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SCHOOL OF MECHANICAL ENGINEERING

DEPARTMENT OF MECHANICAL ENGINEERING

UNIT – I – ACTUATORS AND CONTROL VALVES – SMRA 1401

1. CONTROL VALVES:

Control valves automatically regulate pressure and/or flow rate, and are available for any pressure. If different plant systems operate up to, and at pressure/temperature combinations that require Class 300 valves, sometimes (where the design permits), all control valves chosen will be Class 300 for interchange-ability. However, if none of the systems exceeds the ratings for Class 150 valves, this is not necessary. Process plants consist of hundreds, or even thousands, of control loops all networked together to produce a product to be offered for sale. Each of these control loops is designed to keep some important process variable such as pressure, flow, level, temperature, etc. within a required operating range to ensure the quality of the end product. Each of these loops receives and internally creates disturbances that detrimentally affect the process variable, and interaction from other loops in the network provides disturbances that influence the process variable.

To reduce the effect of these load disturbances, sensors and transmitters collect information about the process variable and its relationship to some desired set point. A controller then processes this information and decides what must be done to get the process variable back to where it should be after a load disturbance occurs. When all the measuring, comparing, and calculating are done, some type of final control element must implement the strategy selected by the controller.

1.1 Introduction:

The control valve is a controlled device that regulates the flow of a liquid or gas in a system. This regulation is accomplished by the varying resistance that the valve introduces into the system as the valve is stroked. As the valve modulates to the closed position the system pressure drop shifts to the valve and reduces the flow in the system.

1.1.1 Principles of Operation:

A control valve is comprised of an actuator mounted to a valve. The valve modulates flow through movement of a valve plug in relation to the port(s) located within the valve body. The valve plug is attached to a valve stem, which, in turn, is connected to the actuator. The actuator, which can be pneumatically or electrically operated, directs the movement of the stem as dictated by the external control device.

1.1.2 Pneumatic/Diaphragm Actuated:

Pneumatic Actuators are direct acting and utilize an air signal from an external control device to create a modulating control action. The force of the air signal is received into the actuator through a top port and distributed across the full area of the actuator‘s diaphragm. The diaphragm presses down on the diaphragm plate and spring return assembly, which then moves the valve stem and plug assembly downward to stroke the valve.

1.1.3 Electric Actuated:

Electric Actuators are motor driven devices that utilize an electrical input signal to generate a motor shaft rotation. This rotation is, in turn, translated by the unit‘s linkage into a linear motion, which drives the valve stem and plug assembly for flow modulation.
The valve is very important to the operation of the system. Without a properly sized valve the system will never operate at an efficient level.

1.2 Control valves contain four basic sections:

1.2.1 Body:

The Body contains the orifice and is the main housing through which the controlled fluid flows.

1.2.2 Trim:

The Trim is the part of the valve excluding the body that comes in contact with the fluid. It is composed of the valve seat, plug, disc and disc holder, and stem.

1.2.3 Bonnet:

The Bonnet is an assembly that provides a mounting for the actuator and a guide through which the stem must pass. It is composed of the centerpiece, packing, packing guide, and packing nut. The packing provides a seal between the stem and bonnet to prevent leakage.

1.2.4 Actuator:

The Actuator consists of either pneumatic or electric means to provide the force to stroke the valve. The control valve is the most widely used type of final element. Other types of final control elements are dampers or louvers, and variable pitch fan blades.

1.2.5 Final Control Element:

A final control element is defined as a mechanical device that physically changes a process in response to a change in the control system setpoint. Final control elements relevant to actuators include valves, dampers, fluid couplings, gates, and burner tilts to name a few.

Final control elements are an essential part of process control systems, allowing an operator to achieve a desired process variable output by manipulating a process variable set point.

1.3 Valve characteristics

The cage of a valve can have different shapes of holes. The different shapes can control the flow in different characteristics. There are three main types of control characteristics. They are:

- Linear
- Equal percentage
- Quick opening

1.3.1 Linear valve characteristics:

This characteristic provides a linear relationship between the valve position and the flowrate. The flow through a linear valve varies directly with the position of the valve stem. This flow- travel relationship, if plotted on rectilinear coordinates, approximates a straight line, thereby giving equal volume changes for equal lift changes regardless of percent of valve opening.

These valves are often used for liquid level control and certain flow control operations requiring constant gain.

