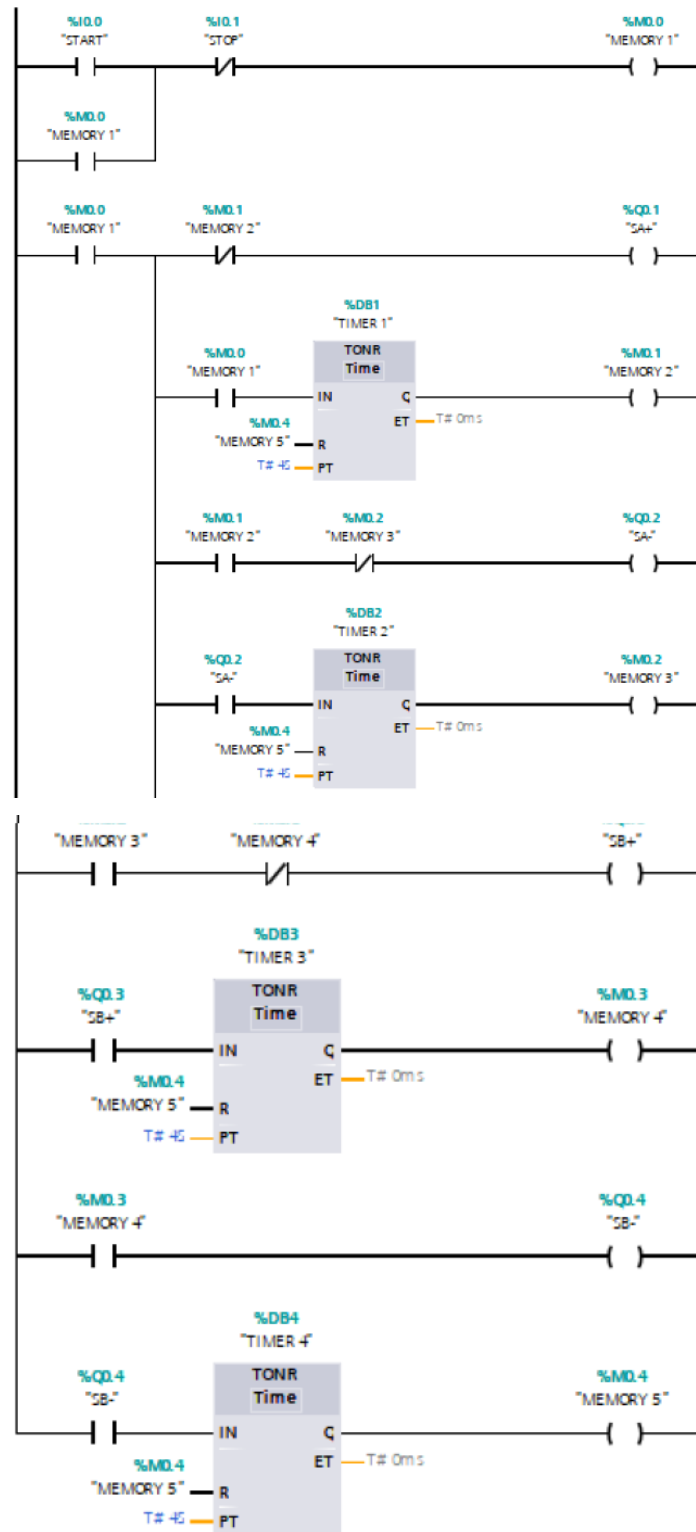


Fig: Ladder Diagram for A+ A-: B+ B- with TONR operation

Double Cylinder Operation for A+ B+: A- B- with Sensor

To program a double-cylinder operation with the sequence **A+ B+ A- B-** using a PLC, you'll need ladder logic that relies on sensors to advance the sequence. This is a basic, common control problem in industrial automation. The core principle is that the completion of one step (detected by a sensor) is the condition for starting the next step.

System Components

- **Cylinders:** Two double-acting pneumatic or hydraulic cylinders, Cylinder A and Cylinder B.
- **Solenoid Outputs:** Four solenoid valves to control the cylinders' movements:
 - **A+** (extends cylinder A)
 - **A-** (retracts cylinder A)
 - **B+** (extends cylinder B)
 - **B-** (retracts cylinder B)
- **Sensors (Inputs):** Four position sensors (e.g., limit switches or proximity sensors) to detect the cylinders' positions:
 - **A0** (Cylinder A is retracted)
 - **A1** (Cylinder A is extended)
 - **B0** (Cylinder B is retracted)
 - **B1** (Cylinder B is extended)
- **Control Inputs:** A **Start** pushbutton to initiate the cycle and a **Stop** button for halting the sequence.

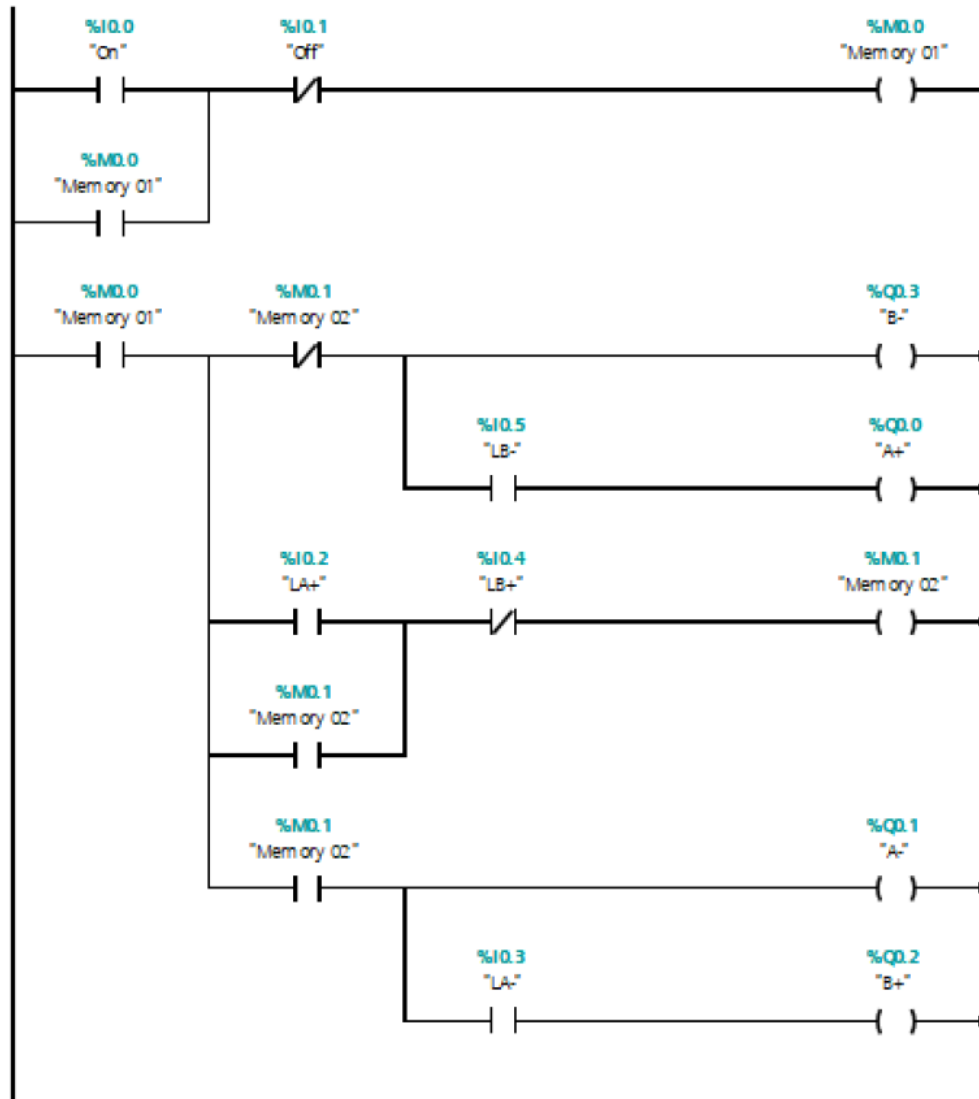


Fig: Ladder Diagram for A+ B+: A- B- with Sensor operation

Double Cylinder Operation for A+ B+: B- A- with Sensor

To program a double-cylinder operation with the sequence **A+ B+ B- A-** using a PLC, you'll need ladder logic that relies on sensors to advance the sequence. This is a fundamental sequence in automation where the completion of one step (detected by a sensor) is the condition for starting the next.

System Components

- **Cylinders:** Two double-acting pneumatic or hydraulic cylinders, Cylinder A and Cylinder B.
- **Solenoid Outputs:** Four solenoid valves to control the cylinders' movements:
 - **A+** (extends cylinder A)
 - **A-** (retracts cylinder A)
 - **B+** (extends cylinder B)
 - **B-** (retracts cylinder B)
- **Sensors (Inputs):** Four position sensors (e.g., limit switches or proximity sensors) to detect the cylinders' positions:
 - **A0** (Cylinder A is retracted)
 - **A1** (Cylinder A is extended)
 - **B0** (Cylinder B is retracted)
 - **B1** (Cylinder B is extended)
- **Control Inputs:** A **Start** pushbutton to initiate the cycle and a **Stop** button for halting the sequence.

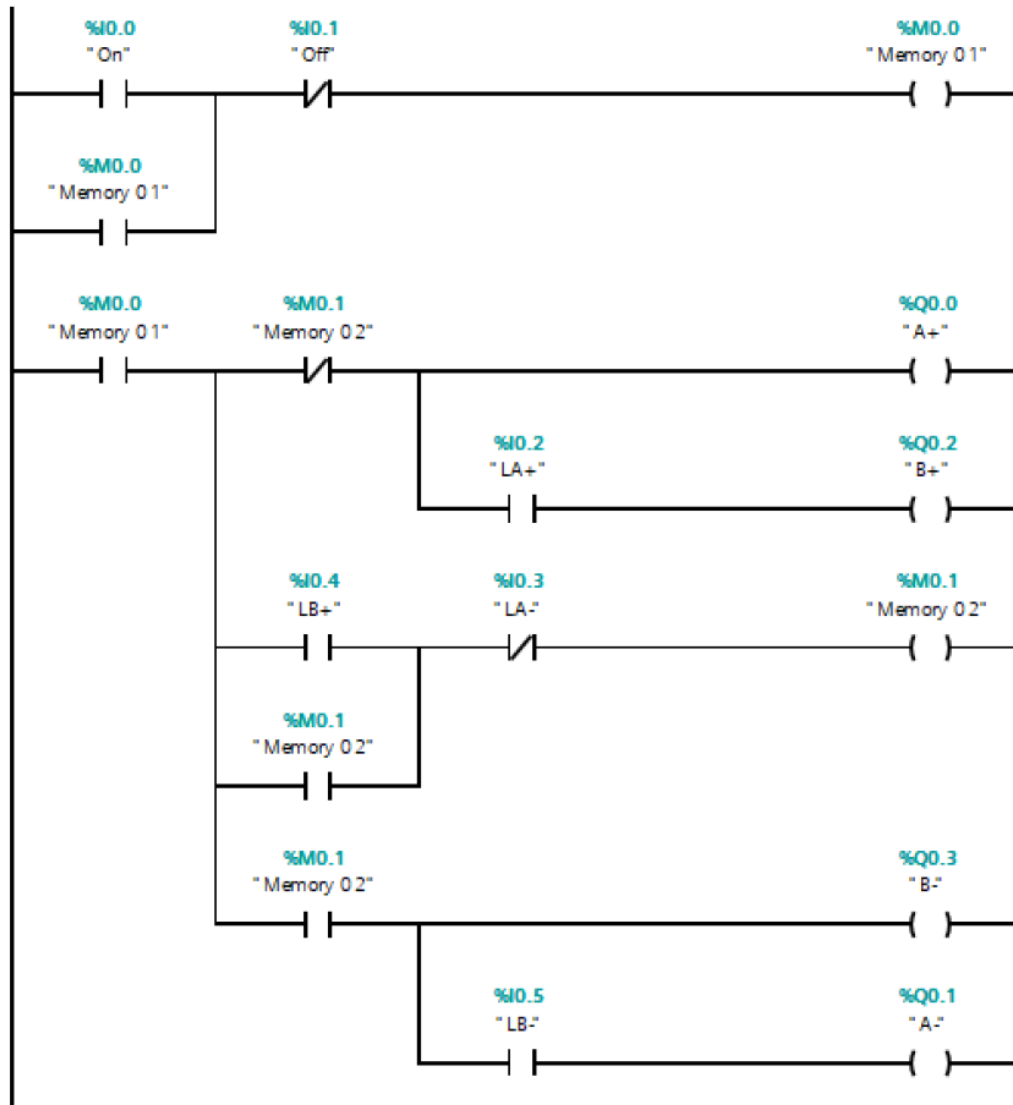


Fig: Ladder Diagram for A+ B+ B- A- with Sensor operation

Double Cylinder Operation for A+ A-: B+ B- with Sensor

To program a PLC for the double-cylinder sequence **A+ A- B+ B-** using sensors, you will create a ladder logic program where the activation of each subsequent step depends on a sensor confirming the completion of the previous step.

System Components

- **Cylinders:** Two double-acting cylinders, Cylinder A and Cylinder B.
- **Solenoid Outputs:** Four solenoid valves to control the cylinders:
 - **A+** (extends cylinder A)
 - **A-** (retracts cylinder A)
 - **B+** (extends cylinder B)
 - **B-** (retracts cylinder B)
- **Sensors (Inputs):** Four position sensors to detect the cylinders' positions:
 - **A0** (Cylinder A is retracted)
 - **A1** (Cylinder A is extended)
 - **B0** (Cylinder B is retracted)
 - **B1** (Cylinder B is extended)
- **Control Inputs:** A **Start** pushbutton to initiate the cycle and a **Stop** button for halting the sequence.

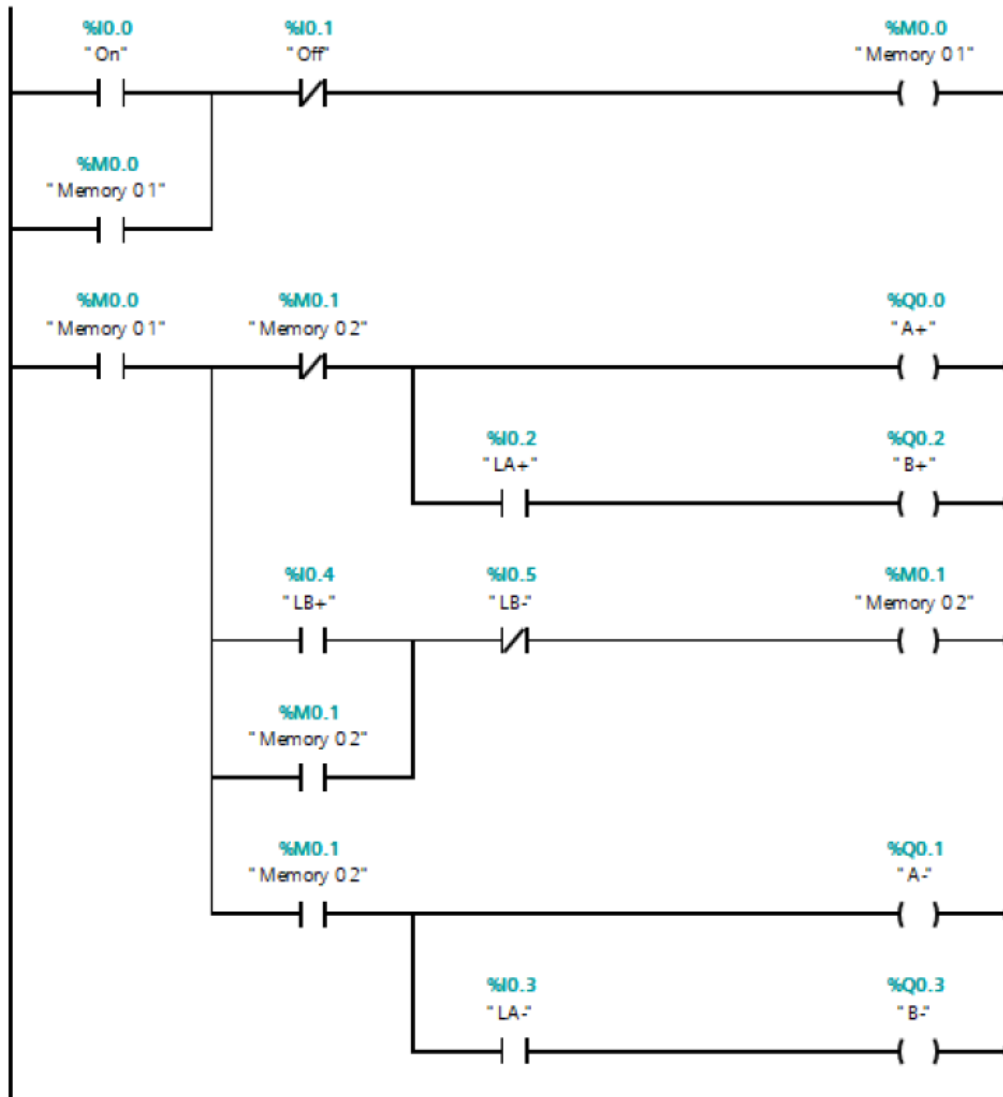


Fig: Ladder Diagram for A+ A-: B+ B- with Sensor operation



Self-Check 6.3-1

1. In a basic single-cylinder sequence, what two conditions are required in the PLC logic to energize the solenoid for Cylinder A to Extend (A+)?

2. A hydraulic system uses an NC (Normally Closed) pressure switch to confirm minimum pressure. Which PLC instruction is used to activate a Pressure Fault bit when the switch opens (pressure drops too low)?
3. What two mandatory safety conditions must interlock (inhibit) the hydraulic Pump Motor Start Output for safe operation?
4. Which PLC function block or instruction is necessary to convert a desired Speed value (Slow to Fast) into the required 4-20mA analog current signal for a proportional flow control valve?
5. After Cylinder A extends (A+), what is the primary PLC input signal used to trigger the start of the next movement, Cylinder B Extend (B+)?
6. In a hydraulic circuit where a solenoid is LATCHED ON until a pressure limit is reached, which PLC logic instruction is best suited to turn OFF the solenoid when the High Pressure Limit is reached?
7. What is the best programming practice for integrating the E-Stop system status into the PLC logic to ensure maximum safety?



Answer Paper 6.3-1

1. The Start Button must be pressed AND the cylinder must currently be in the Retracted position (A0 ON).
2. An Examine if Open (XIO) instruction addressed to the NC pressure switch input. When the pressure drops, the switch opens, making the XIO instruction TRUE.
3. Confirmation that the hydraulic fluid level is above minimum AND the motor overload is not tripped (not faulted).
4. A Scaling Function Block (SCL or CALE instruction) is used to map the desired engineering units (Speed) to the raw analog output units (4-20mA).
5. The ON state of the Extended Limit Switch A1 (A at end position) is the primary sensor feedback that triggers the next step (B+).

6. A Compare Instruction (Greater Than) feeding a RESET instruction for the solenoid is best, as it explicitly clears the latching bit when the pressure condition is met.
7. The status signal from the Dedicated Safety Relay System should be used as a MASTER OFF condition in series with every solenoid and motor output rung (in addition to the hardwired circuit).

	Job Sheet 39
Qualification	Industrial Automation
Learning Unit	Double Cylinder Operation for A+ B+: A- B- with TONR in both Pneumatic and Hydraulic System
Trainee Name	
PPE	Safety glasses, insulated gloves, safety boots, ear protection
Tools & Equipment	PLC unit, HMI (optional), programming laptop with ladder logic software, pneumatic/hydraulic trainer with double-acting cylinders, sensors, solenoid valves, power supply, cables, timers (TONR function)
Notes	TONR: Timer On Delay Retentive (used to delay activation with memory retention). Ensure both cylinders are correctly plumbed and sensors are aligned. Simulate or test with care to avoid damage from incorrect sequencing.
Procedure	1. Wear required PPE. 2. Set up the pneumatic and hydraulic systems with two double-acting cylinders (A and B). 3. Wire and connect sensors and solenoid valves to the PLC I/O. 4. Program the PLC to operate the sequence A+ B+: A- B- using TONR for both extension and retraction delays. 5. Ensure TONR timers retain their time when inputs go false. 6. Download and test the program in steps to verify correct operation.

	7. Observe system behavior and adjust time values as needed for safe operation. 8. Log the PLC program and document the timing settings and sequence diagram. 9. Power down the system and store all tools and equipment safely.
Trainee's Signature	
Assessor's Signature	
QA Signature	
Assessor's Comment	

	Job Sheet 40
Qualification	Industrial Automation
Learning Unit	Double Cylinder Operation for A+ B+: B- A- with TONR in both Pneumatic and Hydraulic System
Trainee Name	
PPE	Safety glasses, insulated gloves, safety boots, ear protection
Tools & Equipment	PLC unit, programming laptop with ladder logic software, pneumatic/hydraulic training rig with double-acting cylinders (A and B), proximity or magnetic sensors, solenoid valves, power supply, cables, HMI (optional), timer blocks using TONR
Notes	- Ensure all connections are secure and verified before powering the system. - Sequence: A+ → B+ → B- → A- using TONR timers. - TONR = Timer On Delay Retentive; retains accumulated time when input turns off. - Monitor cylinder response times closely and adjust delays as needed.
Procedure	1. Wear all necessary PPE.

	2. Connect double-acting cylinders (A and B) on pneumatic and hydraulic trainers. 3. Wire the sensors and solenoid valves to the PLC input/output modules. 4. Open ladder logic programming software and create a sequence: A+ → B+ → B- → A-, with TONR timers controlling each step. 5. Assign sensors to detect full extension and retraction of each cylinder. 6. Simulate and test the PLC program to ensure correct sequencing. 7. Validate operation by observing the real-time actuation of the cylinders. 8. Adjust timer values for proper synchronization and smooth motion. 9. Save the program and back up the file. 10. Power down system safely and store all equipment.
Trainee's Signature	
Assessor's Signature	
QA Signature	
Assessor's Comment	

	Job Sheet 41
Qualification	Industrial Automation
Learning Unit	Double Cylinder Operation for A+ A-: B+ B- with TONR in both Pneumatic and Hydraulic System
Trainee Name	
PPE	Safety glasses, insulated gloves, safety boots, ear protection
Tools & Equipment	PLC unit, laptop with ladder logic programming software, pneumatic/hydraulic training setup with double-acting cylinders A and B, solenoid valves, proximity sensors, power supply, TONR timer blocks, wiring tools

Notes	- Operation sequence: $A^+ \rightarrow A^- \rightarrow B^+ \rightarrow B^-$ using TONR for delays between actions. - TONR (Timer On Delay Retentive) is used for retaining delay timing even if the input condition is interrupted. - Ensure sensor alignment and proper feedback during operation.
Procedure	1. Wear required PPE at all times. 2. Set up double-acting cylinders (A and B) on both pneumatic and hydraulic systems. 3. Connect sensors and solenoid valves to the PLC's I/O terminals. 4. Program the PLC using ladder logic to control the sequence: $A^+ \rightarrow A^- \rightarrow B^+ \rightarrow B^-$ with TONR delays inserted between each stage. 5. Validate sensor inputs for cylinder positions (fully extended/retracted). 6. Simulate and run the program step by step, checking correct actuation. 7. Adjust TONR delay times for appropriate timing and synchronization. 8. Observe for any misalignment or lag in cylinder movement. 9. Save the PLC program and document the setup. 10. Power down system, disconnect wiring safely, and store equipment.
Trainee's Signature	
Assessor's Signature	
QA Signature	
Assessor's Comment	

	Job Sheet 42
Qualification	Industrial Automation

Learning Unit	Double Cylinder Operation for A+ B+: A- B- with Sensor in both Pneumatic and Hydraulic System
Trainee Name	
PPE	Safety glasses, insulated gloves, safety boots, ear protection
Tools & Equipment	PLC unit, laptop with programming software, pneumatic/hydraulic trainer with double-acting cylinders A and B, proximity or magnetic sensors, solenoid valves, power supply, wiring kit, indicator lights (optional)
Notes	- Sequence: A+ → B+ → A- → B- using sensor-based feedback for precise control. - Sensors must be accurately placed to detect full extension and retraction of each cylinder. - Manual override or emergency stop should be included where applicable.
Procedure	1. Wear all appropriate PPE. 2. Set up double-acting cylinders (A and B) on the pneumatic and hydraulic training benches. 3. Mount sensors to detect full extension and retraction of each cylinder (typically 4 sensors total). 4. Connect sensors and solenoid valves to the PLC I/O terminals. 5. In the ladder logic program, implement the sequence A+ → B+ → A- → B-, using sensor feedback to trigger the next step. 6. Simulate the sequence and verify sensor feedback in real-time. 7. Test the system under controlled conditions and fine-tune the response based on sensor accuracy. 8. Save the program, label all connections, and document the wiring and logic flow. 9. Shut down system and disconnect all equipment safely. 10. Clean the workspace and store tools properly.
Trainee's Signature	

Assessor's Signature	
QA Signature	
Assessor's Comment	

	Job Sheet 43
Qualification	Industrial Automation
Learning Unit	Double Cylinder Operation for A+ B+: B- A- with Sensor in both Pneumatic and Hydraulic System
Trainee Name	
PPE	Safety glasses, insulated gloves, safety boots, ear protection
Tools & Equipment	PLC unit, laptop with programming software, pneumatic/hydraulic trainer with double-acting cylinders (A and B), proximity/magnetic sensors, solenoid valves, power supply, indicator lights (optional), wiring tools
Notes	- Sequence: A+ → B+ → B- → A-, with sensors providing position feedback for each cylinder. - Four sensors needed: A extended, A retracted, B extended, B retracted. - Sensor accuracy is critical to prevent mis-sequencing or mechanical interference. - Include safety features such as emergency stop or manual override.
Procedure	1. Wear all required PPE before starting. 2. Set up double-acting cylinders A and B on the pneumatic and hydraulic systems. 3. Mount sensors to detect full extension and retraction of both cylinders. 4. Connect sensors and solenoid valves to the PLC's input and output terminals.

