MODULE 6

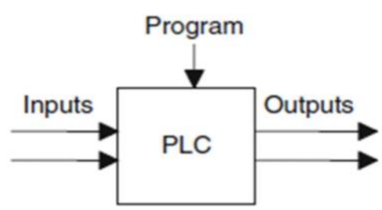
PROGRAMMABLE LOGIC CONTROLLERS (PLC)

SYLLABUS

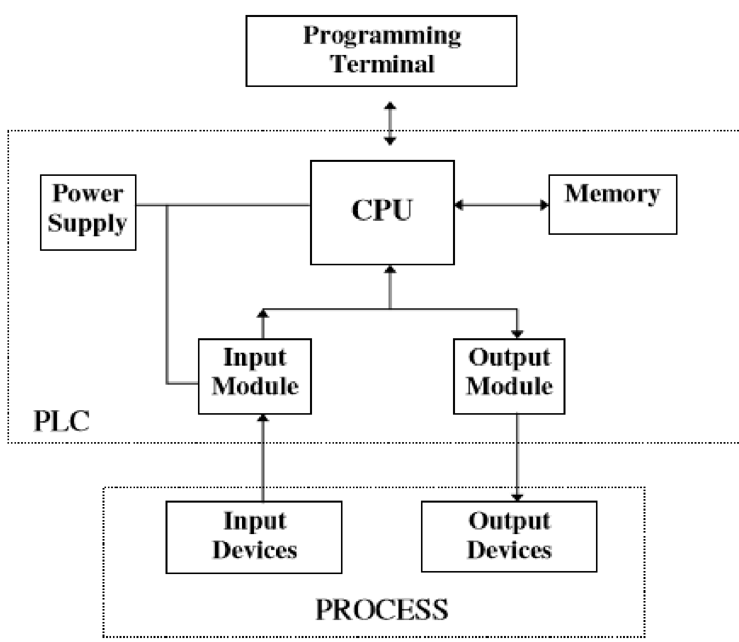
- Introduction to Sequence Control, PLCs - Working, Specifications of PLC Onboard/Inline/Remote IO’s, Comparison of PLC & PC,
- Relay Ladder Logic-
- PLC Programming- realization of AND, OR logic, concept of latching,
- Introduction to Timer/Counters, Exercises based on Timers, Counters. Basic concepts of SCADA, DCS and CNC

A programmable logic controller (PLC) or programmable controller is an industrial digital computer which has been ruggedized and adapted for the control of manufacturing processes, such as assembly lines, or robotic devices, or any activity that requires high reliability control and ease of programming and process fault diagnosis.

PLCs were first developed in the automobile manufacturing industry to provide flexible, ruggedized and easily programmable controllers to replace hard-wired relays, timers and sequencers. Since then, they have been widely adopted as high-reliability automation controllers suitable for harsh environments. A PLC is an example of a "hard" real-time system since output results must be produced in response to input conditions within a limited time, otherwise unintended operation will result



PLC architecture



It consists of a central processing unit (CPU) containing the system microprocessor, memory, and input/output circuitry. The CPU controls and processes all the operations within the PLC.It is supplied with a clock that has a frequency of typically between 1 and 8 MHz. This frequency determines the operating speed of the PLC and provides the timing and synchronization for all elements in the system. The information within the PLC is carried by means of digital signals. The internal paths along which digital signals flow are called buses. In the physical sense, a bus is just a number of conductors along which electrical signals can flow. It might be tracks on a printed circuit board or wires in a ribbon cable. The CPU uses the data bus for sending data between the constituent elements, the address bus to send the addresses of locations for accessing stored data, and the control bus for signals relating to internal control actions. The system bus is used for communications between the input/output ports and the input/output unit.

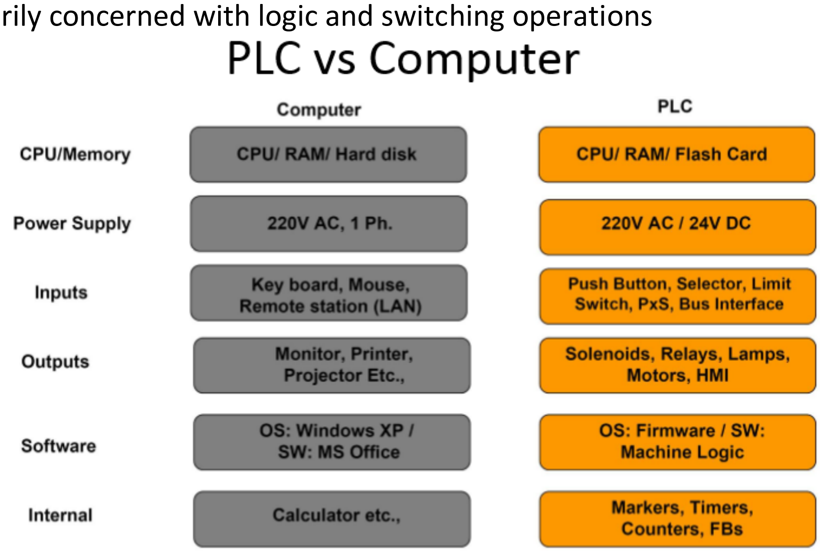
The operator enters a sequence of instructions (a program) into the memory of the PLC. The controller monitors the inputs carries out the control rules .The control loop is a continuous cycle of the PLC reading inputs, solving the logic instructions, and then changing the outputs.

Advantages

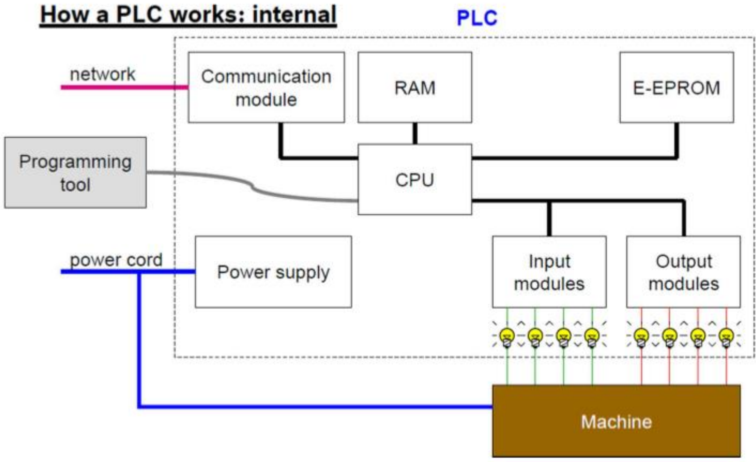
- The same basic controller can be used with a wide range of control systems.
- To modify a control system, the rules are to be modified (much easier to program and reprogram)
- There is no need to rewire
- The result is a flexible, cost-effective system

Comparison of PLC & PC

- PLCs are similar to computers, but computers are optimized for calculation and display tasks
- PLCs are optimized for control tasks and the industrial environment.
- PLCs: – Are rugged and designed to withstand vibrations, temperature, humidity, and noise –
- Have interfacing for inputs and outputs, already inside the controller –
- Are easily programmed and have an easily understood programming language – Primarily concerned with logic and switching operations



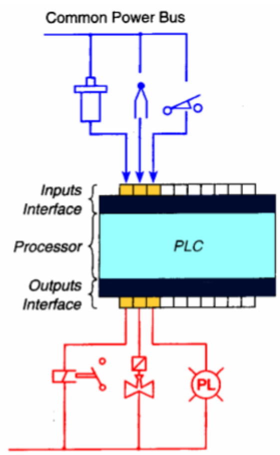
How a PLC works: internal



I/O Configurations

Fixed I/O

- Is typical of small PLCs
- Comes in one package, with no separate removable units.
- The processor and I/O are packaged together.
- Lower in cost – but lacks flexibility.

