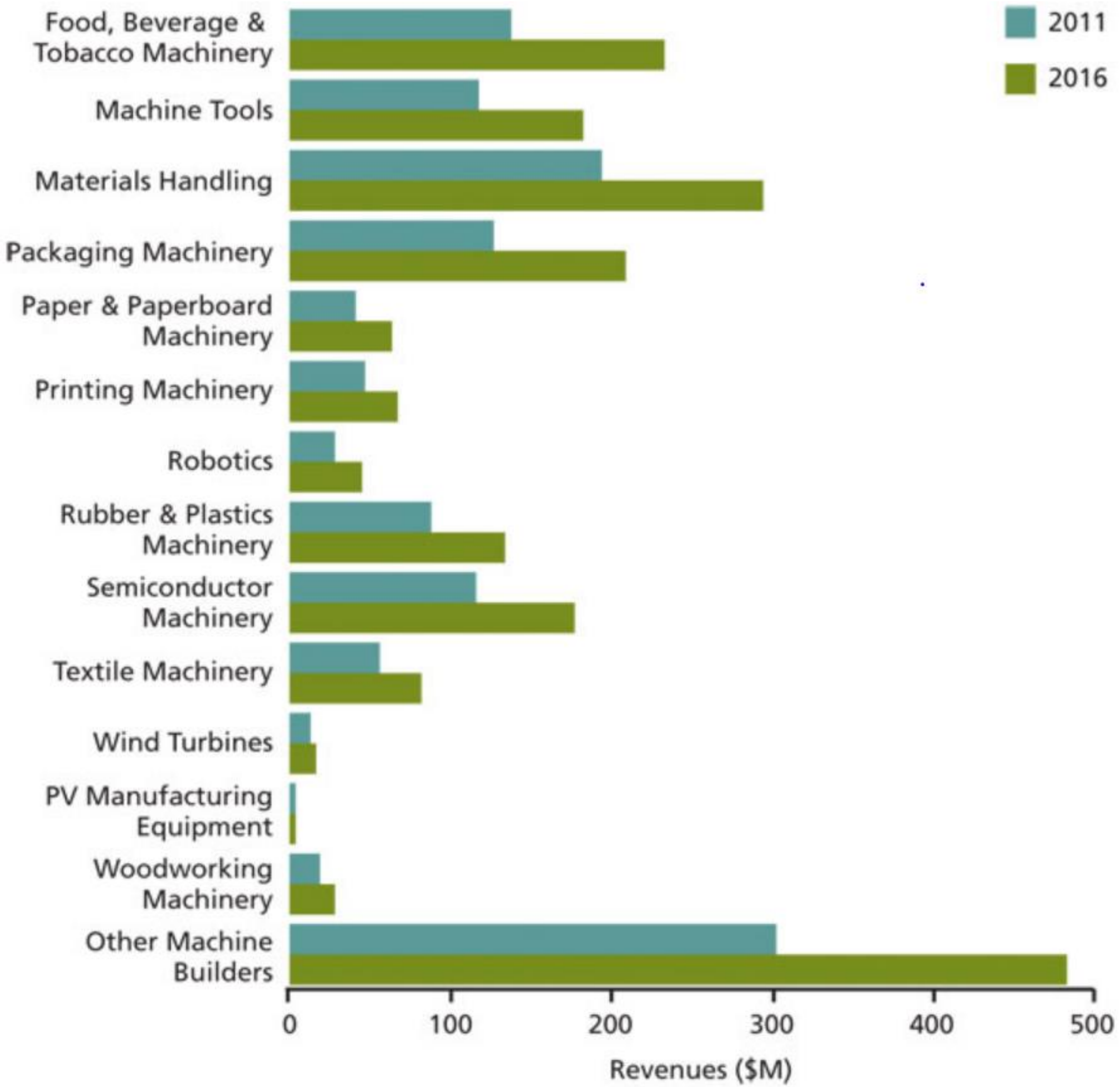
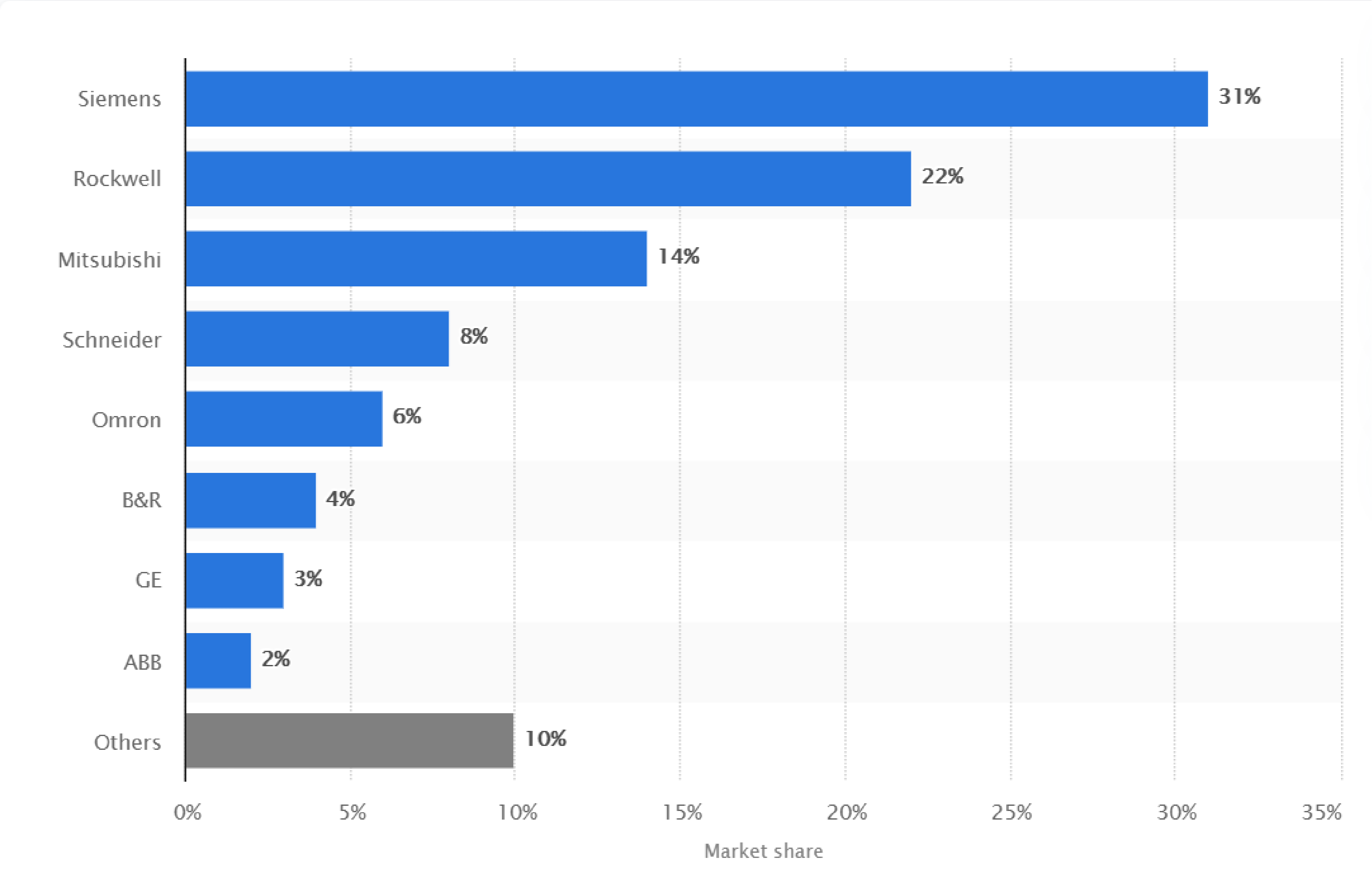
History

- Dick Morley conceived the programmable controller on January 1, 1968.
- His new company, Modicon, installed the first model 084 PLC at the Oldsmobile Division of General Motors Corporation and the Landis Company in Landis, Pennsylvania.



Asia's Market for PLC Hardware

Global PLC market share as of 2017, by manufacturer



PLC Definition

PLCs are defined as follows:

- PLCs are special-purpose industrial computers designed for use in the control of a wide variety of manufacturing machines and systems.

Or

- A PLC is a specialized electronic device based on one or more microprocessors that is used to control industrial machinery.

PLC programming

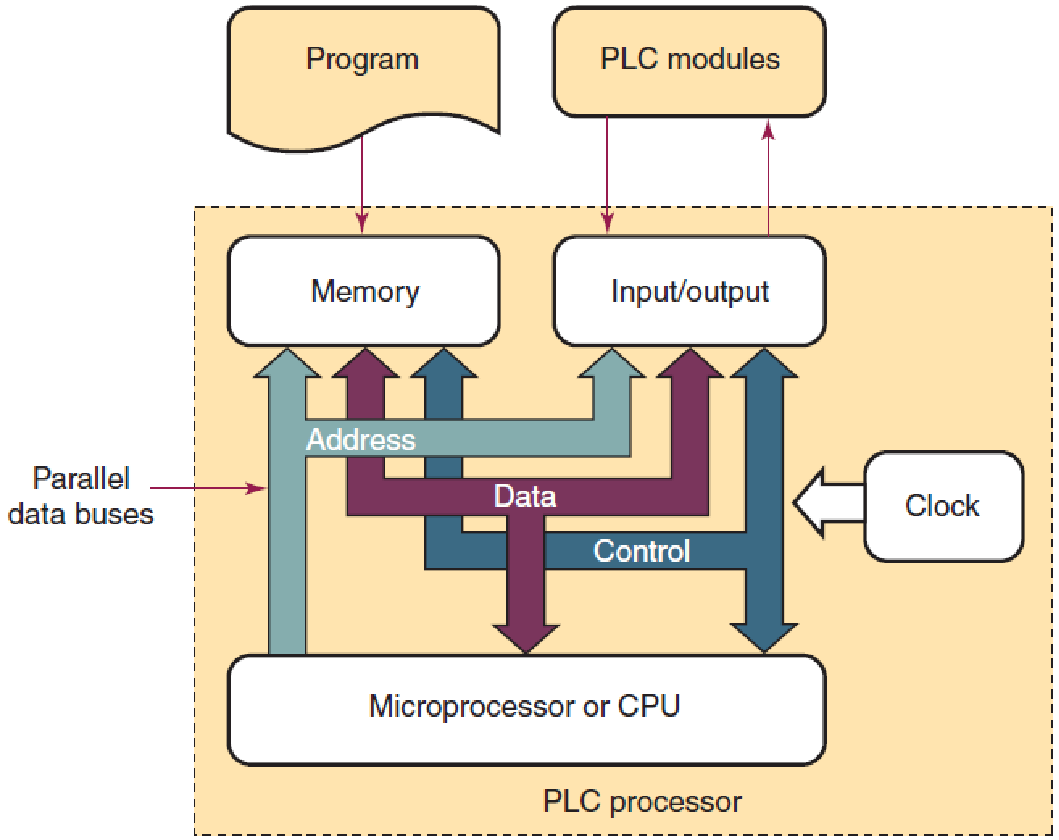
The following new languages present in the PLC standard, called IEC 61131.

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

PC vs PLC

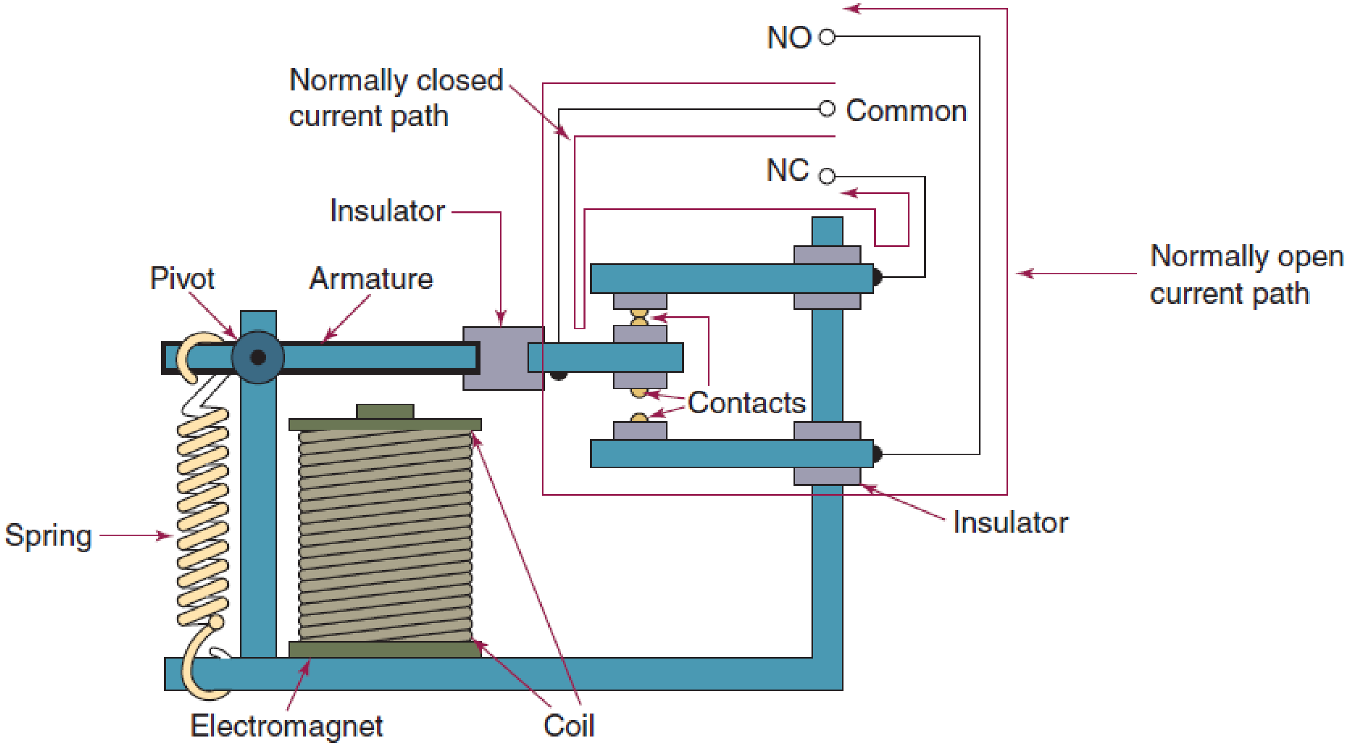
- The architecture of the PC and PLC systems are similar, with both featuring a motherboard, processor, memory, and expansion slots.
- The PLC processor has a microprocessor chip linked to memory and I/O (input/output) chips through parallel address, data, and control buses.
- Generally, PLCs do not have removable or fixed storage media such as floppy and hard disk drives, but they do have solid-state memory to store programs.
- PLCs do not have a monitor, but a human machine interface (HMI) flat screen display is often used to show process or production machine status.
- Both are replacing relay ladder logic.

PLC Processor architecture



Relay ladder logic

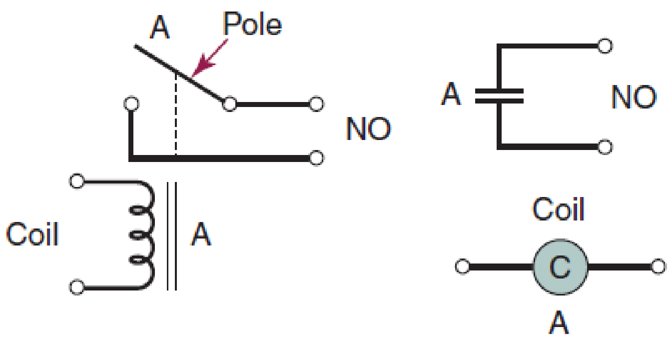
- Industrial automation began with relays used to control the sequence of operations in machines.
- The early PLCs were designed to eliminate the relay logic used for sequential control applications.
- To understand how PLCs accomplished this task, it is important to understand the operation of relays and relay ladder logic.