	5. Develop and program the ladder logic sequence: A+ → B+ → B- → A-, using sensor signals to confirm each step is complete before proceeding. 6. Download the program to the PLC and monitor sensor feedback in real-time. 7. Test the system and validate the correct operation of the sequence. 8. Make any necessary adjustments to sensor positions or PLC logic. 9. Save the final version of the program and label all connections. 10. Shut down the system safely and store all tools and equipment.
Trainee's Signature	
Assessor's Signature	
QA Signature	
Assessor's Comment	

	Job Sheet 44
Qualification	Industrial Automation
Learning Unit	Double Cylinder Operation for A+ A-: B+ B- with Sensor in both Hydraulic and Pneumatic System
Trainee Name	
PPE	Safety glasses, insulated gloves, safety boots, ear protection
Tools & Equipment	PLC unit, programming laptop with ladder logic software, pneumatic/hydraulic trainer with double-acting cylinders (A and B), proximity/magnetic sensors, solenoid valves, power supply, wiring tools, HMI (optional)
Notes	- Sequence: A+ → A- → B+ → B- with sensor-based feedback to control and confirm each stage. - Each cylinder requires two sensors (extended/retracted). - Ensure that sensor positions are tested for accuracy.

	- Include safety controls and emergency stop mechanism in system design.
Procedure	1. Wear all necessary PPE before starting work. 2. Set up double-acting cylinders A and B on both the pneumatic and hydraulic system trainers. 3. Mount and test sensors to detect full extension and retraction positions for each cylinder. 4. Connect sensors and solenoid valves to the PLC's input/output terminals. 5. Write a ladder logic program that follows the sequence: $A^+ \rightarrow A^- \rightarrow B^+ \rightarrow B^-$, with each stage triggered by appropriate sensor feedback. 6. Download the program to the PLC and test each stage of the operation, verifying sensor feedback at each step. 7. Troubleshoot and adjust sensor positions or logic if necessary. 8. Save the PLC program and document the system layout and sensor configuration. 9. Power down the system safely and disconnect all components. 10. Clean up the work area and store all tools and equipment.
Trainee's Signature	
Assessor's Signature	
QA Signature	
Assessor's Comment	

Learning Outcome 6.4 – Test and Run PLC-Controlled Pneumatic and Hydraulic System



Content

- **System Startup and Pre-Checks:** Learn the safe power-up sequence for the combined PLC and fluid power systems, including checking for correct air pressure/hydraulic fluid level and verifying all E-Stop circuits are functional.
- **Dry Run and Commissioning:** Understand the process of testing the PLC program logic in a step-by-step or manual mode, followed by a no-load (dry) run of the fluid power sequence to check for mechanical interference.
- **Full Load and Fault Testing:** Practice running the system under normal operating conditions (full cycle) and systematically introducing simulated faults (e.g., sticking limit switch, low air pressure) to verify the program's robust fault recovery logic.



Assessment Criteria

- Safe and Compliant Startup
- Reliable Sequence Execution
- Effective Fault Response



Necessary Equipment

- Fully Integrated System
- Digital Multimeter (DMM)

- Pressure/Flow Measuring Tools
- Safety Gear
- Programming Computer and Documentation



Learning Activity 6.4-1

Learning Activity	Resources/ Instructions/ References
Test and Run PLC-Controlled Pneumatic and Hydraulic System	• Information Sheet: 6.4-1 • Self-Check: 6.4-1 • Answer Paper: 6.4-1



Information Sheet 6.4-1

Learning Objective: The learner will be able to safely commission and debug a fully integrated PLC-controlled fluid power system, successfully executing the sequence under normal operation and verifying the correct response to simulated faults.

Testing and Commissioning

1. **Forced Testing:** Temporarily **force** DO points ON one-by-one to verify correct wiring to the solenoid valves and check mechanical action.
2. **I/O Verification:** Monitor DI points while manually actuating sensors (limit switches) to confirm they register correctly in the PLC software.

3. **Automatic Cycle Test:** Download the full sequence logic and execute the automatic cycle, monitoring the logic and I/O status simultaneously to debug and fine-tune timing (e.g., using **TON/TOF timers**) for optimal system performance.



Self-Check 6.4-1

1. What is the main goal of performing a dry run or manual mode test on a fluid power system before starting the automatic sequence?
2. What is the most common non-electrical component fault when a cylinder fails to Extend (A+), even though its solenoid output is confirmed ON by the PLC?
3. When the sequential logic is stuck because the B1 Extended limit switch fails to turn ON, what is the first systematic troubleshooting step?
4. If an Analog Input from a pressure sensor reads 0PSI on the HMI despite the physical gauge reading 500PSI, what is the most likely PLC software error?
5. What physical diagnostic tool on the PLC modules provides the engineer with an immediate, real-time visual status of the ON/OFF state of field devices?
6. If a safety interlock fails during PLC program testing, allowing an unauthorized sequence to start, what immediate action must be taken?
7. What is the single most critical step that should be performed after the PLC sequence has been successfully debugged and run for the first time?



Answer Paper 6.4-1

1. The main goal is to confirm that all physical wiring and plumbing connections for solenoids and sensors are correct, and that actuators move smoothly without collision.
2. The most likely non-electrical fault is a severe drop in system pressure (due to a regulator failure or leak), as the solenoid cannot shift or move the piston with insufficient force.

3. The first systematic step is to verify the cylinder B has physically reached the B1 position, and then check the voltage at the B1 input terminal on the PLC module.
4. The most likely software error is that the Analog Scaling Function in the PLC program is incorrectly set or bypassed, failing to convert the raw data to PSI.
5. The Physical LED Indicators on the I/O Modules are used to confirm the real-time ON/OFF state of I/O points.
6. The immediate action is to Stop ALL motion (using E-Stop or Main Disconnect) and place the PLC in PROGRAM mode to fix the interlock logic.
7. The critical step is to create a final backup of the verified PLC program and HMI project file with the current date and version, ensuring a working copy is saved for future maintenance.

Module 7: Control Variable Frequency Drive (VFD) using PLC



Contents of Module

Module Description

This unit of competency covers the knowledge, skills and attitudes required to control variable frequency drive (VFD). It specifically includes the tasks of interpreting variable frequency drive (VFD), installing and configuring variable frequency drive (VFD) and operating variable frequency drive (VFD) in different modes.

Minimum Time: 15 Hours



Learning Outcome

- 7.1. Interpret Variable Frequency Drive (VFD)
- 7.2. Install and configure Variable Frequency Drive (VFD)
- 7.3. Operate Variable Frequency Drive (VFD) in different mode



Performance Criteria

1. Installation site for the VFD is inspected.
2. VFD unit is installed securely according to manufacturer guidelines.
3. Power cables are connected to the VFD following wiring diagrams.

4. Motor is connected to the VFD, ensuring proper wiring and compatibility.
5. Controlling circuit for the VFD is installed and integrated with the control system.
6. Motor parameters are set accurately in the VFD.
7. Controlling parameters are configured according to application requirements.
8. Motor speed control is performed using local or keypad control mode as per operational procedures.
9. Motor control is executed using terminal control mode or remote-control mode.
10. Motor direction control is applied to enable both forward and reverse operations safely.
11. VFD alarms and fault indicators are interpreted accurately to diagnose system status.
12. Appropriate responses to alarms are implemented following troubleshooting guidelines.
13. Operational parameters are monitored and adjusted to maintain desired motor performance.

Learning Outcome 7.1 – Interpret Variable Frequency Drive (VFD)



Content

- **VFD Operating Principles:** Understand the core function of a VFD, including its Rectifier, DC Bus, and Inverter sections, and how it controls an AC induction motor's speed and torque by varying both frequency and voltage (V/F control).
- **Key Parameters and Motor Nameplate:** Learn to identify and interpret critical VFD setup parameters (e.g., maximum frequency, acceleration/deceleration time, motor FLA) and relate them to the motor nameplate data.
- **Drive Interface and Control:** Understand how to read status displays on the VFD keypad, interpret fault codes, and identify methods for control (e.g., keypad, digital inputs, analog reference, communication networks).



Assessment Criteria

- Parameter Interpretation
- Fault Diagnosis
- Nameplate Matching



Necessary Equipment

- Variable Frequency Drive (VFD)
- AC Induction Motor
- Technical Documentation
- Digital Multimeter (DMM)
- Wiring and Tools



Learning Activity 7.1-1

Learning Activity	Resources/ Instructions/ References
Interpret Variable Frequency Drive (VFD)	• Information Sheet: 7.1-1 • Self-Check: 7.1-1 • Answer Paper: 7.1-1



Information Sheet 7.1-1

Learning Objective: The learner will be able to explain the operating principles of a VFD and correctly interpret key drive parameters, fault codes, and motor nameplate data for a given application.

Control Variable Frequency Drive (VFD) using PLC

To control a Variable Frequency Drive (VFD) with a Programmable Logic Controller (PLC), you'll need to establish communication between the two devices. The PLC can send various commands to the VFD, such as **start/stop**, **direction** (forward/reverse), and **speed reference**. The speed reference can be a digital value sent over a communication protocol like Modbus or an analog signal (e.g., 0-10V or 4-20mA). The PLC's program will define the logic for these commands, allowing for automated control of the VFD's output frequency and, consequently, the motor's speed. This setup is widely used in industrial automation to precisely manage motor speed in applications like conveyors, pumps, and fans, optimizing process efficiency and saving energy.

Variable Frequency Drive (VFD)

A Variable Frequency Drive (VFD) is an electronic device that controls the speed of an AC motor by varying the frequency and voltage of the electrical power supplied to the motor. It consists of three main sections: a rectifier that converts incoming AC power into DC, a DC bus that stores this power, and an inverter that converts the DC power back into a variable frequency and variable voltage AC output. This process allows for precise control over the motor's speed, enabling it to operate at speeds lower than its maximum, which is crucial for applications where motor speed needs to be adjusted. VFDs are widely used in industrial and commercial settings to improve process control, reduce energy consumption, and lower mechanical stress on equipment like pumps, fans, and conveyor belts.



Fig: Mitsubishi VFD

Benefits of VFD

- ✓ Controls the speed of an induction motor.
- ✓ Controls the torque of an induction motor.
- ✓ Easily changes the direction of rotation.
- ✓ Controls the starting current.
- ✓ Saves energy.
- ✓ Can be installed very simply.

Working Principle of VFD

A **variable frequency drive (VFD)**, also known as a variable speed drive or inverter, is a motor controller that works by adjusting the frequency and voltage of the power supplied to an AC electric motor. By doing so, it can control the motor's speed, torque, and direction.

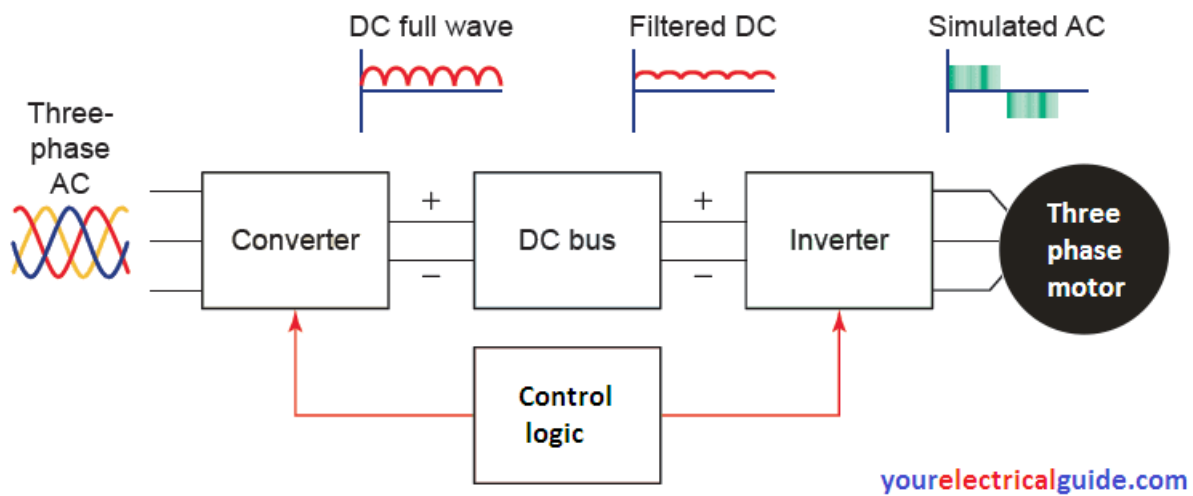


Fig: Working Principle of VFD

The working principle of a VFD involves three main stages:

Rectification (AC to DC)

The first stage takes the incoming alternating current (AC) power from the main power supply and converts it into direct current (DC). This is typically done using a **rectifier**, which is a circuit with diodes. Think of these diodes as one-way valves that allow current to flow in only one direction, effectively converting the alternating waveform into a pulsating DC waveform.

DC Bus (Filtering and Storage)

The pulsating DC power from the rectifier is not yet suitable for the next stage. The DC bus acts as a filter and storage unit, using **capacitors** to smooth out the ripples in the DC voltage. This creates a clean, stable DC voltage that is ready for the final stage of conversion.

Inversion (DC to Variable AC)

In the final stage, an **inverter** converts the DC voltage back into an AC waveform with the desired frequency and voltage. The inverter is made up of high-speed electronic switches, such as **Insulated Gate Bipolar Transistors (IGBTs)**. These switches turn the DC voltage on and off at

a very rapid rate, creating a series of voltage pulses. This technique is called **Pulse Width Modulation (PWM)**. By varying the width of these pulses and the switching frequency, the VFD can simulate a smooth, variable AC sine wave. This new, variable AC power is then sent to the motor, allowing precise control of its speed.

Ultimately, the VFD's ability to adjust the frequency and voltage supplied to the motor allows it to operate at speeds lower than its nameplate rating, leading to energy savings, reduced mechanical stress on the motor and equipment, and improved process control.

Manufacturer of VFD

There are many companies around the world that manufacture Variable Frequency Drives (VFDs), ranging from large, multinational conglomerates to more specialized producers. Here are some of the most prominent and well-known VFD manufacturers:

- ✓ ABB Ltd. (Switzerland/Sweden)
- ✓ Siemens AG (Germany)
- ✓ Schneider Electric (France)
- ✓ Rockwell Automation / Allen-Bradley (USA)
- ✓ Danfoss A/S (Denmark)
- ✓ Yaskawa Electric Corporation (Japan)
- ✓ Mitsubishi Electric (Japan)
- ✓ Fuji Electric (Japan)
- ✓ Hitachi (Japan)

Types of VFD

VFDs can be classified in several ways, but the most common classifications are based on their **control method, inverter type, and voltage level**.

By Control Method

The control method determines how the VFD regulates the motor's speed and torque.

- **V/Hz Control (Volts per Hertz):** This is the simplest and most common method. It maintains a constant ratio between the output voltage and frequency, which is suitable for basic applications like fans and pumps where the torque demand is proportional to the square of the speed. It's cost-effective and can control multiple motors simultaneously.
- **Vector Control (Field-Oriented Control):** This is a more advanced method that provides precise control over both motor speed and torque, similar to a DC drive. It works by independently controlling the motor's magnetic flux and torque-producing current. This method is ideal for high-performance applications like conveyors, cranes, and elevators where high starting torque and precise speed regulation are needed.
- **Direct Torque Control (DTC):** Considered one of the most advanced control methods, DTC provides a very fast and accurate torque response without needing an encoder for feedback. It directly controls the motor's magnetic flux and torque, making it suitable for applications with frequent starts, stops, and rapid changes in speed, such as in grinding mills and extruders.

By Inverter Type

This classification is based on how the VFD's inverter stage handles the power.

- **Voltage Source Inverter (VSI):** This is the most widely used type. It uses a DC bus with large capacitors to create a stable DC voltage, which is then inverted into a variable AC voltage using Pulse Width Modulation (PWM). VSI drives are known for their efficiency and versatility.
- **Current Source Inverter (CSI):** Unlike VSI, a CSI drive uses a DC bus with a large inductor to maintain a constant current. They are typically used in high-power applications and are known for their regenerative braking capability and ruggedness.
- **Multi-level Inverter:** These VFDs use a series of switching devices to produce a stepped, high-quality output voltage waveform that is closer to a pure sine wave. This reduces harmonics and is often used in medium-voltage and high-power applications where harmonic mitigation is crucial.

By Voltage Level

VFDs are also categorized by the voltage level they are designed to operate at.

- **Low Voltage (LV):** These are the most common VFDs, typically operating at voltages below 1,000 V AC. They are used in a vast range of industrial, commercial, and residential applications.
- **Medium Voltage (MV):** These drives are designed for voltages above 1,000 V AC. They are used for high-power applications in industries like mining, oil and gas, and utilities where large motors are required.

Basic Controls of VFD

- ✓ Preset Speeds
- ✓ Minimum and Maximum Speeds
- ✓ Acceleration and Deceleration Control
- ✓ Controlled Starting Current
- ✓ Multiple speed Mode
- ✓ Motor rotation forward and reverse Control
- ✓ Motor Start Stop through remote and Communication
- ✓ Speed Control through Analog
- ✓ Speed Control via Communication



Self-Check 7.1-1

1. What is the primary function of a Variable Frequency Drive (VFD) in controlling an AC induction motor?

2. What motor operating data does the VFD commonly send back to the PLC or HMI via its Analog Output (e.g., 4-20mA) terminal?
3. Setting a long Acceleration Ramp Time on a VFD helps to prevent which two critical issues?
4. If a VFD displays an OC (Overcurrent) Fault during the early stage of deceleration, what is the most likely cause?
5. Which VFD terminal type is used to receive the Speed Reference signal (0-10V or 4-20mA) from an external PLC?
6. For standard V/Hz control, why must the VFD reduce the output voltage when it reduces the output frequency?
7. What is the primary risk to a standard motor (not VFD-rated) when it is run continuously at a very slow speed (e.g., 5Hz) by a VFD?



Answer Paper 7.1-1

1. The primary function is to control the motor's speed and torque by adjusting the frequency (Hz) and voltage (V) supplied to the motor.
2. The VFD commonly sends real-time Output Frequency (Speed), Load Current, or Torque Percentage back to the controller.
3. A long ramp time prevents excessive mechanical shock to the driven equipment and an Overcurrent Fault due to high starting current.
4. The most likely cause is that the Deceleration Ramp Time is set too short, causing the motor to regenerate voltage back into the VFD.
5. The Analog Input Terminal (AI) is used to receive the continuous, variable signal that dictates the motor's speed set point.
6. The VFD reduces the voltage to maintain a constant magnetic flux in the motor, preventing saturation, high currents, and overheating.

7. The primary risk is that the motor will overheat because its internal cooling fan speed is too slow to dissipate the heat generated by the motor's windings.

Learning Outcome 7.2 – Install and Configure Variable Frequency Drive (VFD)



Content

- **VFD Mounting and Wiring:** Learn the proper procedures for mechanically mounting the VFD (adhering to ventilation and space requirements) and correctly connecting the power circuit (line supply, motor output, grounding) and control circuit (I/O signals).
- **Initial Parameter Configuration:** Understand and practice setting the essential start-up parameters in the VFD, including motor nameplate data (voltage, frequency, FLA), acceleration/deceleration times, and maximum/minimum speed limits.
- **Control Source Setup:** Configure the VFD to accept control signals from the required source, such as digital inputs (Start/Stop), an analog input (speed reference via 0-10V or 4-20mA), or communication network (e.g., Modbus).



Assessment Criteria

- Installation Compliance
- Accurate Parameterization
- Functional Control Verification



Necessary Equipment

- Variable Frequency Drive (VFD)
- AC Induction Motor
- Digital Multimeter (DMM) and Clamp Meter
- VFD Manual and Wiring Diagrams
- Wiring Tools and PPE



Learning Activity 7.2-1

Learning Activity	Resources/ Instructions/ References
Install and Configure Variable Frequency Drive (VFD)	• Information Sheet: 7.2-1 • Self-Check: 7.2-1 • Answer Paper: 7.2-1 • Job Sheet 45



Information Sheet 7.2-1

Learning Objective: The learner will be able to safely install and wire a VFD to a motor and correctly configure all essential operating parameters to ensure stable and compliant motor speed control.

Frequency Setting Method of VFD

Frequency settings on a **Variable Frequency Drive (VFD)** can be controlled through several methods, often referred to as speed reference or speed control inputs. These methods allow you to tell the VFD what output frequency, and therefore motor speed, you want.

- **Keypad/Display:** Most VFDs have a built-in control panel with a digital display and buttons. You can manually enter a specific frequency or adjust it in real-time. This method is often used for initial setup or applications where the speed doesn't change frequently.
- **Analog Input:** This is a common method for continuous speed control. You connect an external device, such as a **potentiometer** or a PLC (Programmable Logic Controller) with an analog output, to the VFD's input terminals. The VFD reads the voltage (e.g., 0-10V) or current (e.g., 4-20mA) signal from the device and translates it into a corresponding frequency. For example, a 5V input might correspond to 30 Hz, and a 10V input would correspond to the maximum set frequency.
- **Digital/Preset Speeds:** You can program the VFD with several discrete, pre-set frequencies. By using digital inputs (simple on/off switches), you can select which of these preset speeds the motor should run at. This is useful for applications that require a limited number of fixed speeds, such as a machine with low, medium, and high-speed settings.
- **Communication:** Many modern VFDs can be controlled through industrial communication protocols like Modbus-RTU, Ethernet/IP, or Profibus. This allows a central controller or computer to send commands to the VFD to set the frequency, start/stop the motor, and monitor its status. This method is common in automated systems and large-scale industrial processes.

Setting the frequency is a crucial part of programming a VFD, and it's essential to also configure related parameters like acceleration and deceleration times, as well as minimum and maximum frequency limits, to ensure safe and efficient operation.

Motor Control Methods in VFD

In Variable Frequency Drives (VFDs), the motor control method determines how the drive regulates the motor's speed and torque. These methods range from simple to highly precise, with each suited for different applications.

V/f – (Volts per Hertz)

V/f control, also known as scalar control, is the most common and basic method. It operates on the principle of keeping a constant ratio between the voltage (V) and frequency (f) supplied to the motor. By maintaining this ratio, the VFD ensures the motor's magnetic flux remains constant, which in turn maintains the motor's torque. This method is considered an open-loop control because it doesn't use feedback from the motor to verify its actual speed. It assumes the motor is running at the commanded frequency.

V/f – (With Encoder)

This is a variation of V/f control that adds an encoder for speed feedback. The VFD uses the encoder's signal to check the motor's actual speed against the commanded speed and make minor adjustments. This converts the system from an open-loop to a **closed-loop** system. This method is not commonly used because the added cost of an encoder doesn't provide the high-performance benefits of a vector control system.

Open Loop Vector

Open Loop Vector control, also known as sensorless vector control, is an advanced method that does not require an encoder. Instead, the VFD uses a complex mathematical model of the motor to estimate the motor's speed, flux, and torque in real-time. It independently controls the magnetic flux and torque-producing components of the motor's current, providing better performance than V/f control.

Closed Loop Vector

Closed Loop Vector control is the most advanced and precise VFD control method. It uses a motor-mounted encoder to provide direct, real-time feedback on the motor's speed and rotor position to the VFD. This feedback allows the VFD to know the exact position and speed of the motor at all times and make precise adjustments. This method is used in high-performance applications like cranes, elevators, machine tools, and robotics, where precise position and torque control are critical.



Self-Check 7.2-1

1. What is the most critical wiring requirement for the VFD motor power cables (U, V, W) to prevent signal corruption?
2. Which parameter setting must be changed on the VFD to allow the PLC to command the Start/Stop and Speed functions?
3. When using a 4-20mA Analog Input to control frequency (20Hz to 60Hz), what four values must be defined in the VFD's scaling parameters?
4. What is the primary purpose of Auto-Tuning (Motor Identification) before running a motor with a VFD for the first time?
5. What is the primary danger to a standard AC motor if it is run by a VFD at very low speeds (below 10Hz) for extended periods?
6. For safety, the VFD's Enable Digital Input should be wired in series with which external component?
7. What is the likely result if the Motor Rated Current parameter is set too low in the VFD's configuration?



Answer Paper 7.2-1

1. The motor's power cables must be separated from control and feedback wiring by using separate conduits or cable trays to prevent EMI (Electromagnetic Interference) from corrupting low-voltage signals.
2. The Control Source parameter must be switched from Keypad/Local to Terminal Strip/Network (depending on the PLC connection type).
3. The VFD must know the Minimum Analog Input Value (4mA), the Minimum Frequency (20Hz), the Maximum Analog Input Value (20mA), and the Maximum Frequency (60Hz).
4. The purpose is to automatically determine and record the motor's electrical properties (resistance and inductance) to optimize torque and efficiency at all speeds.
5. The primary danger is that the motor's insulation will fail due to excessive heat buildup from inadequate cooling provided by its shaft-mounted fan.
6. It should be wired in series with the Normally Closed (NC) contact of a Safety Relay or E-Stop circuit, ensuring that a safety trip immediately removes the Enable signal.
7. The VFD will prematurely trip on a Motor Overload Fault (OL) under normal operating load, as it incorrectly assumes the motor is drawing too much current.

	Job Sheet 45
Qualification	Industrial Automation
Learning Unit	Install and Configure Variable Frequency Drive
Trainee Name	
PPE	Safety glasses, insulated gloves, safety boots, ear protection
Tools & Equipment	Variable Frequency Drive (VFD), multimeter, control panel, motor (AC), programming keypad or software, laptop (if applicable), screwdrivers, wiring tools, user manual.