1.3.2 Equal percentage valve characteristics:

The equal percentage valve plug produces the same percentage change in flow per fixed increment of valve stroke at any location on its characteristic curve.

For example, if 30% stem lift produces 5 gpm and a lift increase of 10% to 40% produces 8 gpm or a 60% increase over the previous 5 gpm, then a further stroke of 10% now produces a 60% increase over the previous 8 gpm for a total flow of 12.8 gpm. These types of valves are commonly used for pressure control applications and are most suitable for applications where a high variation in pressure drop is expected.

1.3.3 Quick opening valve characteristics:

A quick opening valve plug produces a large increase in flow for a small initial change in stem travel. Near maximum flow is reached at a relatively low percentage of maximum stem lift. Quick opening plugs are normally utilized in two position –On-Off‖ applications but may be used in some linear valve applications. This is possible because of its initial linear characteristic at a low percentage of stem travel.

The slope of this linear region is very steep which produces a higher initial gain than the linear plug but also increases the potential instability of the control valve.

1.3.4 Inherent valve characteristics:

An inherent flow characteristic is the relation between valve opening and flow under constant pressure conditions. The inherent characteristic of a valve is obtained when there is a constant pressure drop across the valve for all valve positions; the process fluid is not flashing, cavitating or approaching sonic velocity (choked flow); and the actuator is linear (valve stem travel is proportional to the controller output).

Some valves have inherent characteristics that cannot be changed, such as full port ball valves and butterfly valves. For other valve types, such as the globe type, the inherent characteristics can be changed to suit the application.

1.3.5 Installed flow characteristic:

When valves are installed with pumps, piping and fittings, and other process equipment, the pressure drop across the valve will vary as the valve travel changes.

When the actual flow in a system is plotted against valve opening, the curve is called the installed flow characteristic and it will differ from the inherent valve characteristic which assumed constant pressure drop across the valve. When in service, a linear valve will in general resemble a quick opening valve while an equal percentage valve will in general resemble a linear valve.

1.4 Typical applications:

General applications of of quick opening, linear and equal percentage valves are :

1.4.1 Quick opening valve:

a) Frequent on-off service.

b) Used for systems where _instant‘ large flow is needed (safety or cooling water systems).

1.4.2 Linear valve:

a) Liquid level and flow control loops.

b) Used in systems where the pressure drop across the valve is expected to remain fairly constant.

1.4.3 Equal percentage valve (most commonly used in valves):

a) Temperature and pressure control loops.

b) Used in systems where large changes in pressure drop across the valve are expected.

1.5 BASIC VALVE TYPES:

- Valves are available with a wide variety of valve bodies in various styles, materials, connections and sizes.
- Selection is primarily dependent on the service conditions, the task, and the load characteristics of the application.
- The most common types are ball valves, butterfly valves, globe valves, and gate valves.

1.5.1 Ball Valves:

- Ball valves are a quick opening valves that give a tight shutoff. As shown in Fig 1.1
- When fully open, a ball valve creates little turbulence or resistance to flow. The valve stem rotates a ball which contains an opening.
- The ball opening can be positioned in the fully open or fully closed position but must not be used to throttle flow as any abrasive wear to the ball will cause leakage when the valve is closed.
- Ball valves are considered high recovery valves, having a low pressure drop and relatively high flow capacity.

Fig-1.1: Ball Valves

• Compliant with ASME is the flange rating, either 150, 300, 600, 900# or occasionally higher classes, enabling high performance ball valves to withstand up to 2250 psi.

• The operating temperature which is primarily dependent on seats and seals may be rated as high as 550°F.

• Standard valves comply with ASME face-to-face dimensions, making the ball valv easy to retrofit and replace.

1.5.2 Butterfly Valves:

- Butterfly valves consist of a disc attached to a shaft with bearings used to facilitate rotation as shown in Fig 1.2
- These are considered high recovery valves, since only the disc obstructs the valve flow path.
- The flow capacity is relatively high and the pressure drop across the valve is relatively low.
- The butterfly valves are used for limited throttling where a tight shut off is not required.
- When fully open, the butterfly creates little turbulence or resistance to flow.

Fig-1.2: Butterfly valve.