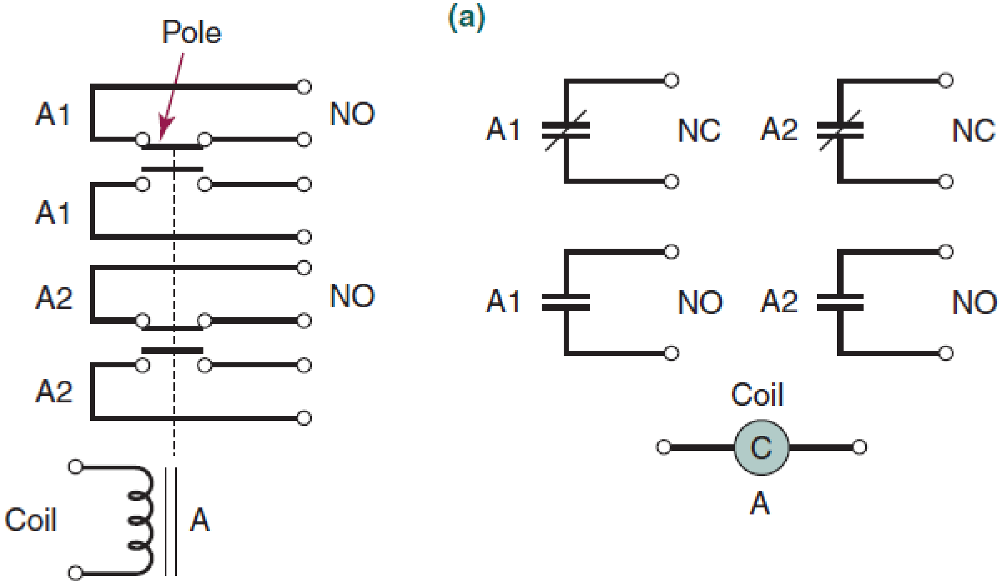
Electromagnetic Relay

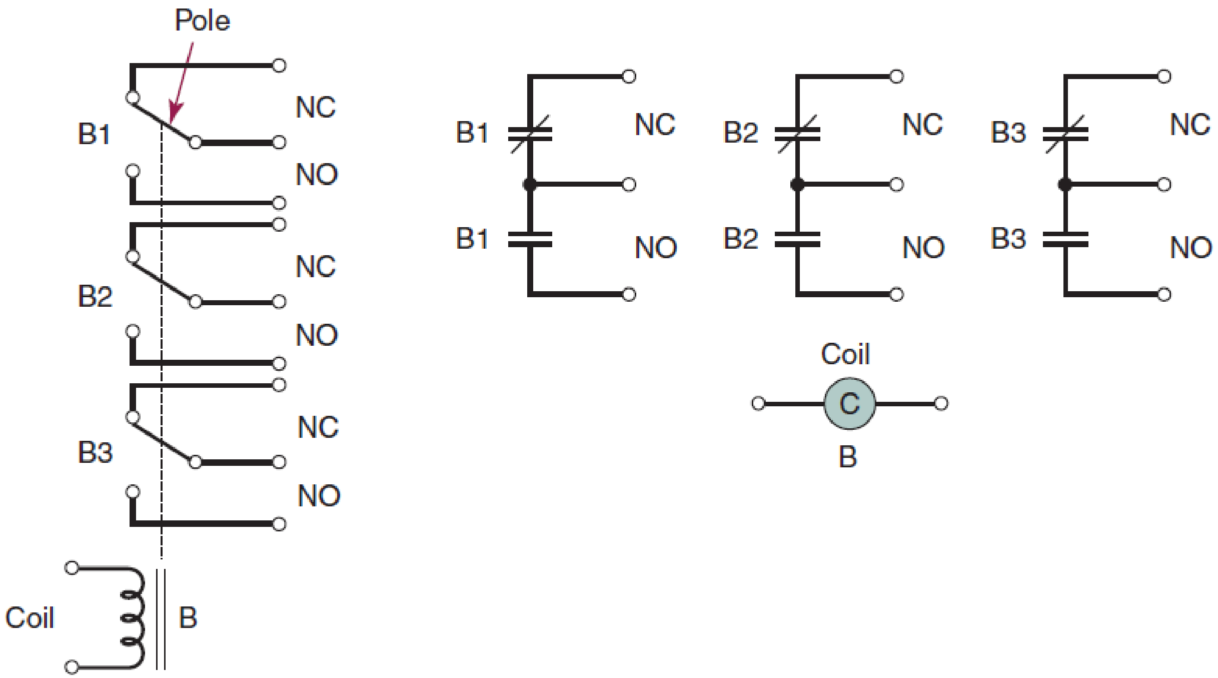
Three components

1. Electromagnet- A magnet, which is created by passing a current through wire wound around a steel core.
2. The armature- Called a clapper, is a hinged metal plate that is pulled toward the coil by the electromagnet when the coil is energized and pulled away from the coil by the spring when the coil is deenergized.
3. Contacts- which create one electrical path through the normally closed (NC) contacts when the coil is not energized (armature up) and a second path through the normally open (NO) contacts when the coil is energized (armature down).


A
Pole
NO
A
NO
Coil
A
Coil
C
A

(a)


Pole
A1
NO
A1
A2
NO
A2
Coil
A
A1
NC
A2
NC
A1
NO
A2
NO
Coil
C
A

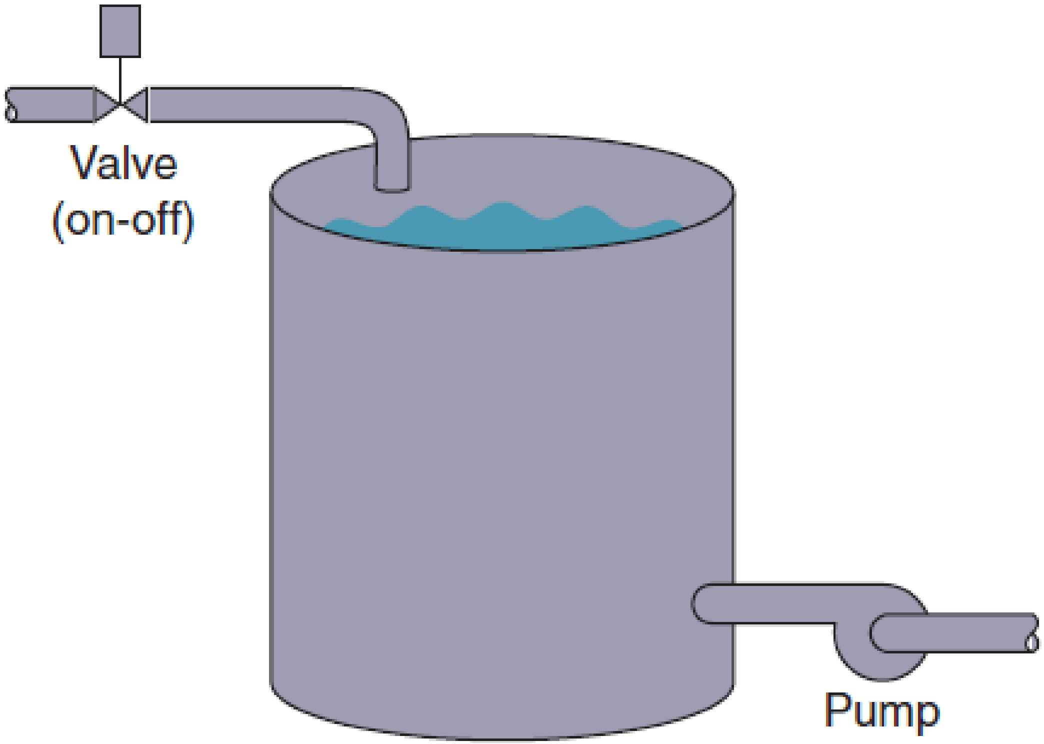

Pole
B1
NC
NO
B2
NC
NO
B3
NC
NO
Coil
B
B1
NC
B1
NO
B2
NC
B2
NO
B3
NC
B3
NO
Coil
C
B

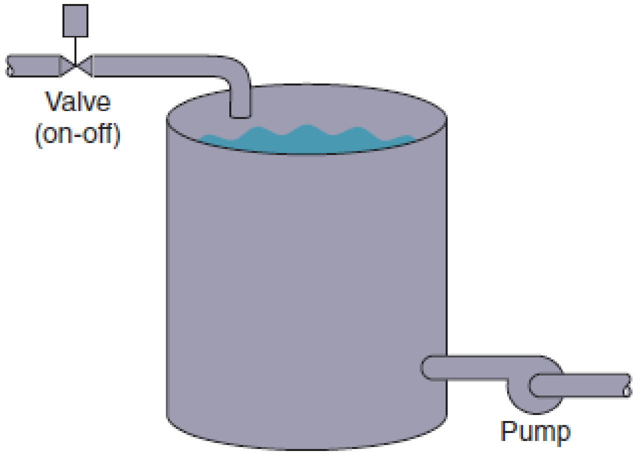
Relay Control Systems

Example- A tank is filled through an electrically operated valve and emptied by a motor-driven pump. Control of the valve and pump must satisfy the following logic:

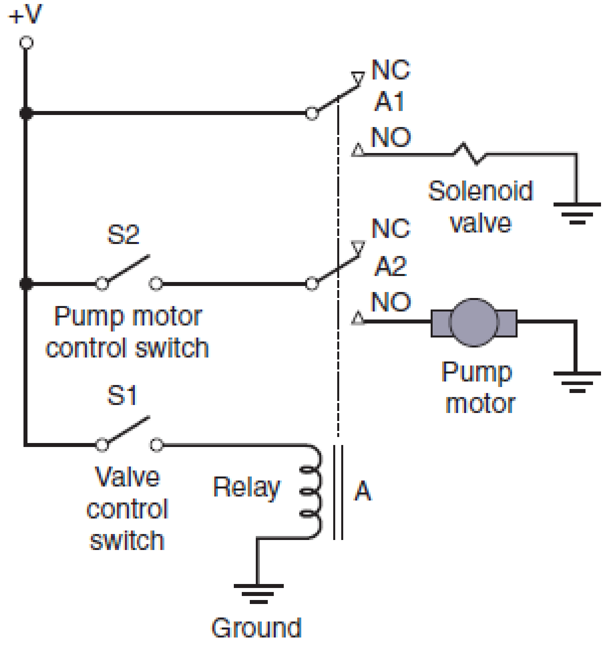
1. The pump can operate only when the input valve to the tank is open.

2. The input valve can be opened when the pump is either operating or not operating.

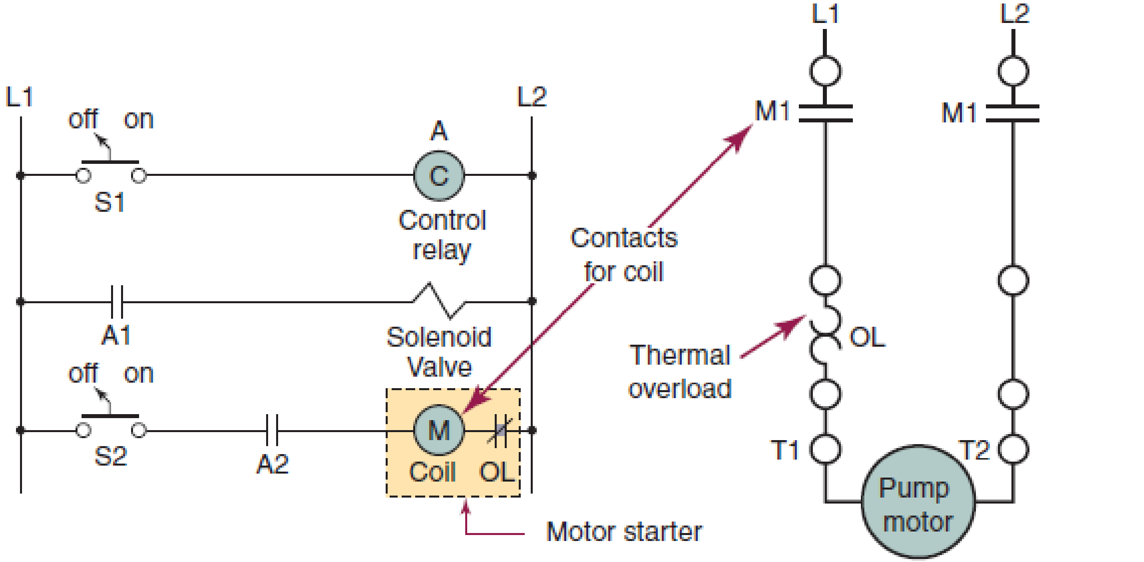




(a) Process Tank



(b) Electronic schematic



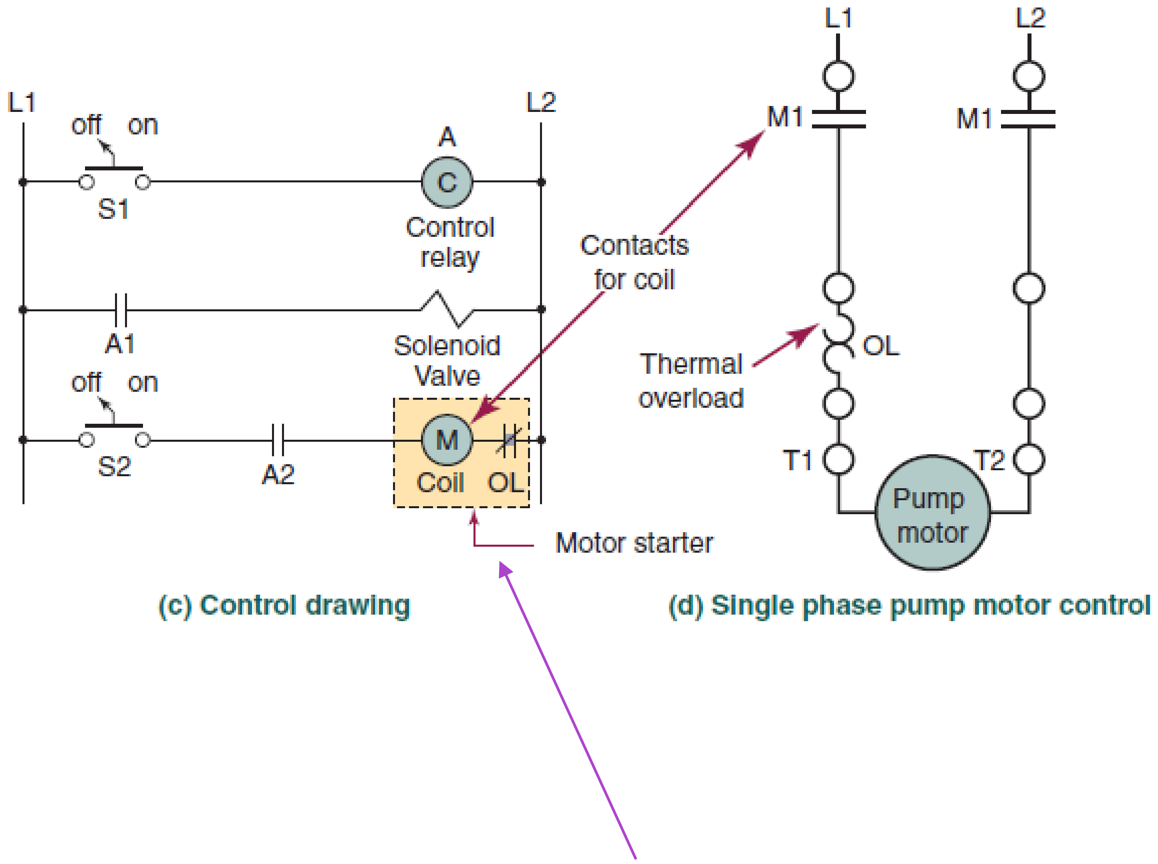
(c) Control drawing

(d) Single phase pump motor control

Relay ladder logic diagram

- It is called this because it uses relays, looks like a ladder, and satisfies the logic control requirements specified for control of the output device.
- Standard control drawing symbols are used to represent the different input and output devices, such as mechanical switches, sensors, magnetic contactors and relays, and electrical contacts.

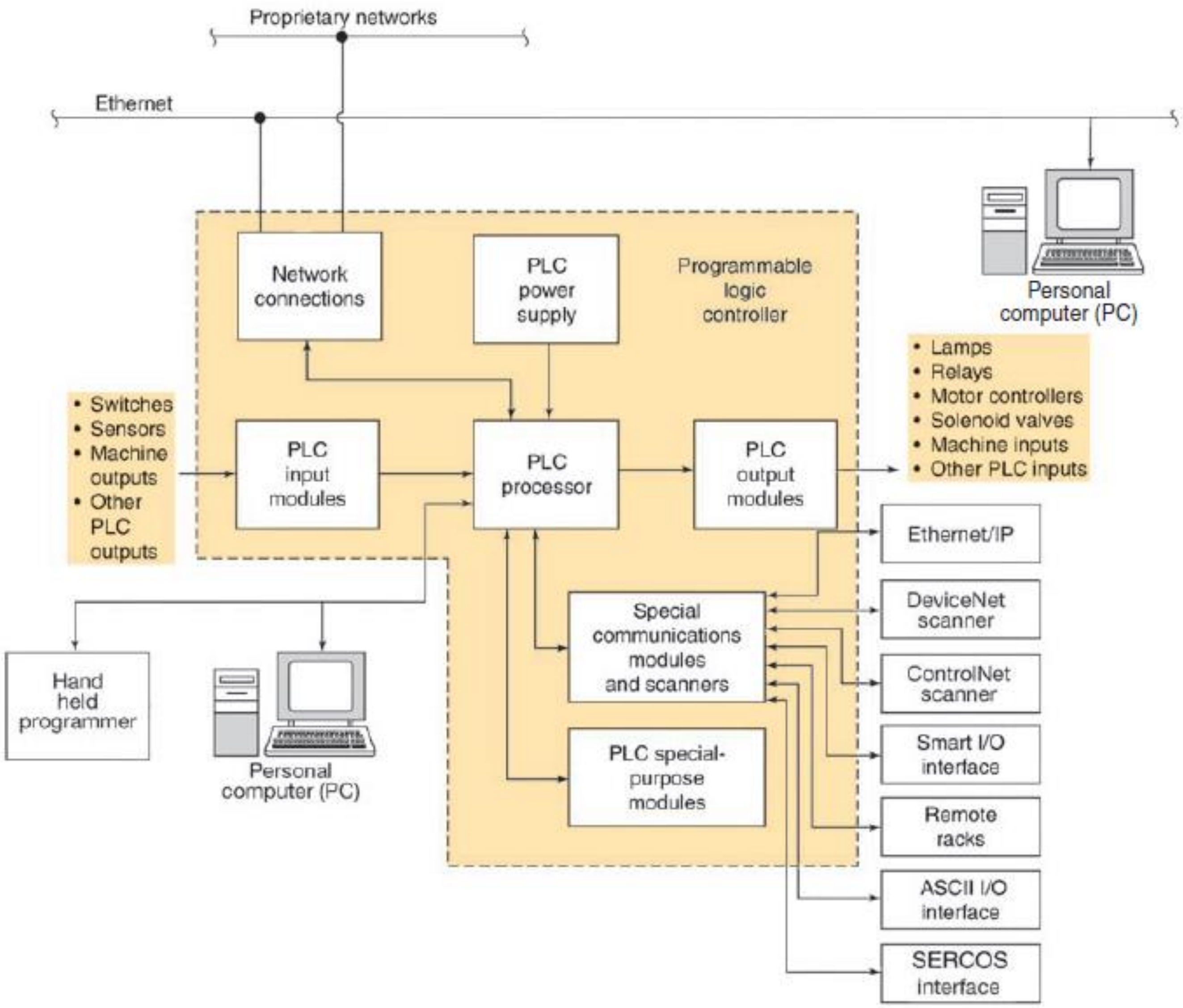
- These diagrams have a vertical line at the left (marked L1) and right (marked L2) sides.
- The left vertical line, sometimes called the left power rail, usually represents the positive, hot, or high side of the power source; the right vertical line, called the right power rail, represents the power return, neutral, or ground.
- All the circuits containing the switches, sensors, and output actuators used to operate a machine are drawn between these two vertical lines.



