Module 4

Programmable Logic Control Systems

Lesson
18

Introduction to Sequence/Logic Control and Programmable Logic Controllers

Instructional Objectives

After learning the lesson students should be able to

A. Define Sequence and Logic Control

B. State three major differences between Logic Control and Analog Control

C. Define a Programmable Logic Controller and name its major structural components

D. Name the major functions performed by a PLC

What is Sequence and Logic Control?

Many control applications do not involve analog process variables, that is, the ones which can assume a continuous range of values, but instead variables that are set valued, that is they only assume values belonging to a finite set. The simplest examples of such variables are binary variables, that can have either of two possible values, (such as 1 or 0, on or off, open or closed etc.). These control systems operate by turning on and off switches, motors, valves, and other devices in response to operating conditions and as a function of time. Such systems are referred to as sequence/logic control systems. For example, in the operation of transfer lines and automated assembly machines, sequence control is used to coordinate the various actions of the production system (e.g., transfer of parts, changing of the tool, feeding of the metal cutting tool, etc.).

Typically the control problem is to cause/ prevent occurrence of

- particular values of outputs process variables
- particular values of outputs obeying timing restrictions
- given sequences of discrete outputs
- given orders between various discrete outputs

Note that some of these can also be operated using analog control methods. However, in specific applications they may be viewed as discrete control or sensing devices for two reasons, namely,

A. The inputs to these devices only belong to two specific sets. For example in the control of a reciprocating conveyor system, analog motor control is not applied. Simple on-off control is adequate. Therefore for this application, the motor-starter actuation system may be considered as discrete.

B. Often the control problem considered is supervisory in nature, where the problem is provide different types of supervisory commands to automatic control systems, which in turn carry out analog control tasks, such that over all system operating modes can be maintained and coordinated to achieve system objectives.

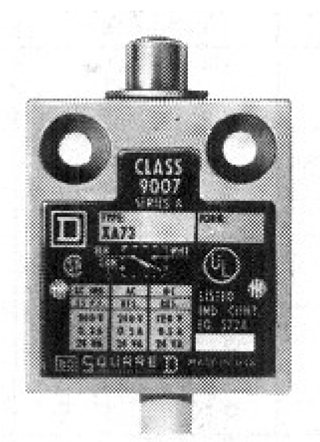
Examples of some such devices is given below.

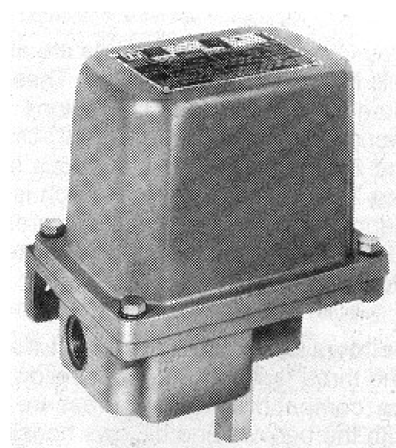
Industrial Example of Discrete Sensors and Actuators

There are many industrial sensors which provide discrete outputs which may be interpreted as the presence/absence of an object in close proximity, passing of parts on a conveyor, For example, tables x.y and a.b below show a set of typical sensors which provide a discrete set of output corresponding to process variables.

Type	**Signal**	**Remark**
Switch	**Binary Command**	**External Input Device**
Limit switch	**Position**	**Feedback Sensor Device**
Thumbwheel switch	**Set valued Command**	**External Input Device**
Thermostat	**Temperature Level**	**Feedback Sensor Device**
Photo cell	**Position of objects**	**Feedback Sensor Device**
Proximity detector	**Position of objects**	**Feedback Sensor Device**
Push button	**Command (unlatched)**	**External Input Device**

Table 3.1 Discrete Sensors





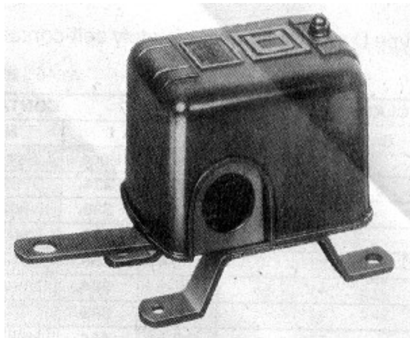


Fig. 18.1 Example Industrial Discrete Input and Sensing Devices:

Type	Output Quantity	Energy Source
Relay, Contactor	**voltage**	electrical
Motor Starter	**motion**	electrical
Lamp	**indication**	electrical
Solenoid	**motion**	electrical
On-off Flow Control valve	**Flow**	pneumatic, hydraulic
Directional Valves	**Hydraulic Pressure**	pneumatic, hydraulic

Table 18.2 Example Industrial Discrete Output and Actuation Devices

Below we provide an industrial example of Industrial Sequence Control

Point to Ponder: 1

A. *Categorise the following sensor systems as Discrete or Continuous*
   a) thermostat b)clinical thermometer c) the infrared sensor in TV sets

B. *Categorise the following actuator systems as Discrete or Continuous*

   a)the trigger of a gun b) the steering wheel of the car c) a step motor

Industrial Example

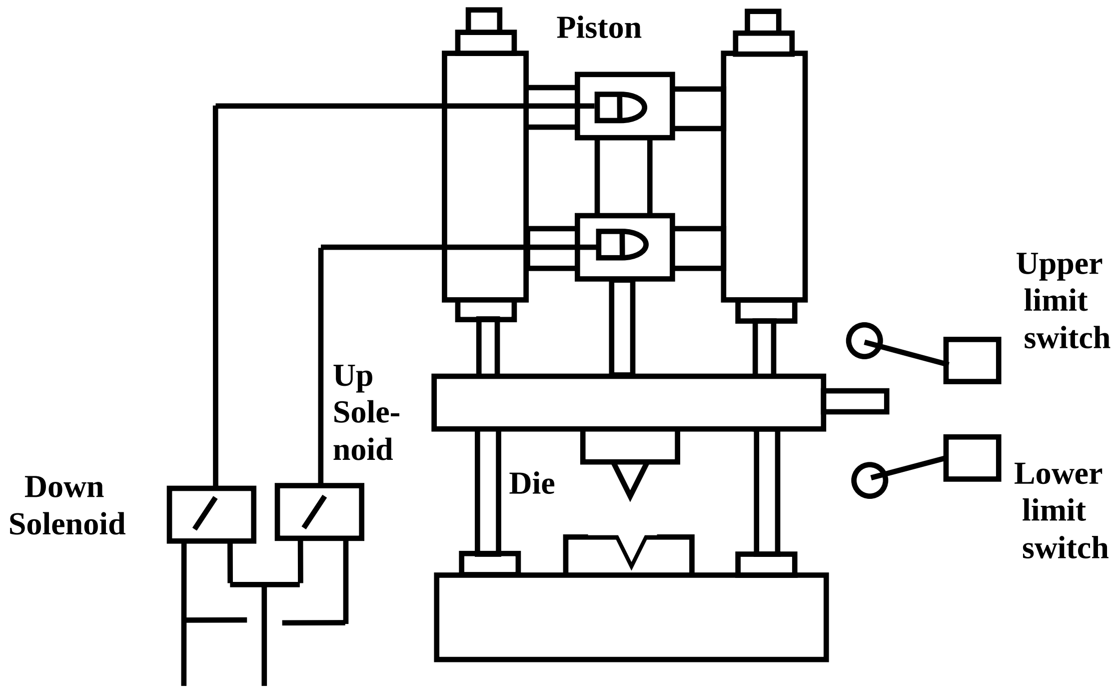


Fig. 18.2 An Industrial Logic Control Example

The die stamping process is shown in figure below. This process consists of a metal stamping die fixed to the end of a piston. The piston is extended to stamp a work piece and retracted to allow the work piece to be removed. The process has 2 actuators: an up solenoid and a down solenoid, which respectively control the hydraulics for the extension and retraction of the stamping piston and die. The process also has 2 sensors: an upper limit switch that indicates when the piston is fully retracted and a lower limit switch that indicates when the piston is fully extended. Lastly, the process has a master switch which is used to start the process and to shut it down.

The control computer for the process has 3 inputs (2 from the limit sensors and 1 from the master switch) and controls 2 outputs (1 to each actuator solenoid).

The desired control algorithm for the process is simply as follows. When the master switch is turned on the die-stamping piston is to reciprocate between the extended and retracted positions, stamping parts that have been placed in the machine. When the master switch is switched off, the piston is to return to a shutdown configuration with the actuators off and the piston fully retracted.