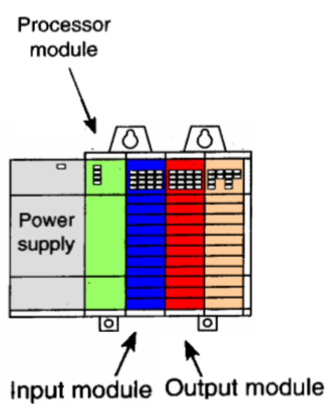


I/O Configurations

Modular I/O

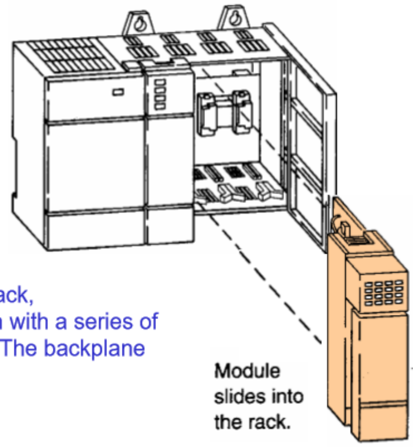
Is divided by compartments into which separate modules can be plugged.

This feature greatly increases your options and the unit's flexibility. You can choose from all the modules available and mix them in any way you desire.



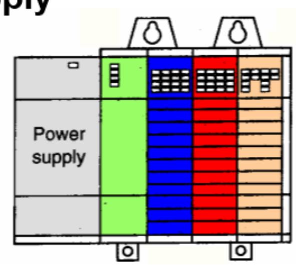
I/O Configurations

Modular I/O



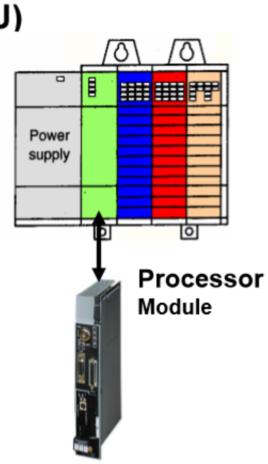
When a module slides into the rack, it makes an electrical connection with a series of contacts - called the *backplane*. The backplane is located at the rear of the rack.

Power Supply



- Supplies DC power to other modules that plug into the rack.
- In large PLC systems, this power supply does not normally supply power to the field devices.
- In small and micro PLC systems, the power supply is also used to power field devices.

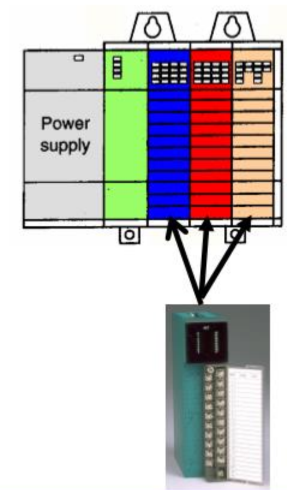
Processor (CPU)



- Is the “brain” of the PLC.
- Consists of a microprocessor for implementing the logic, and controlling the communications among the modules.
- Designed so the desired circuit can be entered in relay ladder logic form.
- The processor accepts input data from various sensing devices, executes the stored user program, and sends appropriate output commands to control devices.

I/O Section

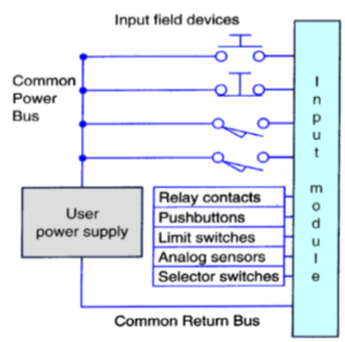
Consists of:
- Input modules
- Output modules.



I/O Section

Input Module

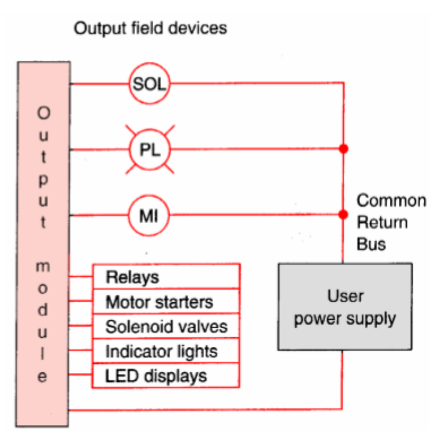
- Forms the interface by which input field devices are connected to the controller.
- The terms "field" and "real world" are used to distinguish actual external devices that exist and must be physically wired into the system.

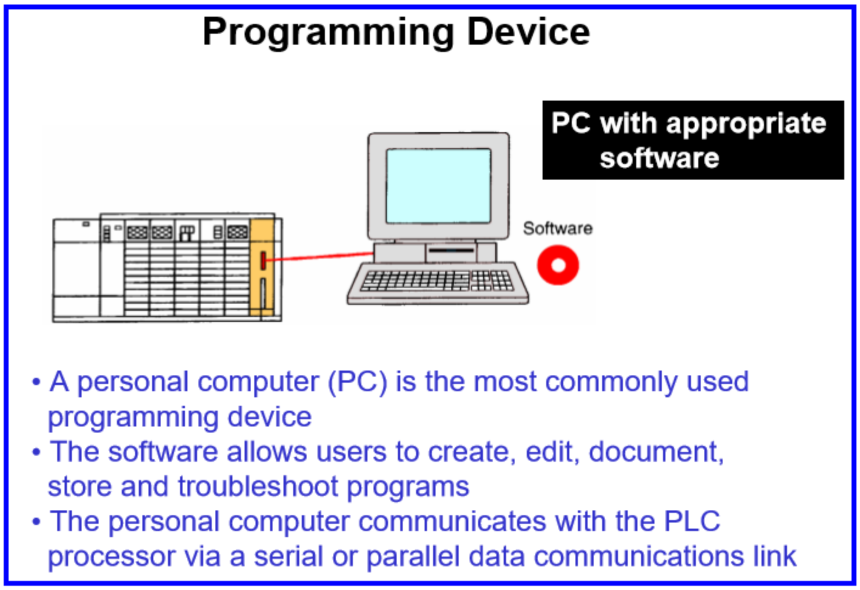


I/O Section

Output Module

- Forms the interface by which output field devices are connected to the controller.
- PLCs employ an optical isolator which uses light to electrically isolate the internal components from the input and output terminals.