DOL Starting

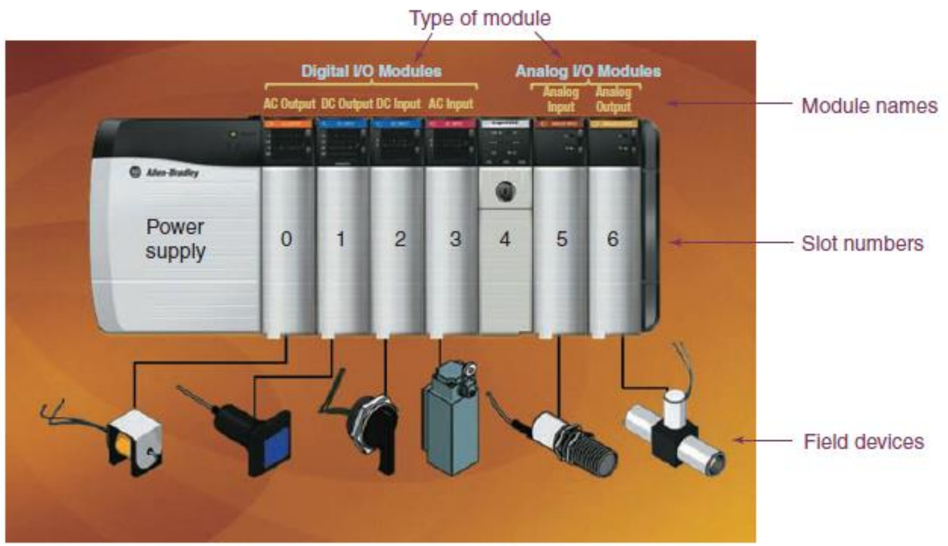
PLC SYSTEM AND COMPONENTS

- The processor communicates with input and output devices through input and output modules

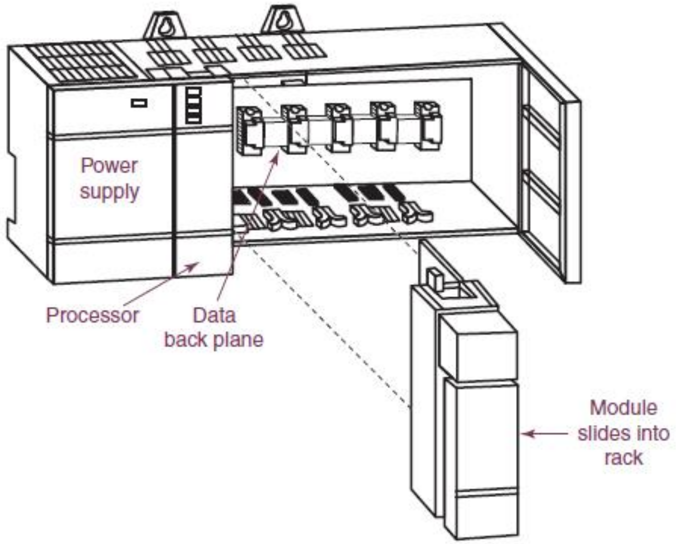


PLC Rack

- For the larger systems, the PLC blocks mounted in a rack.
- The rack provides mechanical support and all the electrical interconnections plus the data interface between all of the PLC modules using the backplane bus structure.
- In smaller PLC systems, the component modules are integrated into a single unit



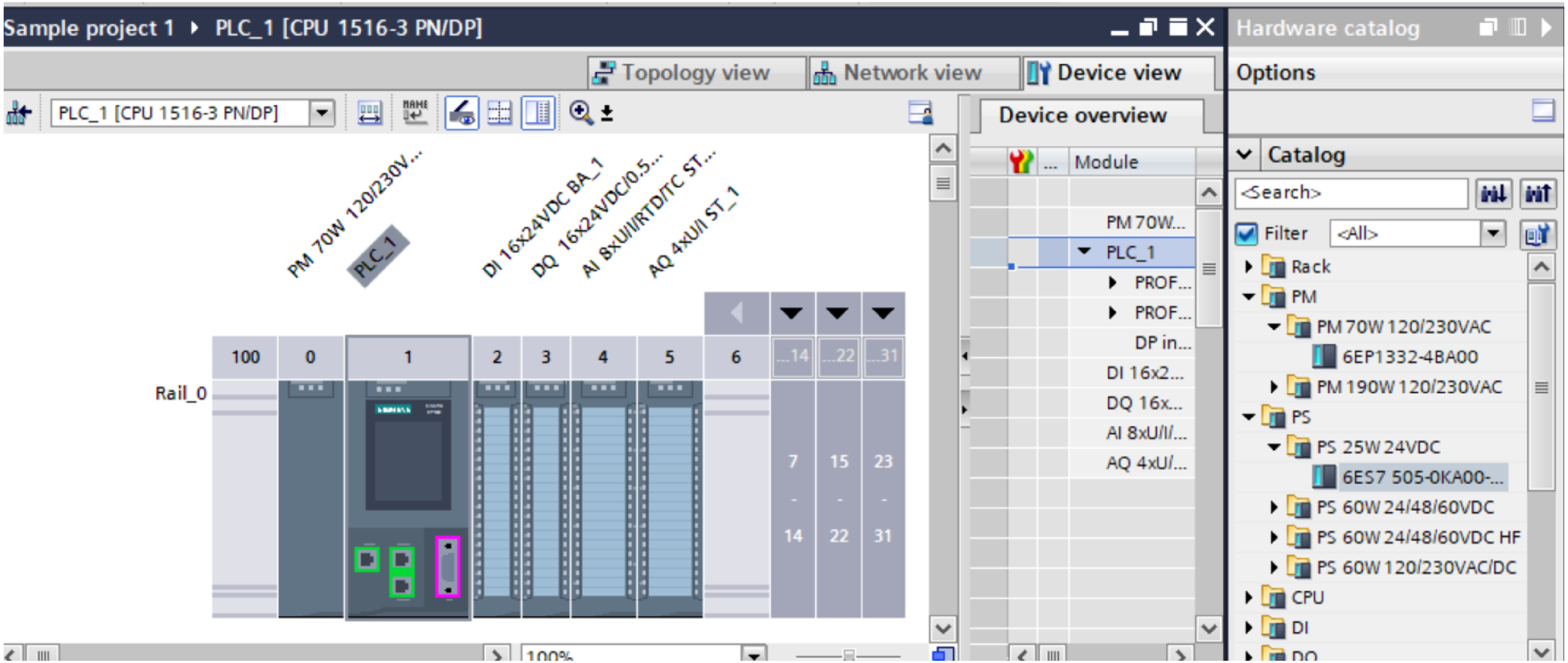
(a) Front panel and rack with seven modules for ControlLogix PLC



Backplane

- The power and data interface for the modules is provided by the backplane in the rack.
- The backplane has copper conductors, called lands, that deliver power to the modules and also provide a data bus to exchange data between the modules and the processor.
- Modules slide into the rack and engage connectors on the backplane to access the backplane's power and data buses.
- The number of slots in the rack is determined by the number and type of modules required for the control application.

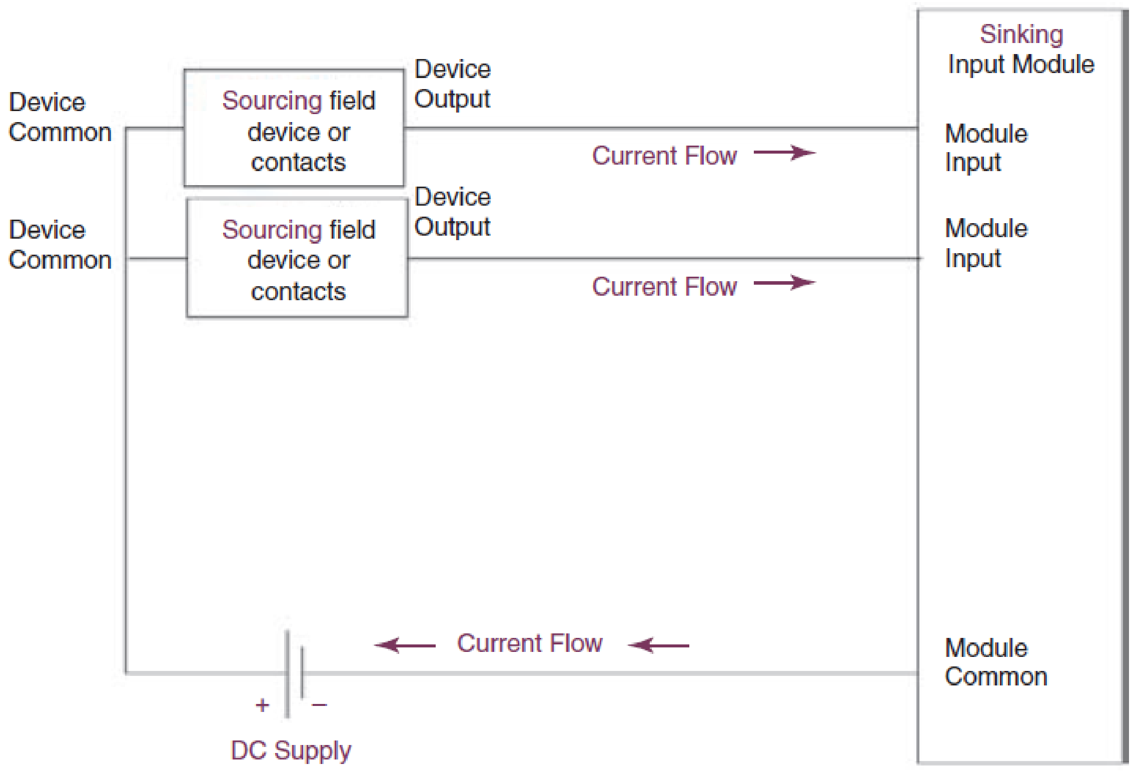
Processor and Power Supply



Input and Output Interface

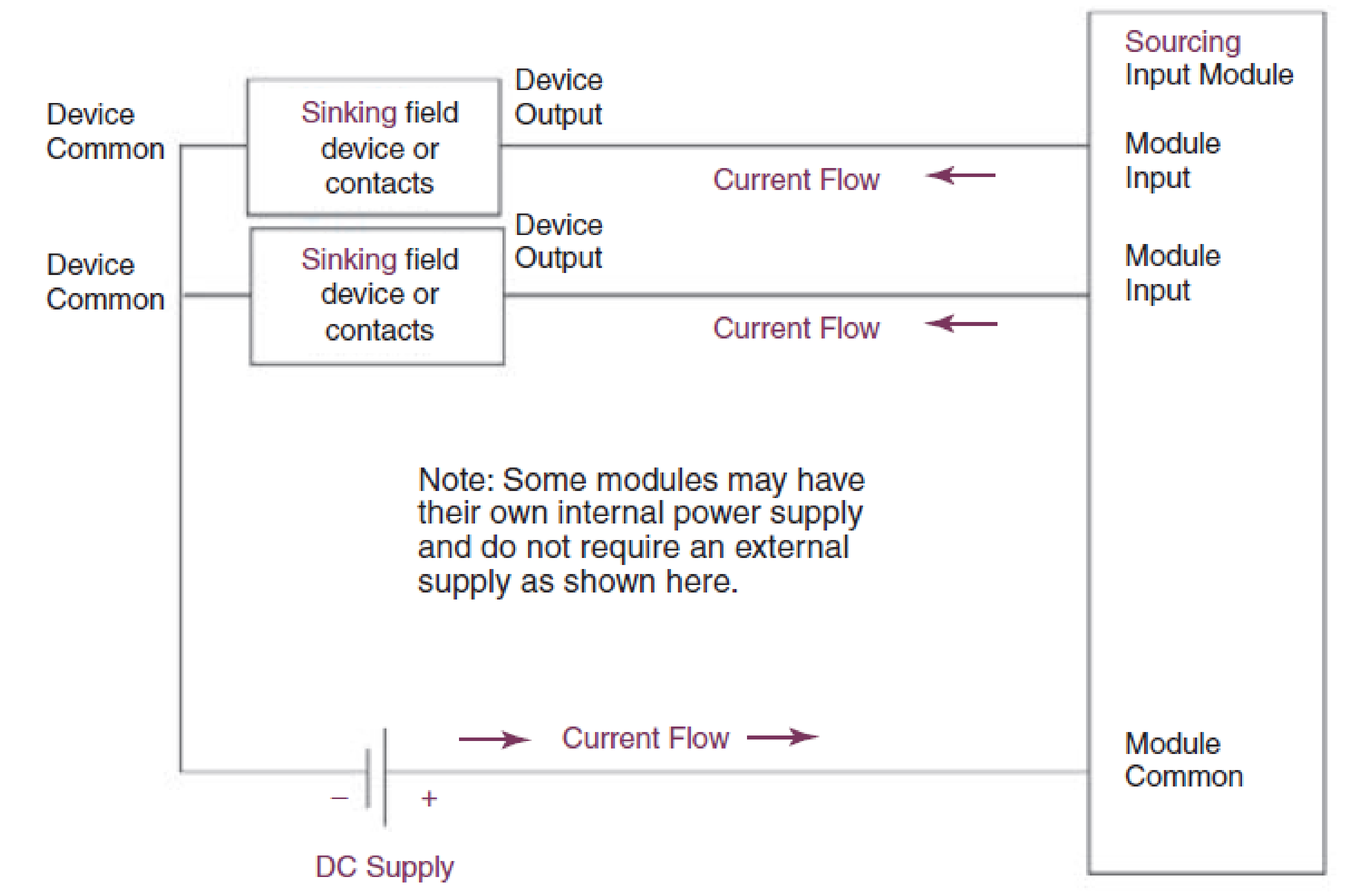
- The input and output (I/O) interface used in PLCs can take two forms: fixed or modular.
- Inputs (***field Devices)***- switches, sensors, machine outputs, or other PLC outputs.
- PLC input modules act as signal conditioners changing the many different types of input voltages to the 0 to 5 volt DC voltage levels used in the PLC processor.
- Outputs- lamps, relays, motor and heater contactors, solenoid valves, and machine inputs.
- Selection of input/ output modules- TIA portal example

Input current sinking and sourcing circuits.

Input Interface Description	Input Module Interface
(a) DC Input Module (Current Sinking) Most DC modules are either current **sinking** or current sourcing, but some will work with either current mode. The sinking input modules have a current flow into the module input terminal when the input is active. Therefore, the current must be flowing out of the field device, so the sensor or switch is current sourcing. This configuration has a single module common terminal, while others have both a signal and common for each input port.	

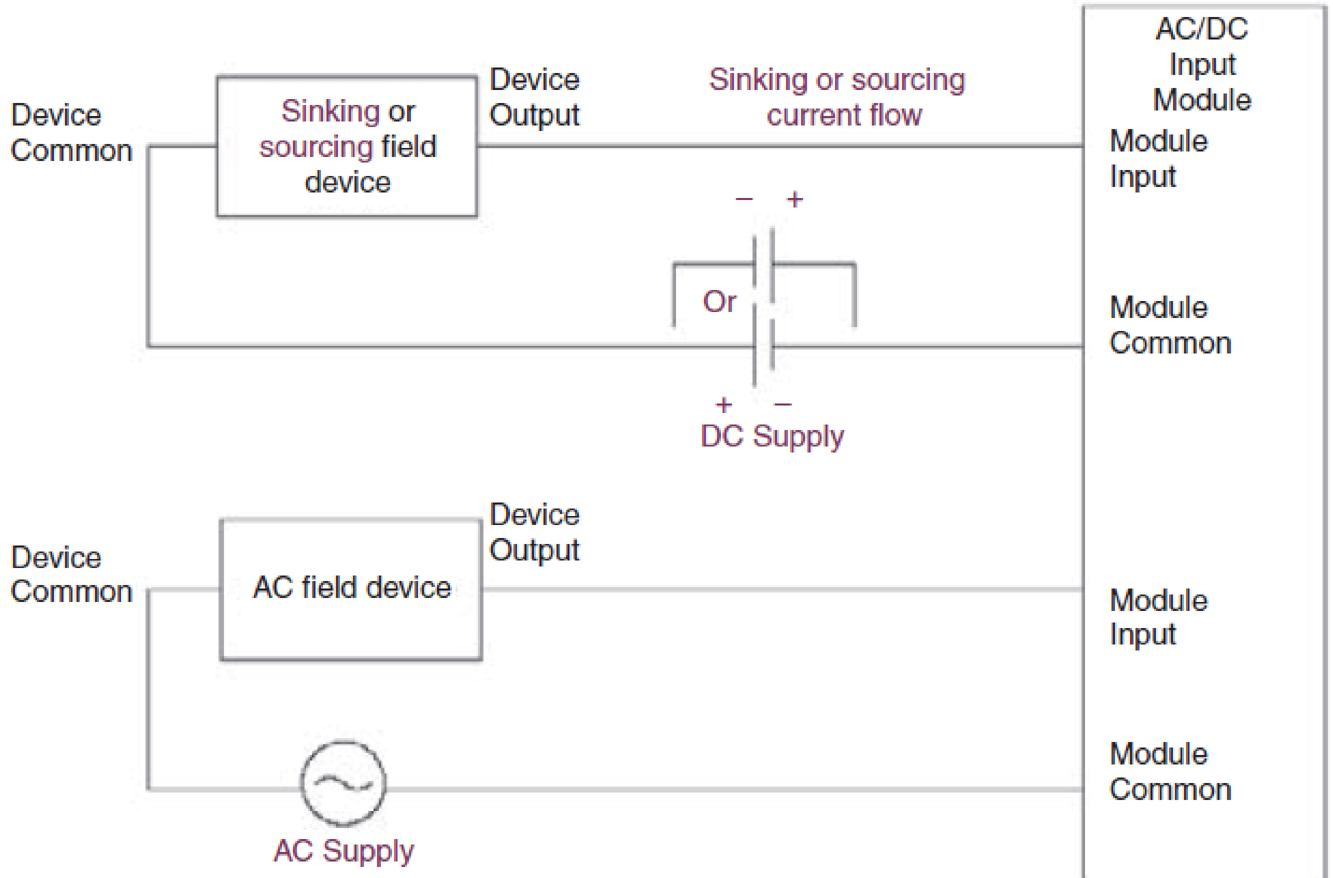
(b) DC Input Module (Current Sourcing)

The **sourcing** input modules have a current flow out of the input terminal when the input is active. Therefore, the current must be flowing into the field device, so the sensor or switch is current sinking. As a result the signal at the field device output terminal must be a ground for an active input.