Notes	- Ensure the power supply is isolated before beginning any installation. - Always follow the manufacturer's wiring diagram and configuration settings. - Verify motor specs match VFD output ratings. - Proper grounding is essential to avoid electrical faults or noise interference.
Procedure	1. Wear all required PPE before beginning the task. 2. Inspect the VFD and ensure compatibility with the motor and supply voltage. 3. Mount the VFD securely in the control panel or on a DIN rail, as required. 4. Connect the power input (L1, L2, L3) and motor output (U, V, W) wires correctly. 5. Ground the VFD and motor according to standard wiring practices. 6. Power up the VFD and use the keypad or software to configure basic parameters: - Motor voltage and current - Rated frequency and speed - Acceleration/deceleration time - Control mode (V/f, sensorless vector, etc.) 7. Perform a test run in jog mode to verify motor direction and adjust if necessary. 8. Save configuration settings and document all parameter values. 9. Shut down the system and check for any loose connections or abnormal noise/vibration. 10. Clean the work area and store tools properly.
Trainee's Signature	
Assessor's Signature	
QA Signature	
Assessor's Comment	

Learning Outcome 7.3 – Operate Variable Frequency Drive in Different Mode



Content

- **Control Modes and Configuration:** Understand the principles and setup required for operating the VFD in different control modes, specifically Local (Keypad/HMI), External Terminal Control (Digital/Analog I/O), and Communication Network Control (e.g., Modbus).
- **Speed Reference Sources:** Learn to configure the speed command source (reference) within the VFD parameters to accept input from a potentiometer (analog input), fixed speed settings, or a communication command value.
- **Transition and Interlocks:** Practice safely switching control between modes (e.g., Local to External) and implement PLC or control wiring interlocks to prevent simultaneous control commands from different sources.



Assessment Criteria

- Mode Switching Proficiency
- Speed Accuracy Verification
- Interlock Functionality



Necessary Equipment

- Variable Frequency Drive (VFD)

- External Control Inputs
- Programming Computer and Cable
- Tachometer (Non-Contact)
- Digital Multimeter (DMM)



Learning Activity 7.3-1

Learning Activity	Resources/ Instructions/ References
Operate Variable Frequency Drive in Different Mode	• Information Sheet: 7.3-1 • Self-Check: 7.3-1 • Answer Paper: 7.3-1 • Job Sheet 46 – Job Sheet 48



Information Sheet 7.3-1

Learning Objective: The learner will be able to safely configure and operate a Variable Frequency Drive (VFD), accurately controlling the motor speed and direction by switching between local, external I/O, and communication network control modes.

Starting Methods of VFD

There are three primary methods for starting a motor controlled by a VFD. Each method dictates how the VFD receives its "run" command.

Local Switch

This method involves using a switch directly on the VFD itself or on a nearby control panel.

- **Function:** This is typically a simple "Start" and "Stop" push-button or a selector switch on the VFD's keypad. The operator can directly control the motor from the drive's location.
- **Use Case:** This method is ideal for applications where the operator is working directly at the machine or for troubleshooting and maintenance purposes. When a VFD is set to local control, the remote and communication signals are usually disabled.

VFD FR-E700-0.4KW Parameter Setting

SL NO	Parameter No/ MODE	Status	Working Status	Comment
01	Pr.77	"0" selected	Writing Mode Enable	When VFD stop condition
02	ALLC	"MODE" selected	Initial all Parameter clear	
03	Pr.CL	"MODE" selected	Default Parameter set	
04	Pr.1	Increase/decrease value	Maximum Frequency setup	0 to 120 Hz
05	Pr.2	Increase/decrease value	Minimum Frequency setup	0 to 120 Hz
06	Pr.3	Increase/decrease value	Motor Base Frequency setup	50/60 Hz
07	Pr.4	When, SD+ STF/ STR + HF active	Multi speed – High speed	0 to 400 Hz
08	Pr.5	When, SD+ STF/ STR + HM active	Multi speed – Middle speed	0 to 400 Hz
09	Pr.6	When, SD+ STF/ STR + HL active	Multi speed – Low speed	0 to 400 Hz
10	Pr.7	Increase/decrease value	Acceleration time	Start time
11	Pr.8	Increase/decrease value	Deceleration time	Stop time
12	Pr.9	Increase/decrease value	Motor Over Current	Setup current rating
13	Pr.80	Increase/decrease value	Motor Capacity	Setup wattage rating
14	Pr.81	Increase/decrease value	Motor Poles	Setup poles rating
15	Pr.83	Increase/decrease value	Motor Operating Voltage	Setup voltage rating
16	Pr.84	Increase/decrease value	Motor Operating Frequency	Setup frequency rating
17	Pr.15	PU/EXT button press	JOG mode	Frequency for Jog (0 to 400Hz)

18	Pr.161	"0" selected	Dial POT active	Variable to set range Hz
19	Pr.161	"1" selected	EXT POT active	Variable to set range Hz
20	Pr.78	"0" selected	FRW + REV both active	External mode (STF/ STR)
21	Pr.79	"0" selected	EXT/PU both active	Switchover Mode
22	Pr.79	"1" selected	Fixed PU mode active	RUN button & Dial pad active
23	Pr.79	"2" selected	Fixed EXT mode active	(STF/ STR) button & POT active
24	Pr.79	"3" selected	Operation Mode 01	(STF/ STR) button & Dial pad active
25	Pr.79	"4" selected	Operation Mode 02	RUN button & POT active
26	Pr.158	"1" selected	Output Frequency active	Connected to Frequency meter
26	Pr.158	"2" selected	Output Current active	Connected to Current meter
27	Pr.158	"3" selected	Output Voltage active	Connected to voltage meter

Remote Switch

Remote switch control allows you to start and stop the VFD from a separate, often distant, location using simple electrical switches.

- **Function:** The VFD has dedicated digital input terminals for start, stop, forward, and reverse commands. A simple two-wire or three-wire control circuit is wired from the remote switches to these terminals. When a switch is closed, a low-voltage signal is sent to the VFD, which initiates the start sequence.
- **Use Case:** This method is suitable for applications where the motor is in a hazardous or hard-to-reach location, or when a central control station is needed. It's common for applications like conveyors or pumps.

Mitsubishi FR-E700 VFD Wiring & Setup Guide

Wiring for External Potentiometer (Speed Control):

Potentiometer Pin Connections:

- First pin (one side) --> Terminal 10 (10V supply)
- Middle pin (wiper) --> Terminal 2 (Analog voltage input, 0-10V)
- Third pin (other side) --> Terminal 5 (Common ground)

Ensure the following parameters:

- P.0 = 1 (External frequency source)
- P.79 = 2 (Terminal operation mode)

Control Terminal Inputs:

- STF: Forward run (connect to SD)
- STR: Reverse run (optional, connect to SD)
- SD: Common ground for control inputs
- 10: +10V supply (for potentiometer)

- 2: Voltage input (0-10V analog)
- 5: Analog common

Basic Motor Parameters:

- P.1 = 50.0 Hz (Max frequency)
- P.2 = 0.0 Hz (Min frequency)
- P.3 = 5.0 sec (Acceleration time)
- P.4 = 5.0 sec (Deceleration time)
- P.7 = 50.0 Hz (Base frequency)
- P.8 = 220V (Rated motor voltage)

Communication

This is the most advanced starting method, where the VFD is integrated into an automation network.

- **Function:** Instead of a physical switch, the VFD receives its start/stop commands and speed reference over a communication network. Common industrial protocols like Modbus, Ethernet/IP, or Profibus are used. A master device, such as a Programmable Logic Controller (PLC), Human-Machine Interface (HMI), or a computer, sends digital commands to the VFD.
- **Use Case:** This method is essential for modern, automated industrial processes where a central controller manages multiple motors and other equipment. It allows for complex sequences, remote monitoring, and data logging.

Modbus Communication between Mitsubishi E720 VFD and Siemens S7 1200 PLC

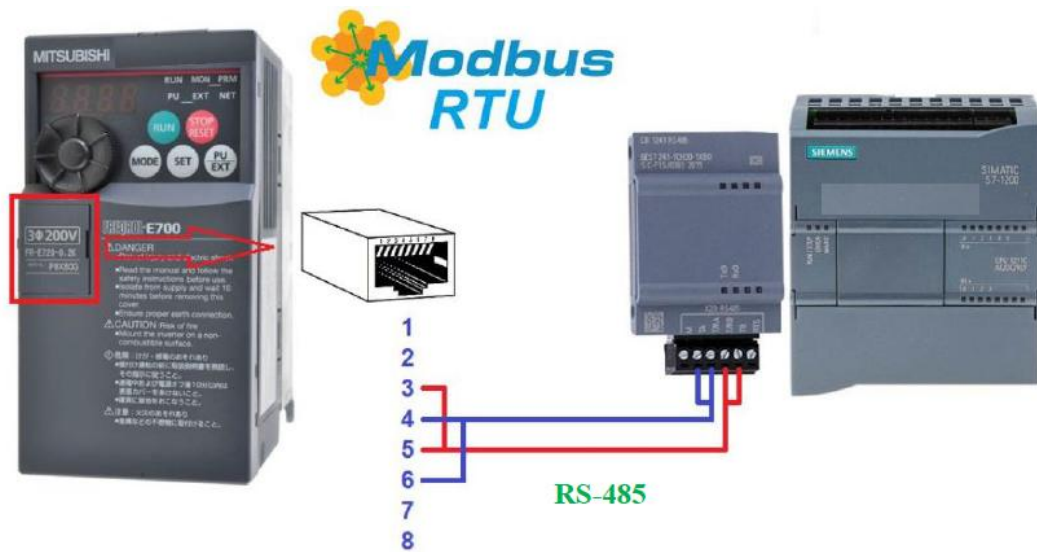


Fig: Modbus RTU Communication between VFD and PLC

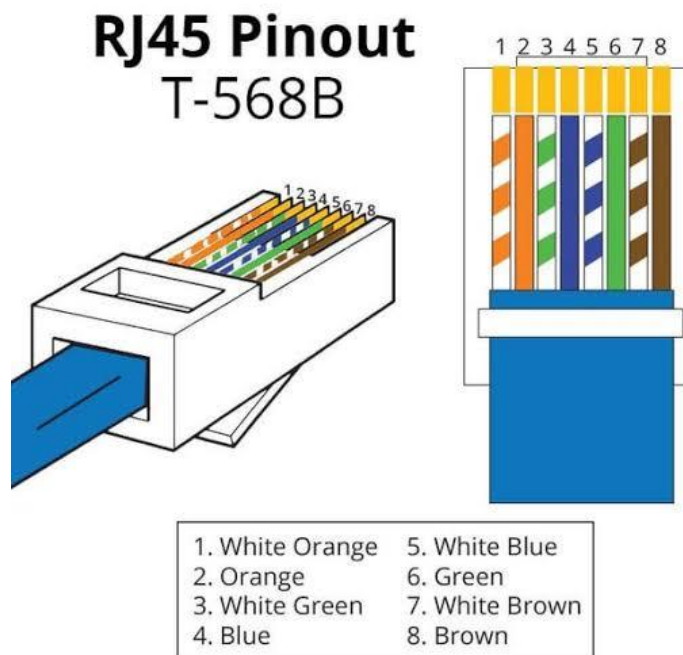


Fig: Color Coding of RJ45 Connector

Configuration of FR E740 Series VFD

- +Pr117 (Slave Address) = 1
- +Pr118 (Baud rate) = 3 (9600bps)
- +Pr119 = 0 (8 bit,stop,bit = 1)
- +Pr120 = 2 (Event)
- +Pr121 = 9999
- +Pr 122 = 9999
- +Pr123 = 9999
- +Pr124 = 1
- +Pr340 = 1
- +Pr549 = 1
- +Pr79 = 2 (Last Setting)

Parameter Number	Name	Initial Value	Setting Range	Description
117	PU communication station number	0	0 to 31 (0 to 247) *1	Inverter station number specification Set the inverter station numbers when two or more inverters are connected to one personal computer.
118	PU communication speed	192	48, 96, 192, 384	Communication speed The setting value X 100 equals the communication speed. Example)19200bps if 192
119	PU communication stop bit length	1	0	Stop bit length
			1	1bit
			10	2bit
			11	7bit
120	PU communication parity check	2	0	Without parity check
			1	With odd parity check
			2	With even parity check
123	PU communication waiting time setting	9999	0 to 150ms	Set the waiting time between data transmission to the inverter and response.
			9999	Set with communication data.
124	PU communication CR/LF selection	1	0	Without CR/LF
			1	With CR
			2	With CR/LF
549	Protocol selection	0	0	Mitsubishi inverter (computer link operation) protocol
			1	Modbus-RTU protocol

Parameter Number	Name	Initial Value	Setting Range	Description
121	Number of PU communication retries	1	0 to 10	Number of retries at data receive error occurrence. If the number of consecutive errors exceeds the permissible value, the inverter will come to trip (depends on <i>Pr. 502</i>). Valid only Mitsubishi inverter (computer link operation) protocol.
			9999	If a communication error occurs, the inverter will not come to trip.
122	PU communication check time interval	0	0	RS-485 communication can be made. Note that a communication fault (E.PUE) occurs as soon as the inverter is switched to the operation mode with command source. (NET mode at initial value).
			0.1 to 999.8s	Communication check (signal loss detection) time interval. If a no-communication state persists for longer than the permissible time, the inverter will come to trip (depends on <i>Pr. 502</i>).
			9999	No communication check (signal loss detection)

<i>Pr. 340</i> Setting	<i>Pr. 79</i> Setting	Operation Mode at Power-on, Power Restoration, Reset	Operation Mode Switching
0 (initial value)	0 (initial value)	External operation mode	Switching among the external, PU and Net operation mode is enabled *1
	1	PU operation mode	Fixed to PU operation mode
	2	External operation mode	Switching between the external and NET operation mode is enabled. Switching to PU operation mode disabled.
	3, 4	External/PU combined mode	Operation mode switching disabled
	6	External operation mode	Switching among the external, PU, and NET operation mode is enabled while running.
	7	X12 (MRS) signal ON External operation mode	Switching among the external, PU and Net operation mode is enabled *1
		X12 (MRS) signal off External operation mode	Fixed to external operation mode (Forcibly switched to external operation mode.)
1	0	NET operation mode	Same as when <i>Pr. 340</i> = "0"
	1	PU operation mode	
	2	NET operation mode	
	3, 4	External/PU combined mode	
	6	NET operation mode	
	7	X12 (MRS) signal ON NET operation mode	
		X12 (MRS) signal off External operation mode	

Modbus registers

● System environment variable

Register	Definition	Read/write	Remarks
40002	Inverter reset	Write	Any value can be written.
40003	Parameter clear	Write	Set H965A as a written value.
40004	All Parameter clear	Write	Set H99AA as a written value.
40006	Parameter clear *1	Write	Set H5A96 as a written value.
40007	All parameter clear *1	Write	Set HAA99 as a written value.
40009	Inverter status/control input instruction*2	Read/write	See below.
40010	Operation mode/inverter setting *3	Read/write	See below.
40014	Running frequency (RAM value)	Read/write	According to the <i>Pr.37</i> settings, the frequency and selectable speed are in 1r/min increments.
40015	Running frequency (EEPROM value)	Write	

<Inverter status/control input instruction>

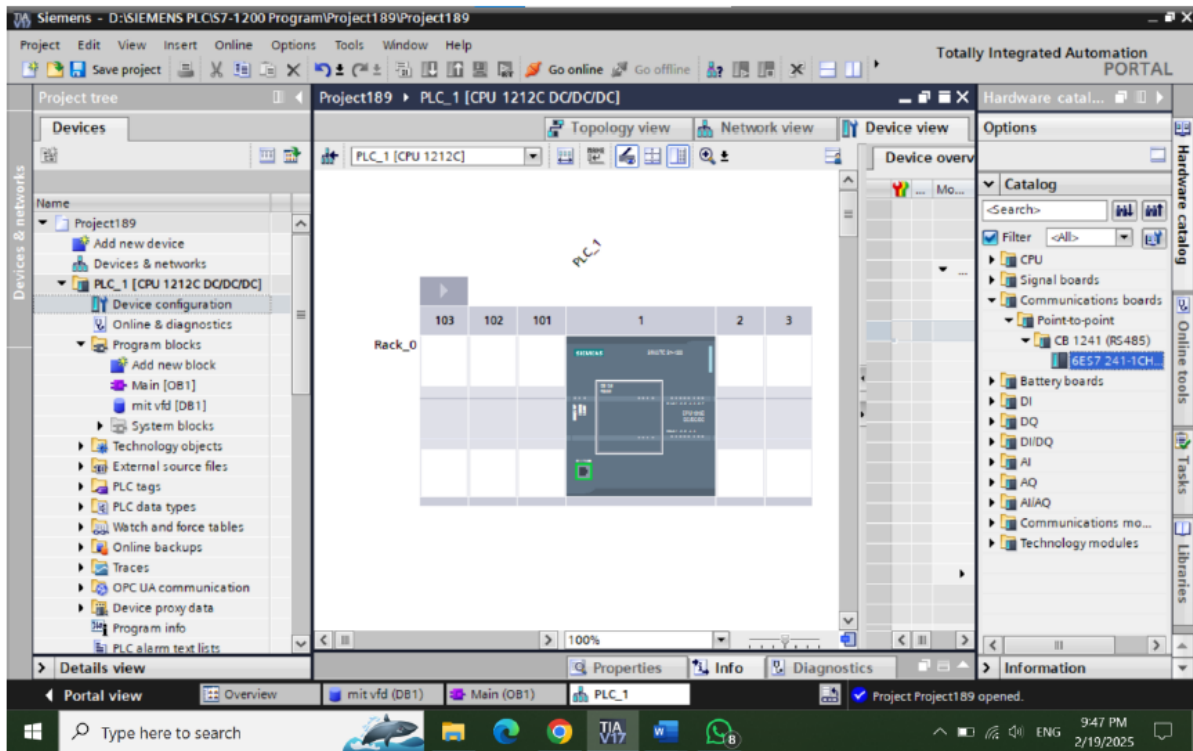
Bit	Definition	
	Control input instruction	Inverter status
0	Stop command	RUN (inverter running) *2
1	Forward rotation command	Forward rotation
2	Reverse rotation command	During reverse rotation
3	RH (high-speed operation command)*1	SU (up-to-frequency)
4	RM (middle-speed operation command)*1	OL (overload)
5	RL (low-speed operation command)*1	0
6	0	FU (frequency detection) *2
7	RT (second function selection)	ABC (fault) *2
8	AU (current input selection)	0
9	0	0
10	MRS (output stop) *1	0
11	0	0
12	RES (reset) *1	0
13	0	0
14	0	0
15	0	Fault occurrence

+ Setting Frequency = **40014** (dec)

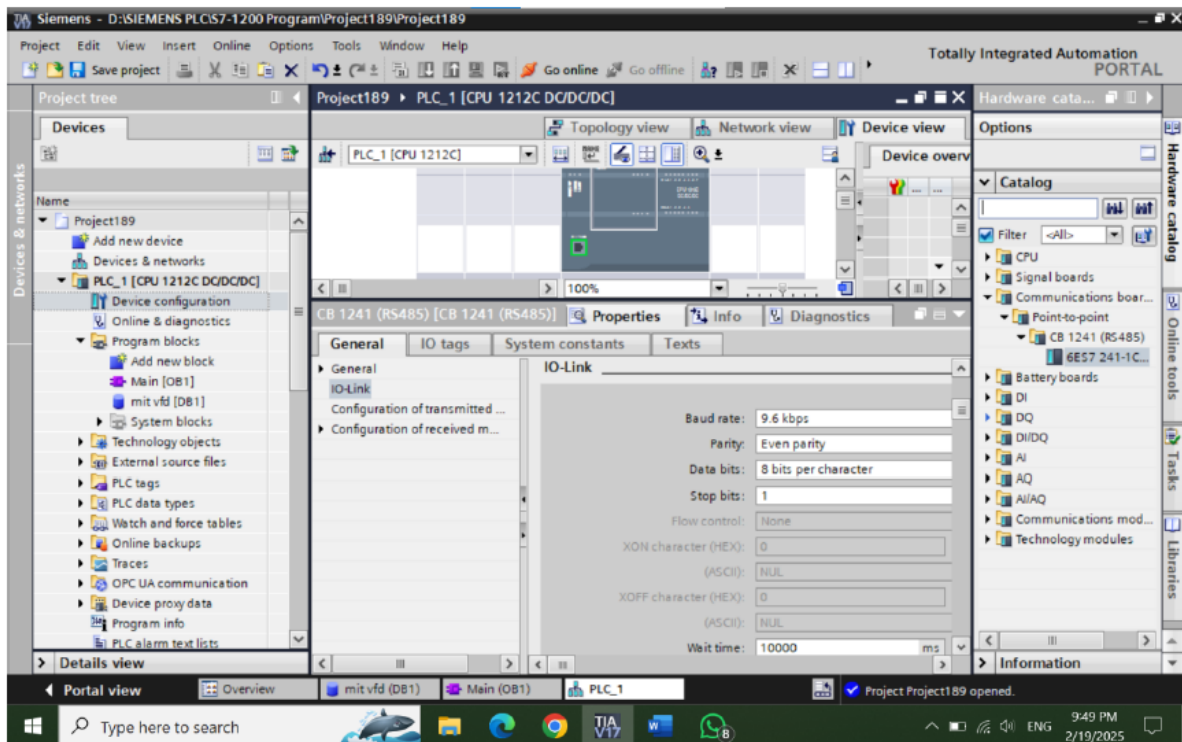
+ Motor Control Address = **40009** (dec)

- Forward Run – Set 40009 = 0000.0000.0000.0010 = **2**
- Reverse Run – Set 40009 = 0000.0000.0000.0100 = **4**
- Stop command – Set 40009 = 0000.0000.0000.0000 = **1**

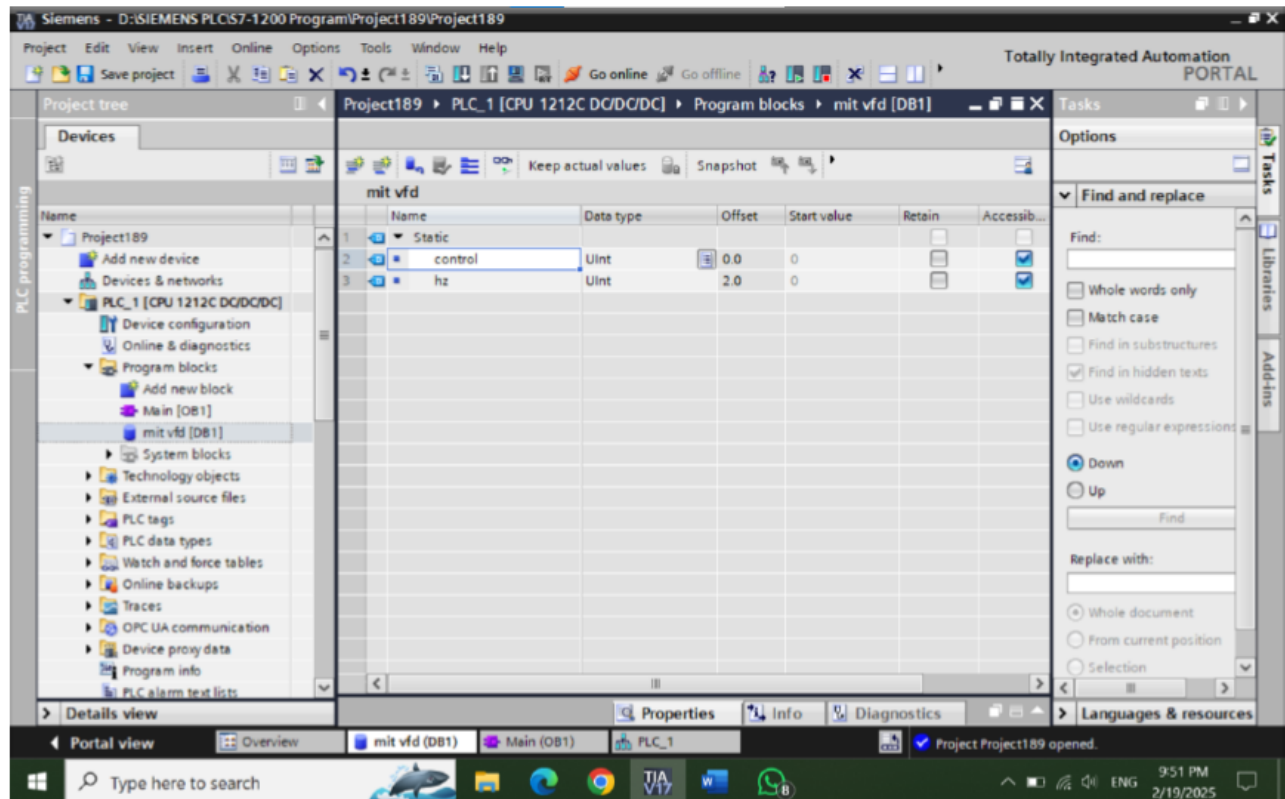
Open TIA Portal and select CPU Model also take Communication boards.



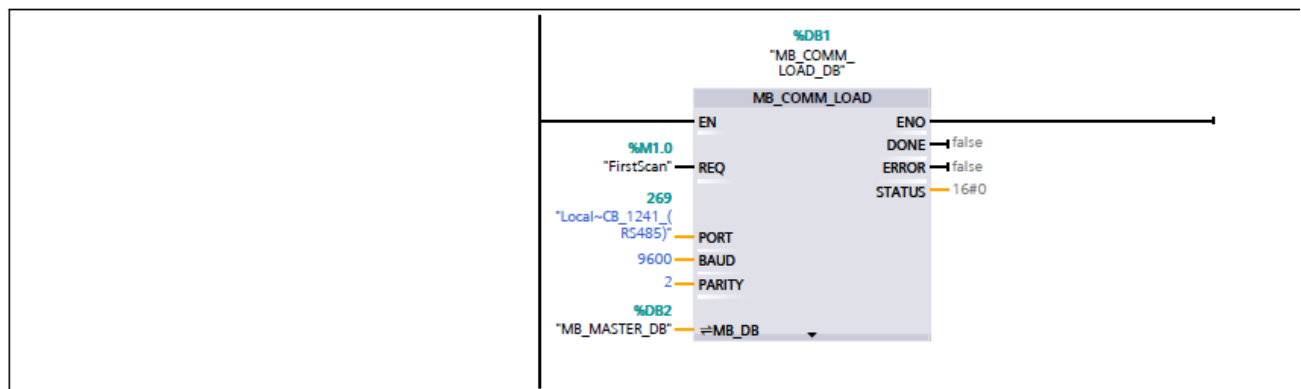
Modbus Protocol Configuration of PLC as like as Mitsubishi VFD.