Point to Ponder: 2

A. *Define what is Logic Control system in your own language. Give an example*

B. *In the context of your example show typical objectives in Logic Control*

Comparing Logic and Sequence Control with Analog Control

The salient points of difference between Analog Control and Logic/Sequence control are presented in the table below.

Issue	**Logic/Sequence Control**	**Analog Control**
Model	Logical State-Transition	Numerical Different ial/Difference Eqn
	Simple Model/Easy to build	Complex Model/Hard to build
	Infrequent	Liable to change
Signal	Signal range/status	Signal value
Temporal Property	(Timed) sequence	(Timed)Function/Trajectory
Control Redesign/Tuning	On-off/logical	linear/non linear analog
	Supervisory	automatic
	Open/Closed Loop	Open/Closed Loop
	Infrequent	Tuning needed

Table 18.3 A Comparison of Continuous Variable (Analog) and Discrete Event (Logic/Sequence) Control

Point to Ponder: 3

C. *Of Logic Control and Analog Control which one appears simpler and why ?*

D. *Can you cite an example system which requires both Analog and Logic Control?*

Programmable Logic Controllers (PLC)

A modern controller device used extensively for sequence control today in transfer lines, robotics, process control, and many other automated systems is the **Programmable Logic Controller** (PLC). In essence, a PLC is a special purpose industrial microprocessor based real-time computing system, which performs the following functions in the context of industrial operations

- Monitor Input/Sensors
- Execute logic, sequencing, timing, counting functions for Control/Diagnostics
- Drives Actuators/Indicators
- Communicates with other computers

Some of the following are advantages of PLCs due to standardized hardware technology, modular design of the PLCs, communication capabilities and improved development program development environment:

- Easy to use to simple modular assembly and connection;
- Modular expansion capacity of the input, outputs and memory;
- Simple programming environments and the use of standardized task libraries and debugging aids;
- Communication capability with other programmable controllers and computers

Evolution of the PLC

Before the advent of microprocessors, industrial logic and sequence control used to be performed using elaborate control panels containing electromechanical or solid-state relays, contactors and switches, indicator lamps, mechanical or electronic timers and counters etc., all hardwired by complex and elaborate wiring. In fact, for many applications such control panels are used even today. However, the development of microprocessors in the early 1980's quickly led to the development of the PLCs, which had significant advantages over conventional control panels. Some of these are:

- Programming the PLC is easier than wiring physical components; the only wiring required is that of connecting the I/O terminals.
- The PLC can be reprogrammed using user-friendly programming devices. Controls must be physically rewired.
- PLCs take up much less space.
- Installation and maintenance of PLCs is easier, and with present day solid-state technology, reliability is grater.
- The PLC can be connected to a distributed plant automation system, supervised and monitored.
- Beyond a certain size and complexity of the process, a PLC-based system compare favorably with control panels.
- Ability of PLCs to accept digital data in serial, parallel and network modes imply a drastic reduction in plant sensor and actuator wirings, since single cable runs to remote terminal I/O units can be made. Wiring only need to be made locally from that point.
- Special diagnostic and maintenance modes for quick troubleshooting and servicing, without disrupting plant operations.

However, since it evolved out of relay control panels the PLCs adopted legacy concepts, which were applicable to such panels. To facilitate maintenance and modification of the physically wired control logic, the control panel was systematically organized so that each control formed a rung much like a rung on a ladder. The development of PLCs retained the ladder logic concept where control circuits are defined like rungs on a ladder where each rung begins with one or more inputs and each rung usually ends with only one output. A typical PLC ladder structure is shown below in Fig. 3.2