(c) AC/DC Input Module

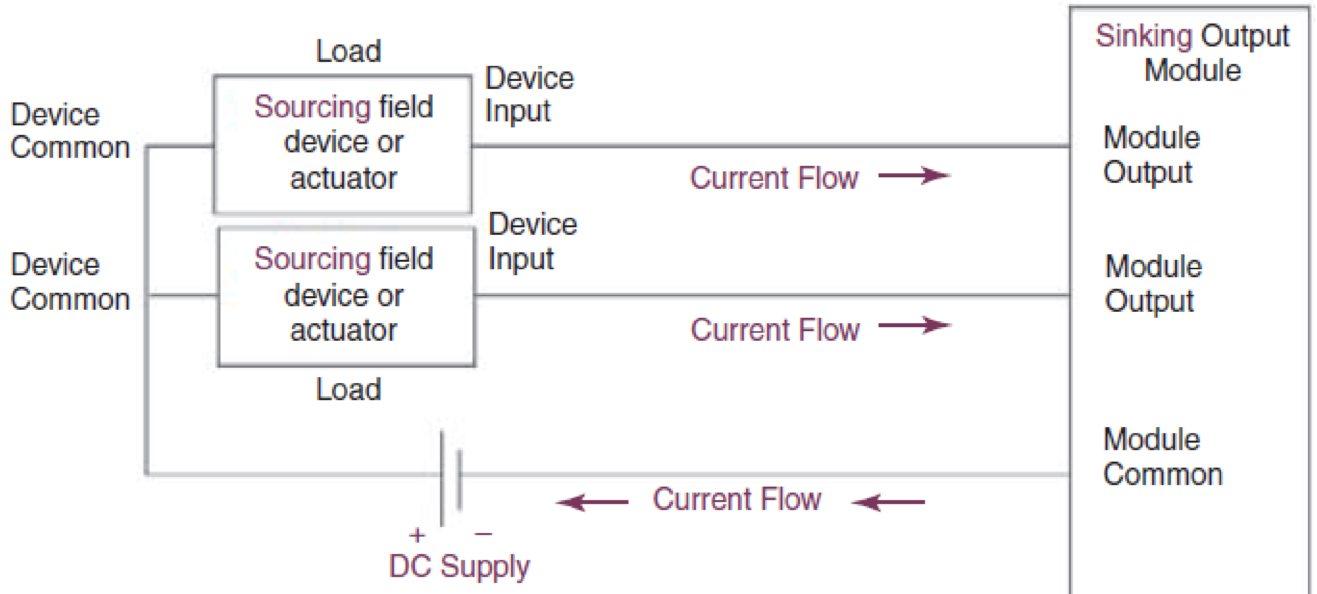
The AC/DC input modules support DC input currents that could be flowing in either direction or AC types where the current flow changes direction every half cycle. The top interface would work with either a current sourcing or sinking field device. The bottom interface is for an AC sensor output or a switch with an AC source.



Output current sinking and sourcing circuits.

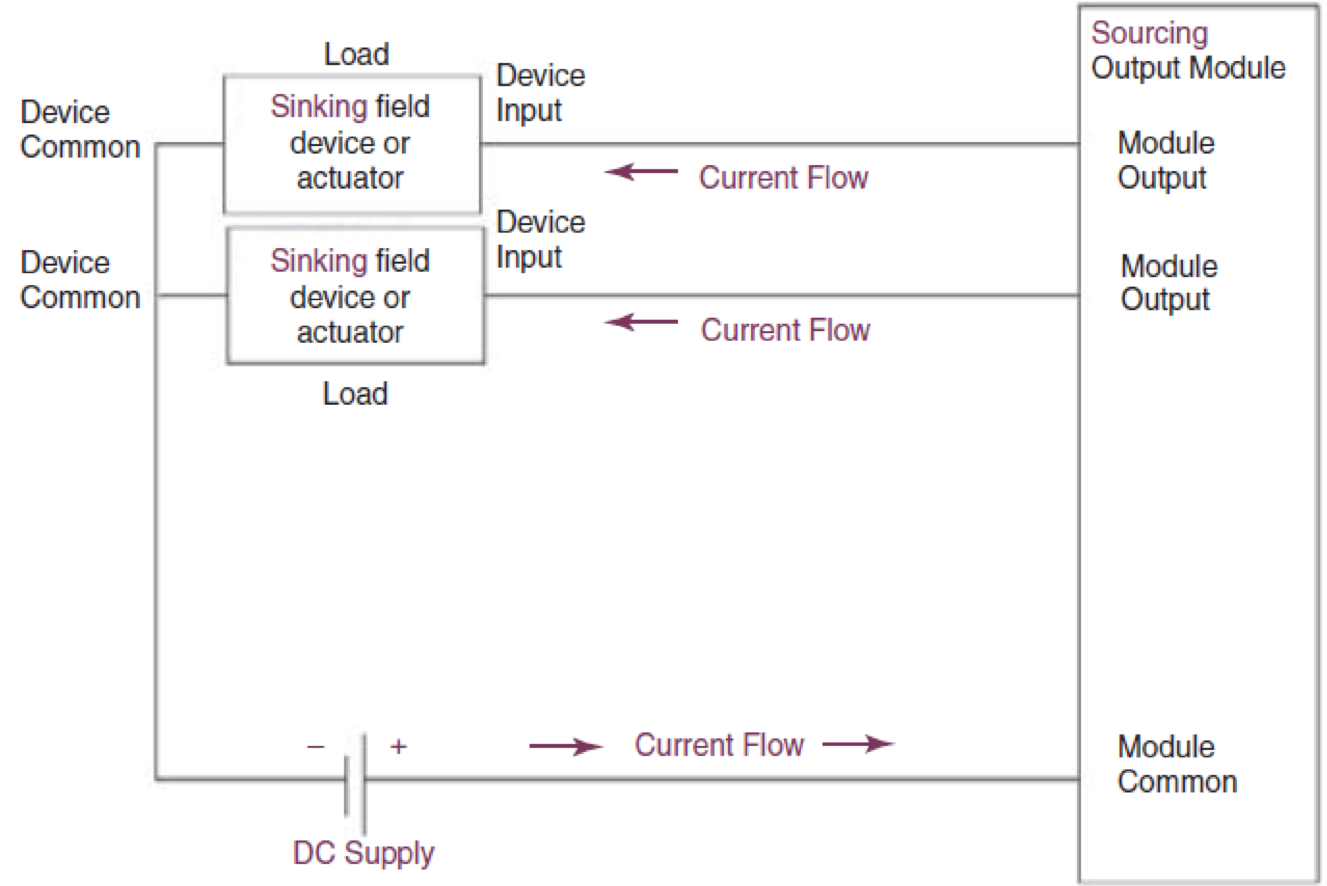
(a) DC Output Module (Current Sinking)

The **sinking** output modules have a current flow into the module output terminal when the output is active. For compatibility, the field device or actuator must have a **sourcing** (current flowing out) type of input. The commons for all field devices are connected to a positive DC supply and the supply common is connected to the module common terminal.



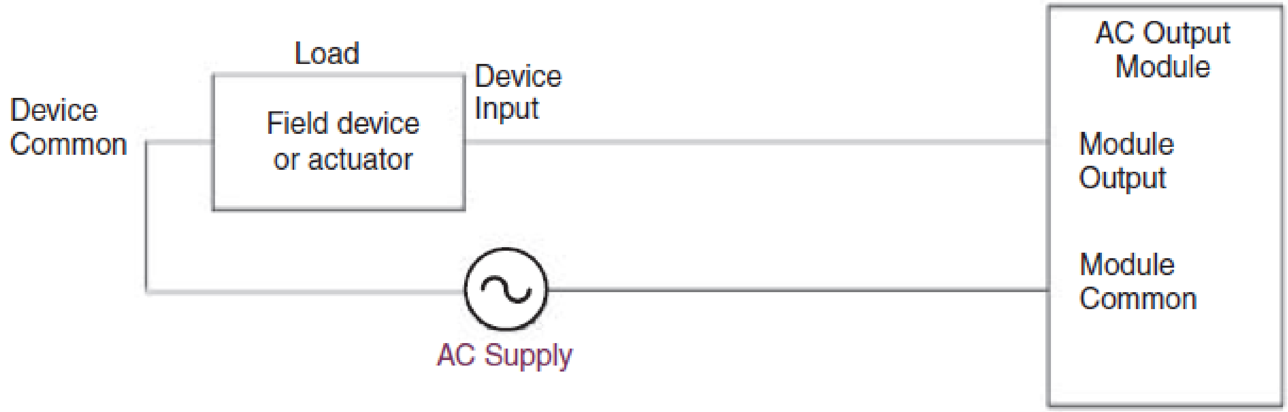
(b) DC Output Module (Current Sourcing)

The **sourcing** output modules have a current flow out of the module output terminal when the output is active. For compatibility, the field device or actuator must have a **sinking** (current flowing in) type of input. The commons for all field devices are connected to the negative side of a DC supply and the high side of the supply voltage is connected to the module common terminal.



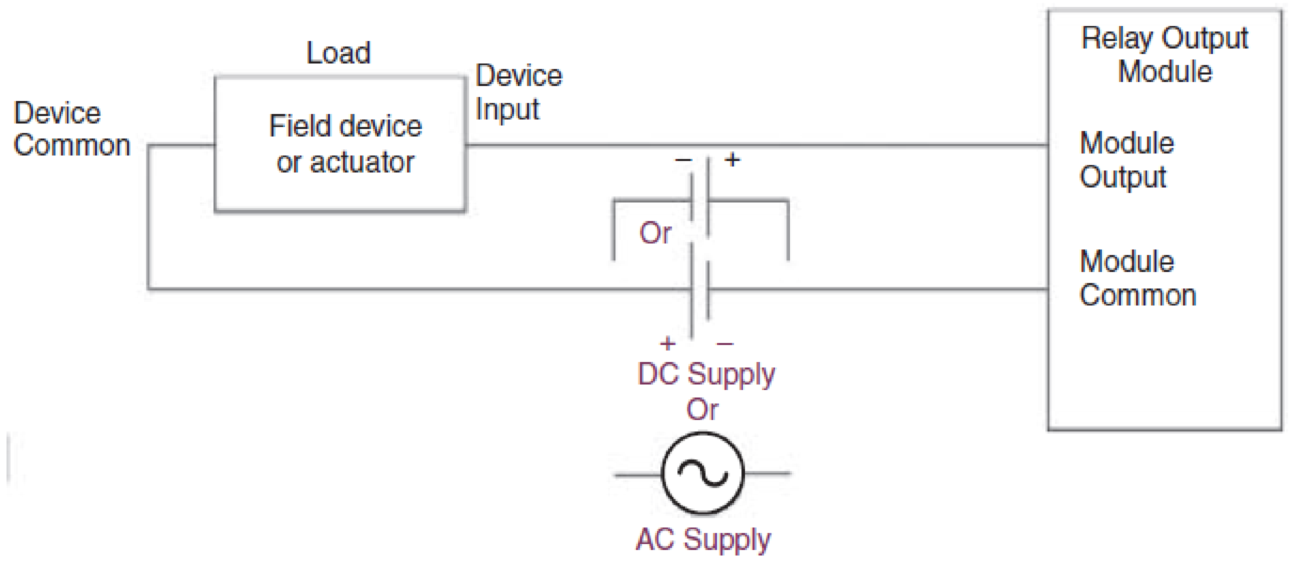
(c) AC Output Module

The AC output modules switch an AC voltage at the output to drive AC type actuators and are never called sourcing or sinking types of outputs. An AC source is connected between the module common and the AC field device or switch as shown. AC modules can be used with all AC field device actuators with compatible voltage levels.



(d) Relay Output Module

The relay output modules have a normally open relay contact for each output port. This permits moderately larger load currents and the ability to switch either AC or DC field devices.

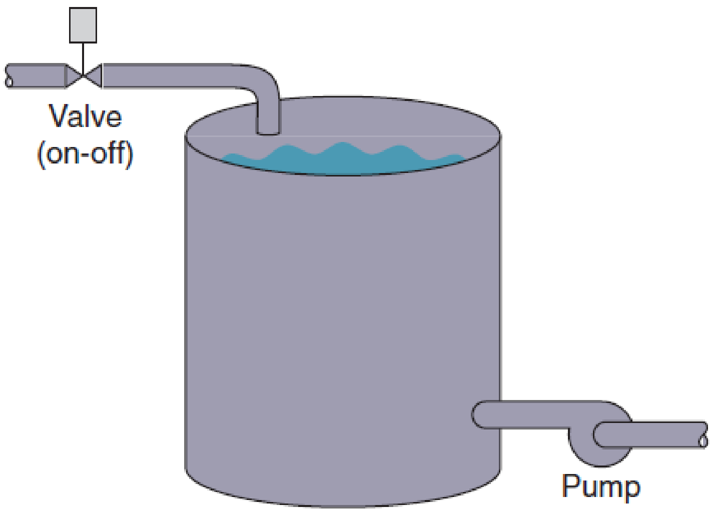


PLC Special-Purpose Modules

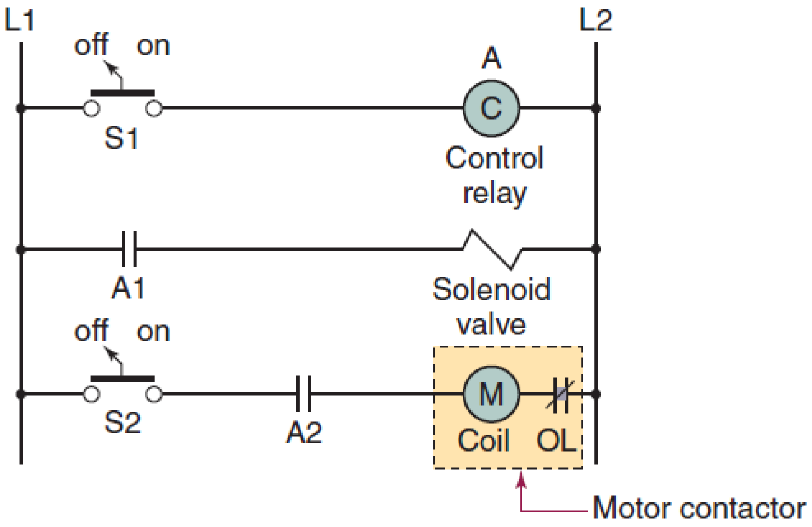
- This term represents a broad collection of modules developed by PLC vendors for PLC control of a variety of automation devices.
- Analog input and output, temperature measurement and control (thermocouple and resistance temperature device), multiple PID loop control, servo motor control, stepper motor control, high-speed counter, and hydraulic ram control.

PLC LADDER LOGIC PROGRAMMING

- Ladder logic is a PLC graphical programming technique that was introduced with the first PLCs more than 35 years ago.

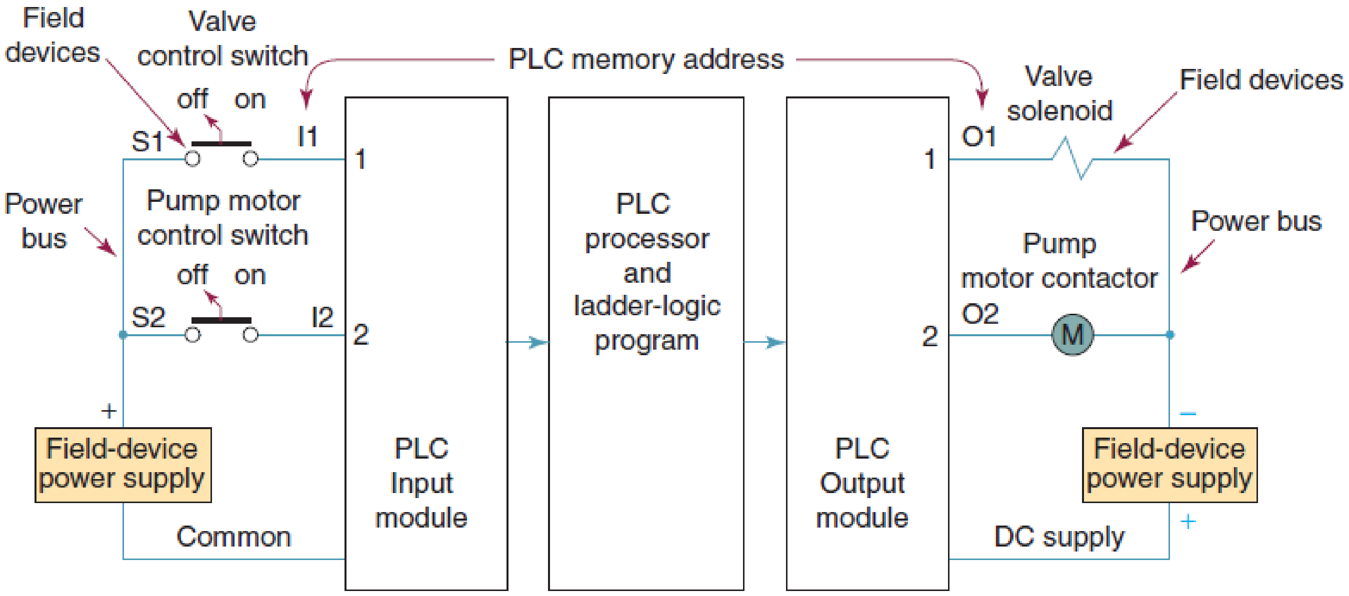


(a) Process Tank

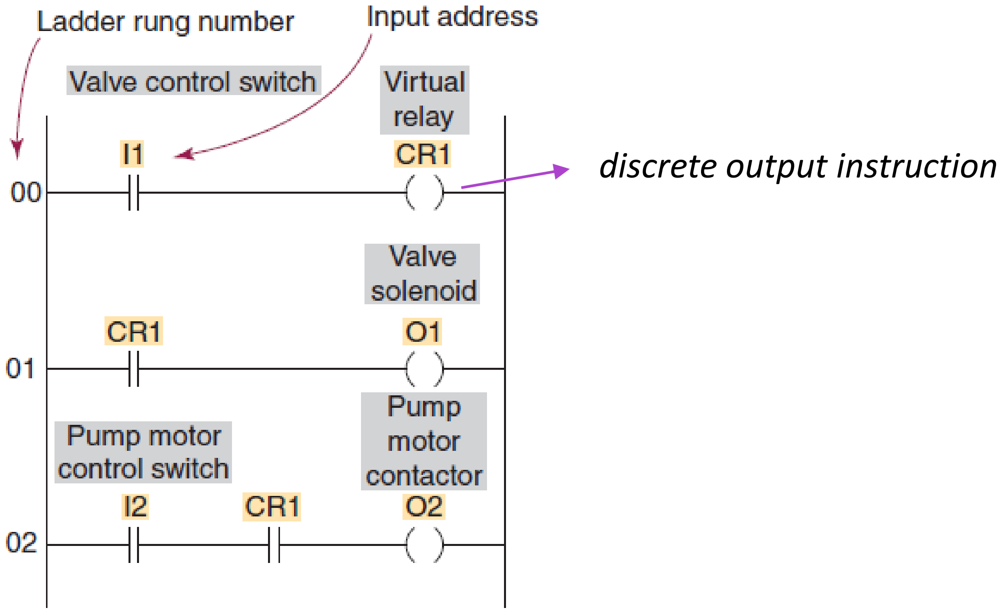


PLC Solution

- The field devices remain but the mechanical relay is eliminated.
- Each rung of the PLC ladder logic represents a logical statement executed i software with inputs on the left and outputs on the right. If the inputs are true, then the output is true or active



(a) PLC and field device interface for one pump



(b) PLC ladder logic

PLC Ladder logic vs Relay logic.