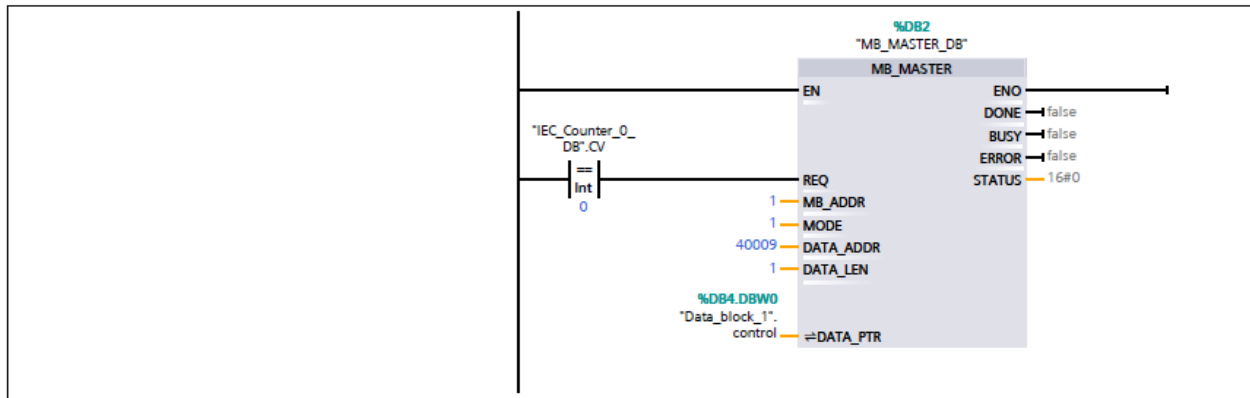
Create a Data Block for Write Data to Mitsubishi VFD.



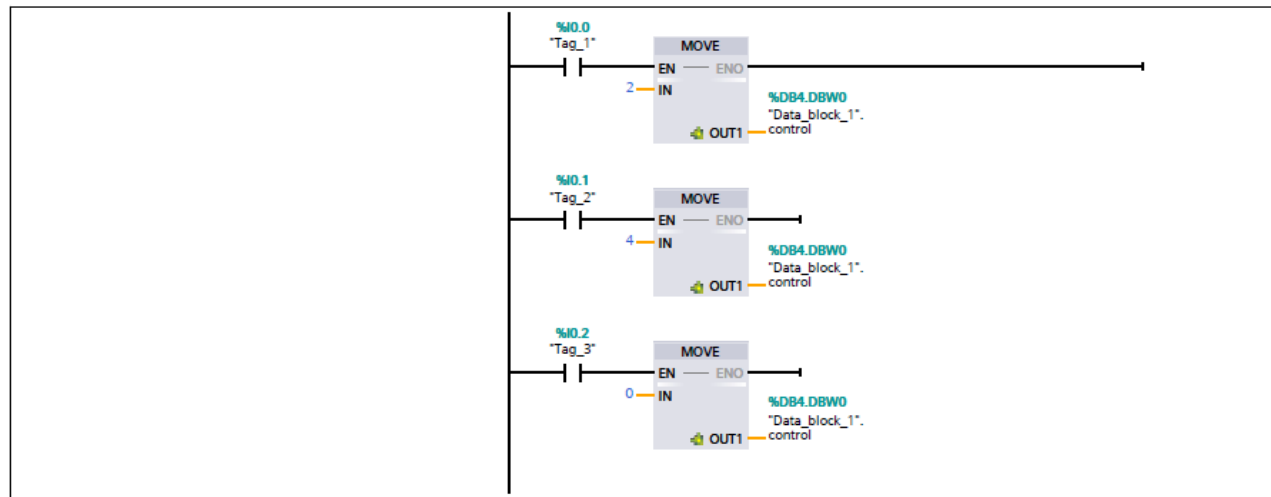
Network 1:

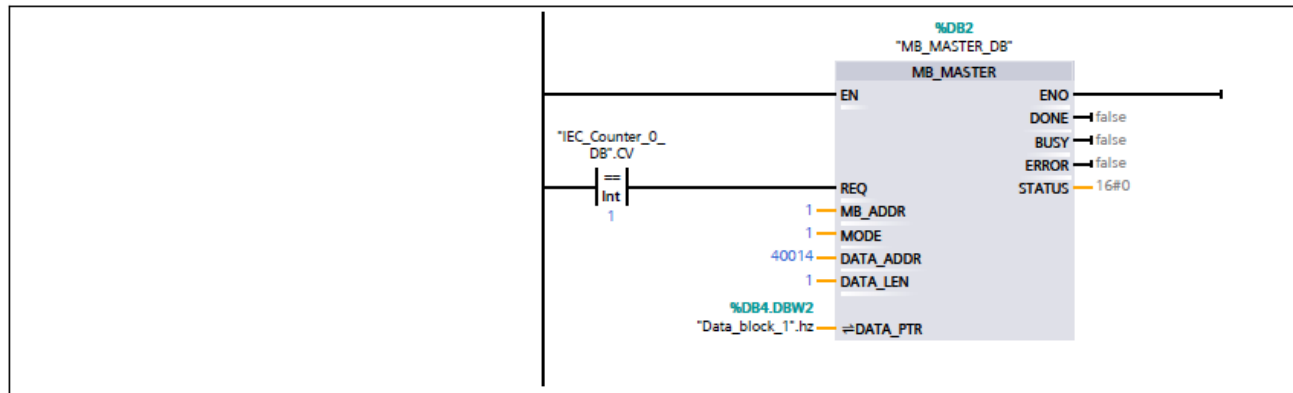


Network 2:



Network 3:





Network 5:

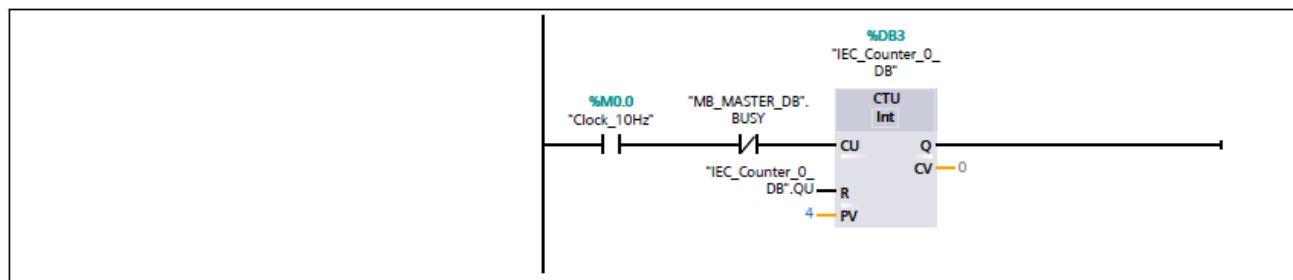


Fig: Ladder Diagram for Modbus Communication between VFD and PLC



Self-Check 7.3-1

1. Which VFD control mode is the simplest, most common, and best suited for simple fan and pump applications (quadratic torque loads)?
2. Which advanced VFD control mode should be configured for a lifting hoist application that requires maximum, precise torque control from standstill (0Hz) without an encoder?
3. If a VFD's Run/Stop Command Source is set to Local or Keypad, how does the drive react to Run/Stop commands received from the PLC?
4. In the Preset Speed Mode of a VFD, what type of PLC interface is used to select the motor's operating frequency?
5. What is the main function of the Jog operating mode on a VFD?

6. In Open-Loop Vector Control, what is the purpose of the Slip Compensation feature?
7. If the Run/Stop Command Source is set to Network and the Speed Reference Source is set to Terminal Strip (Analog Input), what is required to start the motor?



Answer Paper 7.3-1

1. Volts-per-Hertz (V/Hz) or Scalar Control Mode is the best suited, as it is simple and adequate for quadratic torque loads.
2. Sensorless Vector Control (Open-Loop Vector) should be used, as it provides near-closed-loop torque control ideal for high-performance, high-torque applications at low speeds.
3. The VFD will ignore the PLC command entirely, accepting Run/Stop only from the physical buttons on the drive itself, prioritizing local control.
4. A series of Digital Inputs (DI) are used to select a binary combination corresponding to pre-programmed, fixed frequencies.
5. The main function of Jog mode is to allow the motor to run at a very low, fixed speed for a short duration to position a load.
6. Slip Compensation is used to automatically increase the output frequency as the motor load increases to maintain the desired set speed.
7. The Run command must come from the Network (PLC Communication), and the Speed Reference must come from the Analog Input (Terminal Strip), as the sources are split.

	Job Sheet 46
Qualification	Industrial Automation
Learning Unit	Operate VFD in Local Switch Mode

Trainee Name	
PPE	Safety glasses, insulated gloves, safety boots, ear protection
Tools & Equipment	Variable Frequency Drive (VFD), control panel, motor (AC), programming keypad, multimeter, wiring tools, VFD user manual
Notes	- "Local Mode" means control is performed directly from the VFD's built-in keypad/switches. - Ensure all parameters are correctly set before starting the motor. - Confirm motor wiring and rotation direction before full operation. - Always start with low speed during testing.
Procedure	1. Wear all required PPE before starting. 2. Power up the VFD and verify the display is operational. 3. Set the VFD to Local Mode using the keypad (usually via LOC/REM button or parameter settings). 4. Confirm that motor specifications (voltage, frequency, current) are correctly programmed into the VFD. 5. Use the keypad to: - Start the motor - Adjust speed using up/down keys or speed potentiometer - Stop the motor 6. Observe motor behavior and monitor parameters like frequency, voltage, current. 7. Check for abnormal sounds, vibrations, or overheating. 8. Stop the motor and power off the system. 9. Document the procedure, including VFD model, operating frequency range, and any abnormalities. 10. Return tools and clean the work area.
Trainee's Signature	
Assessor's Signature	
QA Signature	
Assessor's Comment	



Job Sheet 47

Qualification	Industrial Automation
Learning Unit	Operate VFD in Remote Switch Mode
Trainee Name	
PPE	Safety glasses, insulated gloves, safety boots, ear protection
Tools & Equipment	Variable Frequency Drive (VFD), control panel, remote switches (Start/Stop, Speed Potentiometer), motor (AC), multimeter, wiring tools, VFD user manual
Notes	- "Remote Mode" means the VFD is controlled via external devices (switches, relays, PLCs). - Wiring must follow the VFD terminal configuration diagram. - Proper signal levels and grounding must be verified before operation. - Ensure the VFD is configured to accept remote control inputs.
Procedure	1. Wear all appropriate PPE. 2. Confirm that the VFD is properly installed and wired to external control devices (e.g., start/stop switches, speed pot, or PLC). 3. Access VFD settings and switch from Local Mode to Remote Mode (usually via LOC/REM button or parameter setting). 4. Verify correct input terminal assignments for remote control (e.g., DI1 = Start, DI2 = Stop, AI1 = Speed). 5. Use remote Start switch to run the motor. 6. Adjust motor speed using external speed reference (potentiometer or analog input). 7. Use Stop switch to stop the motor. 8. Observe motor performance: direction, speed response, vibrations, and temperature. 9. Monitor VFD output parameters (frequency, current, voltage) during operation. 10. After testing, power off the system and return to safe state.

	11. Record wiring diagram, input configuration, and test results. 12. Clean the work area and store all tools.
Trainee's Signature	
Assessor's Signature	
QA Signature	
Assessor's Comment	

	Job Sheet 48
Qualification	Industrial Automation
Learning Unit	Operate VFD in Modbus Communication Mode
Trainee Name	
PPE	Safety glasses, insulated gloves, safety boots, ear protection
Tools & Equipment	Variable Frequency Drive (VFD), PLC or PC with Modbus software, RS-485 communication cable, motor (AC), multimeter, USB to RS-485 converter (if needed), VFD user manual
Notes	-Ensure correct Modbus settings: Slave ID, Baud Rate, Parity, Stop Bits. -Always confirm wiring polarity (A/B or D+/D-) on RS-485 line. -Test communication before running motor. -Use manufacturer-provided Modbus register table for correct parameter mapping.
Procedure	1. Wear all required PPE before starting. 2. Connect the VFD to the PLC or PC using RS-485 communication (2-wire) or appropriate serial converter. 3. Configure Modbus parameters on the VFD: - Set communication protocol to Modbus RTU - Assign unique Slave ID

	- Set Baud Rate (e.g., 9600), Parity (None/Even/Odd), and Stop Bits 4. On the PLC or PC, open Modbus communication software or program to connect to the VFD. 5. Read/write test values to confirm successful communication (e.g., read frequency, write run command). 6. Map correct Modbus register addresses to control Start, Stop, Speed Reference, etc. 7. Use the Modbus master device (PLC/PC) to: - Start the motor - Adjust speed by writing frequency reference - Stop the motor 8. Monitor the motor response and VFD status in real time. 9. Log communication settings, registers used, and test results. 10. Power down the system and disconnect safely. 11. Clean up the work area and store all tools.
Trainee's Signature	
Assessor's Signature	
QA Signature	
Assessor's Comment	

Module 8: Design and Develop PLC Based Control System



Contents of Module

Module Description

This unit of competency covers the knowledge, skills and attitudes required to design and develop PLC based control system. It specifically includes the tasks of analyzing control system requirements, designing PLC control system architecture, develop PLC program, simulating the PLC program, installing and configuring PLC hardware, and commissioning and debugging control system.

Minimum Time: 55 Hours



Learning Outcome

- 8.1. Analyze Control System Requirements
- 8.2. Design PLC Control System Architecture
- 8.3. Develop PLC Program
- 8.4. Simulate the PLC Program
- 8.5. Install and Configure PLC Hardware
- 8.6. Commission and Debug Control System



Performance Criteria

1. Control system objectives and functional requirements are identified according to projects.
2. System inputs, outputs, and interfaces are analyzed to determine operational needs.
3. Hardware and software requirements for the control system are specified and evaluated.
4. Constraints and limitations of the control system are identified and addressed in the analysis.
5. Flow charts or algorithms for the PLC control system are developed according to project requirements.
6. Process steps and control sequences are mapped to ensure effective automation.
7. Control inputs, outputs, and feedback loops are incorporated into the system design.
8. Safety interlocks and error handling mechanisms are integrated into the control architecture.
9. Designed architecture is reviewed and validated for completeness and accuracy.
10. Appropriate programming language are selected and applied according to project requirements.
11. PLC programs are developed based on designed algorithms and control sequences.
12. Input and output devices are mapped within the program to ensure control.
13. Program code is written, structured, and commented to maintain readability and facilitate troubleshooting.
14. Simulation results are analyzed to identify errors, bugs, or inefficiencies in the program.
15. Corrective actions are implemented based on simulation feedback to improve program performance.
16. Installation site is inspected and prepared to ensure compliance with safety and operational standards.
17. PLC hardware components are identified and assembled.
18. PLC hardware is installed and connected according to project requirements.
19. Power and signal cables are connected correctly to PLC modules and peripheral devices.
20. Hardware configuration settings are set according to system requirements.
21. Functional tests are conducted to verify correct hardware installation.
22. Program is tested on live hardware to validate operation under actual working conditions.
23. Modifications and debugging are performed as required.
24. System responses are monitored and evaluated.

25. Faults and malfunctions are identified, analyzed, and resolved systematically.
26. Commissioning procedures are documented and reported.

Learning Outcome 8.1 – Analyze Control System Requirements



Content

- **System Specification Interpretation:** Learn to analyze and break down a control narrative (e.g., sequence of operations, safety requirements, process constraints) provided by the client or engineering documentation.
- **I/O List Development:** Develop a comprehensive Input/Output (I/O) list by identifying every necessary sensor (input) and actuator (output) and assigning preliminary PLC addresses and data types.
- **Functional Requirements Definition:** Define the specific control logic functions required, including conditions for start/stop, timing, counting, alarming, and necessary safety interlocks to meet the operational goals.



Assessment Criteria

- Complete I/O Mapping
- Accurate Logic Translation
- Safety Feature Identification



Necessary Equipment

- Control Narrative/Specifications Document
- P&ID and Electrical Schematics
- Computer/Software (e.g., Excel/Word)
- PLC Manufacturer Documentation
- Engineering Tools/Templates



Learning Activity 8.1-1

Learning Activity	Resources/ Instructions/ References
Analyze Control System Requirements	• Information Sheet: 8.1-1 • Self-Check: 8.1-1 • Answer Paper: 8.1-1



Information Sheet 8.1-1

Learning Objective: The learner will be able to analyze a control narrative or specification to correctly define all functional requirements and develop a complete Input/Output (I/O) list necessary for a PLC-based control system design.

Design and Develop PLC-based Control System

To design and develop a PLC-based control system, you need to follow a structured process that includes several key steps.

System Design and Component Selection

The first step is to define the system's purpose and select the right components. You will need to determine the PLC's requirements, including the number and type of inputs and outputs (I/O) needed for your application. This could include digital inputs (for switches and sensors), digital outputs (for relays and indicators), and analog I/O (for devices like potentiometers and meters). You'll also need to select a motor control method, such as V/f (Volts per Hertz) or vector control, based on the application's needs for speed and torque precision. Finally, choose a VFD that is compatible with your motor and the chosen control method.

PLC and VFD Programming

Once the hardware is selected, you can begin programming the PLC and VFD. The PLC program will handle the control logic, such as receiving start/stop commands from a remote switch or through communication, and sending run commands to the VFD. You can program the VFD for various control functions, including minimum and maximum speeds, acceleration and deceleration times, and multiple preset speeds. For communication-based control, you'll need to set up the PLC and VFD parameters for network protocols, baud rate, and slave addresses.

Wiring and Integration

Proper wiring is essential for the system to function correctly and safely. The motor should be wired to the VFD's output terminals. For control, wire the external devices to the VFD's control terminals, using a common ground for digital inputs like STF (forward run) and STR (reverse run). If using an external potentiometer for speed control, connect it to the VFD's analog input terminals, typically for a 0-10V analog voltage input.

System Commissioning and Testing

After wiring is complete, the final step is to commission and test the system. This involves setting key parameters on the VFD to match the motor's specifications, such as rated voltage, base frequency, and capacity. You should also test all control methods, including starting and stopping the motor via local and remote switches as well as through communication. It's also important to verify that all safety functions are working as intended.

Learning Outcome 8.2 – Design PLC Control System Architecture



Content

- **System Topology Selection:** Understand and select the appropriate PLC system architecture (e.g., centralized, distributed I/O, networked multi-controller) based on the application's physical layout and performance requirements.
- **Component Sizing and Selection:** Determine the necessary CPU processing power, memory capacity, and the required number and type of I/O modules (DI/DO/AI/AO) based on the finalized I/O list and functional requirements.
- **Communication Network Design:** Define the industrial communication network (e.g., Ethernet/IP, Profinet, Modbus TCP) to connect the PLC to HMIs, VFDs, and distributed I/O, including IP addressing schemes and bandwidth considerations.



Assessment Criteria

- Architectural Appropriateness
- I/O Capacity Verification
- Network Integrity



Necessary Equipment

- System Requirements Documentation
- PLC Manufacturer Selection Tools
- Network Design Tools/Software
- Engineering Standards and Best Practices



Learning Activity 8.2-1

Learning Activity	Resources/ Instructions/ References
Design PLC Control System Architecture	• Information Sheet: 8.2-1 • Self-Check: 8.2-1 • Answer Paper: 8.2-1



Information Sheet 8.2-1

Learning Objective: The learner will be able to select and size the appropriate PLC hardware components and network topology to design a complete, scalable control system architecture that meets the specified application requirements.

Analyze, Develop, Design, Simulate, and Implement PLC-based Control Systems

The process of analyzing, developing, designing, simulating, and implementing a PLC-based control system is a comprehensive, multi-step engineering effort. It begins with analysis, where you define system requirements by examining documentation such as the Mitsubishi VFD manual to understand the necessary inputs, outputs, and control parameters for motor functions like speed and direction. Next, you design the system's architecture, creating a logic flow and selecting hardware components like the PLC and VFD based on the analysis. Development involves writing the PLC program, often in Ladder Logic, and configuring the VFD with parameters for communication and motor control to ensure they function as a unified system. Before physical implementation, you simulate the entire system using specialized software to perform virtual commissioning, testing the PLC and VFD logic for errors and optimizing performance in a safe, virtual environment. Finally, you implement the system by physically wiring all components, conducting a full commissioning by setting motor-specific parameters, and performing live testing to verify that the system operates correctly and safely in the real world.

Learning Outcome 8.3 – Develop and Simulate PLC Program



Content

- **Program Translation and Coding:** Learn to accurately translate the defined control logic (from the design analysis) into the specific PLC programming language (Ladder Diagram, Structured Text, etc.) using the appropriate instruction set.
- **Simulation Environment Setup:** Understand how to set up and utilize the software's built-in PLC simulator or emulator to test the program logic without requiring physical hardware.
- **Code Debugging and Verification:** Master techniques for step-by-step execution, force/unforce I/O bits, and online monitoring within the simulator to debug logic errors and verify the program meets all functional requirements.



Assessment Criteria

- Functional Logic Execution
- Error and Fault Handling
- Efficiency and Documentation



Necessary Equipment

- Programming Computer/Laptop
- PLC Simulation Software
- Control Requirements Documents
- Code Development Standards
- Simulation Test Scenarios



Learning Activity 8.3-1

Learning Activity	Resources/ Instructions/ References
Develop and Simulate PLC Program	• Information Sheet: 8.3-1 • Self-Check: 8.3-1 • Answer Paper: 8.3-1 • Job Sheet 49 – Job Sheet 64



Information Sheet 8.3-1

Learning Objective: The learner will be able to translate design requirements into a complete PLC program and utilize simulation tools to systematically debug and verify the logic's functionality before physical deployment.

Three-Phase Induction Motor Operation Project – 1

Project Name: Operation of a Three-Phase Induction Motor by Direct On-Line (DOL) Starter using PLC

Project Description: A PLC-based Direct On-Line (DOL) starter project for a three-phase induction motor automates the motor's operation while providing essential protection. The PLC acts as the central control unit, managing the motor's run logic via an internal program. When an operator initiates a start command, the PLC energizes a contactor, which directly connects the motor to the full line voltage, causing it to start. The PLC also monitors the motor's status and incorporates safety features like an overload relay, which is wired to a PLC input. If the overload relay trips, the PLC detects this condition and de-energizes the contactor, safely shutting down the motor. This system is a reliable and straightforward method for controlling a motor in applications where a high starting current is acceptable and variable speed control is not required.

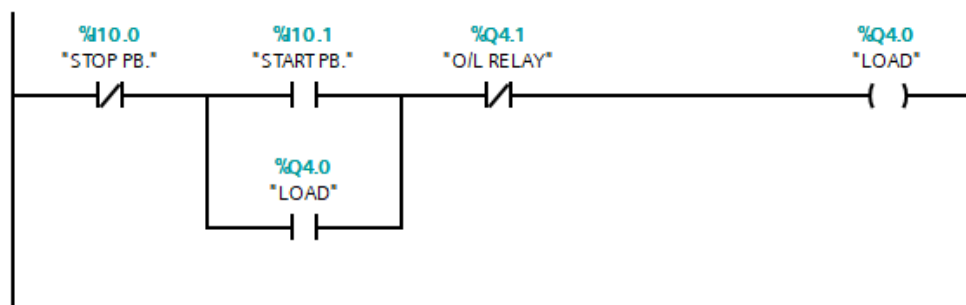


Fig: Ladder Diagram for Project 9.1.1

Three-Phase Induction Motor Operation Project – 2

Project Name: Starting a Three-Phase Induction Motor Instantly Using a Push Button Switch or Sensor and then stopping the Motor after 30 seconds using PLC.

Project Description: A PLC-based system to start a three-phase induction motor with a push button and stop it after 30 seconds uses a latching circuit and a timer function. When the push button is pressed, the PLC's logic is activated, which latches the motor's contactor output to start the motor instantly. This action simultaneously triggers an internal timer set for a 30-second delay. Once the timer completes its countdown, its associated "done" bit opens a normally closed contact within the ladder logic, which unlatches the circuit and de-energizes the motor's contactor, causing the motor to stop automatically. This method provides simple, automated control over the motor's run time.