Specifications of PLC Input Output Modules

1. Input modules convert process level signals from sensors
2. Output modules may be used to drive actuators

Typical Parameters for an Analog Input Module

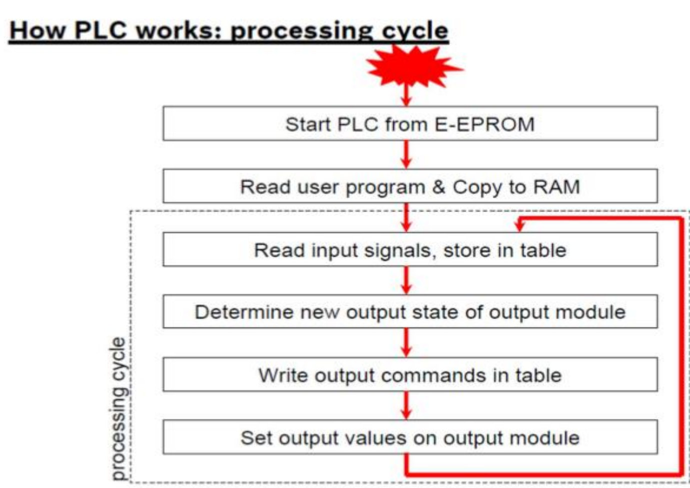
Module Parameter	Type/Number/Typical Value
Number of input	8/16 voltage/current/Pt 100/ RTD
Galvanic isolation	Yes /No
Input ranges	±50 mV to ±10 V; ±20 mA; Pt 100
Input impedance for various ranges (ohm)	±50mV: > 10 M ; ±10 V: > 50k; ±20 mA : 25; Pt 100 : > 10 M
Types of sensor connections	2-wire connection; 4-wire connection for Pt 100
Data format Conversion principle Conversion time	11 bits plus sign or 12 bit 2's complement Integrating /successive approximation In ms (integrating) , µs (successive approx.)

Typical Parameters for an Analog Output Module

Number of outputs	8 voltage and current output
Galvanic isolation	yes
Output ranges (rated values)	**± 10 V; 0…20 mA**
Load resistance - for voltage outputs min. - for current outputs max.	 3.3 k 300
Digital representation of the signal	11 bits plus sign
Conversion time	In µs
Short-circuit protection	yes
Short-circuit current approx.	25 mA (for a voltage output)
Open-circuit voltage approx.	18 V (for a current output)
Linearity in the rated range	±0.25% + 2 LSB
Cable length max.	200 m

Sequential control

- Sequential problems have long been solved using conventional logic gates as building blocks, but using certain techniques to express and identify the sequence logic equations that control the system outputs
- The software design procedure is as follows:
    - The process is verbally described
    - This description is translated into a function diagram
    - The conditions are identified and converted into Boolean equations
    - The Boolean equations are converted into ladder logic for the PLC



RELAY LOGIC

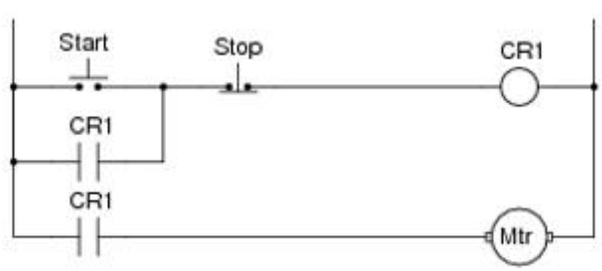
- Relays are the most popular components of the PLC hardware
- Relays are used as outputs in the ladder diagram
- They can be used to control ON/OFF actuation of powered device
- A relay can be latching or non latching
- A latching relay needs an electrical impulse to close the power circuit. Another impulse is needed to release the latch
- Non latching relays hold only while the switching relay is energized and require continuous electrical signal

Relay logic is a method of implementing combinational logic in electrical control circuits by using several electrical relays wired in a particular configuration.The schematic diagrams for relay logic circuits are often called line diagrams, A relay logic circuit is an electrical network consisting of lines, or rungs, in which each line or rung must have continuity to enable the output device. A typical circuit consists of a number of rungs, with each rung controlling an output. This output is controlled by a combination of input or output conditions, such as input switches and control relays. Relay logic diagrams represent the physical interconnection of devices.

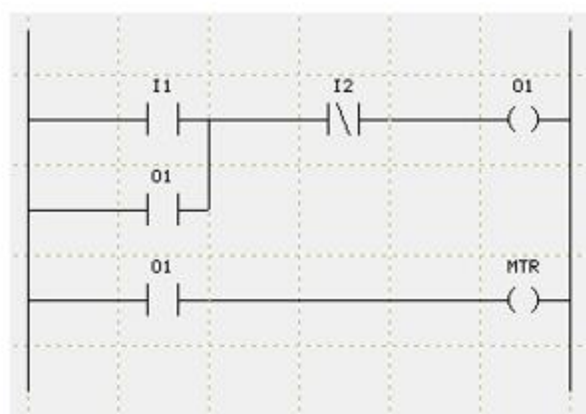
Main Elements of ladder logic

1. Rails- These are vertical lines and provide the sources of energy to relays and logic system
2. Rungs- These are horizontal and contains the branches ,inputs and outputs
3. Branches
4. Inputs
5. Outputs
6. Timer
7. Counter

Motor Control PLC Ladder Logic



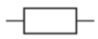
Motor Control Relay Logic

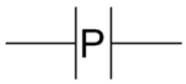


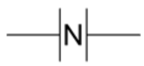
Symbol format in Ladder logic

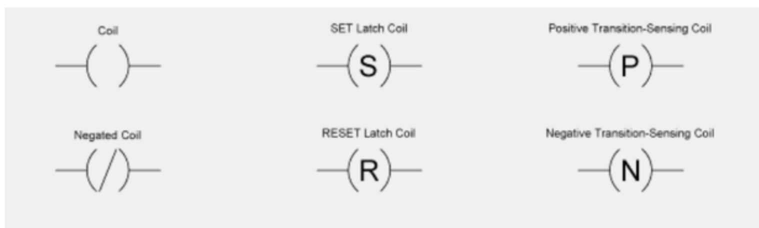

Normally open contact(Switches, Relay etc.)