- The number of virtual relays, output instructions, and referenced input instructions in the PLC ladder logic is only limited by the size of the PLC memory, while the number of contacts for the mechanical relay is limited to the number of poles present on the relay selected.
- The input and output instructions in the PLC ladder logic do not represent the switches and actuators directly.
- The PLC input instructions are logical symbols associated with the input signals (voltages) at the input module terminals.
- The output symbol is associated with the signal (voltage) that will be presented to the actuator connected to the output module.
- The input and output devices have separate power sources that are isolated from the power for the PLC processor.

PLC Advantages

- In the PLC solution, the only physical wires in the system are the interfaces between the input and output field devices and the PLC input and output modules.
- All the elements on the ladder program rungs, namely the virtual relays, virtual relay instructions, field device input instructions, and output instructions, exist only in software in the PLC memory.
- The similarity between the PLC ladder logic program and the control diagram used for relay ladder logic provides an easy transition to PLCs for electricians, technicians, and design engineers who must work with both.

- **Reliability**: Relays are electro-mechanical devices, and physical wear in relay logic controls occurs every time the devices are turned on. PLCs have reliability inherent in all electronic devices.
- **Improved maintenance and troubleshooting**: If a problem occurs in any PLC module or in the processor, the module or processor can be changed in a matter of minutes without any changes in wiring.
- **Off-line programming**: The new programming software allows downloads directly to the PLC, through a serial connection, or over the Internet. In most situations, the application programming is performed using only PC hardware and software resources while the PLC is running the process. This allows new program development and current program modifications without taking the PLCs out of the production process.
- **On-line programming**: This allows the programmer to edit ladder logic rungs while the PLC is executing a production program. The changes are made in a special on-line mode and when change is complete the new ladder logic is made an active part of the current ladder program.
- **Broad application base**: PLC software supports a broad range of discrete and analog applications in numerous industries
- **Low cost and small footprint**
- **High-end control grows exponentially:** Although cost and size are dropping on the low end, the capability of large PLC systems expand as well.

Safe Electrical Practices

- Whenever possible, work on all industrial systems should be performed when the system is in a zero-energy state.
- Energy sources-Voltage sources, Compressed springs, High pressure fluids, High pressure air, Potential energy from suspended weight, Chemical energy (flammable and reactive substances), Nuclear energy (radioactivity)
- Systems that are controlled by a PLC often have multiple power sources.
- The PLC is usually powered from 110/230 volts AC, and the input and output modules can have AC and DC sources with a wide range of voltages from 5 volts DC to 440 volts AC.
- In addition, the system often controls valves that switch high pressure air and fluid.
- It is often not possible to work or troubleshoot a PLC system in the zero-energy state, so good practices should be used to avoid electrical shock.
- Contact with high pressure air and fluid should also be avoided, and attention paid to the pneumatic and hydraulic devices powered by these energy sources.

- The primary safety process used throughout industry is a lock-out/tag-out procedure.
- This technique is normally not used in instructional laboratories but is quite common in industry. In the PLC laboratory is it good practice to check for the presence of voltage with a meter before actually touching any conductors in the circuit.
- This is especially important when AC voltage is present or when a DC voltage greater than 5 volts is used. Many industry safety manuals include the following three-step procedure when measuring a voltage:

1. Verify that that the meter is working by measuring a known voltage source.
2. Use the meter to test the circuit you plan to touch for the presence of a voltage.
3. Verify again that that the meter is working by measuring a known voltage source.

- This may seem excessive but avoiding accidental contact with dangerous voltage levels is important, and this is a proven technique for preventing electrical shock.

- A final precaution is to make initial contact with the conductor(s) with the back of one hand or fingers before grasping it between the fingers.
- If voltage is present when the back of the hands or fingers contact the conductor, then the natural muscle reaction will throw the fingers away from the conductor.
- This is a final precaution and should never be done to determine if a conductor has voltage present.
- Another suggestion often stated when working around high power circuits is to work with one of your hands in your pocket. This is just a way of emphasizing that you never want to permit shock current to pass through the chest region.

Input devices and output actuators

- MANUALLY OPERATED INDUSTRIAL SWITCHES
- MECHANICALLY OPERATED INDUSTRIAL SWITCHES
- INDUSTRIAL SENSORS
- INTERFACING INPUT FIELD DEVICES
- ELECTROMAGNETIC OUTPUT ACTUATORS
- VISUAL AND AUDIO OUTPUT DEVICES
- TROUBLESHOOTING INPUT AND OUTPUT DEVICES

MANUALLY OPERATED INDUSTRIAL SWITCHES

- Input devices to perform a simple on-off function
- Toggle switch, push button switch, selector switch, and push wheel


OFF
ON


1
0
2

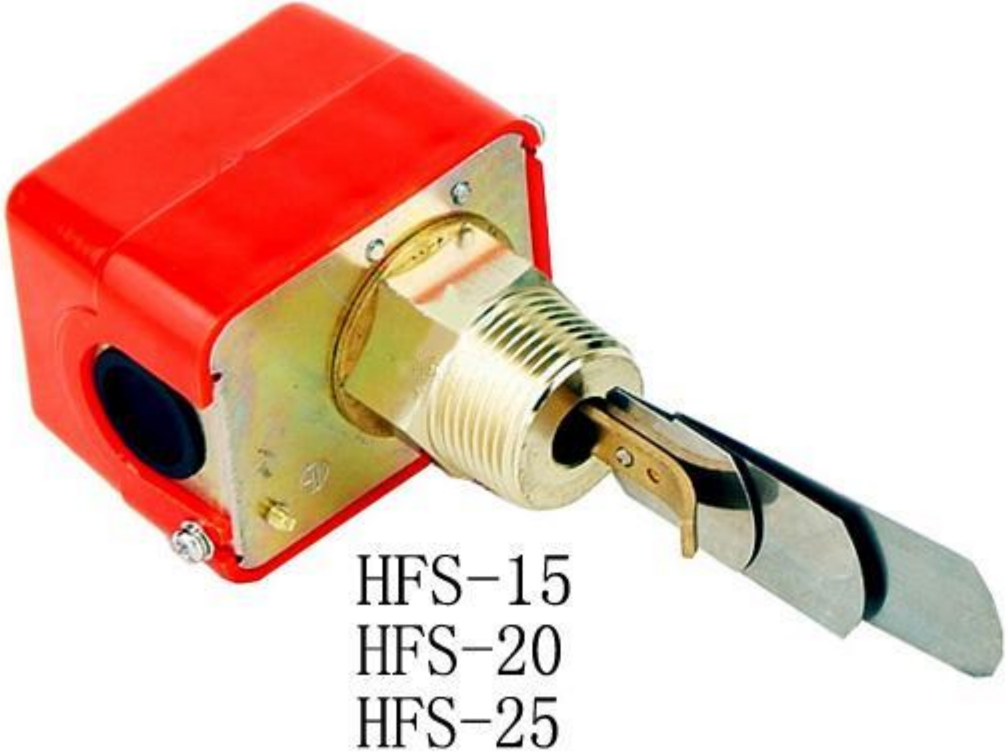

START
STOP

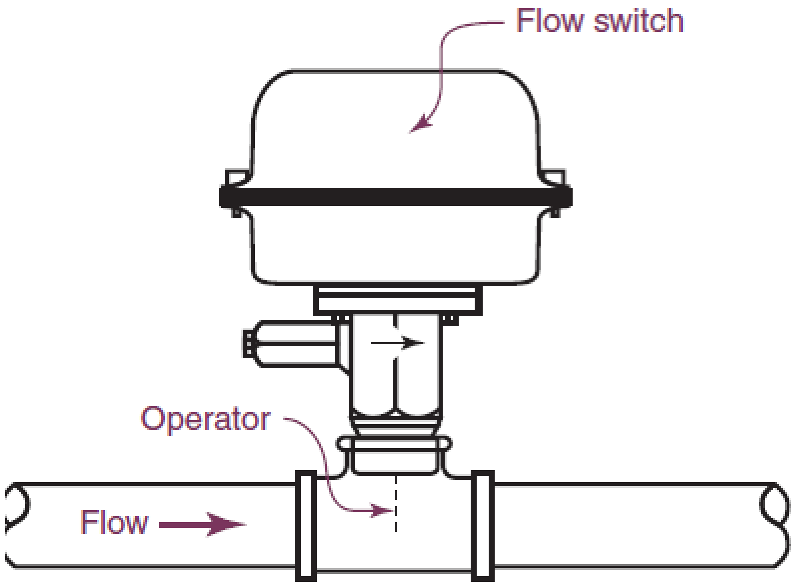
MECHANICALLY OPERATED INDUSTRIAL SWITCHES

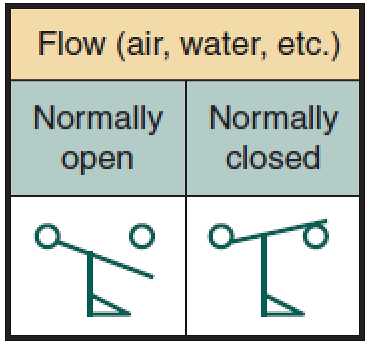
- Mechanically operated industrial switches are automatically opened or closed by a process parameter such as position, pressure, or temperature.
- Limit Switches, Flow switches

Flow switch

- Flow switches are used to detect a change in the flow of a liquid or a gas in a pipe or duct.







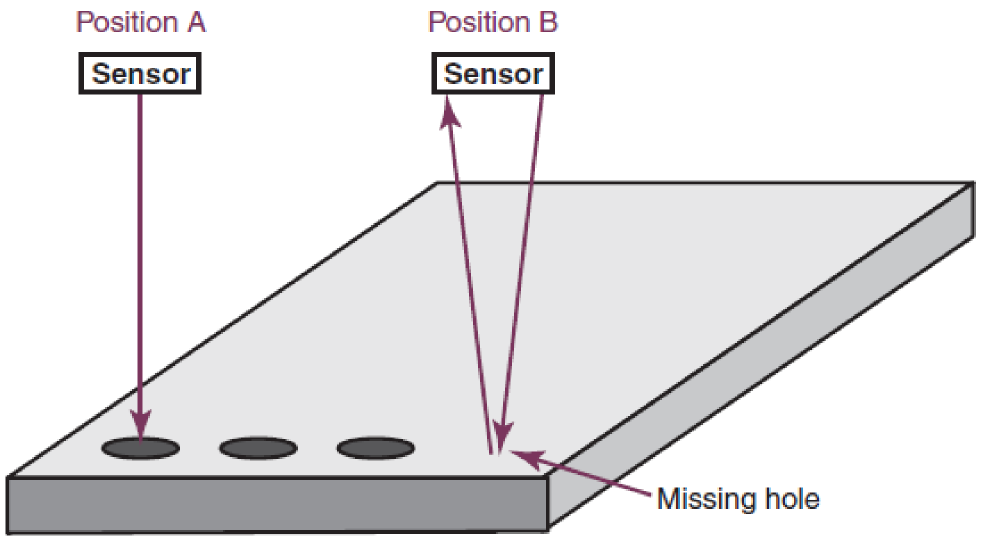
Level Switches

- Level switches or float switches are discrete switches used for control of liquid and granular material levels in tanks and bins.

INDUSTRIAL SENSORS

- Industrial sensors are the eyes, ears, and tactile senses of the PLC in an automated system.
- Strategically mounted sensors provide the automation system with the same data that an operator gathers using the five human senses

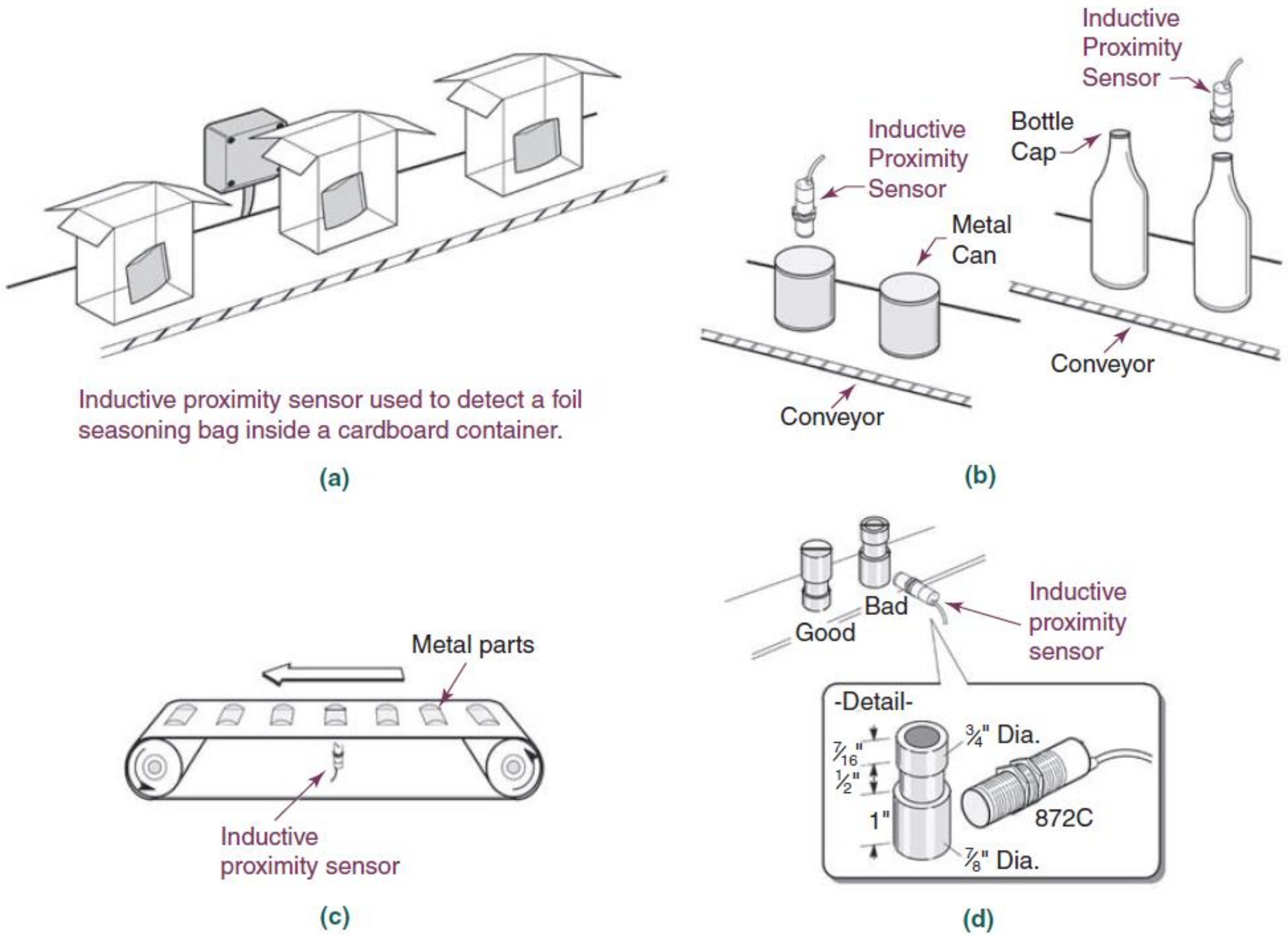
Hole inspection with sensor.