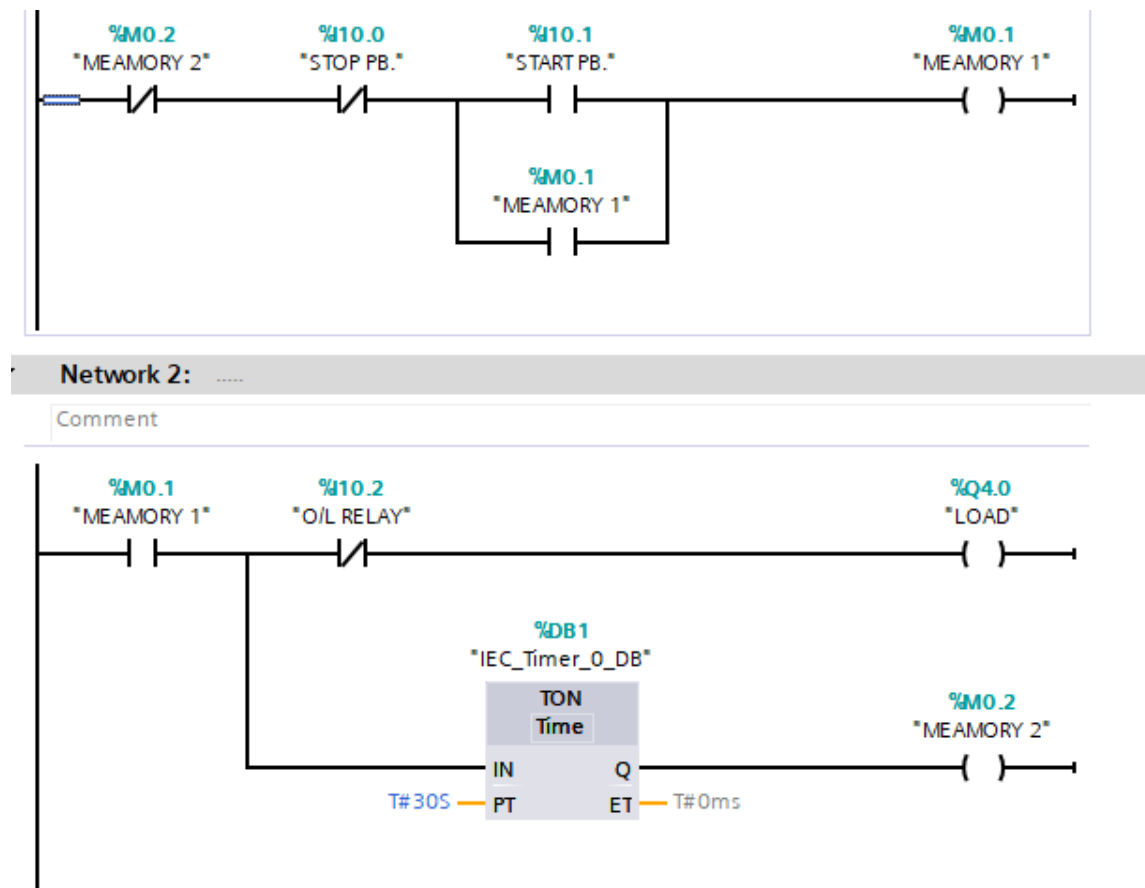


Fig: Ladder Diagram for Project 9.1.2

Three-Phase Induction Motor Operation Project – 3

Project Name: A Three-Phase Induction Motor will be started after 10 seconds from using a Push Button Switch or Sensor using PLC.

Project Description: This project involves controlling a three-phase induction motor with a delayed start using a Programmable Logic Controller (PLC). When a push button or sensor provides an input signal to the PLC, the program logic activates an internal timer function. This timer is programmed to count for 10 seconds. After the 10-second delay has elapsed, the PLC's timer output is set to a "true" state. This output is wired to energize the coil of a motor starter contactor. The energized contactor then closes its main contacts, allowing three-phase power to flow to the motor, causing it to start. This PLC-based system provides precise, repeatable, and easily modifiable timing for the motor's start-up sequence.

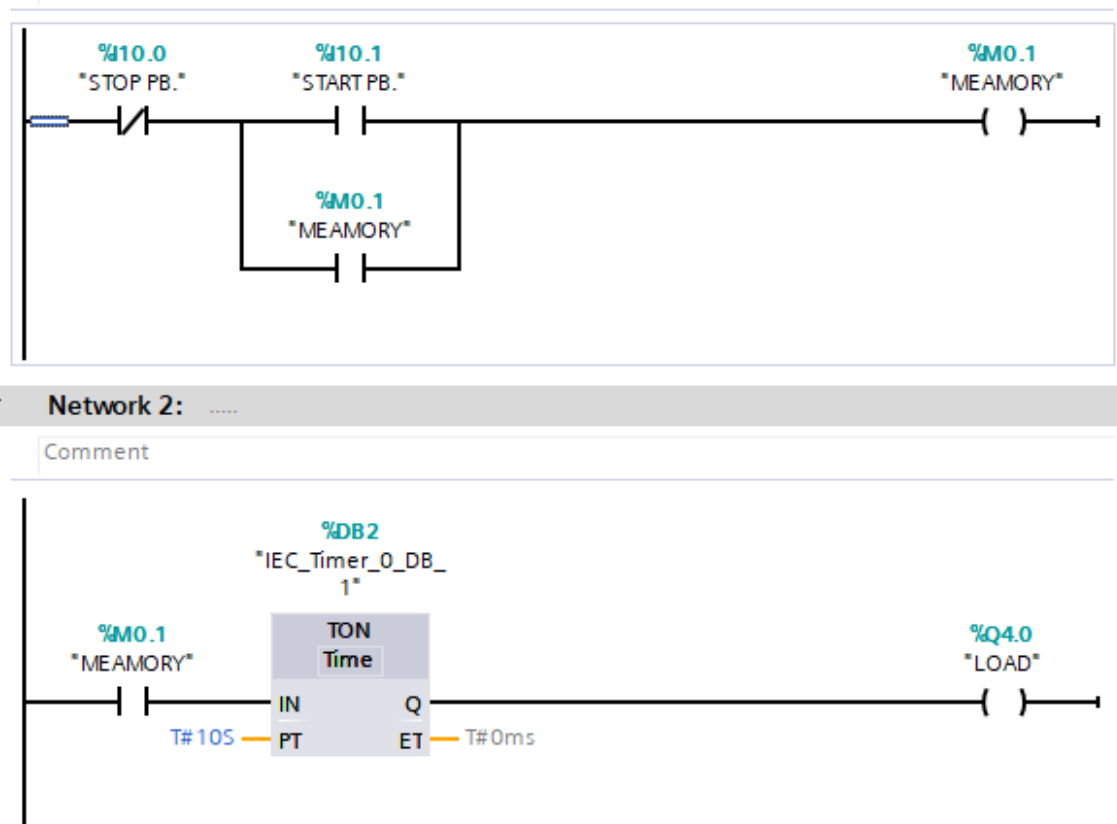


Fig: Ladder Diagram for Project 9.1.3

Three-Phase Induction Motor Operation Project – 4

Project Name: A Three-Phase Induction Motor will be started using PLC instantly after pressing a Push Button Switch or Sensor and will stop after 30 seconds from the start time. And again, another Three-Phase Induction Motor will be started instantly after stopping the first Motor.

Project Description: This project outlines an automated, PLC-controlled sequence for two three-phase induction motors. The sequence begins when a push button or sensor provides an input signal to the PLC, which is programmed to instantly energize an output that starts the first motor. Simultaneously, the PLC's internal logic activates a timer function set for 30 seconds. When the timer elapses, the PLC's logic de-energizes the first motor's output and simultaneously energizes the output for the second motor, causing the first motor to stop and the second motor to start instantly. This PLC-based system provides a precise, automated, and interlocked sequence that ensures the second motor starts immediately after the first one has stopped, which is ideal for applications requiring a sequential but non-overlapping operation.

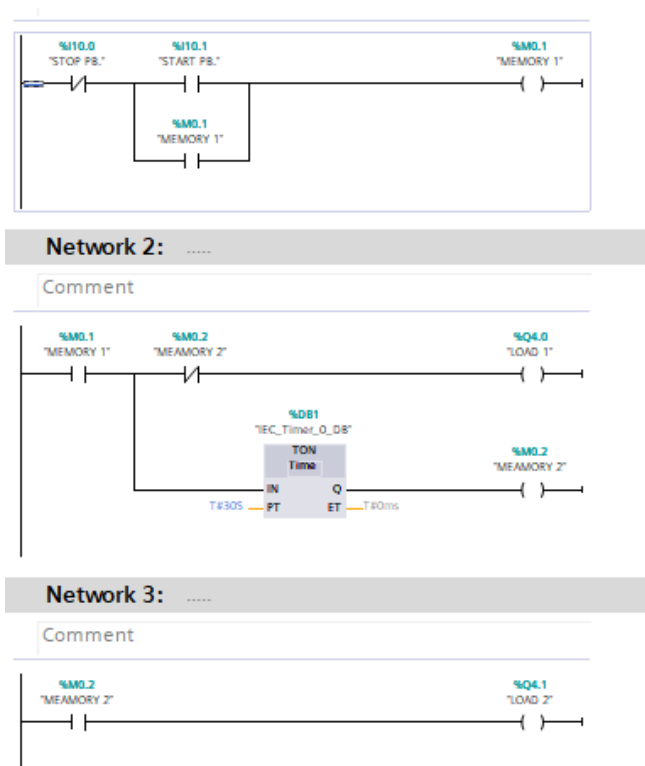


Fig: Ladder Diagram for Project 9.1.4

Three-Phase Induction Motor Operation Project – 5

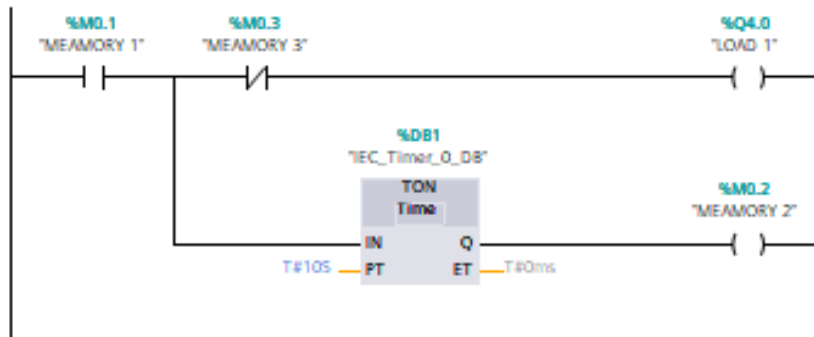
Project Name: One Three-Phase Induction Motor will be started using PLC instantly after pressing a Switch or activating any Sensor, Another Three-Phase Induction Motor will be started after 10 seconds of starting Motor-1. And again the Motor-1 will be stopped after 2 minutes of Motor-2 starting.

Project Description: This project outlines an automated control sequence for two three-phase induction motors, M1 and M2, using a Programmable Logic Controller (PLC). When a switch is pressed or a sensor is activated, the PLC is programmed to instantly start Motor 1 and simultaneously initiate a timer (Timer 1). After a 10-second delay, Timer 1's output is activated, which then starts Motor 2. The start of Motor 2 simultaneously triggers a second timer (Timer 2). After two minutes, Timer 2's output is activated, and the PLC's logic deactivates the output for Motor 1, causing it to stop, while Motor 2 continues to run. This PLC-based system ensures a precise, staggered start-up for both motors and an automated, time-delayed shutdown for the first motor after the second one has been running for a specific duration.



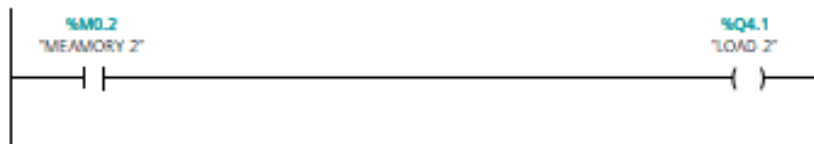
Network 2:

Comment



Network 3:

Comment



Network 4:

Comment

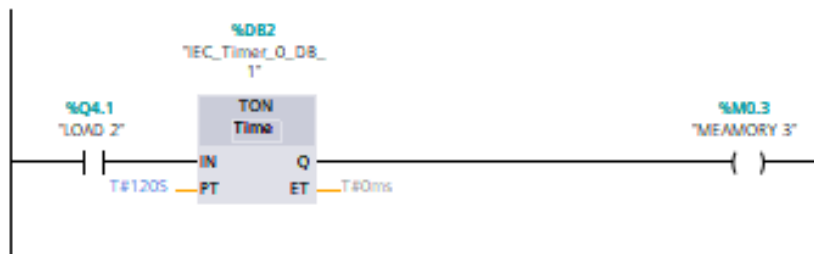


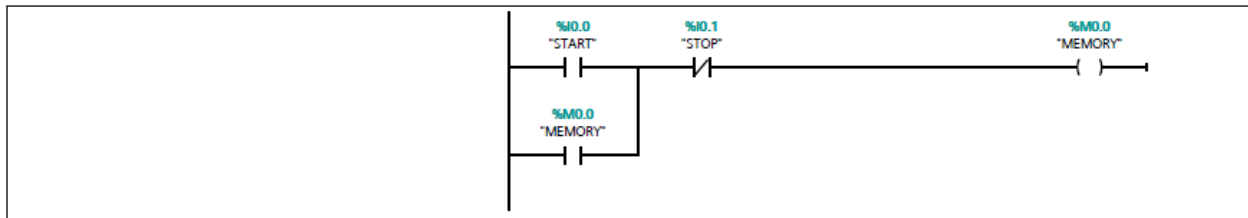
Fig: Ladder Diagram for Project 9.1.5

Three-Phase Induction Motor Operation Project – 6

Project Name: Motor-1 will be started after 20 seconds of pressing a switch or activating a sensor, Motor-2 will be started after 10 seconds of Motor-1 starting, and finally only Motor-2 will be stopped after 1 minute of starting it using PLC.

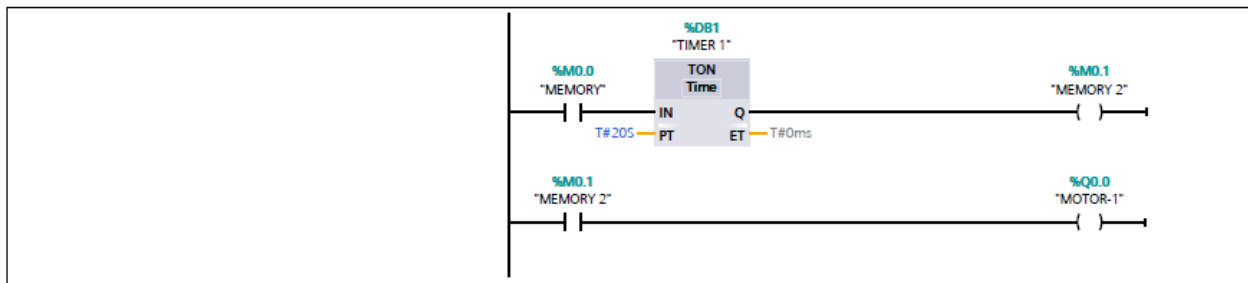
Project Description: This project outlines an automated, PLC-based control sequence for two three-phase induction motors, Motor 1 (M1) and Motor 2 (M2). The process is initiated by a push-button switch or sensor, which provides an input signal to the PLC. The PLC program is configured to activate a timer (Timer 1) for a 20-second delay. After this delay, Timer 1's output is activated, starting M1. The start of M1 simultaneously triggers a second timer (Timer 2). After a 10-second delay, Timer 2's output is activated, starting M2. The start of M2 also triggers a third timer (Timer 3). After a 1-minute delay, Timer 3's output is activated, and the PLC's logic is programmed to de-energize the output for M2 only, causing it to stop, while M1 continues to operate. This system provides a precisely timed and sequenced operation for both motors, with an independent, time-delayed shutdown for M2.

Network 1:



Network 2:

Motor-1 will be started after 20 seconds of pressing a switch or activating a sensor



Network 3:

Motor-2 will be started after 10 seconds of Motor-1 starting and finally only Motor-2 will be stoped after 1 minute of starting it

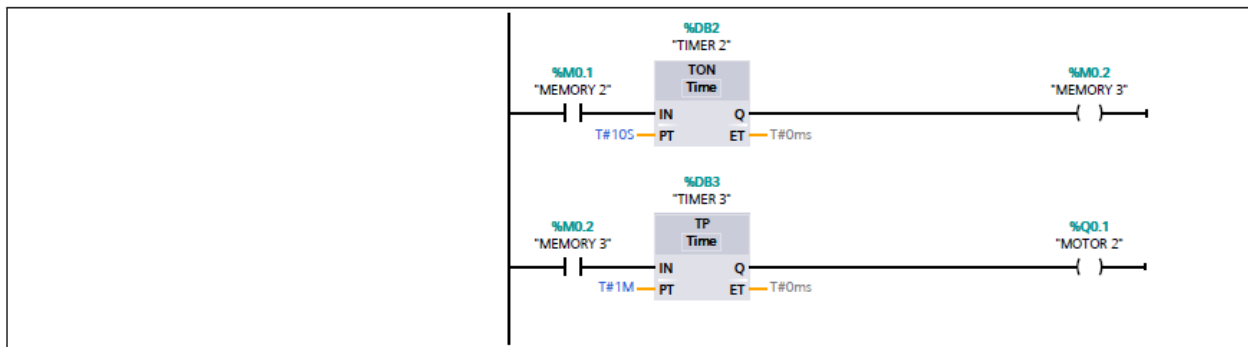


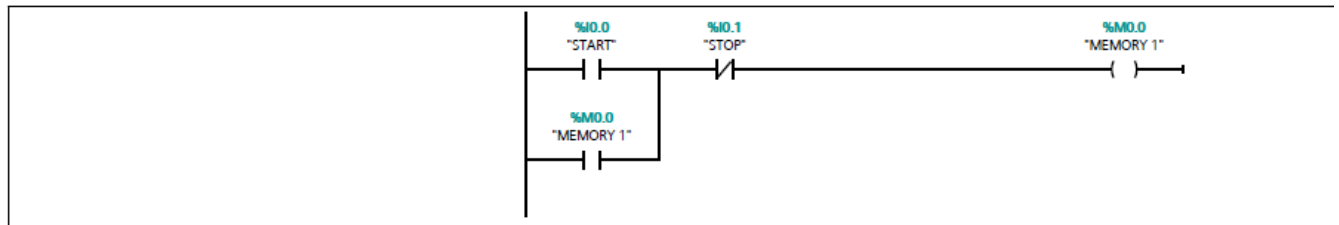
Fig: Ladder Diagram for Project 9.1.6

Three-Phase Induction Motor Operation Project – 7

Project Name: Motor-1 will be started after 20 seconds of pressing a switch or activating a sensor, Motor-2 will be started after 10 seconds of Motor-1 starting, and finally both Motor will be stopped after 1 minute of Motor-2 starting using PLC.

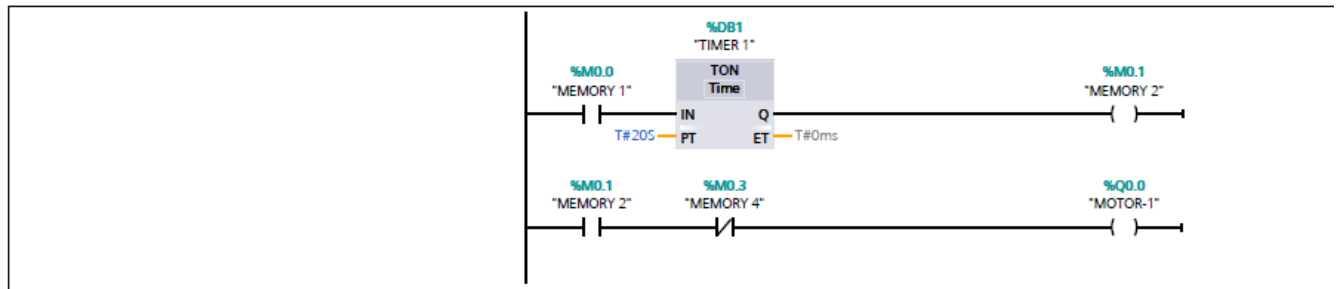
Project Description: This project outlines a sequential and automated control system for two three-phase induction motors, Motor 1 (M1) and Motor 2 (M2), using a Programmable Logic Controller (PLC). The process starts when a switch or sensor provides an input signal to the PLC. The PLC's program is configured with a timer (Timer 1) that delays the start of M1 by 20 seconds. Once M1 starts, it activates a second timer (Timer 2), which is set for a 10-second delay. After this delay, Timer 2 starts M2. The start of M2 simultaneously triggers a third timer (Timer 3), which is set to a 1-minute delay. When Timer 3 completes its countdown, the PLC's logic deactivates the outputs for both M1 and M2, causing them to stop simultaneously. This PLC-based system ensures a precise, time-delayed, and synchronized start and stop sequence for both motors.

Network 1:



Network 2:

Motor-1 will be started after 20 seconds of pressing a switch or activating a sensor



Network 3:

Motor-2 will be started after 10 seconds of Motor-1 starting and finally both motor will be stoped after 1 minute of starting Motor-2

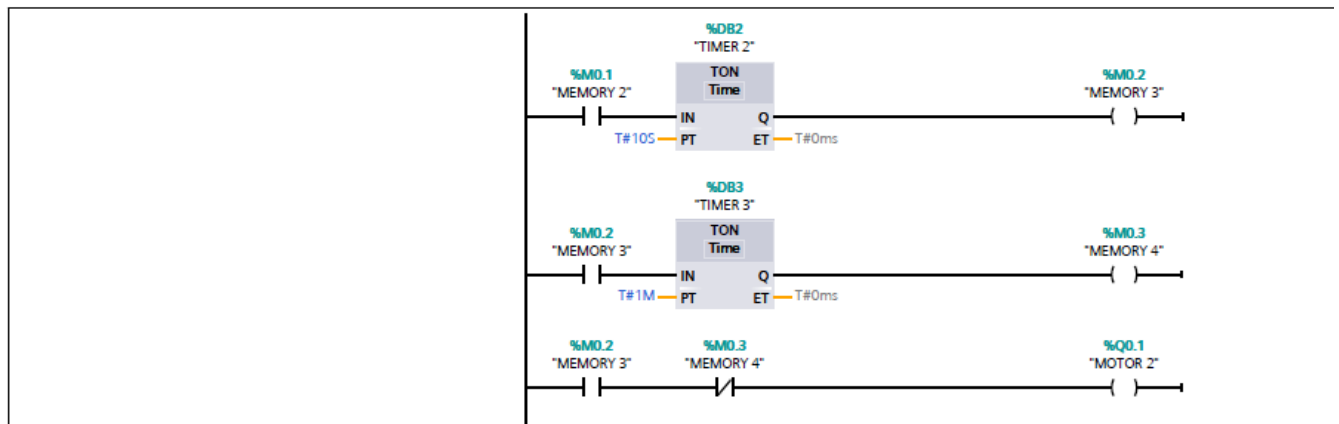


Fig: Ladder Diagram for Project 9.1.7

Three-Phase Induction Motor Operation Project – 8

Project Name: Operating a Three-Phase Induction Motor by constructing a Manual Forward-Reverse Starter using PLC.

Project Description: This project outlines the creation of a PLC-controlled manual forward-reverse starter for a three-phase induction motor. Instead of traditional push buttons and relay logic, a Programmable Logic Controller (PLC) handles the control. Two momentary push buttons—one for "Forward" and one for "Reverse"—are wired to PLC digital inputs. A third "Stop" button is also connected as an input. The PLC program is written to energize the "Forward" contactor's coil output when the "Forward" button is pressed, causing the motor to run in one direction. Similarly, pressing the "Reverse" button energizes the "Reverse" contactor's coil output, reversing the motor's direction. Crucially, the PLC's internal logic provides both electrical and software interlocking, preventing both forward and reverse contactors from being active at the same time and thus protecting the motor and circuit from a short circuit. The "Stop" button input is programmed to de-energize either output, safely stopping the motor. This PLC-based approach offers enhanced safety, flexibility, and easier modification compared to a traditional relay logic circuit.

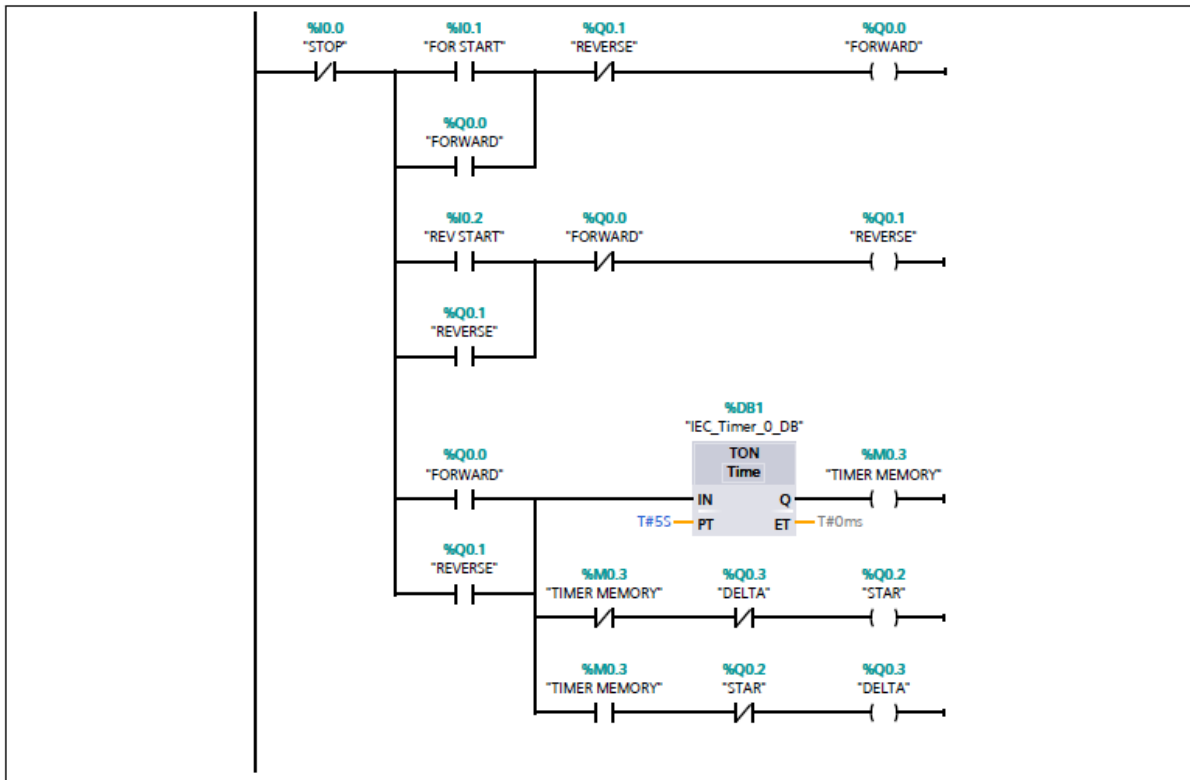


Fig: Ladder Diagram for Project 9.1.8

Three-Phase Induction Motor Operation Project – 9

Project Name: Operating a Three-Phase Induction Motor by constructing an Automatic Forward-Reverse Starter using PLC.