Normally closed contact


Special Instruction


Positive Transition-Sensing Contact


Negative Transition-Sensing Contact

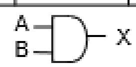


PLC INSTRUCTION CODE

INSTRUCTION CODE	DESCRIPTION
LD	Start a rung with an open contact
LDI	Start a rung with closed contact
AND	A series element with an open contact
ANI	A series element with a closed contact
ANB	Branch two blocks in series
OR	A parallel element with an open contact
ORI	A parallel element with closed contact
ORB	Branch two blocks in parallel
OUT	An output

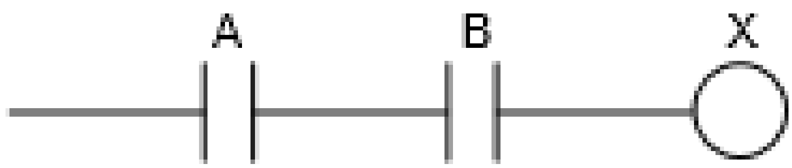
PLC Programming- realization of AND, OR logic

AND		
Input A	Input B	Out X
0	0	0
0	1	0
1	0	0
1	1	1



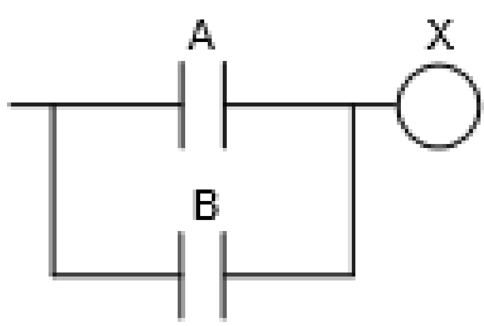
$$A \cdot B = X$$

LD A
AND B
OUT X



OR		
Input A	Input B	Out X
0	0	0
0	1	1
1	0	1
1	1	1

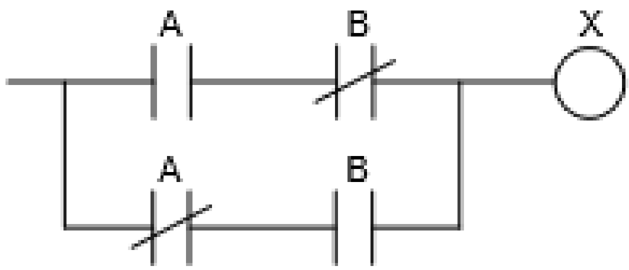
$$A + B = X$$



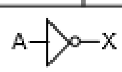
LD A
OR B
OUT X

XOR		
Input A	Input B	Out X
0	0	0
0	1	1
1	0	1
1	1	0

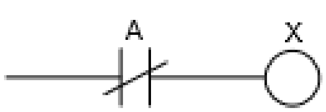
$$(A \cdot \overline{B}) + (\overline{A} \cdot B) = X$$



NOT	
Input A	Out X
0	1
1	0

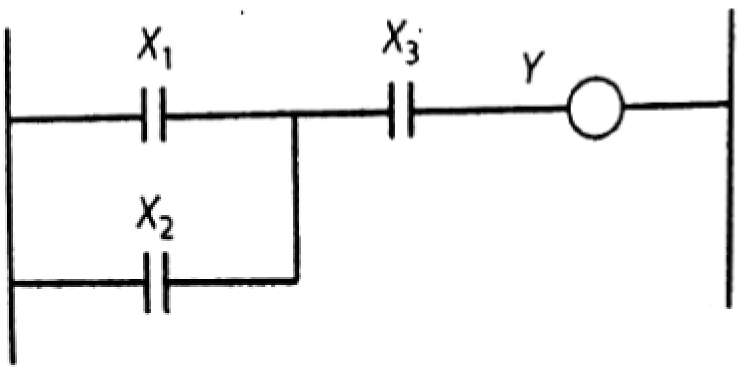


$$\overline{A} = X$$

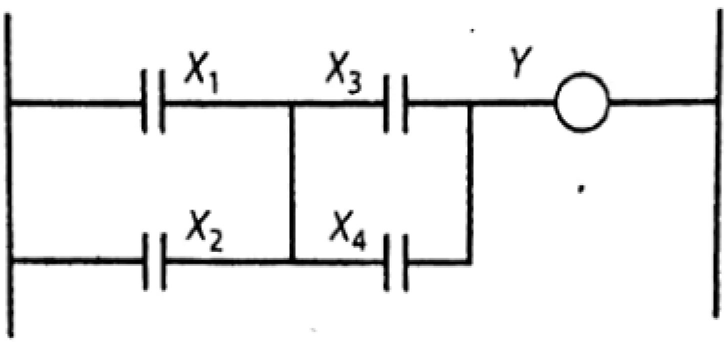


Draw ladder diagram for the equations given below

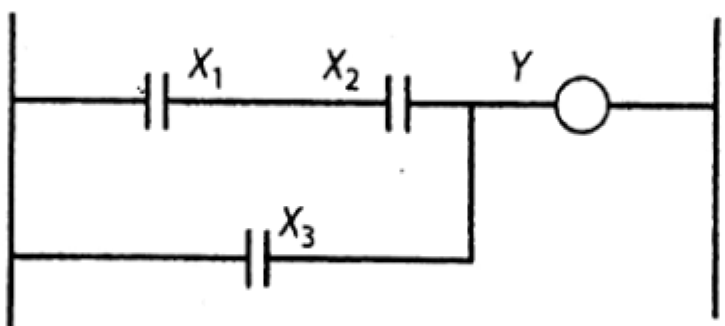
Y=(X1+X2)X3



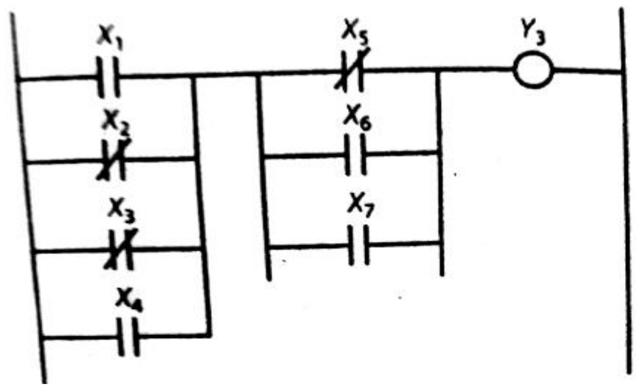
Y=(X1+X2)(X3+X4)