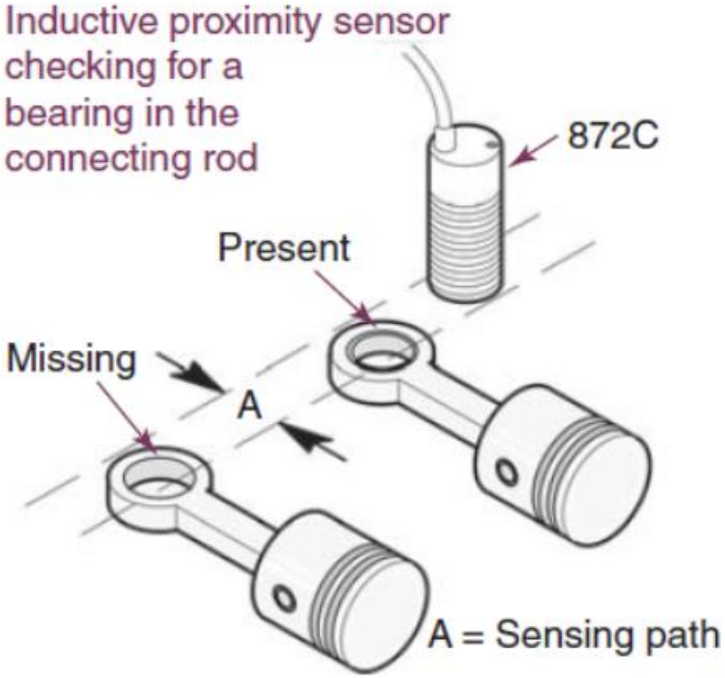


Sensors

1. Contact devices, which physically touch the parameter being measured.
2. Non-contact devices, which sense or measure the process parameter without physically touching it.

Inductive sensor applications.





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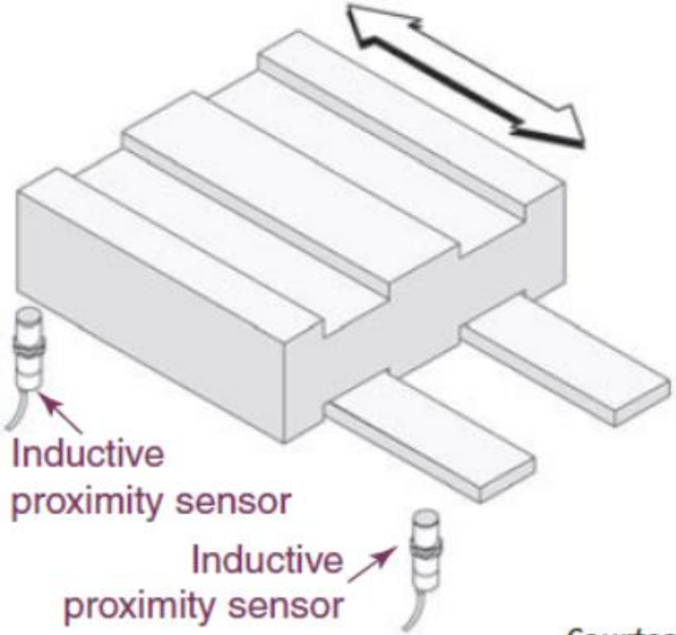
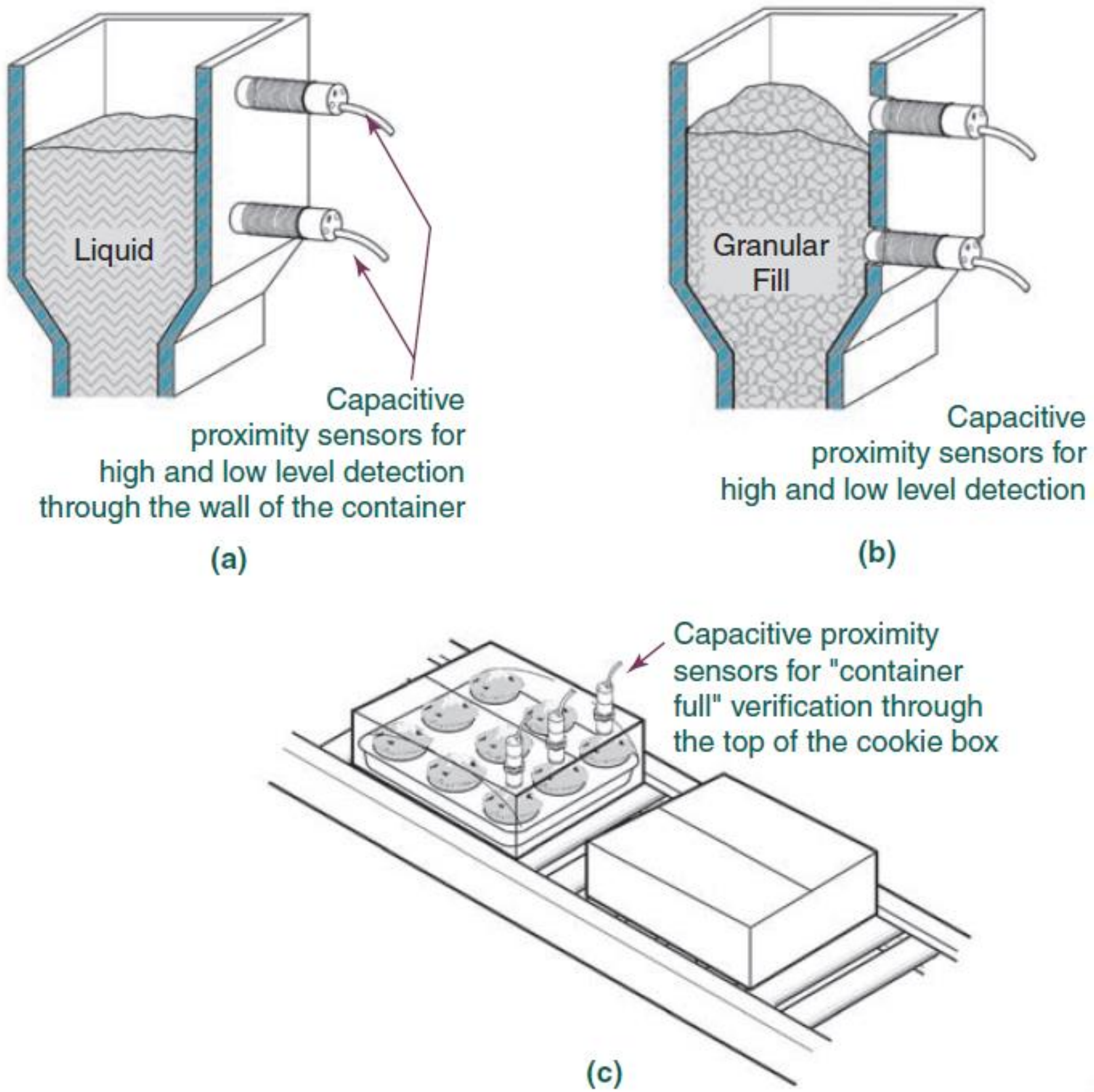
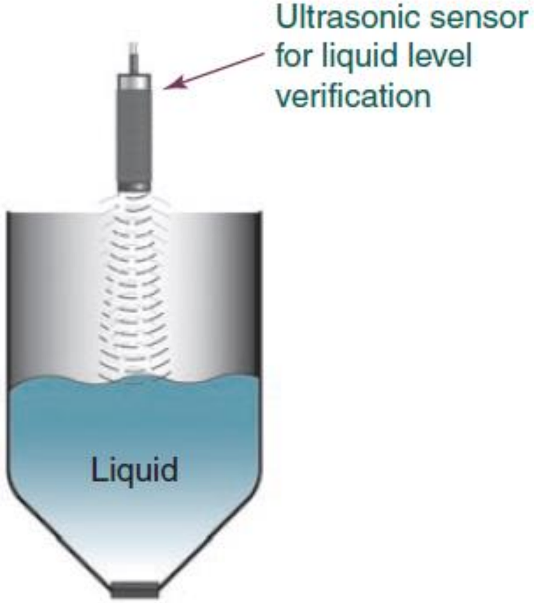


(f)

Courtesy of Rockwell Automation, Inc.

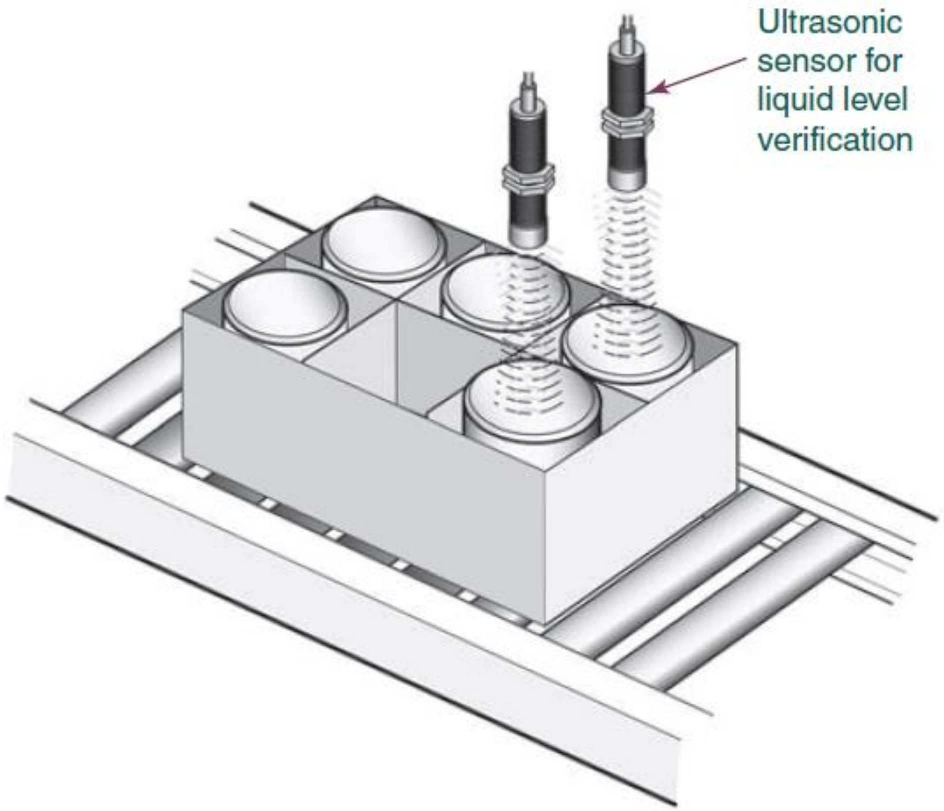
FIGURE 25: Capacitive and ultrasonic proximity sensor applications.





Ultrasonic sensor
for liquid level
verification
Liquid

(d)



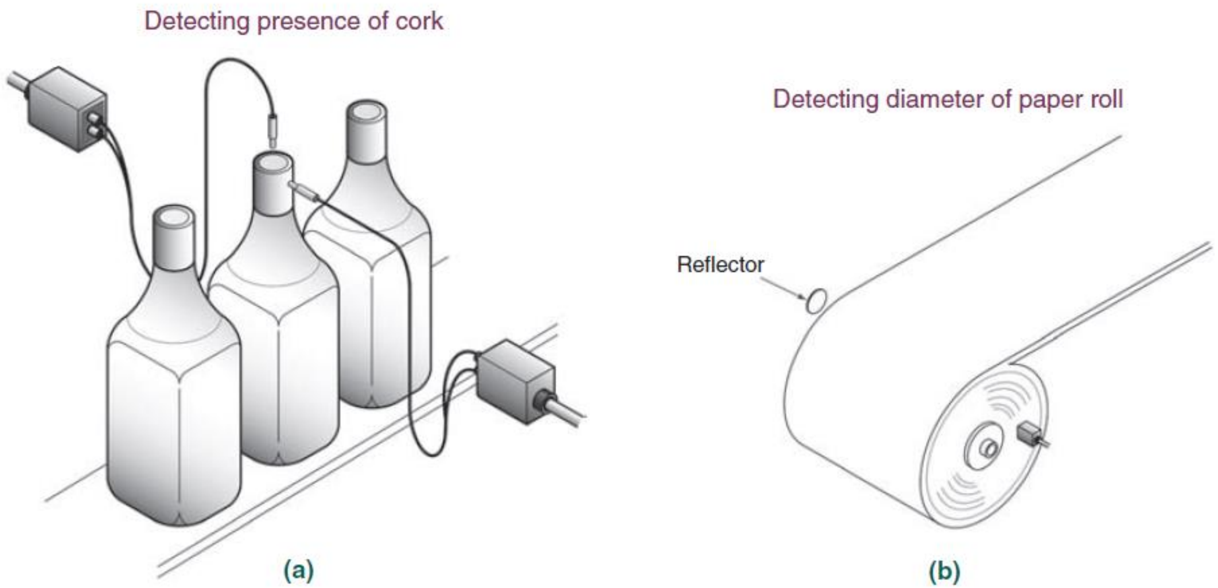
Ultrasonic
sensor for
liquid level
verification

(e)

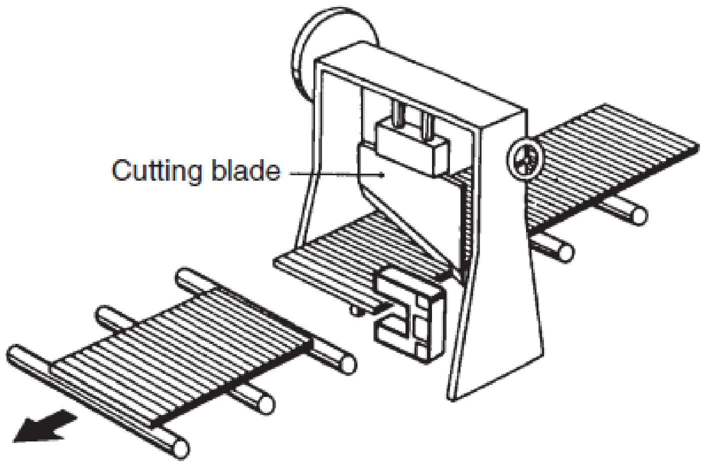
Photoelectric Sensing Modes Advantages and Cautions

Sensing Mode	Applications	Advantages	Cautions
Transmitted Beam	General purpose sensing Parts counting	• High margin for contaminated environments • Longest sensing distances • Not affected by second surface reflections • Probably most reliable when you have highly reflective objects	• More expensive because separate light source and receiver required, more costly wiring • Alignment important • Avoid detecting objects of clear material
Retroreflective	General purpose sensing	• Moderate sensing distances • Less expensive than transmitted beam because of simpler wiring • Ease of alignment	• Shorter sensing distance than transmitted beam • Less margin than transmitted beam • May detect reflections from shiny objects (use polarized instead)
Polarized Retroreflective	General purpose sensing of shiny objects	• Ignores first surface reflections • Uses visible red beam for ease of alignment	• Shorter sensing distance than standard retroreflective • May see second surface reflections
Standard Diffuse	Applications where both sides of the object cannot be accessed	• Access to both sides of the object not required • No reflector needed • Ease of alignment	• Can be difficult to apply if the background behind the object is sufficiently reflective and close to the object
Sharp Cutoff Diffuse	Short-range detection of objects with the need to ignore backgrounds that are close to the object	• Access to both sides of the object not required • Provides some protection against sensing of close backgrounds • Detects objects regardless of color within specified distance	• Only useful for very short distance sensing • Not used with backgrounds close to object
Background Suppression Diffuse	General purpose sensing Areas where you need to ignore backgrounds that are close to the object	• Access to both sides of the target not required • Ignores backgrounds beyond rated sensing distance regardless of reflectivity • Detects objects regardless of color at specified distance	• More expensive than other types of diffuse sensors • Limited maximum sensing distance
Fixed Focus Diffuse	Detection of small targets Detects objects at a specific distance from sensor Detection of color marks	• Accurate detection of small objects in a specific location	• Very short distance sensing • Not suitable for general purpose sensing • Object must be accurately positioned
Wide Angle Diffuse	Detection of objects not accurately positioned Detection of very fine threads over a broad area	• Good at ignoring background reflections • Detects objects that are not accurately positioned • No reflector needed	• Short distance sensing
Fiber Optics	Allows photoelectric sensing in areas where a sensor cannot be mounted because of size or environment considerations	• Glass fiber optic cables available for high ambient temperature applications • Shock and vibration resistant • Plastic fiber optic cables can be used in areas where continuous movement is required • Insert in limited space • Noise immunity • Corrosive areas placement	• More expensive than lensed sensors • Short distance sensing

Photoelectric sensor applications.

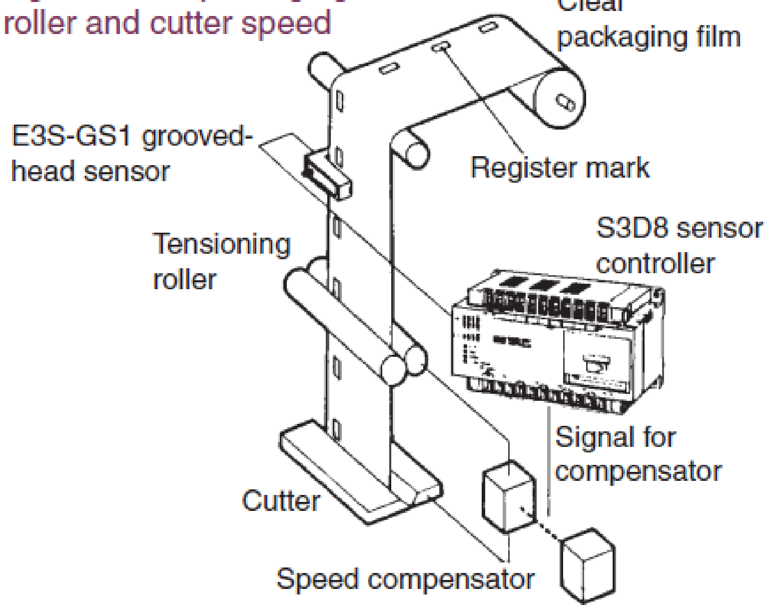


Detecting edge of material to activate cutter



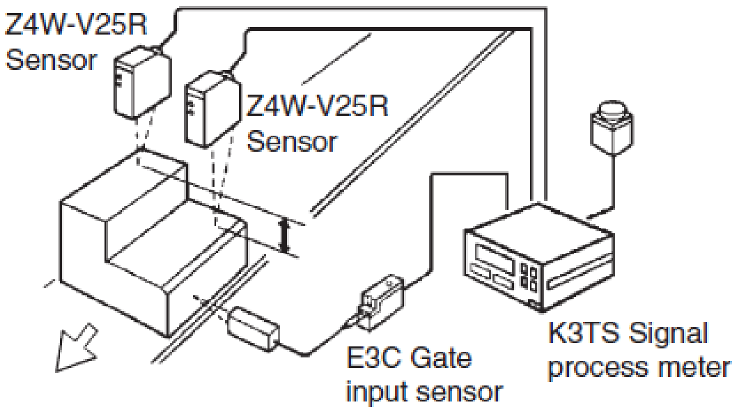
(c)

Detecting marks on packaging film to adjust roller and cutter speed



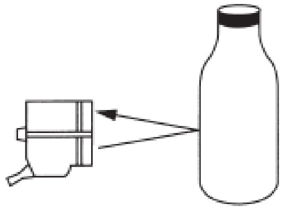
(d)

Measuring height difference



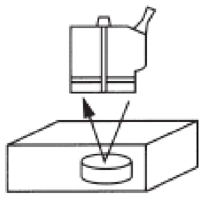
(e)

Sensing of transparent objects



Typical examples
(1) Sensing of transparent or translucent objects.
(2) Sensing of transparent greases, film, or plastic plates.
(3) Sensing of the liquid level.