Project Description: This project outlines an automated forward-reverse starter for a three-phase induction motor controlled by a Programmable Logic Controller (PLC). The system is initiated by a single push button or sensor. When the PLC receives this input, its program logic is configured to first energize the output for the forward contactor, causing the motor to run in the forward direction. After a pre-set time delay, the PLC automatically de-energizes the forward contactor and, after a brief pause to allow the motor to stop and prevent a short circuit, energizes the output for the reverse contactor, causing the motor to run in the opposite direction. This automated sequence is ideal for applications that require repetitive and timed forward-reverse cycles, such as

in conveyor systems, packaging machinery, or automated gates. The PLC's internal logic handles all the timing and interlocking, eliminating the need for complex hardwired relay circuits and offering greater flexibility for adjustments and modifications.

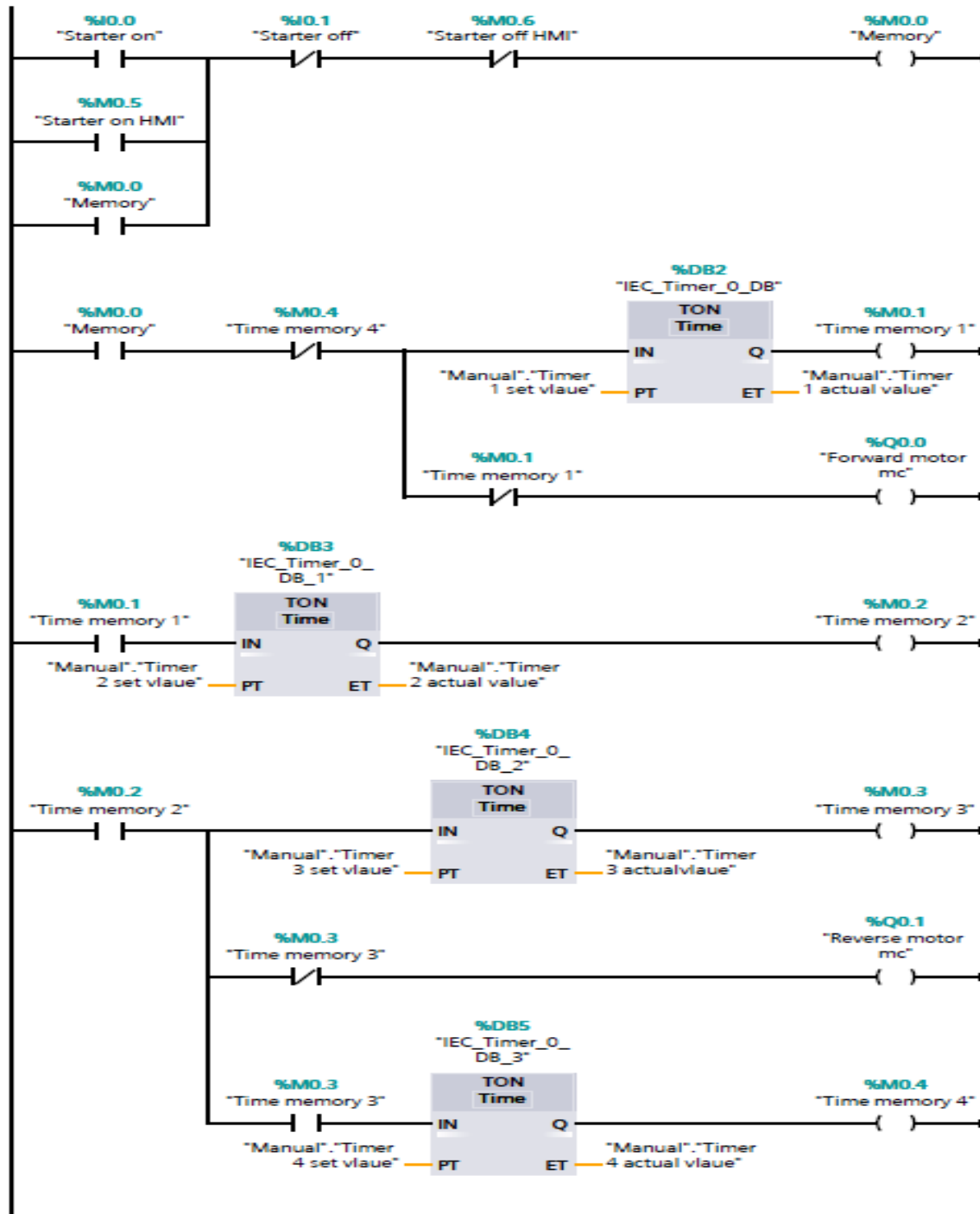


Fig: Ladder Diagram for Project 9.1.9

Three-Phase Induction Motor Operation Project – 10

Project Name: Operating a Three-Phase Induction Motor by constructing an Automatic Star-Delta Starter using PLC.

Project Description: This project describes the creation of an automated Star-Delta starter for a three-phase induction motor using a Programmable Logic Controller (PLC). A Star-Delta starter is used for large motors to reduce high starting current. The sequence is initiated by a single push button or sensor input to the PLC. The PLC's program first energizes the main and Star contactors simultaneously, causing the motor to start in a star configuration, which limits the initial inrush current. A PLC timer begins counting at this moment. After a pre-set duration (typically around 10-20 seconds), the PLC's logic de-energizes the Star contactor and, after a short transition delay, energizes the Delta contactor. The motor then runs in a delta configuration, receiving full line voltage and achieving its full operational torque and speed. The PLC's software ensures precise timing and critical interlocking between the Star and Delta contactors, preventing both from being active at the same time and thus protecting the motor and power system.

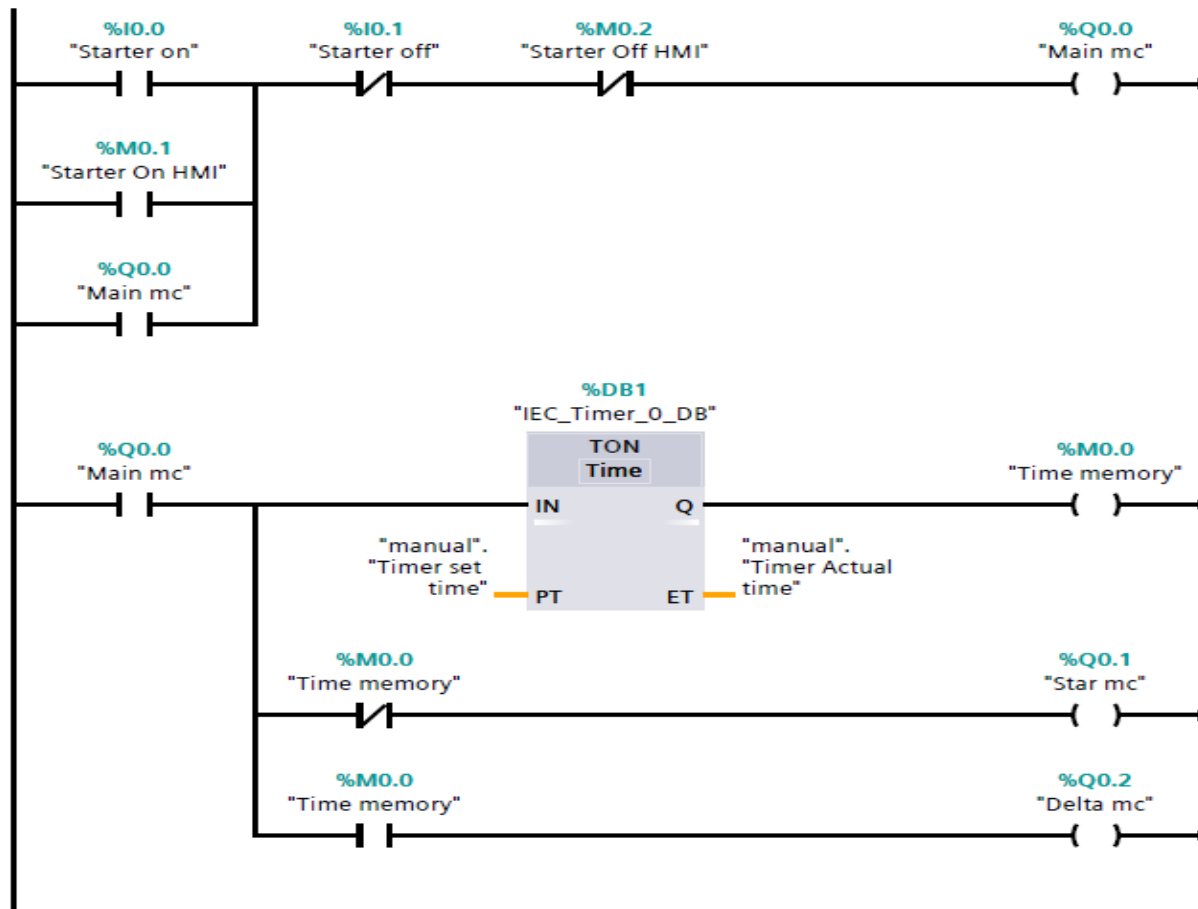


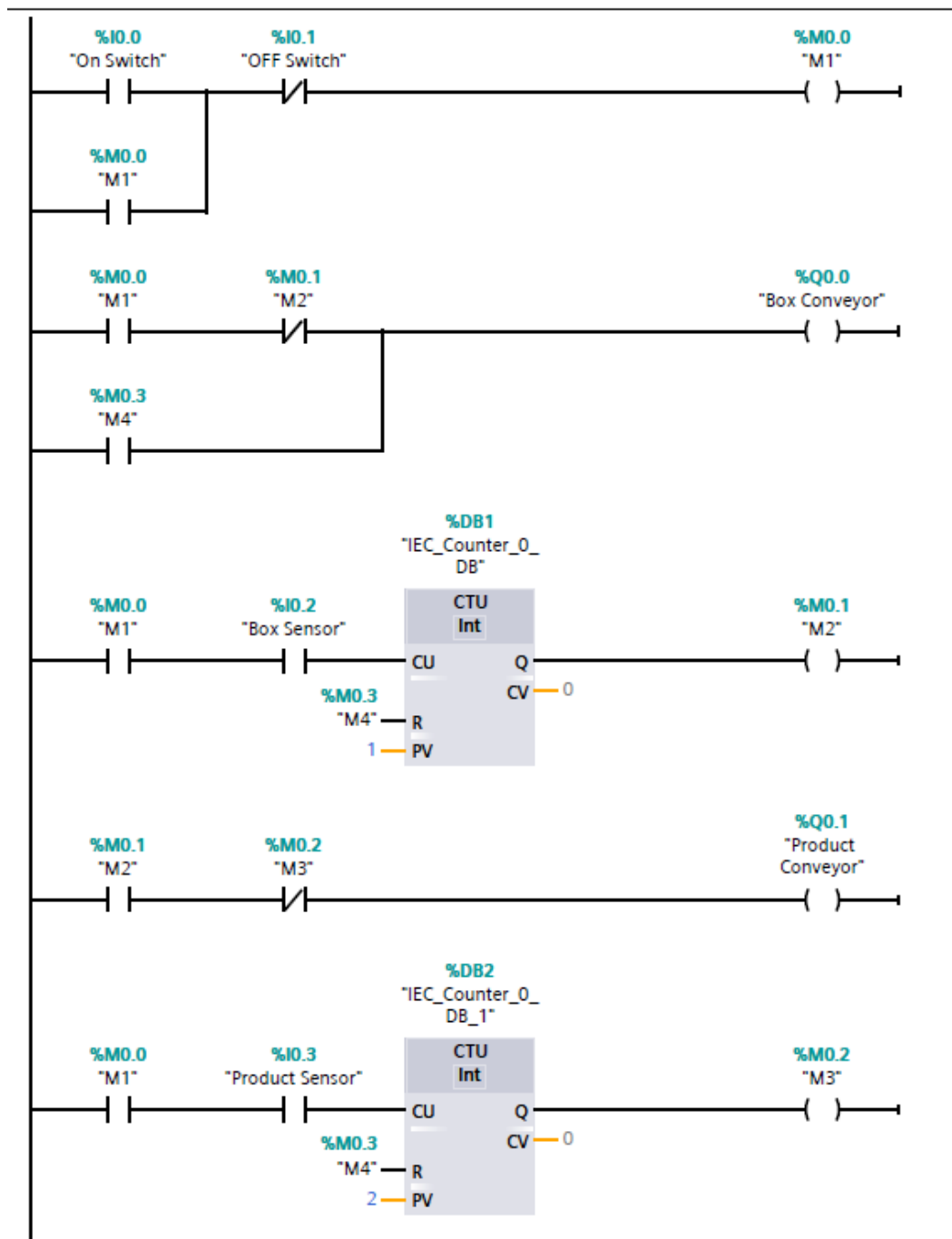
Fig: Ladder Diagram for Project 9.1.10

Automatic Packaging and Conveyor Belt Operation Project

Project Name: Developing an automated system using PLC for packaging products onto a pallet. The system utilizes two separate conveyor belts and a series of sensors and actuators to perform a precise, sequential operation.

Project Description: This project outlines an automated system for packaging products onto a pallet, controlled by a Programmable Logic Controller (PLC). The system uses two separate conveyor belts—one for products and another for boxes—along with sensors and a hydraulic pusher to perform a precise, sequential operation. The process begins with a product being moved into position by the product conveyor, confirmed by a sensor. Simultaneously, an empty box is

positioned by the box conveyor. A hydraulic pusher then transfers the product into the box. Finally, the box conveyor transports the newly filled box to a pallet, and the system resets to repeat the process.



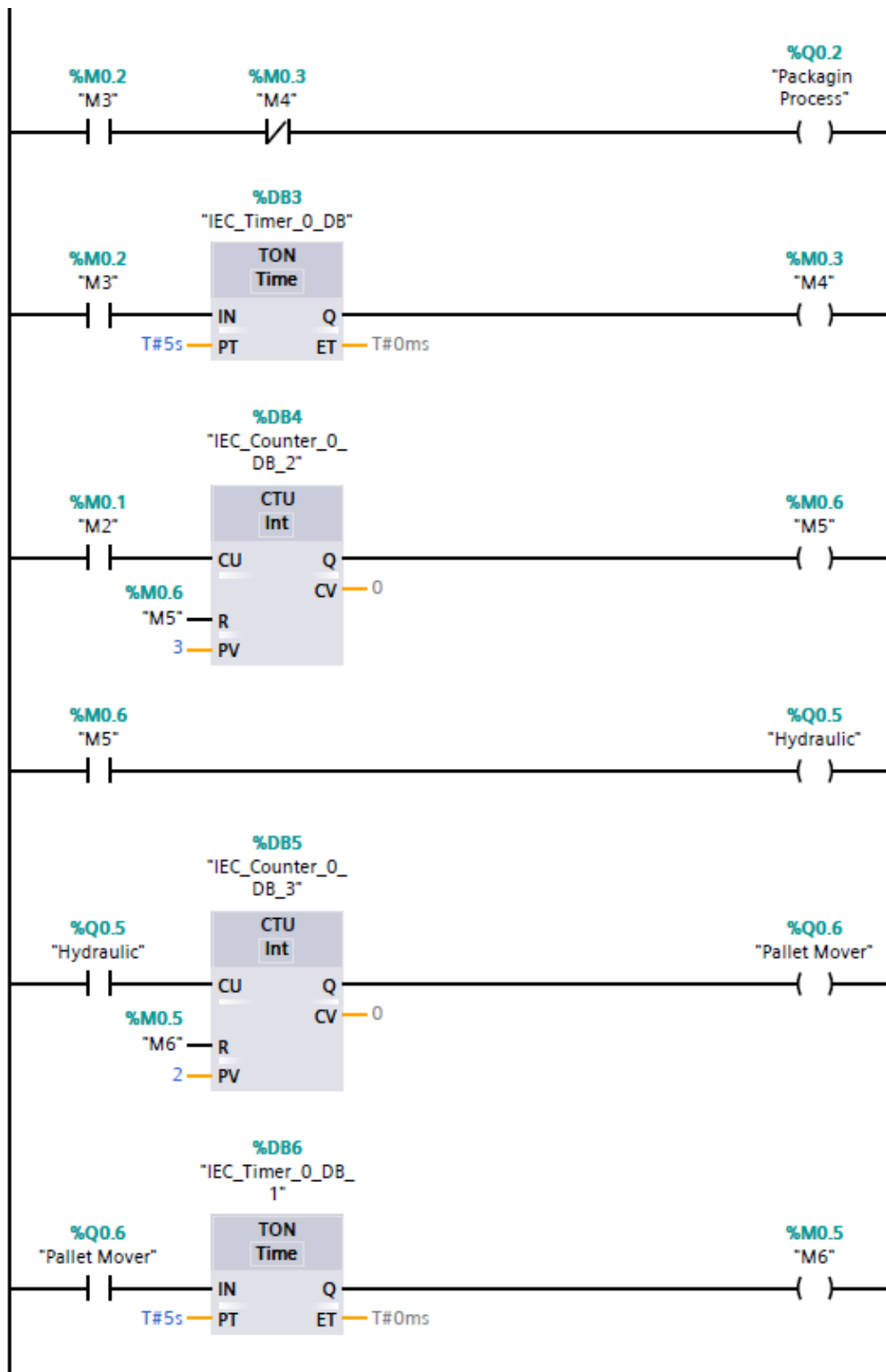


Fig: Ladder Diagram for Project 9.1.11

Pumping and Mixing Operation Project

Project Name: Using PLC, one pump should run for 30 seconds to fill a tank, then valve 1 and valve 2 will get open for 2 seconds each one after other, and then a mixer should operate for 30 seconds and finally the pump should drain the tank for 30 seconds.

Project Description: This project describes a time-based industrial process controlled by a PLC. The system operates in a precise sequence to fill a tank, introduce additives, mix the contents, and then drain the tank. Initially, a pump runs for 30 seconds to fill the tank. Upon completion, two separate valves, valve 1 and valve 2, are opened sequentially for 2 seconds each to dispense their respective contents. A mixer then activates for 30 seconds to ensure the tank's contents are thoroughly combined. Finally, the pump is reversed to drain the tank, completing the cycle after 30 seconds.

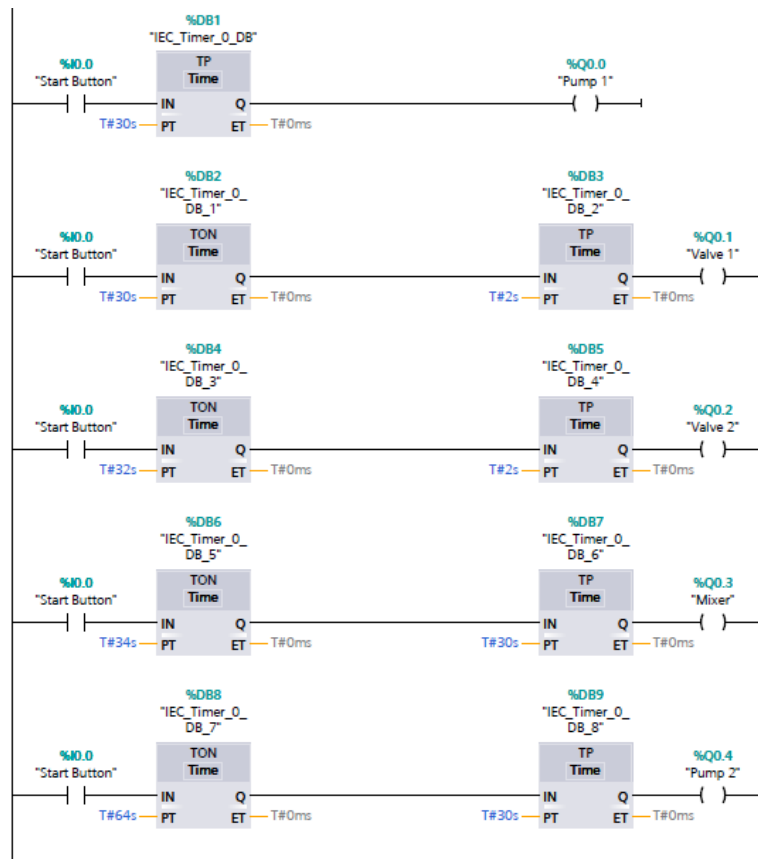


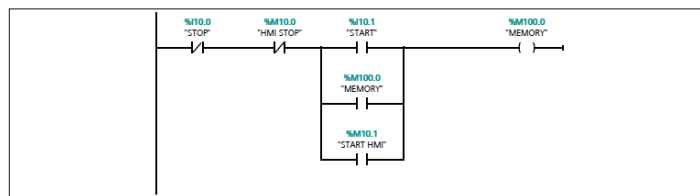
Fig: Ladder Diagram for Project 9.1.12

Car Parking Project

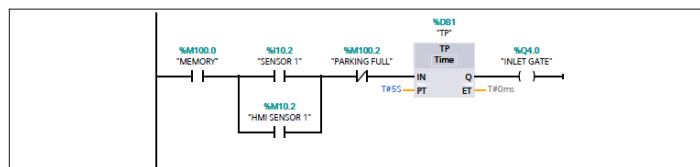
Project Name: Using PLC and HMI, Developing a project, when the inlet gate sensor of a car parking detects a car, the inlet gate will open for 5 seconds and do this up to 5 cars as the parking has 5 car slot. Again when a car exit from the parking, the exit sensor will detect and will open for 5 seconds.

Project Description: This project involves using a **Programmable Logic Controller (PLC)** and a **Human-Machine Interface (HMI)** to automate a small car parking system with five slots. When a car approaches the **inlet gate**, a sensor (e.g., an inductive loop or a proximity sensor) detects its presence. The PLC, which is the "brain" of the system, receives this signal. Upon detection, it triggers the **inlet gate motor** to open. The gate remains open for **5 seconds**, allowing the car to enter, and then automatically closes. A counter is implemented within the PLC's program to track the number of cars that have entered. This process repeats for up to five cars, at which point the system signals that the parking lot is full. The **HMI** serves as the user interface, providing real-time information such as the number of available parking slots, and can also be used to manually open/close the gates or reset the counter. Similarly, when a car is at the **exit gate**, another sensor detects its presence. The PLC receives this signal and commands the exit gate to open for **5 seconds** before closing. The PLC also decrements the car counter each time a car exits, making the parking slot available again. The integration of the PLC for logic control and the HMI for visual feedback and interaction ensures a safe and efficient automated system.

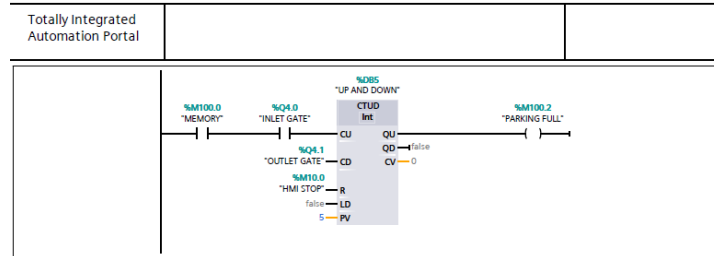
Network 1:



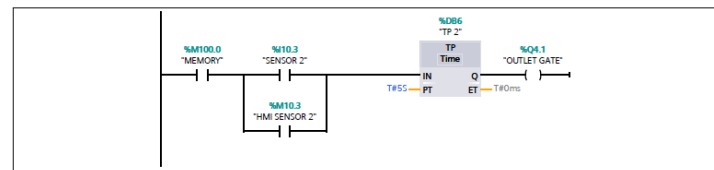
Network 2: WHEN INLET SENSOR DETECT A CAR THEN THE INLET GATE ON FOR 5 SEC



Network 3: C1 SENSOR COUNT HOW MANY CAR ENTRY IN PARKING SLOT



Network 4: IF CAR EXIT FROM PARKING SLOT THEN OUTLET SENSOR SENSE AND OUTLET GATE WILL OPEN FOR 5 SEC



Network 5: AND C2 COUNT HOW MANY CAR EXIT FROM PARKING SLOT

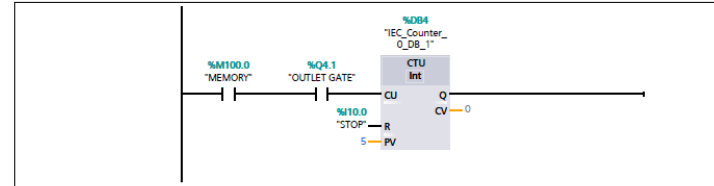


Fig: Ladder Diagram for Project 9.1.13

Water level detection and control system

Project Name: Water level detection and control system that uses a ladder logic program to manage a motor, likely a pump, based on tank levels.

Project Description: The system reads an analog input from a level sensor, then uses NORM_X and SCALE_X function blocks to convert the raw sensor data into a normalized "Percentage" value. The PLC's logic then uses this percentage to control outputs, activating signals for "LOW," "Mid," and "High" levels. The control logic for the motor itself is driven by the "LOW" and "High" level signals, which are used in a simple start-stop circuit to ensure the motor turns on when the water level is low and turns off when it reaches the high-level setpoint.