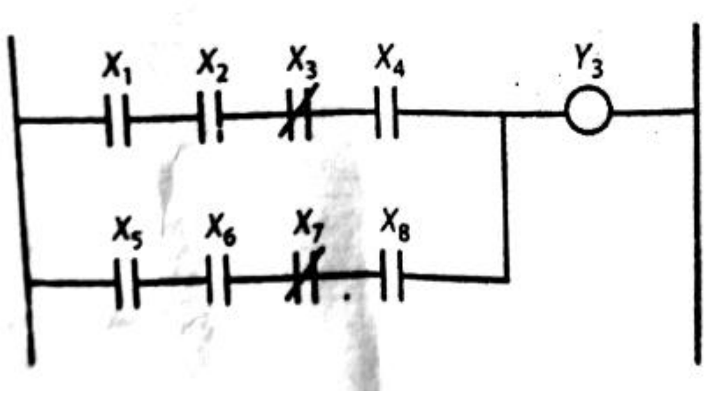
Y=(X1X2)+X3



Write PLC program for the given ladder diagram

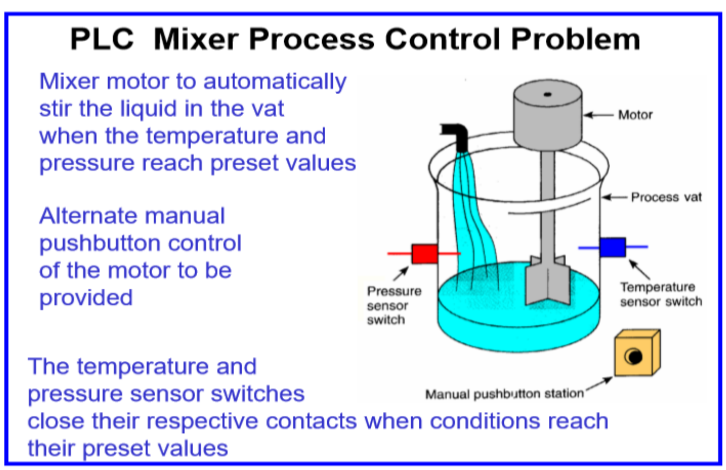


LD X1
ORI X2
ORI X3
OR X4
LDI X5
OR X6
OR X7
ANB
OUT Y3

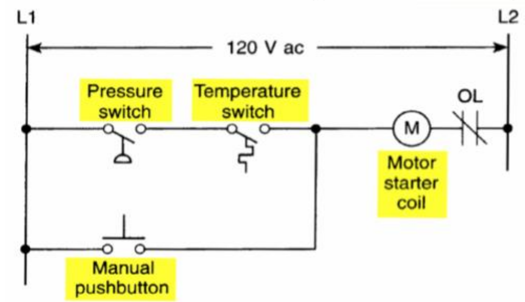


LD X1
AND X2
ANI X3
AND X4
LD X5
AND X6
ANI X7
AND X8
ORB
OUT Y3

Example of PLC program to automatically stir the liquid in the vat



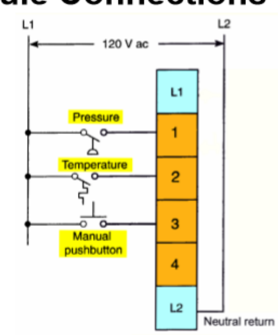
Process Control Relay Ladder Diagram



Motor starter coil is energized when both the pressure and temperature switches are closed or when the manual pushbutton is pressed

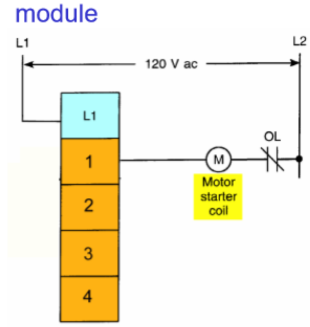
PLC Input Module Connections

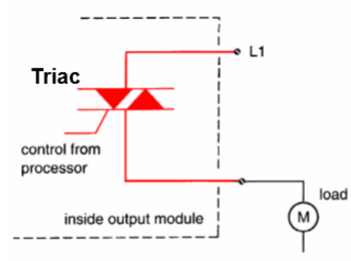
- The same input field devices are used
- These devices are wired to the input module according to the manufacturer's labeling scheme



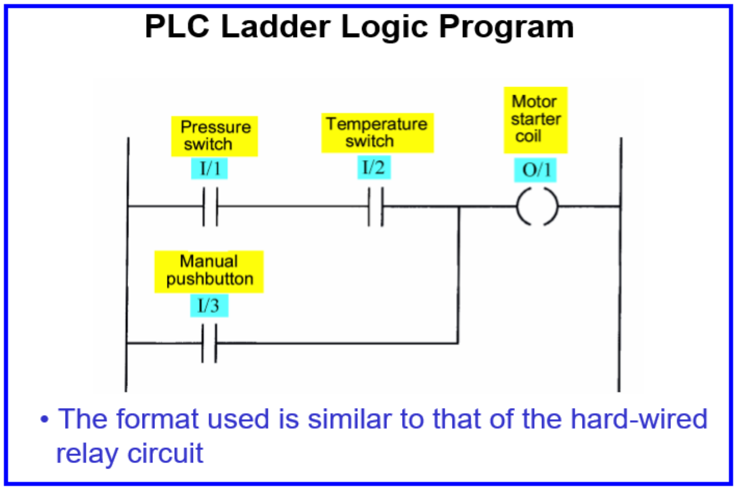
PLC Output Module Connections

Same output field device is used and wired to the output module





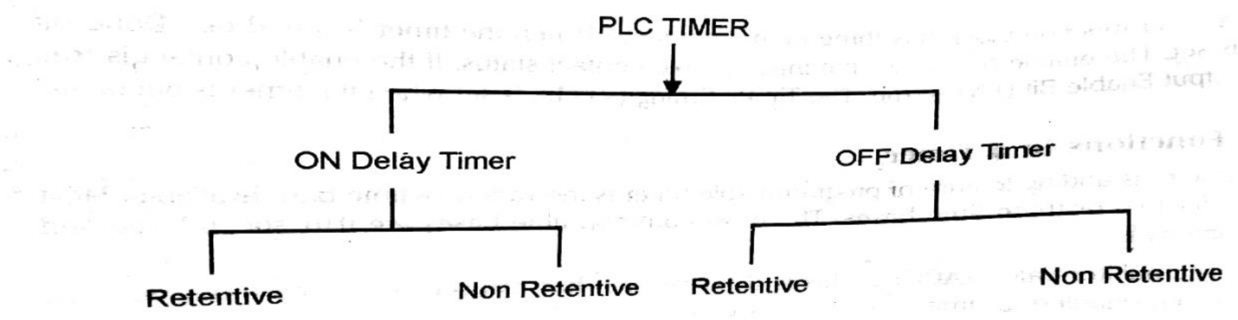
Triac switches motor ON and OFF in accordance with the control signal from the processor



TIMERS AND COUNTERS

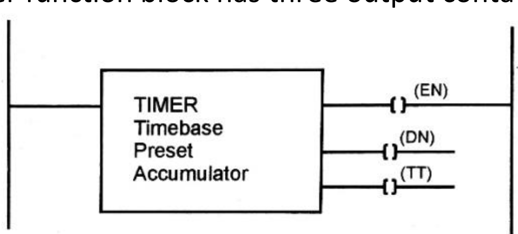
A timer is device that introduce a time delay in a circuit or system during its ON or OFF condition.PLC timer, the time delay is introduced by programming

Classification of timers



Schematic diagram of a function block PLC timer.