Sensing of objects through a transparent cover

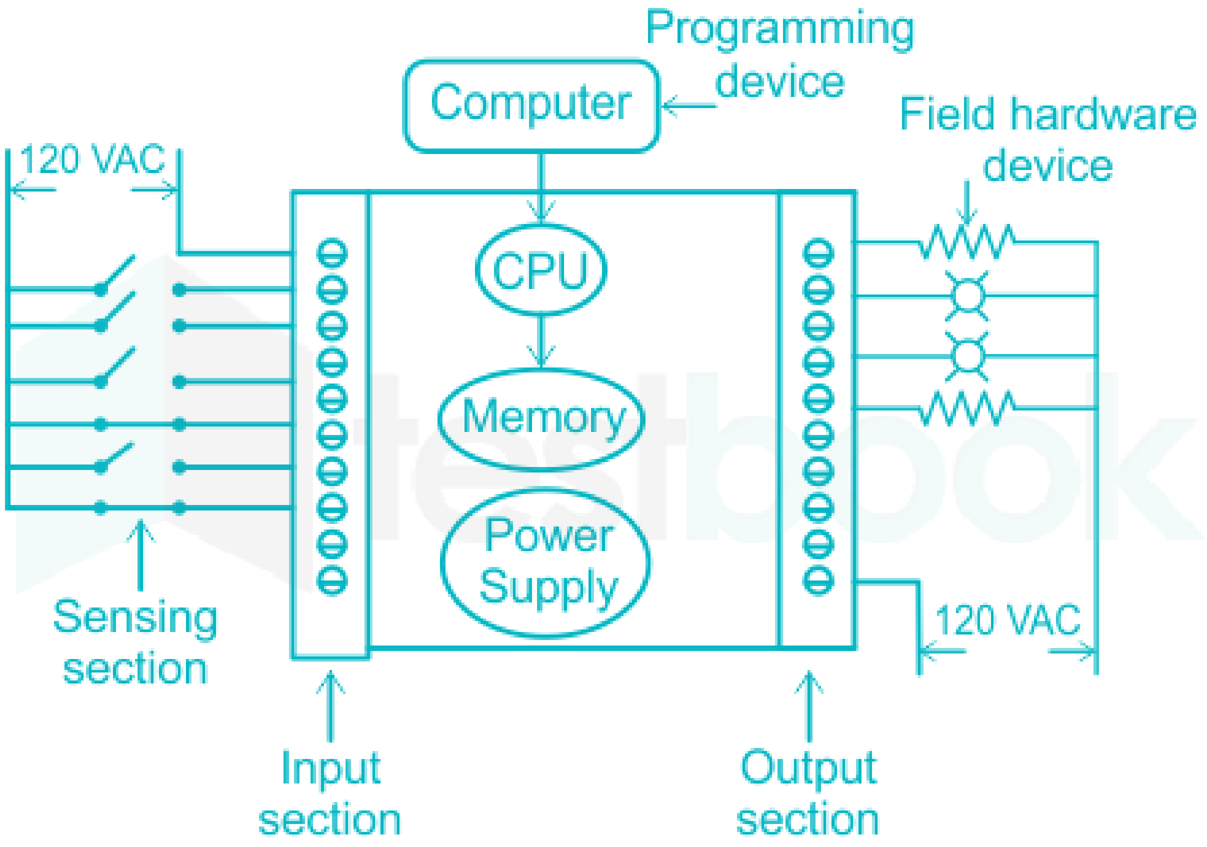


Typical examples
(1) Sensing of the contents in a transparent case.
(2) Sensing of the position of meter pointer.

(f)

INTERFACING INPUT FIELD DEVICES

- Interfacing input field devices to the PLC involves the physical connection of the device, the powering of the device, the sizing of the wiring to ensure adequate current carrying capability, and the routing of the wiring to minimize electrical interference and safety.

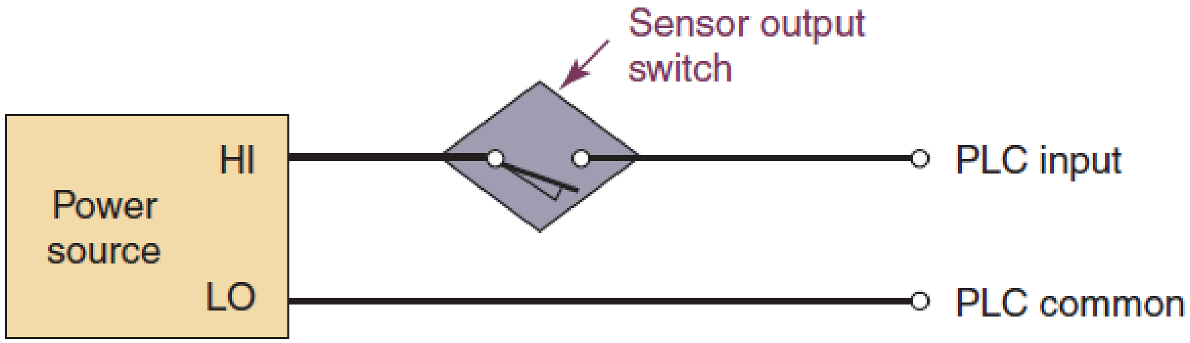


Powering Input Field Devices

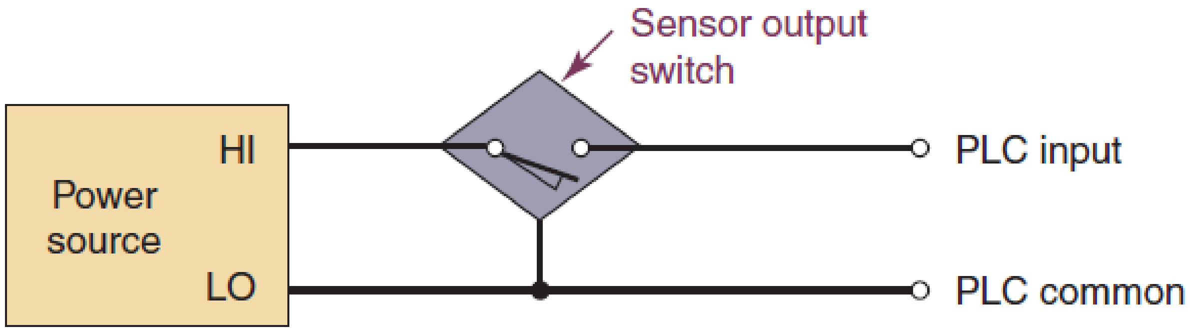
- Sensors typically have the following power voltage ratings: 10–30 VDC, 20–130 VAC, 90–250 VAC, and 20–250 VAC/DC.
- AC sensors power the load and sensor from the same power source, but most DC sensors require a separate DC supply that isolates the sensor electronics from the AC power line.

Two-wire and three-wire sensor outputs

Generally, the three-wire switch is only for electronic sensors that have an output wire plus two power wires.



(a) Two-wire sensor output

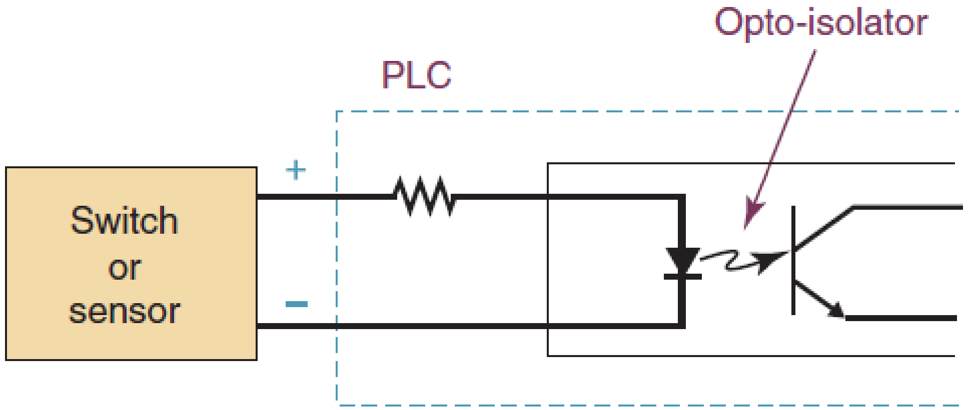


(b) Three-wire sensor output

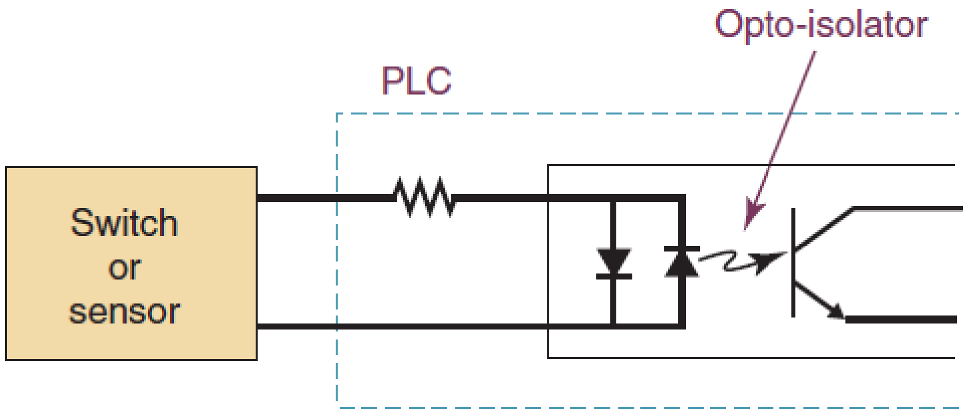
Input Wiring

- The PLC input is both a physical interface for the connection of wires and an electrical/data interface to determine the on/off state or level of the signal from the attached field device.
- Generally, the input circuitry signal conditions the input voltage before it's fed into an opto-isolator integrated circuit.
- The purpose of the opto-isolator is to isolate the incoming voltage and grounds from the rest of the PLC circuitry.

PLC opto-isolator inputs.

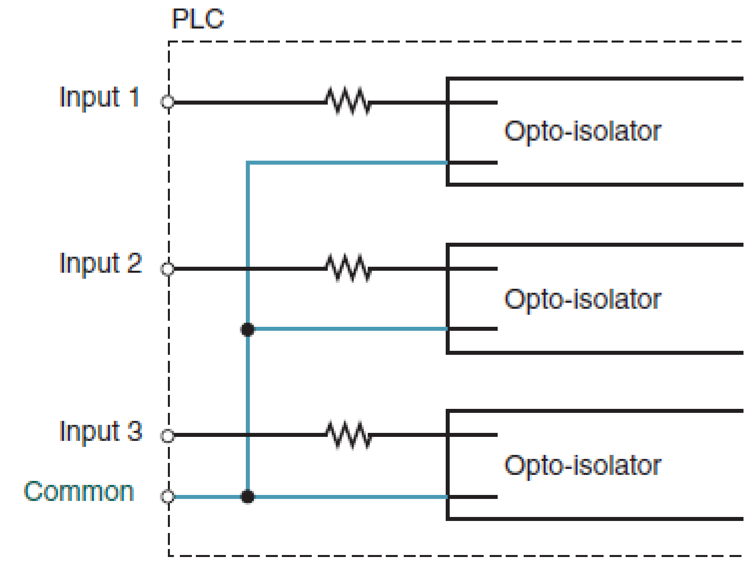


(a) PLC DC unit input

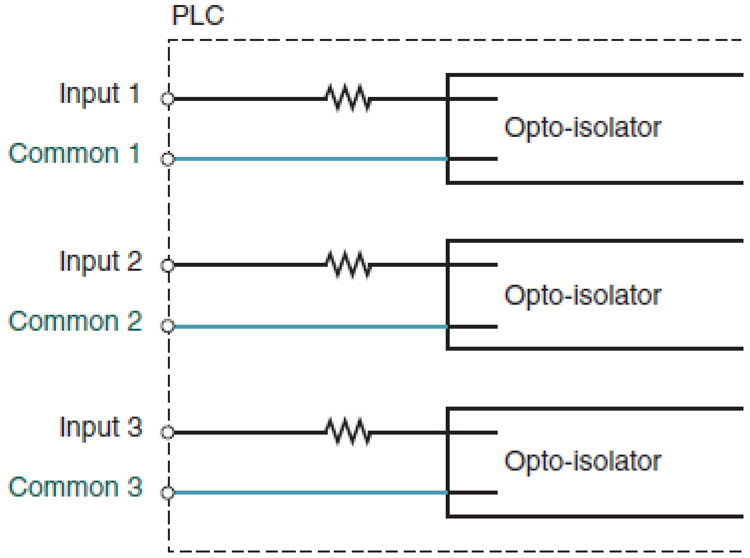


(b) PLC AC unit input

- The series resistor limits the current into the PLC input from the switch or sensor connected to the input.
- For the DC unit, the input polarity must be observed for the opto-isolator to turn on. For the AC unit, the opto-isolator will turn on with either polarity.
- This AC unit is typically designated as an AC/DC-type of PLC input module and is used for both AC and DC inputs because the input polarity does not matter.
- In general, a PLC input module has either all inputs isolated from each other with no common input connection or groups of inputs share a common connection.
- For example, inputs are grouped in fours, so every four inputs has a common ground.



(a) PLC inputs with one common terminal

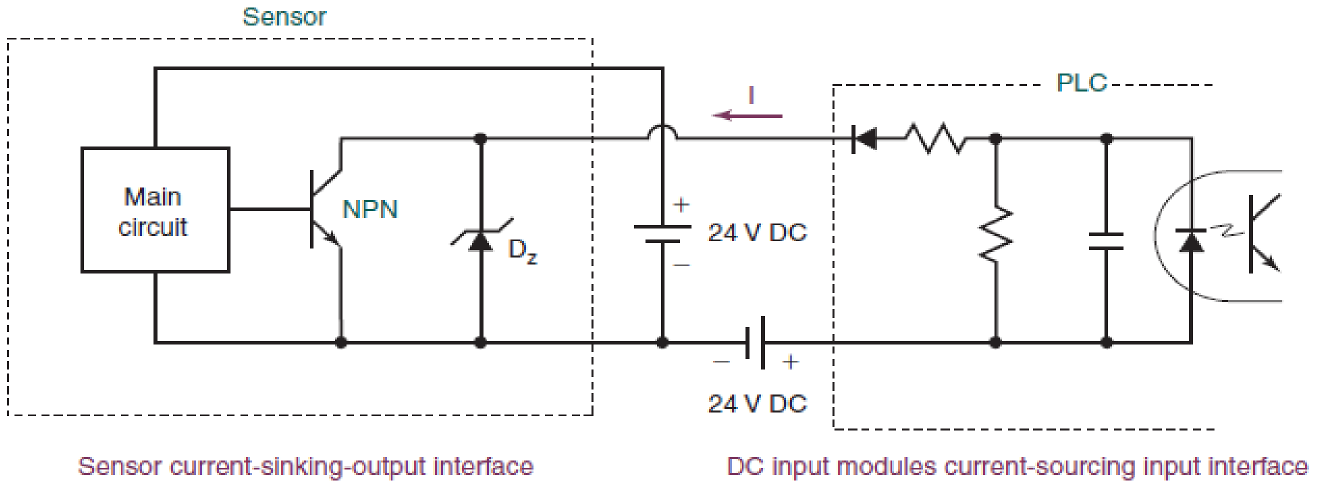


(b) PLC inputs with individual common terminal

Current Sinking and Current Sourcing Devices

- Current sinking sensors must be matched to current sourcing PLC inputs.
- Current sourcing sensors must be matched with current sinking PLC inputs.

Sensor and PLC input interface.