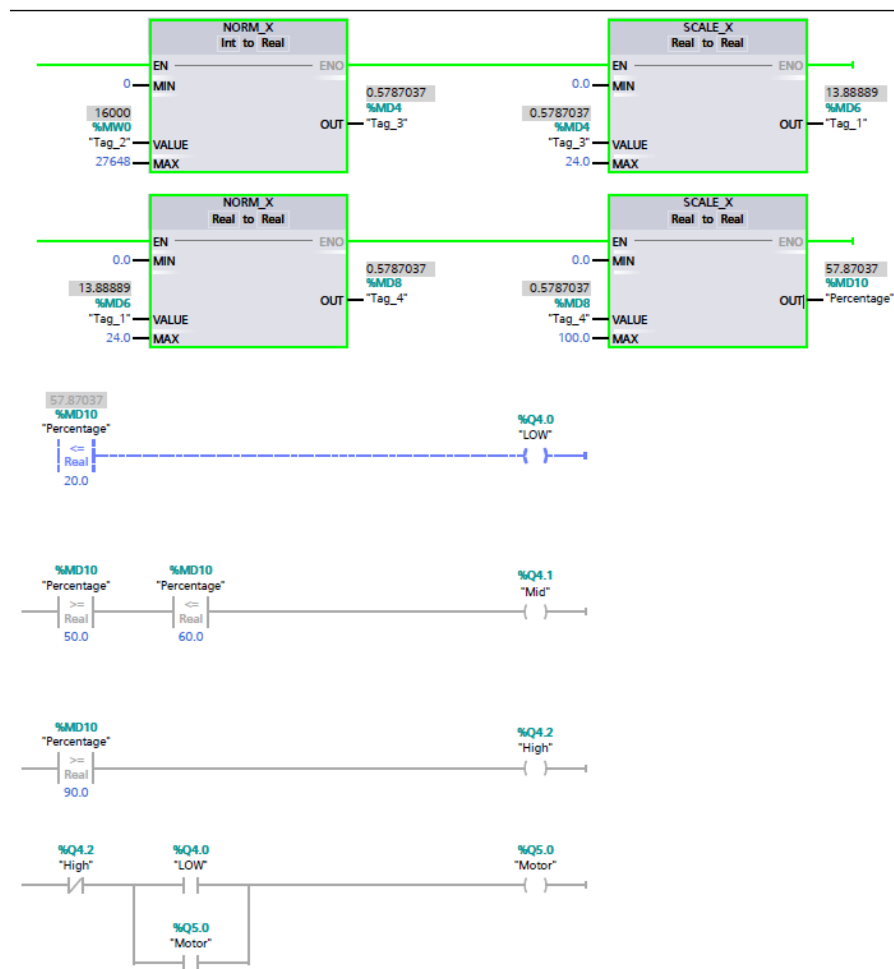


Fig: Ladder Diagram for Project 9.1.14

PLC to PLC Communication Project

Project Name: PLC to PLC Communication for VFD Operation

Project Description: This project describes a PLC-to-PLC communication system that enables distributed control of a Variable Frequency Drive (VFD) and a connected motor. The system uses a master PLC to send commands and a slave PLC to receive them and directly operate the VFD. The master PLC's logic, triggered by a push button or sensor, uses a TSEND_C function block to transmit data over the network. The slave PLC continuously listens for these commands via a TRCV_C function block, and upon reception, its logic activates an output to the VFD's control terminal to start the motor. The VFD itself is configured for network control with a specific Slave Address (Pr117=1) and Baud Rate (Pr118=3) to ensure seamless communication with the slave PLC. This setup allows the master PLC to remotely control the motor's basic functions, such as starting and stopping, or to set speed and direction via the communication link.

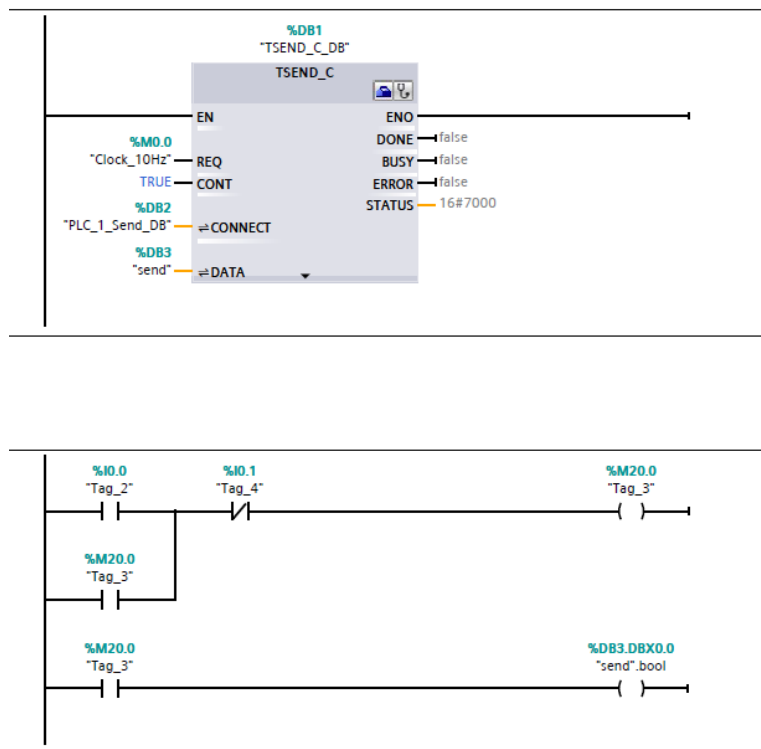


Fig: Ladder Diagram for Project 9.1.15 (PLC-1)

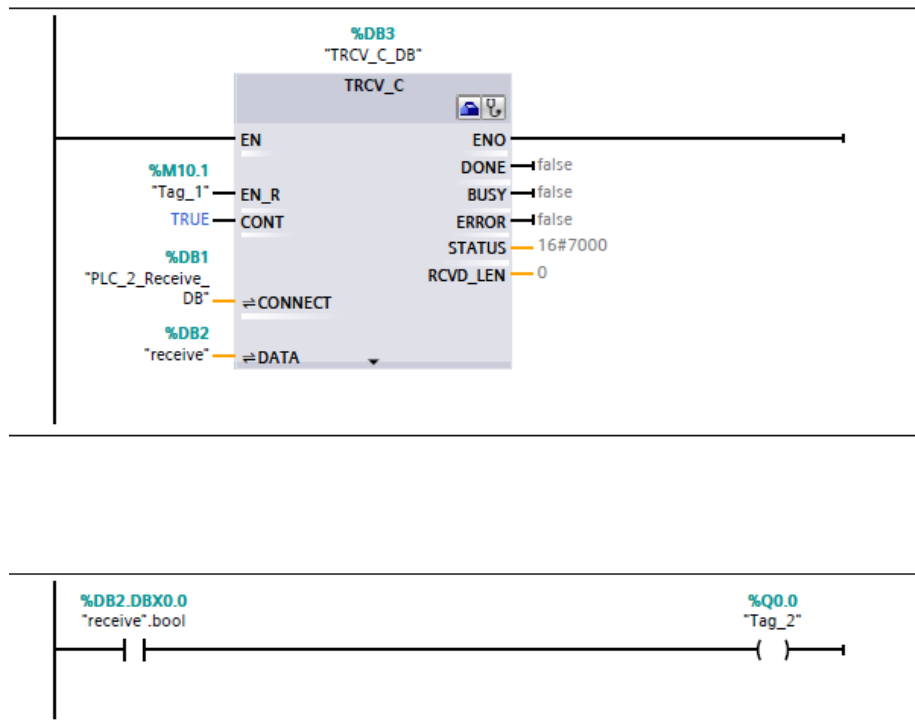


Fig: Ladder Diagram for Project 9.1.15 (PLC-2)



Self-Check 8.3-1

1. What specific logic element does the timer's "done" bit open to stop the motor? Project 3:
Delayed Start (10s)
2. What is the delay time for the motor start in Project 3?
3. When does the PLC's timer output become "true" to energize the contactor?
4. What kind of motor operation does this system provide due to its PLC control? Project 4:
Sequential Non-Overlapping Start
5. How is the first motor started in Project 4?
6. What two actions occur simultaneously when the 30-second timer elapses?

7. What characteristic of the second motor's start is ensured by this sequential system? Project 5: Staggered Start and Delayed Stop
8. What event triggers Timer 1, and what is its delay duration?
9. What event triggers Timer 2, and what is its delay duration?
10. Which motor continues to run after Timer 2 completes its countdown? Project 6: Independent Timed Shutdown
11. What is the total time delay from the input activation until Motor 2 starts?
12. What is the total time Motor 2 runs before it is stopped?
13. Which motor continues to operate after the sequence's final timer (Timer 3) stops Motor 2? Project 7: Synchronized Timed Shutdown
14. What is the main difference in the final outcome between Project 6 and Project 7?
15. What event triggers Timer 3, and what is its delay duration?
16. What happens to the motor outputs when Timer 3 completes its countdown? Project 8: Manual Forward-Reverse
17. What crucial feature does the PLC's internal logic provide to protect the circuit in this project?
18. What are the three digital inputs wired to the PLC for this project?
19. How does the "Stop" button input function in this PLC-based system? Project 9: Automatic Forward-Reverse
20. How does the PLC prevent a short circuit during the transition from forward to reverse?
21. What type of application is this automated sequence ideal for? Project 10: Automatic Star-Delta Starter
22. What is the primary reason a Star-Delta starter is used for large motors?
23. Which two contactors does the PLC energize simultaneously at the start of the sequence?
24. What two motor characteristics are achieved when the motor runs in the Delta configuration? Projects 11, 13, 15: Other Systems
25. In the PLC-to-PLC Communication Project, what are the VFD parameters set for Slave Address and Baud Rate?



Answer Paper 8.3-1

1. The timer's "done" bit opens a normally closed contact within the ladder logic.
2. The delay time for the motor start is 10 seconds.
3. The timer output is set to a "true" state after the 10-second delay has elapsed.
4. The system provides precise, repeatable, and easily modifiable timing for the motor's start-up sequence.
5. The first motor is started instantly by a single input signal (push button or sensor) to the PLC.
6. The PLC's logic de-energizes the first motor's output and simultaneously energizes the output for the second motor.
7. The system ensures a sequential but non-overlapping operation (the second motor starts immediately after the first stops).
8. Timer 1 is triggered by the start of Motor 1 and is set for a 10-second delay.
9. Timer 2 is triggered by the start of Motor 2 and is set for a 2-minute delay.
10. Motor 2 continues to run after Timer 2 completes its countdown.
11. The total time delay is 30 seconds (20 seconds for Timer 1 + 10 seconds for Timer 2).
12. Motor 2 runs for 1 minute before being stopped by Timer 3.
13. Motor 1 continues to operate after Timer 3 stops Motor 2.
14. In Project 7, both motors stop simultaneously after the final timer, while in Project 6, only Motor 2 stops.
15. Timer 3 is triggered by the start of Motor 2 and is set for a 1-minute delay.
16. The PLC's logic deactivates the outputs for both M1 and M2, causing them to stop simultaneously.
17. The PLC provides both electrical and software interlocking to prevent both contactors from being active simultaneously.
18. The three inputs are: Forward Push Button, Reverse Push Button, and Stop Button.
19. The "Stop" button input is programmed to de-energize either the forward or reverse output, safely stopping the motor.

20. The PLC allows a brief pause between de-energizing the forward contactor and energizing the reverse contactor.
21. This automated sequence is ideal for applications that require repetitive and timed forward-reverse cycles (e.g., conveyor systems).
22. A Star-Delta starter is used to reduce high starting current for large motors.
23. The PLC first energizes the Main and Star contactors simultaneously.
24. The motor achieves its full operational torque and speed when running in the Delta configuration.
25. The VFD parameters are set for Slave Address (Pr117=1) and Baud Rate (Pr118=3).

Learning Outcome 8.4 – Install and Configure PLC Hardware



Content

- **Physical Mounting and Installation:** Learn the correct procedures for mechanically mounting the PLC components (e.g., CPU, power supply, I/O modules) onto the DIN rail, ensuring proper grounding and ventilation space.
- **Power Supply and Wiring:** Understand and perform the correct electrical connections for the PLC's power supply, including line voltage verification, fusing, and low-voltage DC distribution to modules.
- **Module Addressing and Configuration:** Verify the physical addressing (slot numbers) of all installed I/O modules and perform the corresponding software configuration within the programming tool to reflect the hardware layout.



Assessment Criteria

- Correct Mechanical Installation
- Safe and Accurate Power-Up
- Hardware/Software Match



Necessary Equipment

- PLC Hardware Components
- Insulated Hand Tools

- Digital Multimeter (DMM)
- Programming Computer and Software
- Cabinet Installation Components



Learning Activity 8.4-1

Learning Activity	Resources/ Instructions/ References
Install and Configure PLC Hardware	• Information Sheet: 8.4-1 • Self-Check: 8.4-1 • Answer Paper: 8.4-1



Information Sheet 8.4-1

Learning Objective: The learner will be able to safely install and correctly wire the PLC hardware components into a control panel and configure the module addressing and settings within the software to match the physical layout.

Physical Installation and Mounting

The PLC and its modules must be mounted to ensure long-term reliability, proper cooling, and electrical compliance.

Step	Action	Key Consideration
2.1. Mechanical Mounting	Securely mount the backplane, rack, or DIN rail inside the control cabinet.	Ensure the mounting surface is clean, flat, and stable.
2.2. Component Placement	Mount the Power Supply Unit (PSU) , CPU/Processor , and I/O Modules in their designated slots/positions.	Spacing: Leave specified vertical and horizontal clearance (e.g., 2-3 inches) around the unit for ventilation and heat dissipation.
2.3. Earthing/Grounding	Connect the system ground (chassis ground) from the PSU/Rack directly to the main cabinet ground bus using the shortest possible heavy-gauge wire.	Noise Reduction: Use proper bonding techniques to minimize electrical interference.

Electrical Wiring (Power and I/O)

Wiring involves connecting the main power, the low-voltage DC bus, and the field device signals.

Power Supply Wiring

1. Input Power: Wire the main AC/DC power source to the PSU input terminals (Line/Neutral or +DC/-DC) via a dedicated, correctly sized circuit breaker and/or fusing.
2. DC Bus Verification: Measure and verify the PSU output voltage (typically 24V DC) before connecting it to the PLC backplane or subsequent modules.

I/O Wiring

1. Signal Isolation: Route low-voltage (control) wiring (e.g., sensor signals) and high-voltage (power) wiring (e.g., 120V AC) in separate, designated wire troughs or conduits to prevent signal noise.
2. Field Device Connection: Connect field device wires (from sensors and actuators) to the respective I/O module terminals (e.g., DI to sensor output, DO to solenoid coil) based on the I/O list.
 - Digital Input (DI): Connect sensor power, common, and signal wire. Ensure sourcing (PNP) or sinking (NPN) types match the module.
 - Digital Output (DO): Connect the load power supply, the DO terminal, and the load (e.g., solenoid valve). Pay attention to relay vs. transistor output types.

3. Termination: Use wire ferrules for all multi-strand wire terminations and securely tighten all terminal screws to the manufacturer's specified torque.

Software Configuration and Addressing

After physical installation, the PLC's software configuration must match the installed hardware.

Step	Action	Importance
4.1. Communication Setup	Connect the programming PC to the PLC via the correct cable (e.g., USB, Ethernet). Set the PC's IP address to be in the same subnet as the PLC.	Enables the programming software to connect and communicate with the CPU.
4.2. New Project Creation	Create a new project in the PLC programming software (e.g., Studio 5000, TIA Portal) and select the exact CPU model and firmware version .	Must match the physical device for compatibility.
4.3. Hardware Configuration	Add and configure all installed I/O modules, communication modules, and the power supply unit in the software's Hardware Configuration Tree .	Crucial: The software configuration must <i>exactly</i> mirror the physical slot location and module type.
4.4. I/O Addressing	Verify that the software-assigned I/O addresses for each point (e.g., <code>Local:3:I.Data.0</code>) correspond correctly to the physical terminal connections in the I/O list.	Ensures the ladder logic can correctly read inputs and control outputs.
4.5. Download and Test	Download the hardware configuration (and initial, basic logic) to the PLC. Switch the PLC to RUN mode and check for any configuration faults.	Verifies the CPU recognizes all installed modules without errors.



Self-Check 8.4-1

1. What industry-standard mounting hardware is used to secure PLC components in a control cabinet?
2. What is the primary reason for maintaining the PLC manufacturer's specified minimum spacing between I/O modules?

3. Which safety device is essential for protecting the 24VDC PLC I/O power wiring and modules from overcurrent faults?
4. What three pieces of network information are most critical to configure on the PLC CPU for an Industrial Ethernet network?
5. What is the primary function of the backplane or bus in a modular PLC rack?
6. What is the likely result if an I/O module's physical slot position does not match its configured position in the PLC software?
7. What is the best practice method for verifying that all digital input wiring and field devices are functioning correctly after power-up?



Answer Paper 8.4-1

1. DIN Rail (Deutsch Industrie Norm Rail) is the industry standard, allowing for snap-on mounting and easy reconfiguration.
2. The primary reason is to ensure adequate air circulation and dissipate heat, preventing component overheating and premature failure.
3. A DC circuit breaker or fuse sized to protect the smallest wire or terminal rating is essential for overcurrent protection.
4. The three critical pieces of information are a unique IP Address, Subnet Mask, and Default Gateway.
5. The primary function is to transfer power and high-speed data signals between the CPU and all connected I/O modules.
6. The PLC will likely enter a Major Fault state (I/O Fault or Configuration Mismatch) and refuse to run the control logic.
7. The best practice is using the programming software to monitor the live state of the input tag while physically actuating each field device.

Learning Outcome 8.5 – Commission and Debug Control System



Content

- **System Commissioning Procedure:** Learn the systematic steps for bringing the fully assembled and wired control system online, including power-up sequence, communications testing, and initial no-load (dry) functional checks.
- **Online Debugging Techniques:** Master the use of PLC software tools (e.g., trend charts, data monitoring, cross-reference) to trace logic execution, identify timing issues, latching problems, and data integrity errors in real-time.
- **Fault Detection and Resolution:** Understand how to isolate the root cause of unexpected behavior, distinguish between logic faults, wiring faults, and device failures, and implement corrective logic changes or field repairs.



Assessment Criteria

- Successful Functional Test
- Effective Debugging and Isolation
- Safety and E-Stop Verification



Necessary Equipment

- Fully Integrated Control System
- Programming Computer and Software
- Digital Multimeter (DMM) and Clamp Meter
- System Documentation

- Safety Gear and Tools

	Learning Activity 8.5-1

Learning Activity	Resources/ Instructions/ References
Commission and Debug Control System	• Information Sheet: 8.5-1 • Self-Check: 8.5-1 • Answer Paper: 8.5-1



Information Sheet 8.5-1

Learning Objective: The learner will be able to systematically commission the integrated PLC control system and effectively use online monitoring tools to diagnose and resolve logical and I/O faults for reliable operation.

Pre-Commissioning: Preparation and Safety Checks

Before loading and running the control program, rigorous hardware and configuration verification is mandatory.

Checklist Item	Purpose	Action Required
Physical Safety	Ensure personnel safety before power-up.	Verify E-STOP circuits are functional and independently wired. Confirm all mechanical guards are in place.
Wiring Continuity	Prevent shorts or miswired devices.	Perform point-to-point continuity checks on all field wiring (I/O) against schematic drawings. Confirm grounding and shielding.
Power Verification	Ensure proper power levels for control and field devices.	Check 24 VDC for sensors/PLC I/O and motor/valve power buses (e.g., 120 VAC or VFD input).
Software Configuration	Ensure PLC knows its hardware setup.	Verify all I/O modules, CPU, and communication cards are correctly defined in the PLC software hardware tree.
Network Integrity	Ensure communication paths are open.	Ping the PLC and any network-enabled devices (HMI, drives) to confirm correct IP addressing and connection.

System Commissioning: Functional Verification

Commissioning involves systematically testing the control system against its functional specifications.

A. Input/Output (I/O) Verification (Device Layer)

1. Input Check: Monitor the PLC's I/O status table while physically actuating each sensor (e.g., manually push a limit switch, cover a proximity sensor). The corresponding input LED on the PLC module and the PLC tag status must change state.
2. Output Check: Use the PLC software's Force Function (or a dedicated HMI screen) to temporarily switch each digital output ON (e.g., a solenoid valve, contactor). Confirm the actuator responds mechanically, and the correct voltage is present at the terminal block.

B. Component and Manual Mode Testing

- Test each major actuator (e.g., pump, motor, cylinder) in isolation using the system's Manual/Jog Mode. This verifies the logic block for manual control, motor rotation direction, and actuator travel limits independently of the automatic sequence.

- Verify all safety interlocks and limit switches function correctly during manual operation.

C. Automatic Sequence Testing

- Initiate the full automatic cycle. Use the Watch Table and Trend Tools within the PLC software to monitor the key I/O and internal memory bits in real-time.
- Verify that time delays (TON/TOF timers) and counters execute their required logic steps within the specified timeframes.
- For Analog Control (e.g., PID loops for flow or temperature), tune the PID parameters to achieve stable and responsive control.

Bug Control and Debugging Techniques

Debugging is the process of identifying, localizing, and correcting errors (bugs) in the hardware, wiring, or program logic.

Bug Type	Common Cause	Debugging Strategy
Hardware Bug	Broken sensor wire, failed solenoid coil, tripped motor thermal overload.	Check physical status LEDs on the PLC module and the field device. Use a multimeter to check voltage/continuity at the terminal block.
Logic/Sequencing Bug	Incorrect address or tag name used in logic; wrong timer/counter preset; interlock preventing a valid action.	Use Cross-Reference tools to see everywhere a tag is used. Use Program Tracing (online monitoring) to see which rung instruction is failing (e.g., a normally closed contact is open when it shouldn't be).
Race Condition	Two competing actions are triggered simultaneously due to program scan time.	Introduce short time delays to ensure one action completes before the next is initiated, or restructure the logic to use explicit state transitions.
Communication Bug	HMI data not updating; drive fault message.	Verify IP addresses, subnet mask, and network protocols (e.g., Profibus address, Ethernet port settings) are identical in the PLC and the device configuration.

Documentation Best Practice

Never leave a bug fix undocumented. Every successful change to the PLC logic or configuration must be commented in the program and the change must be logged in the system's revision history and electrical schematics. This ensures traceability and maintainability.



Self-Check 8.5-1

1. What crucial safety step must be performed first before applying power to the control system cabinet?
2. What is the most effective PLC software method used to debug and verify that the control logic is functioning correctly during initial start-up?
3. When a motor's Seal-in Circuit immediately drops out after the Start Button is released, what is the most likely logic fault?
4. Why is the function of Forcing I/O considered dangerous, even though it is a useful debugging tool?
5. What is the key objective of the Functional Test phase when the system runs for the first time without product?
6. If a field sensor (Photo-eye) is illuminated (ON), but the corresponding PLC input status LED is OFF, what is the first troubleshooting step?
7. What is the main outcome of successfully completing the Acceptance Test Procedure (ATP)?



Answer Paper 8.5-1

1. Performing a point-to-point continuity check of all field wiring to verify no short circuits or miswires exist, preventing damage upon power-up.

2. Using online monitoring in the programming software to view the live state of input/output tags and step through logic rungs in real-time.
3. The most likely fault is that the Normally Open contact of the motor output is missing or wired in series instead of parallel with the Start Button.
4. Forcing I/O is dangerous because it allows the engineer to temporarily override the PLC's logic and disregards all safety and interlock logic.
5. The key objective is to verify that all sequences, interlocks, and safety functions operate correctly and in the expected order, as defined in the specifications.
6. The first step is to check the voltage at the PLC I/O terminal to confirm the electrical signal from the sensor is actually reaching the module.
7. The main outcome is the project is formally signed off by the client as meeting all functional and performance specifications, leading to project closeout.

	Job Sheet 49
Qualification	Industrial Automation
Learning Unit	Operation of a Three-Phase Induction Motor by Direct On-Line (DOL) Starter using PLC
Trainee Name	
PPE	Safety glasses, insulated gloves, safety boots, ear protection
Tools & Equipment	Three-phase induction motor, DOL starter, PLC unit, programming laptop with ladder logic software, contactor, overload relay, push buttons (Start/Stop), control panel, multimeter, wiring tools
Notes	- DOL starters are used for simple and direct control of motors. - PLC replaces traditional hardwiring logic, increasing flexibility and diagnostics. - Ensure motor specifications match supply voltage and DOL ratings. - Overload protection must be correctly set to protect the motor.
Procedure	1. Wear all required PPE before starting work.

	2. Connect the three-phase induction motor to the DOL starter (including contactor and overload relay). 3. Wire the PLC to control the DOL starter using output relays. 4. Connect Start and Stop push buttons to PLC digital inputs. 5. Create a PLC ladder logic program that: - Starts the motor when the Start button is pressed - Maintains the motor run condition using a latch (seal-in) - Stops the motor when the Stop button is pressed 6. Download the program to the PLC and test logic using simulation (if available). 7. Power on the system and test Start/Stop control using push buttons. 8. Monitor motor behavior and check for correct rotation, vibrations, or abnormal noise. 9. Validate overload relay function by simulating overload condition (if safe to do so). 10. Document the wiring diagram, PLC logic, and parameter settings. 11. Power down and disconnect the system safely. 12. Clean up and store all tools and equipment.
Trainee's Signature	
Assessor's Signature	
QA Signature	
Assessor's Comment	

	Job Sheet 50
Qualification	Industrial Automation
Learning Unit	Starting a Three-Phase Induction Motor Instantly Using a Push Button Switch or Sensor and then stopping the Motor after 30 seconds using PLC.

Trainee Name	
PPE	Safety glasses, insulated gloves, safety boots, ear protection
Tools & Equipment	Three-phase induction motor, PLC unit, DOL starter (with contactor & overload relay), programming laptop, push button switch or proximity sensor, timer block in PLC software (TON), wiring tools, multimeter
Notes	- PLC controls motor start/stop logic based on input trigger and time delay. - Use TON (Timer ON Delay) or TP (Pulse Timer) function to achieve auto-stop after 30 seconds. - Ensure motor overload protection is active. - Use indicator lights if needed for system status (Running/Stopped).
Procedure	1. Wear all required PPE before starting the task. 2. Set up the three-phase induction motor with a DOL starter controlled by a PLC. 3. Wire the push button (or sensor) to a PLC digital input and the contactor coil to a PLC digital output via relay. 4. In the PLC program: - When the push button/sensor is activated, start the motor instantly. - At the same time, trigger a TON (ON-delay timer) set to 30 seconds. - When the timer finishes, stop the motor automatically. 5. Download the program to the PLC and simulate/test logic. 6. Power on the system and press the push button (or trigger the sensor). 7. Verify the motor starts immediately and stops automatically after 30 seconds. 8. Confirm system safety and motor performance. 9. Log the program structure and wiring connections. 10. Shut down the system and clean the work area. 11. Store all tools and disconnect safely.
Trainee's Signature	
Assessor's Signature	

QA Signature	
Assessor's Comment	

	Job Sheet 51
Qualification	Industrial Automation
Learning Unit	A Three-Phase Induction Motor will be started after 10 seconds from using a Push Button Switch or Sensor using PLC.
Trainee Name	
PPE	Safety glasses, insulated gloves, safety boots, ear protection
Tools & Equipment	PLC unit, three-phase induction motor, DOL starter (contactor + overload relay), push button or sensor, programming laptop, multimeter, wiring tools, indicator lights (optional)
Notes	- Use a TON (Timer ON Delay) function block in the PLC to delay the motor start by 10 seconds. - Ensure proper debounce/filtering on sensor or push button input. - Overload protection must be in place. - Include status indication (e.g. "Delay Active" or "Motor Running") if required.
Procedure	1. Wear appropriate PPE before starting work. 2. Set up the induction motor and connect it to a DOL starter controlled by the PLC. 3. Connect the push button or sensor to a PLC digital input. 4. Wire the PLC output to control the contactor coil via a relay. 5. Program the PLC as follows: - On receiving a signal from the push button or sensor, start a TON timer set for 10 seconds. - After 10 seconds, energize the output coil to start the motor.