- The contacts on the left side of the timer function block are the timer enable contacts
- When they are closed, power passes to the left terminal of the timer, its clock is enabled and it starts timing.
- When they are open, power stops flowing through this terminal, and the timer stops functioning
- A timer function block has three output contacts.



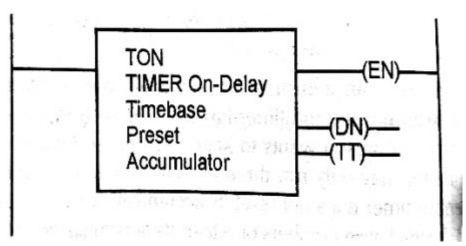
- When the timer is timed out, DONE BIT(DN) is set.
- The ENABLE BIT follows the input enable contact status.
- If the enable contact is true then output ENABLE BIT(EN) is true.
- The timer timing(TT) bit is set when the timer is operating

Functions in TIMER

1. Variety of time base is available
2. The most common time bases are 0.01 sec, 0.1 sec and 1 sec
3. Accumulator value(ACC)- This is the time that has elapsed, since the timer was last reset.
4. When enabled, a timer updates this continuously
5. Preset Value(PRF)- This specifies the value that the timer must reach before the controller sets the done bit
6. The programmer determines the preset time.
7. When the accumulator value becomes equal to or greater than the preset value, the timer stops operating and the done bit is set
8. This bit can be used to control an output device

TIMER ON DELAY

The instruction is used to delay turning an output ON or OFF. The TON instruction begins to count time base intervals when the rung condition become true. As long as the rung condition remains true the time increments its accumulator value, over each scan until reaches the preset value. The accumulator value is reset when the rung condition becomes false, regardless of whether the timer has timed out



FUNCTIONS OF AN **ON** DELAY TIMER

Output bit	Is set when	Remains set until use of the following
Timer Done Bit (DN)	Accumulator value is normally greater than the preset value.	Rung condition becomes false.
Timer Enable Bit (EN)	Rung conditions are true.	Rung conditions become false.
Timer Timing Bit (TT)	Rung conditions are true and the all values are less than the PRESET value.	Rung conditions become false or when the done bit is set.

TIMER OFF DELAY

The TOFF instruction begins t count time base intervals when the rung condition makes a true to false transition. As long as the rung condition remains false the timer increments its accumulator vale over each scan until it reaches the preset value. The controller resets the accumulated value when the rung conditions becomes true regardless of whether the timer has timed out

FUNCTIONS OF AN **OFF** DELAY TIMER

Output bit	Is set when	And remaining set until one of the following
DN	Rung conditions are true.	Rung condition becomes false and the accumulator value is greater than or equal to the preset value.
TT	Rung conditions are false and the accumulator value is less than the preset value.	Rung conditions become true or when the done bit is set.
EN	Rung conditions are true.	Rung conditions become false.

RETENTIVE AND NON RETENTIVE TIMERS

Retentive refers to the device's ability to remember its exact status such that when the circuit is again activated, the timer continues from the previous point. RTO - Retentive Timer. Counts time base intervals when the instruction is true and retains the accumulated value when the instruction goes false or when power cycle occurs. The Retentive Timer instruction is a retentive instruction that begins to count time base intervals when rung conditions become true.Non-retentive timers reset to zero and start from zero each time the timer function block is energized.

FUNCTION BLOCK

	15	14	13	12	11	10	9	8	7 … 0
Word 0	EN	TT	DN						Internal bit
Word 1	Preset value (PRE)								
Word 2	Accumulator value (ACC)								

EN, TT, DN are bit storage. EN is stored in bit 15 Word '0', TT is bit 14 and DN is bit of Word 0. 0-7 bits of Word 0 are the internal bits. Each preset value (PRE) and accumula value (ACC) are 16 bit Words stored in Word 1 and Word 2 of the timer file.

EN- timer enable bit

TT- Timer timing bit

DN-Timer done bit

Each timer address is made up of a 3 word element

Word 0 is the control word

Word 1 stores preset value and word 2 stores accumulated value

COUNTERS

Counters are used to count the number of items produced, and the number of operations performed.PLC counter utilizes a sensor t count operations, which is processed by software execution in the PLC. Thus the failure rate is reduced and the accuracy level is increased in a PLC counter.he major difference between the counter and the timer is that timer instructions will continually increment its accumulative value at a rate determined by the time base when the enable contact is on. Counter must see a complete contact transition from 0 to 1 each time it increments the accumulative value.This means that the contact must returns to its zero state before it can have a transition for a second time.

COUNTER PARAMETERS

1. **Accumulative value(ACC)-**number of false to true transitions that have occurred since the counter was last reset
2. **Preset value(PRE)-** Specifies the value that the counter must reach, before the controller sets the done bit. When the accumulator value becomes equal to or greater than the preset value, the done status bit is set. This can be used to control an output device

	15	14	13	12	11	10	9	8	7					0
Word 0	CU	CD	DN	Internal use										
Word 1	Preset value (PRE)													
Word 2	Accumulator value (ACC)													

'CU' is count-up bit, 'CD' is count down bit and 'DN' is done bit. A few counter instructions are given in the subsequent sections.

Count **UP(CTU)**

The CTU is an instruction that counts false to true rung transition

CTU
Count up
Counter
Preset
Accumulator

3.12.1 Count Up (CTU)

The CTU is an instruction that counts false-to-true rung transitions. Rung transition can be caused by events occurring in the program (from internal logic or by external field devices).

When the rung condition for a CTU instruction has made a false to true transition, the accumulated value is incremented by one count, provided that, the rung containing the CTU instruction is evaluated between these transitions. The ability of the counter to detect a false-to-true transition depends on the speed (frequency) of the incoming signal. The on and off duration of an incoming signal must not be faster than the scan time.

The accumulated value is retained when the rung condition again becomes false. The accumulated count is retained until cleared by a reset (RES) instruction that has the same address as the counter reset.

The accumulated value is retained after the CTU instruction becomes false, or when the power is removed from, and then restored to, the controller. Also the on or off status of a counter done, overflow and underflow bits is retentive. The accumulated value and control bits are reset when the appropriate RES instruction is enabled. The function block of a count-up CTU is shown in Fig. 3.14.

Count DOWN(CTD)

CTD
Count down
Counter
Preset
Accumulator

3.12.2 Count Down (CTD)

The CTD is a retentive output instruction that counts false to true rung transitions. When the rung condition for a CTD instruction has made a false-to-true transition, the accumulated value is decremented by one count, provided that the rung containing the CTD instruction is evaluated between these transitions. The accumulated counts are retained when the rung condition again becomes false. The accumulated count is retained until cleared by a reset (RES) instruction that has the same address as the counter reset. The function block of a count-down CTD is shown in Fig. 3.15.