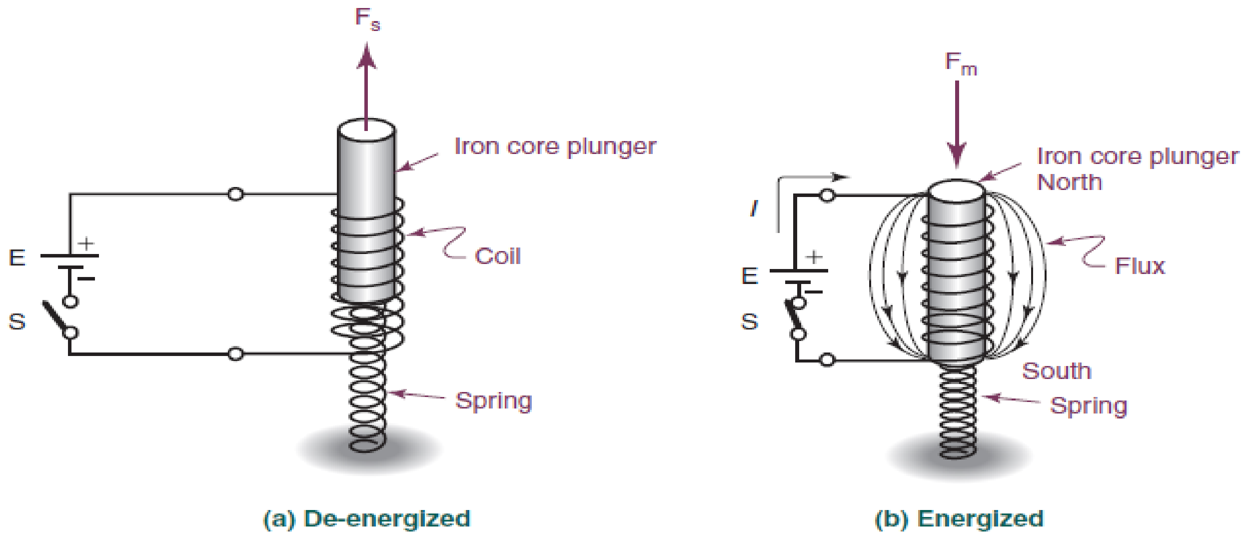
ELECTROMAGNETIC OUTPUT ACTUATORS

- An electromagnetic actuator is any device that contains a magnetic winding or coil that converts electrical energy into mechanical movement.
- The common types of these actuators driven by a PLC are solenoids, relays, contactors, and motor starters.

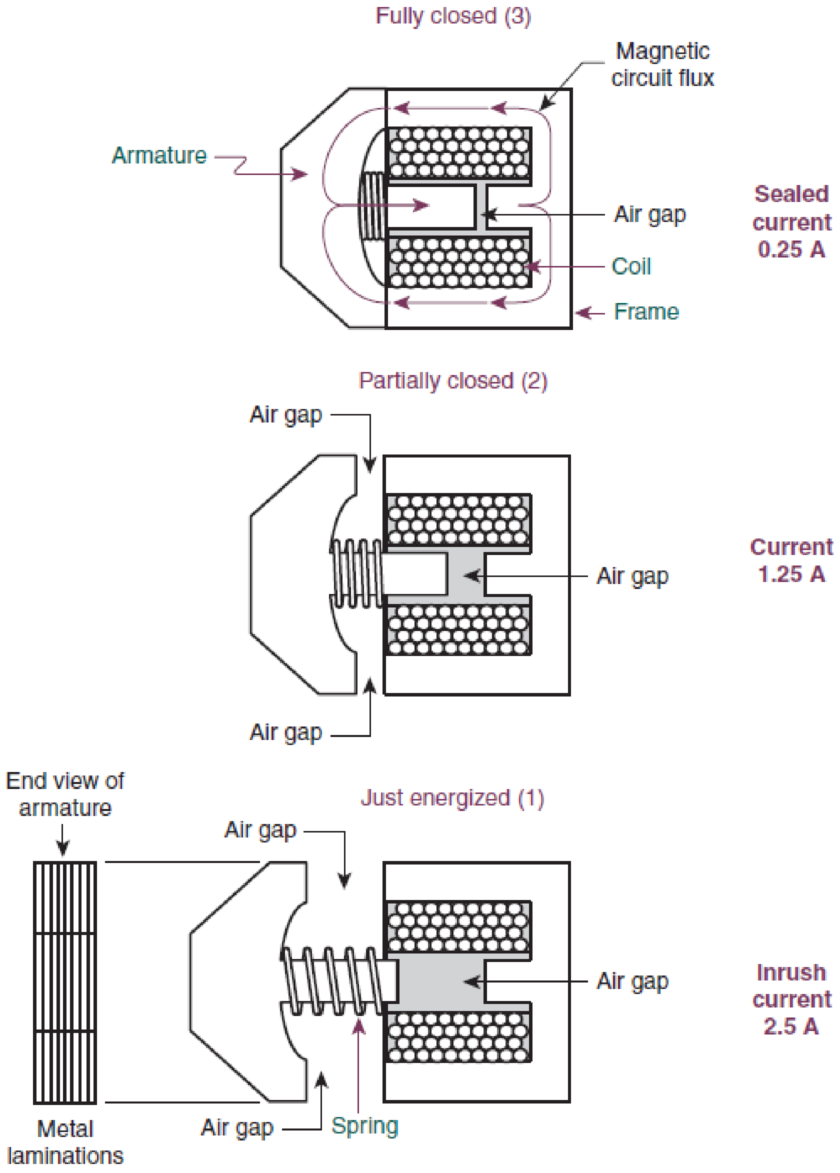
Solenoid-Controlled Devices

- Solenoids convert electrical energy directly into linear mechanical motion

Basic solenoid.



AC solenoid.



(a) Solenoid operation

(b) Solenoid symbol

Control Relays

- Control relays are remotely operated switches that are one of the oldest control devices still in common use.
- They are the combination of electromagnets and solenoids with switch contact configurations.
- Relays have two primary functions:

1. Control of a large current and/or voltage with a small electrical signal
2. Isolation of the power used to control the action from the power that must be switched to cause some action

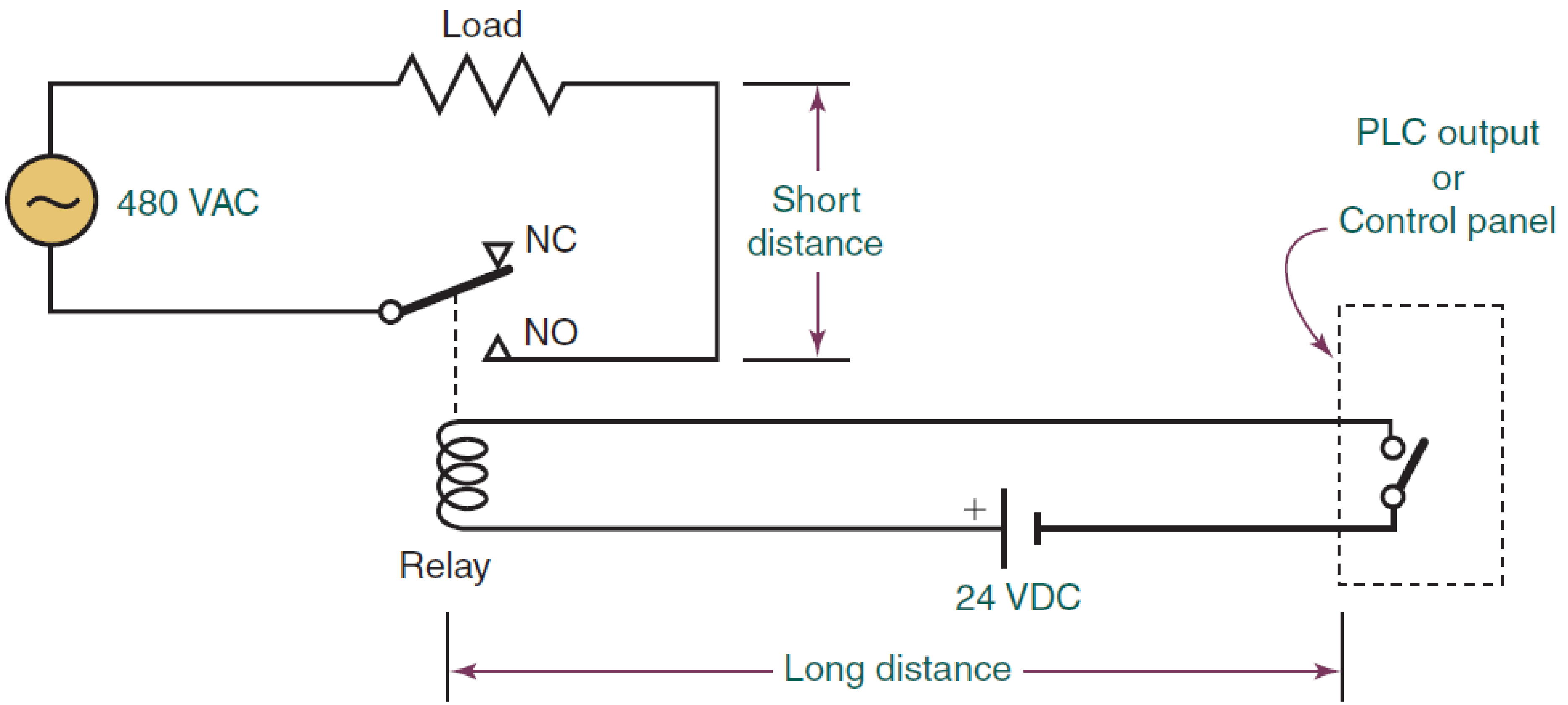
- Usually relay coil currents are typical well below 1 amp, whereas contact ratings for industrial relays are at least 10 amps.
- Relay Contact Ratings-
- **Rated voltage:** the suggested operation voltage for the coil.
- **Rated current:** the maximum current before contact damage, such as welding or melting, occurs.

Contact Ratings

AC Ratings								DC Ratings			
Volts	Inductive 35% Power Factor						Resistive 75% Power Factor	Volts	Inductive		
	UL Rating	Make		Break		Cont. Amps	Make, Break & Cont. Amps		UL Rating	Make & ▲ Break Amps	Cont. Amps
		Amps	VA	Amps	VA						
120	A600	60	7200	6	720	10	10	125	Q600	0.55	2.5
240		30	7200	3	720	10	10	250		0.27	2.5
480		15	7200	1.5	720	10	10	600		0.10	2.5
600		12	7200	1.2	720	10	10				

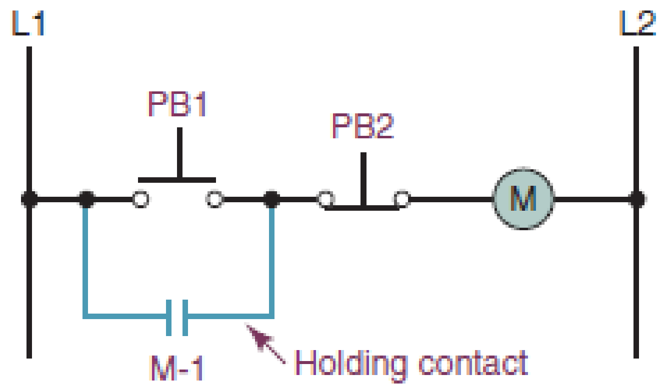
▲ 69 VA maximum up to 300 volts.

Relay control circuit.



Latching Relays

The latching relay is a relay whose contacts remain open and/or closed even after power has been removed from the coil



Contactors

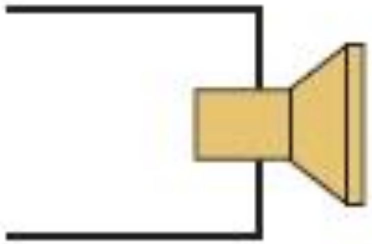
- Contactors are relays designed to switch large currents from large voltage sources.
- Contactors have multiple contacts so that both lines of a single-phase source and all three lines of a three-phase source can be switched.
- In addition to the contacts used to switch the primary voltage, there are usually one or more contacts, called auxiliary contacts, for use in the contactor control circuit.
- These auxiliary contacts are often limited to 120 VAC and may be either normally open or normally closed.

VISUAL AND AUDIO OUTPUT DEVICES

- In addition to driving output actuators, the PLC turns on various visual and audio devices to indicate a specific condition and/or warning.
- Pilot Lamps- Industrial grade lamps used in control panels and machine front panels to indicate events and conditions in the system.
- Lamp voltages include 6.3, 28, and 120 volts.
- Lens cap color options include clear, red, green, amber, and yellow.

Horns and Alarms

- Input voltages typically fall within the ranges of 10 to 24 VDC or 24 to 240 VAC.



Symbol

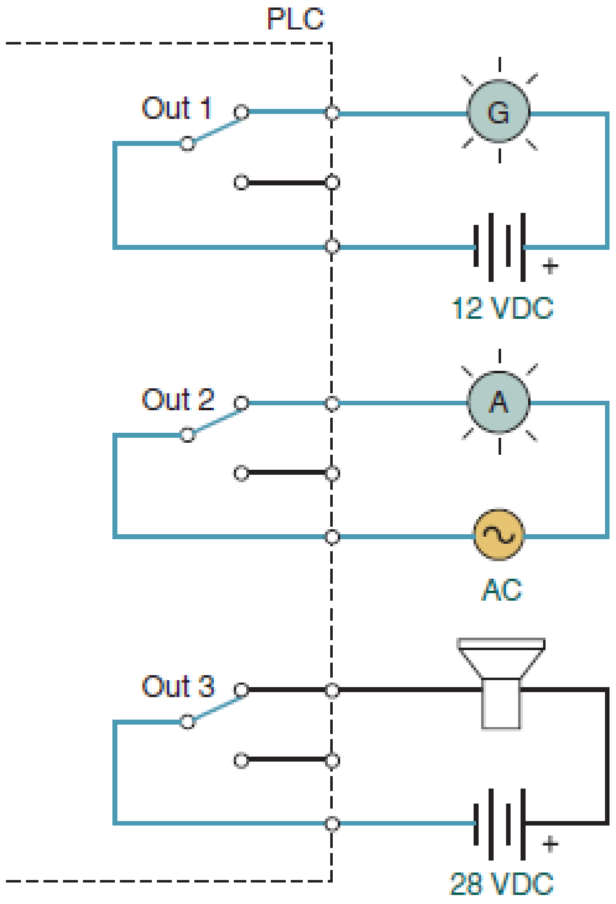
INTERFACING OUTPUT FIELD DEVICES

- Interfacing output devices to a PLC generally involves a PLC output module with either a relay or a solid-state output to which the field device is attached.
- Relay outputs are used for high current requirements in the one- to two-ampere range or for power isolation, whereas solid-state outputs are used to control low-power DC circuitry with transistors or low-power AC circuitry with triacs.
- As with the interface to PLC inputs, PLC outputs are available with a common terminal or totally isolated.

Output Wiring

- Using the PLC relay outputs involves wiring to relays that share a common terminal or connecting to relays that are totally isolated.

FIGURE 57: PLC relay outputs with isolated common terminals.



Note: Out1, Out2, and Out3 are relay contacts

FIGURE 58: PLC current sinking and current sourcing outputs.

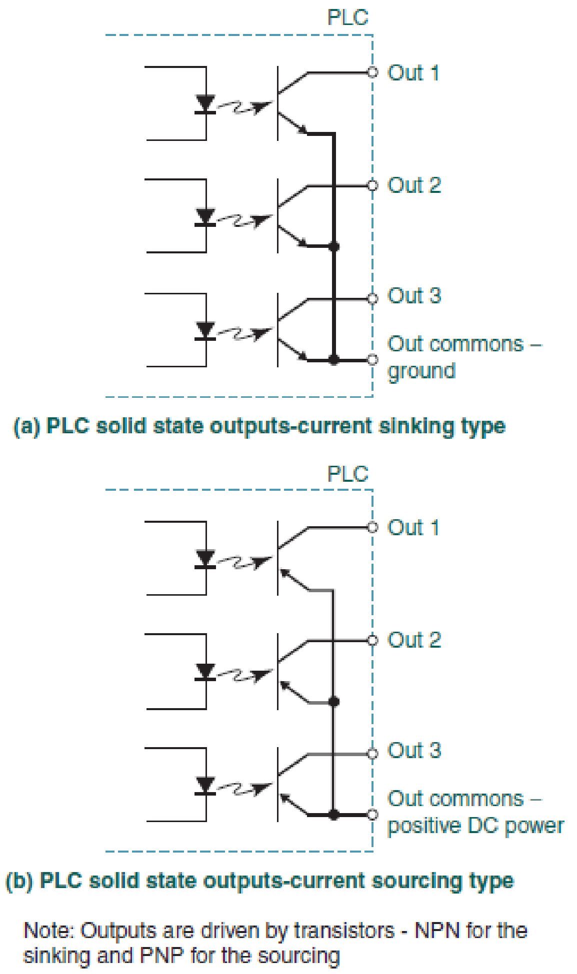
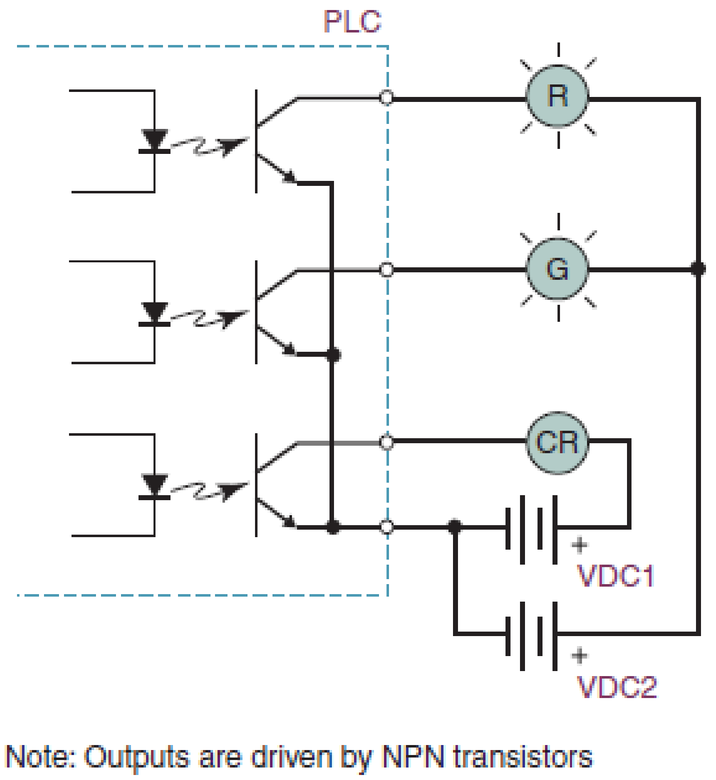


FIGURE 59: Field devices connected to PLC outputs.



- The PLC solid-state outputs are for the most part driven by transistors or logic elements and generally share a common terminal, although triac outputs to switch AC loads are available in the totally isolated configuration.
- As with the transistor PLC input, the transistor PLC output is either current sinking or current sourcing.