	6. Download the PLC program and verify logic with simulation if possible. 7. Power on the system and test the operation: - Activate the push button or sensor - Confirm the 10-second delay - Observe motor starting after delay 8. Check for correct motor rotation and listen for any unusual noise. 9. Record the program structure, timer settings, and wiring layout. 10. Power down the system and disconnect safely. 11. Clean the work area and return tools.
Trainee's Signature	
Assessor's Signature	
QA Signature	
Assessor's Comment	

	Job Sheet 52
Qualification	Industrial Automation
Learning Unit	A Three-Phase Induction Motor will be started using PLC instantly after pressing a Push Button Switch or Sensor and will stop after 30 seconds from the start time. And again, another Three-Phase Induction Motor will be started instantly after stopping the first Motor.
Trainee Name	
PPE	Safety glasses, insulated gloves, safety boots, ear protection
Tools & Equipment	PLC unit, two three-phase induction motors, two DOL starters (each with contactor and overload relay), programming laptop, push button or sensor, multimeter, timer block in PLC software (TON), wiring tools, indicator lights (optional)

Notes	- Use TON (ON-delay Timer) to manage the 30-second stop for Motor 1. - Motor 2 starts immediately after Motor 1 stops. - Use internal memory bits or flags to control sequential logic. - Always confirm motor wiring and overload settings before operation.
Procedure	1. Wear all necessary PPE before starting work. 2. Connect both induction motors to their respective DOL starters. 3. Wire the PLC to control each motor's contactor coil through outputs. 4. Connect the push button or sensor to a PLC digital input. 5. In the PLC program: - When the push button is pressed, start Motor 1 instantly. - Trigger a TON timer for 30 seconds. - After 30 seconds, stop Motor 1. - Immediately after Motor 1 stops, start Motor 2. 6. Download and test the program using simulation if available. 7. Power on the system and verify: - Motor 1 starts instantly after push button is pressed. - Motor 1 runs for 30 seconds and then stops. - Motor 2 starts immediately after Motor 1 stops. 8. Observe motor behavior and check for overheating, vibration, or abnormal sounds. 9. Record the wiring diagram and PLC logic. 10. Safely shut down the system and disconnect all equipment. 11. Clean the workspace and return all tools to storage.
Trainee's Signature	
Assessor's Signature	
QA Signature	
Assessor's Comment	

	Job Sheet 53
Qualification	Industrial Automation
Learning Unit	One Three-Phase Induction Motor will be started using PLC instantly after pressing a Switch or activating any Sensor, Another Three-Phase Induction Motor will be started after 10 seconds of starting Motor-1. And again the Motor-1 will be stopped after 2 minutes of Motor-2 starting.
Trainee Name	
PPE	Safety glasses, insulated gloves, safety boots, ear protection
Tools & Equipment	PLC unit, two three-phase induction motors, two DOL starters (with contactors and overload relays), programming laptop, push button or sensor, multimeter, PLC software with timer functions (TON), wiring tools
Notes	- Use two TON (Timer ON Delay) blocks: • First for 10s delay before starting Motor-2 • Second for 2min delay to stop Motor-1 after Motor-2 starts - Ensure all wiring is per electrical safety standards. - Implement interlocks if needed to prevent overlapping conditions.
Procedure	1. Wear all required PPE before starting. 2. Connect Motor-1 and Motor-2 to their respective DOL starters with overload protection. 3. Wire a push button or sensor to a PLC input and the contactor coils to PLC outputs via relays. 4. Program the PLC with the following logic: - Pressing the push button or triggering the sensor starts Motor-1 immediately. - After 10 seconds, Motor-2 starts. - From the moment Motor-2 starts, start another timer for 2 minutes.

	- After 2 minutes, Motor-1 stops (Motor-2 may continue running if not otherwise specified). 5. Download and test the program using PLC simulation or live test. 6. Power on the system and verify the sequence: - Motor-1 starts instantly on switch/sensor input - Motor-2 starts after a 10-second delay - Motor-1 stops automatically 2 minutes after Motor-2 starts 7. Monitor the motors for proper operation, rotation direction, noise, or overheating. 8. Record the PLC logic, wiring diagram, and timer settings. 9. Safely power off the system and disconnect components. 10. Clean the work area and return all tools to storage.
Trainee's Signature	
Assessor's Signature	
QA Signature	
Assessor's Comment	

	Job Sheet 54
Qualification	Industrial Automation
Learning Unit	Motor-1 will be started after 20 seconds of pressing a switch or activating a sensor, Motor-2 will be started after 10 seconds of Motor-1 starting, and finally only Motor-2 will be stopped after 1 minute of starting it using PLC.
Trainee Name	
PPE	Safety glasses, insulated gloves, safety boots, ear protection
Tools & Equipment	PLC unit, two three-phase induction motors, two DOL starters (with contactors and overload relays), programming laptop with PLC

	software, push button or sensor, multimeter, timer blocks (TON), wiring tools
Notes	- This sequence uses three TON (Timer ON Delay) timers: 1. 20-second delay before starting Motor-1 2. 10-second delay before starting Motor-2 after Motor-1 3. 1-minute delay to stop only Motor-2 - Ensure proper isolation and overload protection for both motors. - Carefully label timers and motor outputs in the PLC program to avoid confusion.
Procedure	1. Wear all required PPE before beginning the task. 2. Wire Motor-1 and Motor-2 through their respective DOL starters and connect the contactors to PLC outputs. 3. Connect a push button or sensor to a PLC digital input. 4. In the PLC program: - On push button/sensor activation, start Timer-1 (20 seconds). - After 20 seconds, Motor-1 starts. - When Motor-1 starts, begin Timer-2 (10 seconds). - After Timer-2 expires, Motor-2 starts. - Immediately on Motor-2 start, begin Timer-3 (1 minute). - After Timer-3 completes, stop Motor-2 only. 5. Download the PLC program and simulate logic if possible. 6. Power on the system and test the sequence: - Motor-1 starts after 20 seconds - Motor-2 starts 10 seconds later - Only Motor-2 stops after 1 minute - Motor-1 continues to run (unless separately stopped) 7. Observe both motors for correct behavior, noise, vibration, and thermal condition. 8. Document the timer settings, wiring, and PLC logic. 9. Power down the system safely and disconnect all components. 10. Clean up the work area and store tools.

Trainee's Signature	
Assessor's Signature	
QA Signature	
Assessor's Comment	

	Job Sheet 55
Qualification	Industrial Automation
Learning Unit	Motor-1 will be started after 20 seconds of pressing a switch or activating a sensor, Motor-2 will be started after 10 seconds of Motor-1 starting, and finally both Motor will be stopped after 1 minute of Motor-2 starting using PLC.
Trainee Name	
PPE	Safety glasses, insulated gloves, safety boots, ear protection
Tools & Equipment	PLC unit, two three-phase induction motors, two DOL starters (with contactors and overload relays), programming laptop, push button or sensor, multimeter, wiring tools, PLC programming software (e.g., TIA Portal, RSLogix, WPLSoft), timers (TON)
Notes	- Use three TON (Timer ON Delay) blocks: 1. 20s delay to start Motor-1 2. 10s delay after Motor-1 starts to start Motor-2 3. 60s delay after Motor-2 starts to stop both motors - Ensure correct sequence logic and timer coordination. - Label PLC memory bits clearly (e.g., M0.0 = StartPressed, M1.0 = Motor1On, etc.). - Safety interlocks and emergency stop should always be available.
Procedure	1. Wear appropriate PPE before beginning the task. 2. Connect Motor-1 and Motor-2 to their DOL starters and wire the contactor coils to PLC outputs.

	3. Connect a push button or sensor to a PLC digital input for start signal. 4. In the PLC program: - When the push button is pressed, activate Timer-1 (20s). - After 20 seconds, Motor-1 starts. - Upon Motor-1 starting, activate Timer-2 (10s). - After Timer-2 expires, Motor-2 starts. - When Motor-2 starts, begin Timer-3 (1 min). - After 1 minute, stop both Motor-1 and Motor-2. 5. Download and test the program in simulation or on real hardware. 6. Power on the system and observe: - Motor-1 starts after 20s delay - Motor-2 starts 10s after Motor-1 - Both motors stop exactly 1 minute after Motor-2 starts 7. Monitor motor direction, temperature, and noise. 8. Log the PLC program logic, timer settings, and wiring diagram. 9. Power off the system safely. 10. Clean the workstation and store all tools properly.
Trainee's Signature	
Assessor's Signature	
QA Signature	
Assessor's Comment	

	Job Sheet 56
Qualification	Industrial Automation
Learning Unit	Operating a Three-Phase Induction Motor by constructing a Manual Forward-Reverse Starter using PLC.
Trainee Name	
PPE	Safety glasses, insulated gloves, safety boots, ear protection

Tools & Equipment	Three-phase induction motor, PLC unit, two contactors (for forward and reverse), overload relay, two push buttons (Forward/Reverse), Stop button, interlocking wiring or logic, programming laptop, multimeter, wiring tools
Notes	- Forward and reverse control uses two contactors with mechanical and electrical interlocking. - PLC logic must ensure only one direction is active at a time. - Implement safety measures such as Stop button override and overload protection. - Always test contactor switching before applying load to the motor.
Procedure	1. Wear all appropriate PPE before starting. 2. Wire the three-phase induction motor to the two contactors: - One contactor wired for Forward rotation - One for Reverse rotation (by swapping any two motor phase wires) 3. Connect the contactor coils to PLC outputs and install mechanical interlocks if using physical contactors. 4. Wire push buttons: - Forward and Reverse buttons to PLC digital inputs - Stop button to a dedicated input with higher priority 5. In the PLC program: - When Forward button is pressed, activate Forward contactor output - When Reverse button is pressed, activate Reverse contactor output - Use logic to prevent both contactors from energizing at the same time - Stop button should immediately deactivate all outputs 6. Download the PLC program and test logic in simulation (if available). 7. Power on the system and perform tests: - Press Forward → Motor runs forward - Press Reverse → Motor runs in reverse - Press Stop → Motor stops

	- Confirm direction change only occurs if motor is stopped 8. Check motor rotation direction, mechanical noise, and contactor switching. 9. Document wiring diagram, PLC logic, and safety features. 10. Power off the system and clean the work area. 11. Store tools and complete reporting.
Trainee's Signature	
Assessor's Signature	
QA Signature	
Assessor's Comment	

	Job Sheet 57
Qualification	Industrial Automation
Learning Unit	Operating a Three-Phase Induction Motor by constructing an Automatic Forward-Reverse Starter using PLC.
Trainee Name	
PPE	Safety glasses, insulated gloves, safety boots, ear protection
Tools & Equipment	PLC unit, three-phase induction motor, two contactors (for forward and reverse), overload relay, timer block (TON), wiring tools, programming laptop, multimeter, protective relays, HMI or push button (optional)
Notes	- Automatic forward-reverse logic is timer-based and requires safe sequencing. - Proper interlocking logic is essential to prevent both contactors from energizing at the same time. - Include a brief delay between stopping one direction and starting the other. - Always verify correct motor rotation direction during testing.
Procedure	1. Put on all necessary PPE before starting the task.

	2. Connect the motor to the two contactors — one for Forward, the other for Reverse operation (by swapping two motor phase wires in the reverse contactor). 3. Wire the contactor coils to PLC digital outputs. 4. Install mechanical and/or electrical interlocks if using physical contactors. 5. In the PLC software, create a program with the following logic: - Start the motor in Forward direction for a fixed time (e.g., 10 seconds). - Stop motor (insert a short delay if needed). - Then start the motor in Reverse direction for a fixed time (e.g., 10 seconds). - Repeat cycle continuously or a fixed number of times. - Ensure outputs are never ON at the same time. 6. Download the PLC program and test in simulation. 7. Power up the hardware setup and verify the operation: - Forward direction runs for programmed time - Reverse direction starts after delay - Only one contactor is energized at a time - Cycle continues automatically 8. Observe motor behavior for abnormal vibration, heating, or noise. 9. Record PLC logic diagram, timer values, and wiring layout. 10. Power down the setup safely and disconnect power. 11. Clean up the workstation and store all tools.
Trainee's Signature	
Assessor's Signature	
QA Signature	
Assessor's Comment	

	Job Sheet 58
Qualification	Industrial Automation
Learning Unit	Operating a Three-Phase Induction Motor by constructing an Automatic Star-Delta Starter using PLC.
Trainee Name	
PPE	Safety glasses, insulated gloves, safety boots, ear protection
Tools & Equipment	PLC unit, three-phase induction motor, Star and Delta contactors with overload relays, timer blocks (TON), wiring tools, programming laptop with PLC software, multimeter, protective devices
Notes	- Star-Delta starting reduces the starting current and mechanical stress on the motor. - PLC logic must provide proper timing between Star and Delta transitions. - Ensure mechanical and electrical interlocking between Star and Delta contactors. - Safety interlocks and emergency stop must be implemented. - The timing usually involves a star run time of 5-15 seconds before switching to delta. - Verify correct wiring of motor terminals and contactors before energizing.
Procedure	1. Wear all required PPE before starting the task. 2. Connect the motor terminals and wire the Star and Delta contactors accordingly. 3. Connect the contactor coils to PLC digital outputs. 4. Wire the Start and Stop push buttons to PLC digital inputs. 5. Ensure mechanical and electrical interlocking between Star and Delta contactors. 6. Program the PLC: - On Start input:

	• Energize Star contactor output • Start Timer-1 (TON) for the star run period (e.g., 10 seconds) - After Timer-1 completes: • De-energize Star contactor output • Energize Delta contactor output - Motor runs in Delta until Stop input is pressed - Stop input stops all outputs 7. Download and test the program in simulation if possible. 8. Power on the system and conduct the following test: - Press Start: Motor starts in Star configuration - After programmed star delay, motor switches to Delta - Motor runs continuously in Delta until Stop pressed - Observe contactors' operation, motor current, and noise 9. Document PLC program logic, timer settings, wiring diagrams, and safety measures. 10. Power down the system safely. 11. Clean the work area and store tools.
Trainee's Signature	
Assessor's Signature	
QA Signature	
Assessor's Comment	

	Job Sheet 59
Qualification	Industrial Automation
Learning Unit	Developing an automated system using PLC for packaging products onto a pallet. The system utilizes two separate conveyor belts and a series of sensors and actuators to perform a precise, sequential operation.

Trainee Name	
PPE	Safety glasses, insulated gloves, safety boots, ear protection
Tools & Equipment	PLC unit, two conveyor belts with motors, sensors (photoelectric/proximity), actuators (pneumatic/hydraulic), limit switches, push buttons, programming laptop with PLC software, wiring tools, multimeter, HMI (optional)
Notes	- Ensure sensor placement covers product detection, position on conveyor, and pallet presence. - Use sequential logic with interlocks to avoid collisions or misplacement. - Implement emergency stop and safety interlocks. - Timing between conveyors and actuators must be carefully controlled. - Sensors must be calibrated and tested prior to system start. - HMI can be used for monitoring and manual overrides.
Procedure	1. Wear required PPE before starting. 2. Install and wire the two conveyor motors to PLC outputs. 3. Position sensors along conveyors to detect products and pallets. 4. Connect actuators controlling product placement mechanisms to PLC outputs. 5. Wire push buttons for Start, Stop, and Emergency Stop to PLC inputs. 6. Program the PLC with the following logic: - Start conveyor 1 when Start button is pressed. - Detect product arrival at end of conveyor 1 via sensor. - Stop conveyor 1 and start conveyor 2 for transferring product. - Use sensors to detect product position on conveyor 2. - Activate actuator to place product on pallet at precise location. - Repeat sequence for multiple products until pallet is full. - Use interlocks to prevent conveyors running simultaneously when not needed. - Stop system safely upon Stop or Emergency Stop. 7. Download the program and perform dry run in simulation.

	8. Power on system and test actual operation: - Verify sensors detect correctly. - Observe product transfer and placement accuracy. - Check actuator response and timing. - Confirm emergency stops work immediately. 9. Log all findings, sensor calibrations, and PLC program details. 10. Power down system safely after testing. 11. Clean work area and store tools.
Trainee's Signature	
Assessor's Signature	
QA Signature	
Assessor's Comment	

	Job Sheet 60
Qualification	Industrial Automation
Learning Unit	Using PLC, one pump should run for 30 seconds to fill a tank, then valve 1 and valve 2 will get open for 2 seconds each one after other, and then a mixer should operate for 30 seconds and finally the pump should drain the tank for 30 seconds.
Trainee Name	
PPE	Safety glasses, insulated gloves, safety boots, ear protection
Tools & Equipment	PLC unit, pump (fill/drain), two solenoid valves (Valve 1 and Valve 2), mixer motor, timer modules (TON), wiring tools, programming laptop with PLC software, multimeter
Notes	- Ensure pump direction can be controlled for filling and draining. - Sequence must be strictly timed with no overlaps except intentional. - Verify all actuators (valves and mixer) function correctly.

	- Safety interlocks and emergency stop must be incorporated. - Test individual components before full sequence run.
Procedure	1. Put on required PPE before starting. 2. Connect the pump, valves, and mixer to PLC outputs. 3. Wire Start and Stop push buttons to PLC inputs. 4. Program PLC sequence: - Step 1: Pump ON to fill tank for 30 seconds. - Step 2: Valve 1 opens for 2 seconds. - Step 3: Valve 1 closes, Valve 2 opens for 2 seconds. - Step 4: Valve 2 closes, Mixer ON for 30 seconds. - Step 5: Mixer OFF, Pump ON to drain tank for 30 seconds. - Step 6: Pump OFF, sequence completes or resets. 5. Download the program to PLC and test logic in simulation. 6. Power on the system and run the full sequence. 7. Observe timing, valve operation, pump function, and mixer. 8. Verify no component operates outside its time or overlaps improperly. 9. Document wiring diagrams, program code, and observations. 10. Power down system safely and clean workspace. 11. Store tools and complete reports.
Trainee's Signature	
Assessor's Signature	
QA Signature	
Assessor's Comment	

	Job Sheet 61
Qualification	Industrial Automation

Learning Unit	Using PLC and HMI, developing a project, when the inlet gate sensor of a car parking detects a car, the inlet gate will open for 5 seconds and do this up to 5 cars as the parking has 5 car slot. Again when a car exit from the parking, the exit sensor will detect and will open for 5 seconds.
Trainee Name	
PPE	Safety glasses, insulated gloves, safety boots, ear protection
Tools & Equipment	PLC unit, HMI panel, inlet gate motor/actuator, exit gate motor/actuator, inlet and exit sensors (proximity/photoelectric), counters, push buttons (Start, Stop), wiring tools, programming laptop with PLC and HMI software, multimeter
Notes	- Parking capacity limited to 5 cars. - Use PLC counters to track number of cars inside. - Ensure gate opens only if parking is not full for entry. - Gate opening time is fixed to 5 seconds. - Implement safety interlocks and emergency stop. - HMI used for monitoring status (slots available) and manual override. - Validate sensor reliability before operation. - Debounce sensors to avoid false counts.
Procedure	1. Wear all necessary PPE. 2. Wire inlet and exit sensors to PLC digital inputs. 3. Connect gate actuators to PLC digital outputs. 4. Configure counters in PLC: - Increment on inlet sensor trigger (car enters), up to max 5. - Decrement on exit sensor trigger (car leaves), minimum 0. 5. Program PLC: - When inlet sensor detects a car and count < 5: • Open inlet gate output for 5 seconds using TON timer. • Increment car count. - When exit sensor detects a car: • Open exit gate output for 5 seconds using TON timer.

	• Decrement car count. - Prevent inlet gate opening if count = 5 (parking full). 6. Design HMI screens to show: - Current car count. - Status of gates (open/closed). - Manual controls for gates. 7. Download PLC and HMI programs. 8. Test the system in simulation mode. 9. Power on system and test: - Verify car detection triggers gate opening. - Confirm parking capacity limit is enforced. - Observe gate timing and closing. - Check decrement on exit sensor trigger. - Test manual overrides and emergency stops. 10. Document wiring, program logic, timer and counter settings, and HMI design. 11. Power down and clean workspace.
Trainee's Signature	
Assessor's Signature	
QA Signature	
Assessor's Comment	

	Job Sheet 62
Qualification	Industrial Automation
Learning Unit	Water level detection and control system that uses a ladder logic program to manage a motor, likely a pump, based on tank levels.
Trainee Name	
PPE	Safety glasses, insulated gloves, safety boots, ear protection

Tools & Equipment	PLC unit, water level sensors (high level, low level), motor/pump, wiring tools, programming laptop with PLC software, multimeter, relay module (if needed)
Notes	- Ensure sensors are calibrated for correct level detection. - Use interlocks to prevent pump damage. - Include manual override and emergency stop. - Protect system from false sensor readings. - Verify motor/pump direction and wiring. - Use timers or delays as necessary to avoid rapid cycling.
Procedure	1. Wear all required PPE. 2. Connect water level sensors to PLC inputs: - Low-level sensor to detect when water is below minimum. - High-level sensor to detect when tank is full. 3. Connect motor/pump to PLC output via relay or suitable driver. 4. Program PLC ladder logic: - When low-level sensor is triggered (tank low), turn pump ON. - Keep pump running until high-level sensor is triggered. - When high-level sensor is triggered, turn pump OFF. - Implement hysteresis or delay to avoid frequent ON/OFF switching. 5. Test program in simulation. 6. Power system and test live: - Verify pump turns ON at low level. - Verify pump turns OFF at high level. - Check for smooth operation with no rapid cycling. 7. Document wiring, program logic, sensor calibration, and test results. 8. Power down system safely. 9. Clean workspace and store tools.
Trainee's Signature	
Assessor's Signature	
QA Signature	

Assessor's Comment	

	Job Sheet 63
Qualification	Industrial Automation
Learning Unit	PLC to PLC Communication for VFD Operation
Trainee Name	
PPE	Safety glasses, insulated gloves, safety boots, ear protection
Tools & Equipment	Two PLC units with communication modules (e.g., Ethernet, Profibus, Modbus), VFD unit, programming laptop with PLC and VFD software, communication cables, wiring tools, multimeter
Notes	- Confirm compatible communication protocols between PLCs. - Ensure proper addressing and data mapping. - Check VFD parameters for remote control. - Include safety interlocks and error handling. - Test communication with simulated data before full operation. - Document network configuration and PLC programs.
Procedure	1. Wear appropriate PPE. 2. Connect two PLCs using the selected communication protocol and cables. 3. Interface the VFD with the receiving PLC via digital/analog outputs or communication module. 4. Configure communication settings on both PLCs: - Set IP addresses or node IDs. - Define data registers for commands and status. 5. Program sending PLC to send control commands (start, stop, speed reference) to receiving PLC. 6. Program receiving PLC to receive commands and control VFD accordingly.

	7. Set up feedback from VFD (status, fault) to sending PLC for monitoring. 8. Test communication in simulation. 9. Power on system and test: - Command VFD operation from sending PLC. - Monitor status and fault signals. - Verify safe start/stop and speed control. 10. Log configuration details, program codes, and test results. 11. Power down system safely. 12. Clean work area and store equipment.
Trainee's Signature	
Assessor's Signature	
QA Signature	
Assessor's Comment	

	Job Sheet 64
Qualification	Industrial Automation
Learning Unit	Designing and implementing a closed-loop Proportional-Integral-Derivative (PID) control system using a PLC to maintain the liquid temperature (Process Variable) in a mixing tank at a desired Setpoint (SP). The system will manipulate the mixing speed of a motor-driven agitator via a Variable Frequency Drive (VFD) as the Control Output.
Trainee Name	
PPE	Safety glasses, insulated gloves, safety boots, ear protection
Tools & Equipment	PLC with PID function block, temperature sensor (RTD/thermocouple), VFD, motor-driven agitator, programming laptop with PLC and VFD software, wiring tools, multimeter, calibration tools
Notes	- Calibrate temperature sensors for accuracy.

	- Tune PID parameters (P, I, D) carefully to avoid instability. - Verify VFD responds properly to speed commands. - Include safety limits on motor speed and temperature. - Implement alarms for sensor faults or out-of-range values. - Document tuning steps and system response. - Use simulation before live testing.
Procedure	1. Wear required PPE. 2. Connect temperature sensor to PLC analog input. 3. Interface PLC output with VFD speed reference input. 4. Configure PID control block in PLC: - Set Setpoint (SP) for desired temperature. - Configure Process Variable (PV) from temperature sensor. - Set output to control VFD speed. 5. Program alarm conditions for high/low temperature and sensor faults. 6. Download program to PLC and simulate PID response. 7. Power system and start operation. 8. Monitor temperature, PID output, and agitator speed. 9. Tune PID parameters to minimize overshoot, steady-state error, and oscillations. 10. Document all parameter settings, system behavior, and tuning adjustments. 11. Test safety features and alarms. 12. Power down system safely and clean workspace.
Trainee's Signature	
Assessor's Signature	
QA Signature	
Assessor's Comment	