BASICS CONCEPTS OF SCADA,DCS,CNC

1. Supervisory Control and Data Acquisition (SCADA)
2. distributed control system (DCS)
3. Computer Numerical Control(CNC)

Supervisory Control and Data Acquisition (SCADA)

Supervisory Control and Data Acquisition (SCADA) is a control system architecture that uses computers, networked data communications and graphical user interfaces for high-level process supervisory management, but uses other peripheral devices such as programmable logic controller (PLC) and discrete PID controllers to interface with the process plant or machinery

Why SCADA?

- Saves Time and Money
    - Less traveling for workers (e.g. helicopter ride)
    - Reduces man-power needs
    - Increases production efficiency of a company
    - Cost effective for power systems
    - Saves energy
- Reliable
- Supervisory control over a particular system

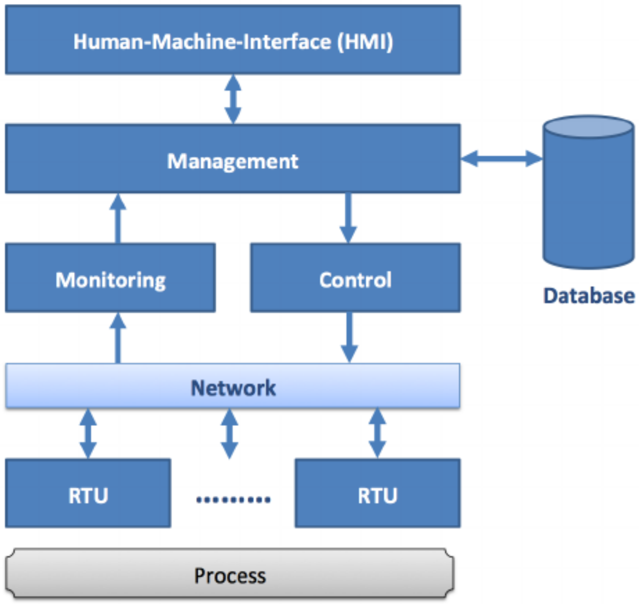
Objectives of SCADA

1. **Monitoring** : Continuous monitoring of the parameters of voltage , current, etc..
2. **Measuremen**t: Measurement of variables for processing.
3. **Data Acquisition**: Frequent acquisition of data from RTUs and Data Loggers / Phasor data Concentrators (PDC)..
4. **Data Communication**: Transmission andreceiving of large amounts of data from field to control centre’s.
5. **Control**: Online real time control for closed loop and open loop processes.
6. **Automation**:: Automatic tasks of switching of transmission lines, CBs, etc.

Functions of SCADA

- Data Acquisition
- Information Display
- Supervisory Control
- Alarm Processing
- Information Storage and Reports
- Sequence of Event Acquisition
- Data Calculation
- Special RTU Processing/Control

ARCHITECTURE OF SCADA



RTU-REMOTE TERMINAL UNIT

A collection of equipment that will provide an operator at remote location with enough information to determine the status of a particular piece of a equipment or entire substation and cause actions to take place regarding the equipment or network.SCADA systems are used to monitor or to control chemical or transport processes in municipal water supply systems, to control electric power generation, transmission and distribution, gas and oil pipelines, and other distributed processes. Supervisory control and data Acquisition (SCADA) achieves this requirement collecting reliable field data through remote terminal units (RTUs) Intelligent Electric Devices (IEDs) and presenting them to user requirement.

The user interface or the man machine interface (MMI) provides various options of data presentation according to specific application and user needs. There are many parts of a working SCADA system. A SCADA system usually includes signal hardware (input and output), controllers, networks, user interface (HMI), communications equipment and software. All together, the term SCADA refers to the entire central system. The central system usually monitors data from various sensors that are either in close proximity or off site. SCADA refers to a system that collects data from various sensors at a factory, plant or in other remote locations and then sends this data to a central computer which then manages and controls the data.A SCADA system refer to a system consisting of a number of remote terminal units (or RTUs) collecting field data connected back to a master station via a communications system.

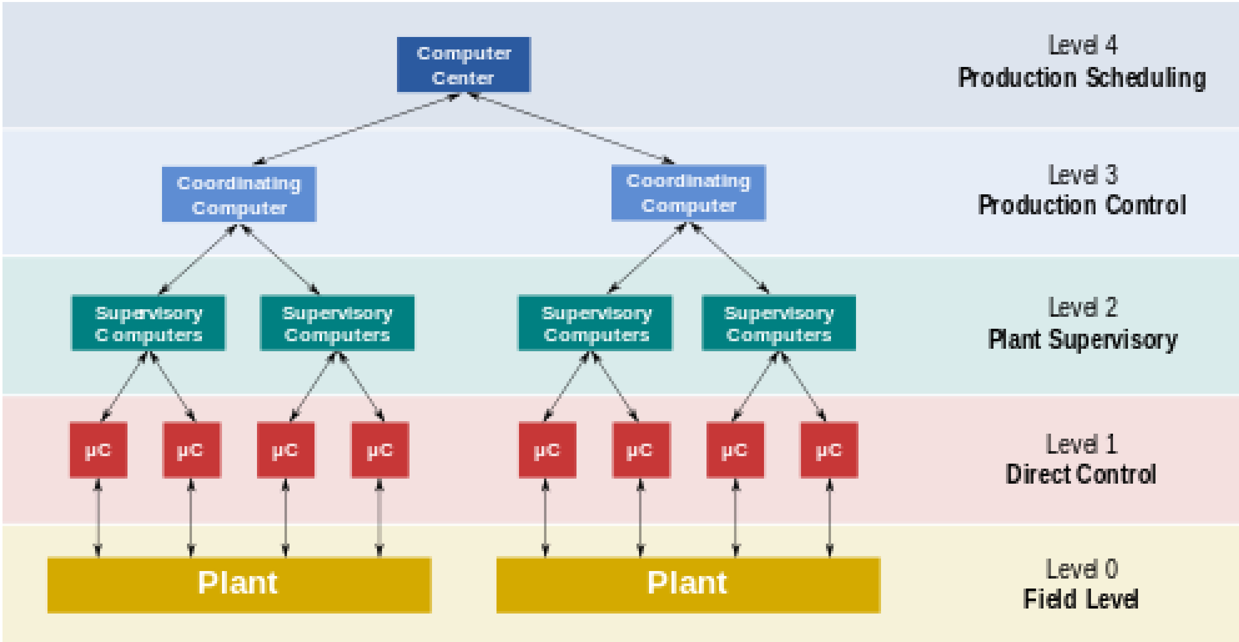
The master station displays the acquired data and also allows the operator to perform remote control tasks. The accurate and timely data (normally real-time) allows for optimization of the operation of the plant and process. A further benefit is more efficient, reliable and most importantly, safer operations. This all results in a lower cost of operation compared to earlier non-automated systems.The RTU provides an interface to the field analog and digital signals situated at each remote site.