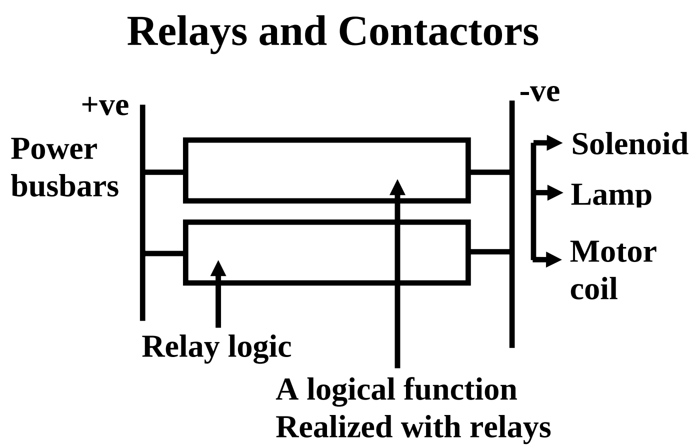


Fig. 18.3 The structure of Relay Logic Circuits

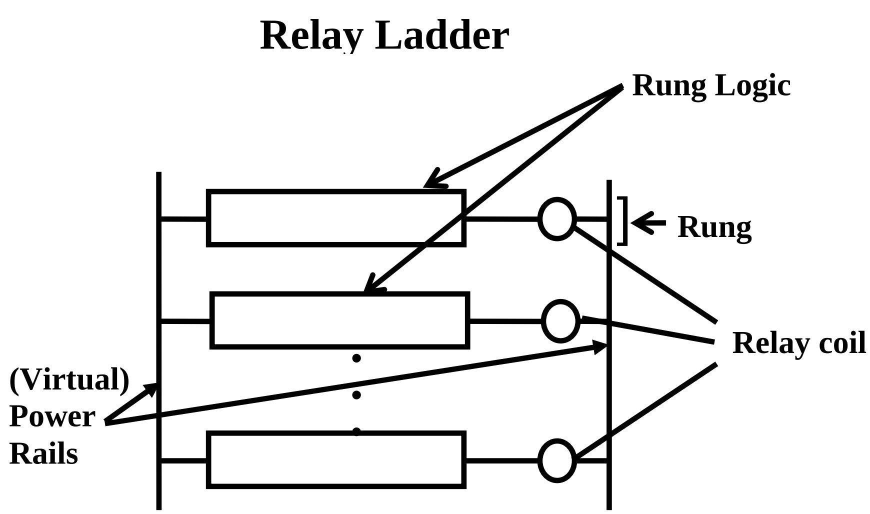


Fig. 18.4 The structure of Relay Ladder Logic Programs for PLCs

Point to Ponder: 4

E. *Name three of the most prominent advantages of the PLCs over hardwired Relay Contactor Logic*

F. *Can you name a single disadvantage in any situation?*

G. *Do you think the idea of developing programs that look like Relay Ladders is very efficient? If so, why? If not, why was it pursued?*

Application Areas

Programmable Logic Controllers are suitable for a variety of automation tasks. They provide a simple and economic solution to many automation tasks such as

- Logic/Sequence control
- PID control and computing
- Coordination and communication

- Operator control and monitoring
- Plant start-up, shut-down

Any manufacturing application that involves controlling repetitive, discrete operations is a potential candidate for PLC usage, e.g. machine tools, automatic assembly equipment, molding and extrusion machinery, textile machinery and automatic test equipment. Some typical industrial areas that widely deploy PLC controls are named in Table x.y. The list is only illustrative and by no means exhaustive.

Chemical/ Petrochemical	**Metals**	**Manufacturing/Machining**
Batch process	Blast Furnace	Material Conveyors, Cranes
Pipeline Control	Continuous Casting	Assembly
Weighing, Mixing	Rolling Mills	Milling, Grinding, Boring
Finished Product Handling	Soaking Pit	Plating, Welding, Painting
Water/ Waste Treatment	Steel Melting Shop	Molding/ casting/forming

Table 18.4 Some Industrial Areas for **Programmable Controller Applications**

Architecture of PLCs

The PLC is essentially a microprocessor-based real-time computing system that often has to handle significant I/O and Communication activities, bit oriented computing, as well as normal floating point arithmetic. A typical set of components that make a PLC System is shown in Fig. 3.5 below.

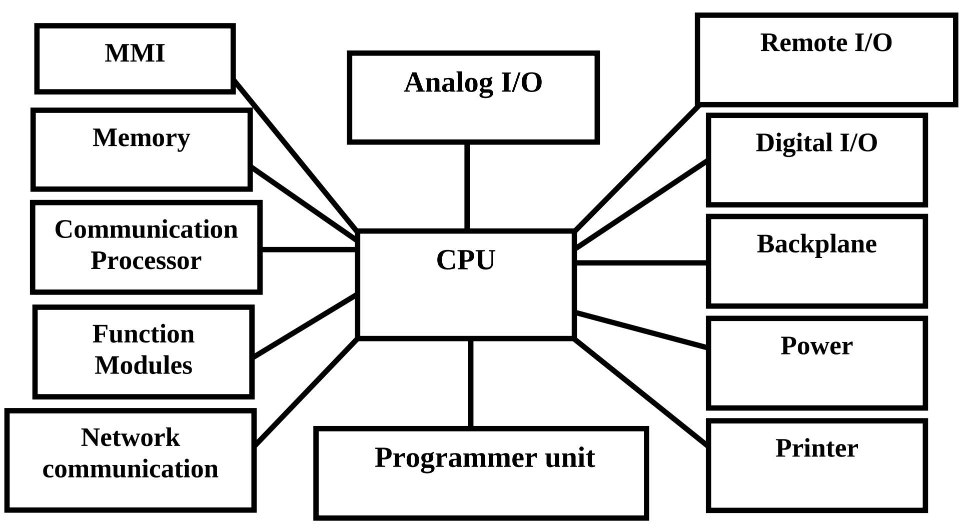


Fig. 18.5 Conventional PLC Architecture

The components of the PLC subsystem shown in Fig. 3.5 are described below.

Central controller

The central controller (CC) contains the modules necessary for the main computing operation of the Programmable controller (PC). The central controller can be equipped with the following:

- Memory modules with RAM or EPROM (in the memory sub modules) for the program (main memory);
- Interface modules for programmers, expansion units, standard peripherals etc;
- Communications processors for operator communication and visualization, communication with other systems and configuring of local area networks.

A bus connects the CPUs with the other modules.

Central Processing units

The CPUs are generally microprogrammed processors sometimes capable of handling multiple data width of either 8, 16 or 24 bits. In addition some times additional circuitry, such as for bit processing is provided, since much of the computing involves logical operations involving digital inputs and auxiliary quantities. Memory with battery backup is also provided for the following:

- Flags (internal relays), timers and counters;
- Operating system data
- Process image for the signal states of binary inputs and outputs.

The user program is stored in memory modules. During each program scan, the processor reads the statement in the program memory, executes the corresponding operations. The bit processor, if it exists, executes binary operations. Often multiple central controllers can be configured in hot standby mode, such that if one processor fails the other can immediately pick up the computing tasks without any failure in plant operations.

Communications processors

Communications processors autonomously handle data communication with the following:

- Standard peripherals such as printers, keyboards and CRTs,
- Supervisory Computer Systems,
- Other Programmable controllers,

The data required for each communications processors is stored in a RAM or EPROM sub module so that they do not load the processor memories. A local area network can also be configured using communications processors. This enables the connection of various PLCs over a wide distance in various configurations. The network protocols are often proprietary. However, over the last decade, interoperable network protocol standards are also supported in modern PLCs.

Program and Data memory

The program and data needed for execution are stored in RAM or EPROM sub modules. These sub modules are plugged into the processors. Additional RAM memory modules can also be connected.

Expansion units

Modules for the input and output of signals are plugged into expansion units. The latter are connected to the central controller via interface modules. Expansion units can be connected in two configurations.

A. Centralized configuration

The expansion units (EU) are located in the same cabinet as the central controllers or in an adjacent cabinet in the centralized configuration, several expansion units can be connected to one central controller. The length of the cable from the central controller to the most distant expansion unit is often limited based on data transfer speeds.

B. Distributed configuration

The expansion units can be located at a distance of up to 1000 m from the central controller. In the distributed configuration, up to 16 expansion units can be connected to one central controller. Four additional expansion units can be connected in the centralized configuration to each distributed expansion unit and to the central controller.

Input/Output Units

A host of input and output modules are connected to the PLC bus to exchange data with the processor unit. These can be broadly categorized into Digital Input Modules, Digital Output Modules, Analog Input Modules, Analog Output Modules and Special Purpose Modules.

Digital Input Modules

The digital inputs modules convert the external binary signals from the process to the internal digital signal level of programmable controllers.

Digital Output Modules

The digital output modules convert the internal signal levels of the programmable controllers into the binary signal levels required externally by the process.

Analog Input Modules

The analog input modules convert the analog signals from the process into digital values which are then processed by the programmable controller.

Analog Output Modules

The analog output modules convert digital values from the programmable controller into the analog signals required by the process.