- S**ensors** (either digital or analog) and control relays that directly interface with the managed system.
- **Remote telemetry units** (RTUs). These are small computerized units deployed in the field at specific sites and locations. RTUs serve as local collection points for gathering reports from sensors and delivering commands to control relays.
- **SCADA master units**. These are larger computer consoles that serve as the central processor for the SCADA system. Master units provide a human interface to the system and automatically regulate the managed system in response to sensor inputs.
- **Communications network** that connects the SCADA master unit to the RTUs in the field.

Usage of SCADA

1. **Electric power generation, transmission and distribution**: Electric utilities use SCADA systems to detect current flow and line voltage, to monitor the operation of circuit breakers, and to take sections of the power grid online or offline.
2. **Water and sewage**: State and municipal water utilities use SCADA to monitor and regulate water flow, reservoir levels, pipe pressure and other factors.
3. **Buildings, facilities and environments**: Facility managers use SCADA to control HVAC, refrigeration units, lighting and entry systems.
4. **Manufacturing**: SCADA systems manage parts inventories for just-in-time manufacturing, regulate industrial automation and robots, and monitor process and quality control.
5. **Mass transit**: Transit authorities use SCADA to regulate electricity to subways, trams and trolley buses; to automate traffic signals for rail systems; to track and locate trains and buses; and to control railroad crossing gates.
6. **Traffic signals**: SCADA regulates traffic lights, controls traffic flow and detects out-of-order signals.

DISTRIBUTED CONTROL SYSTEM(DCS)



A distributed control system (DCS) is a computerised control system for a process or plant usually with a large number of control loops, in which autonomous controllers are distributed throughout the system, but there is central operator supervisory control. This is in contrast to systems that use centralized controllers; either discrete controllers located at a central control room or within a central computer. The DCS concept increases reliability and reduces installation costs by localising control functions near the process plant, with remote monitoring and supervision

The key attribute of a DCS is its reliability due to the distribution of the control processing around nodes in the system. This mitigates a single processor failure. If a processor fails, it will only affect one section of the plant process, as opposed to a failure of a central computer which would affect the whole process. This distribution of computing power local to the field Input/Output (I/O) connection racks also ensures fast controller processing times by removing possible network and central processing delays

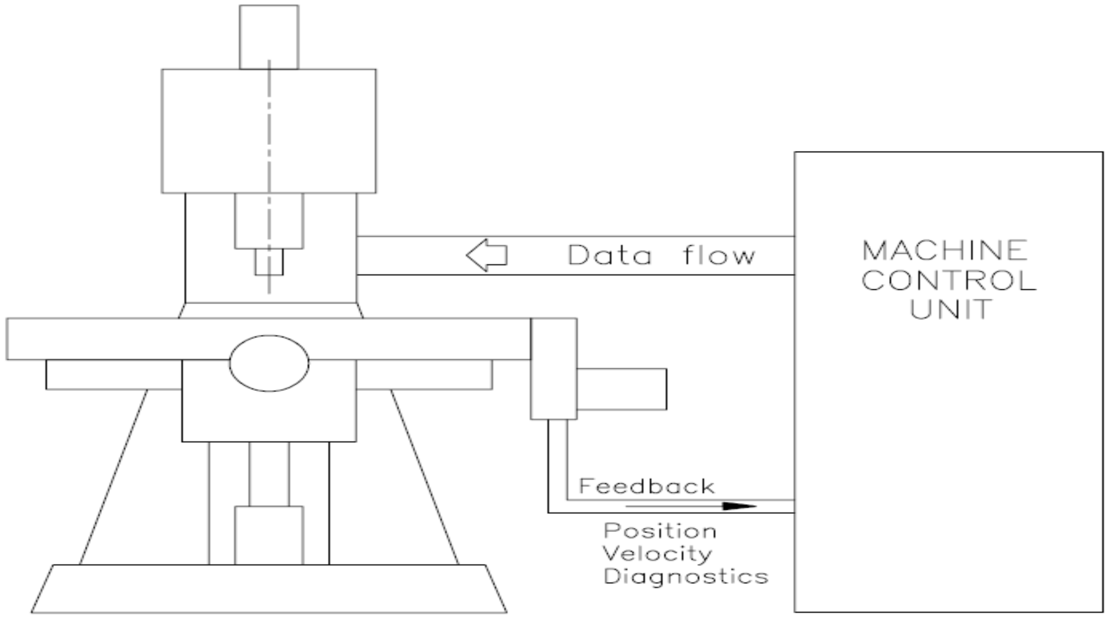
- **Level 0** contains the field devices such as flow and temperature sensors, and final control elements, such as control valves
- **Level 1** contains the industrialised Input/Output (I/O) modules, and their associated distributed electronic processors.
- **Level 2** contains the supervisory computers, which collect information from processor nodes on the system, and provide the operator control screens.
- **Level 3** is the production control level, which does not directly control the process, but is concerned with monitoring production and monitoring targets
- **Level 4** is the production scheduling level.

Advantages of DCS

- Access a large amount of current information from the data highway.
- Monitoring trends of past process conditions.
- Readily install new on-line measurements together with local computers.
- Alternate quickly among standard control strategies and readjust controller parameters in software.
- A sight full engineer can use the flexibility of the framework to implement his latest controller design ideas on the host computer.

Computer Numeric Control (CNC)

Numerical control (NC) refer to control of a machine or a process using symbolic codes consisting of characters and numerals.



Computer Numerical Control (CNC) Machine

Computer numerical control (CNC) is the numerical control system in which a dedicated computer is built into the control to perform basic and advanced NC functions. CNC controls are also referred to as softwired NC systems because most of their control functions are implemented by the control software programs. CNC is a computer assisted process to control general purpose machines from instructions generated by a processor and stored in a memory system.

Advantages and Disadvantages of CNC

Advantages:

- High Repeatability and Precision e.g. Aircraft parts.
- Volume of production is very high.
- Complex contours/surfaces can be easily machined.
- Flexibility in job change, automatic tool settings, less scrap.
- More safe, higher productivity, better quality.
- Less paper work, faster prototype production, reduction in lead times.

Disadvantages:

- Costly setup, skilled operators.
- Computer programming knowledge required.
- Maintenance is difficult.

QUESTION BANK

1. What is PLC
2. Draw and explain the architecture of PLC. Also mention advantages and disadvantages
3. Compare PLC and PC
4. How PLC works
5. What is sequential control
6. What do you mean by relay logic in PLC programming
7. Explain the concept of latching
8. Draw any three symbols used ladder programming
9. What are the basic instructions used in ladder logic
10. Realize AND,OR,NOT logic in PLC leader logic
11. Draw the ladder diagram of NAND,NOR and XOR gate
12. Write ladder program for the given expression and also draw ladder logic

$$Y=(X1+X2)+X3X4$$

$$Y=(X1+X2)(X3+X4)(X5X6)$$

$$Y=(X1X2)+X3$$