Special Purpose Modules

These may include special units for:

- High speed counting
- High accuracy positioning
- On-line self-optimizing control
- Multi axis synchronisation, interpolation

These modules contain additional processors, and are used to relieve the main CPU from the high computational loads involved in the corresponding tasks. These are discussed in detail in Lesson 22

Programmers

External programming units can be used to download programs into the program memory of the CPU. The external field programmers provide several software features that facilitate program entry in graphical form. The programmers also provide comprehensive aids for debugging and execution monitoring support logic and sequence control systems. Printer can be connected to the programmers for the purpose of documenting the program. In some cases, special programming packages that run on Personal Computers, can also be used as programming units. There are two ways of entering the program:

A. Direct program entry to the program memory (RAM) plugged into the central controller. For this purpose, the programmer is connected to the processor or to the programmer interface modules.

B. Programming the EPROM sub modules in the programmer without connecting it to the PC (off-line). The memory sub modules are then plugged into the central controller.

Other Miscellaneous Units

Other units such as Power Supply Units, Bus Units etc. can also be connected to the PLC system.

Point to Ponder: 5

A. *Name three major elements of a PLC System*

B. *What is the need for special purpose I/O modules? Explain with an example*

C. *What is a communication Processor?*

Answers, Remarks and Hints to Points to Ponder

Point to Ponder: 1

A. *Categorise the following sensor systems as Discrete or Continuous*
   a) thermostat : Discrete *b) clinical thermometer :* Continuous *c) the infrared sensor in TV sets :* Discrete

B. *Categorise the following actuator systems as Discrete or Continuous*
   A) the trigger of a gun: Discrete *b) the steering wheel of the car:* Continuous *c) a step motor:* May be considered Discrete or Continuous depending on the mode it is used. If it is used in the incremental mode it may be thought to be discrete (clockwise/anticlockwise). If it is used in the slewing mode, it may be considered continuous

Point to Ponder: 2

A. *Define what is Logic Control system in your own language. Give an example*

Ans: A detailed definition provided in the lesson. The example of a die press is also provided. However, try to give your own example.

B. *In the context of your example show typical objectives in Logic Control*

Ans: The following are valid control objectives for the die press example.

1. When MCS is off Up_lamp should never be 1
2. Every transition of the Up_lamp signal from 0 to 1 should be immediately followed by a transition of Dn_lamp from 0 to 1
3. Up_lamp and Dn_lamp can never simultaneously be 1, although they can simultaneously be 0.

Such statements are specifications in the sense that the logic controller must ensure that they are satisfied in the controlled system.

Point to Ponder: 3

A. *Of Logic Control and Analog Control which one appears simpler and why ?*

Ans: Analog Control is more complex than logic control. This is because of the fact that logic control models are captured by simple state transition systems containing only a few states. The state space of an analog control system is in infinite. The dynamics can be far more complex than simple state transition systems. Factors such as disturbances must be considered, unlike in logic control

B. *Can you cite an example system, which requires both Analog and Logic Control?*

Ans: There are many examples. In a variable air volume air conditioning system, the cooling water temperature is controlled by on-off control of the chiller, while volume of air is controlled by analog speed control of the fan. In a CNC machine the speed of the spindle is controlled by analog means, while auxiliaries, such as coolant flow are controlled by PLCs.

Point to Ponder: 4

A. *Name three of the most prominent advantages of the PLCs over hardwired Relay Contactor Logic*

Ans: 1. Programmability 2. Ability to incorporate complex control 3. Expandability, among many others.

B. *Can you name a single disadvantage in any situation?*

Ans: For very simple and small systems such as power distribution control a relay based control panel may be a cheaper solution.

C. *Do you think the idea of developing programs that look like Relay Ladders is very efficient? If so, why? If not, why was it pursued?*

Ans: It is not efficient. It was pursued, because when PLCs were developed Plant Engineers were more conversant with Relay Logic. So the language was introduced for ease of understanding of Plant Engineers.

Point to Ponder: 5

A. *Name three major elements of a PLC System*

Ans: CPU, I/O Modules, Communication Processor

B. *What is the need for special purpose I/O modules? Explain with an example*

Ans: Some i/o operations like high speed counting of shaft encoder pulses to measure speed is very computationally intensive. Therefore to free the CPU from this load, so that other control logics can be computed, special i/o modules with dedicated processors for the task are used.

C. *What is a communication Processor?*

Ans: It is a special processor that handles all communication related tasks with other supervisory systems.

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