1.5.3 GLOBE VALVE:

Fig-1.3: Globe Valve

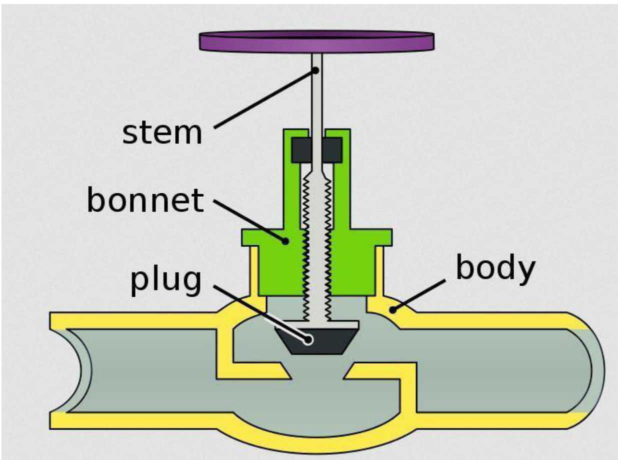

Fig-1.4: Schematic view of Globe valve

1.5.4 GATE VALVE:

- A gate valve, also known as a sluice valve, is a valve that opens by lifting a barrier (gate) out of the path of the fluid.
- Gate valves require very little space along the pipe axis and hardly restrict the flow of fluid when the gate is fully opened.
- The gate faces can be parallel but are most commonly wedge-shaped

Fig-1.5: Schematic view of GATE VALVE

1.6 CONTROL VALVE SELECTION CRITERIA:

Frequently several correct choices may be available, thus it is important for customers to provide control valve manufacturers the following information.

- Type of fluid to be controlled.
- Temperature range of fluid.
- Viscosity range of fluid.
- Specific gravity range of fluid.
- Minimum and maximum flow required.
- Minimum and maximum inlet pressure at the control valve.
- Minimum and maximum outlet pressure at the control valve.
- Pressure drop across the valve expected during normal flowing conditions.
- Pressure drop across the valve at zero flow.
- Maximum permissible noise level, if pertinent, and the measurement reference point.
- Degrees of superheat or existence of flashing across the valve, if known.
- Inlet and outlet pipeline size and schedule of pipe.

1.7 Controlling the valve:

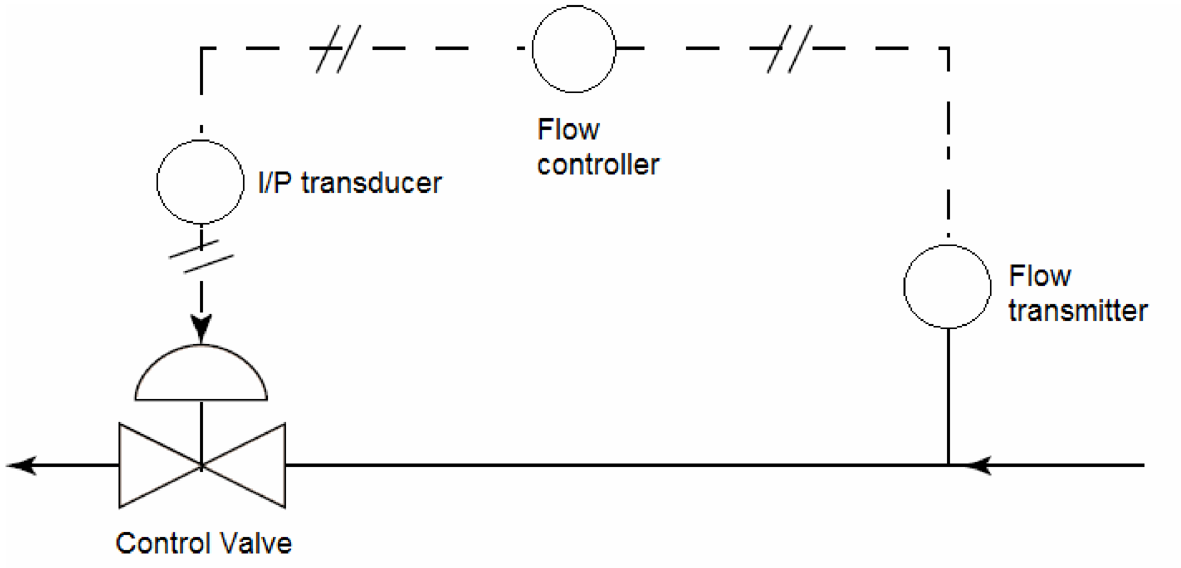

Fig-1.6: Control valve closed 1.9

1.8 LOOPCURRENT TO PRESSURE CONVERTER:

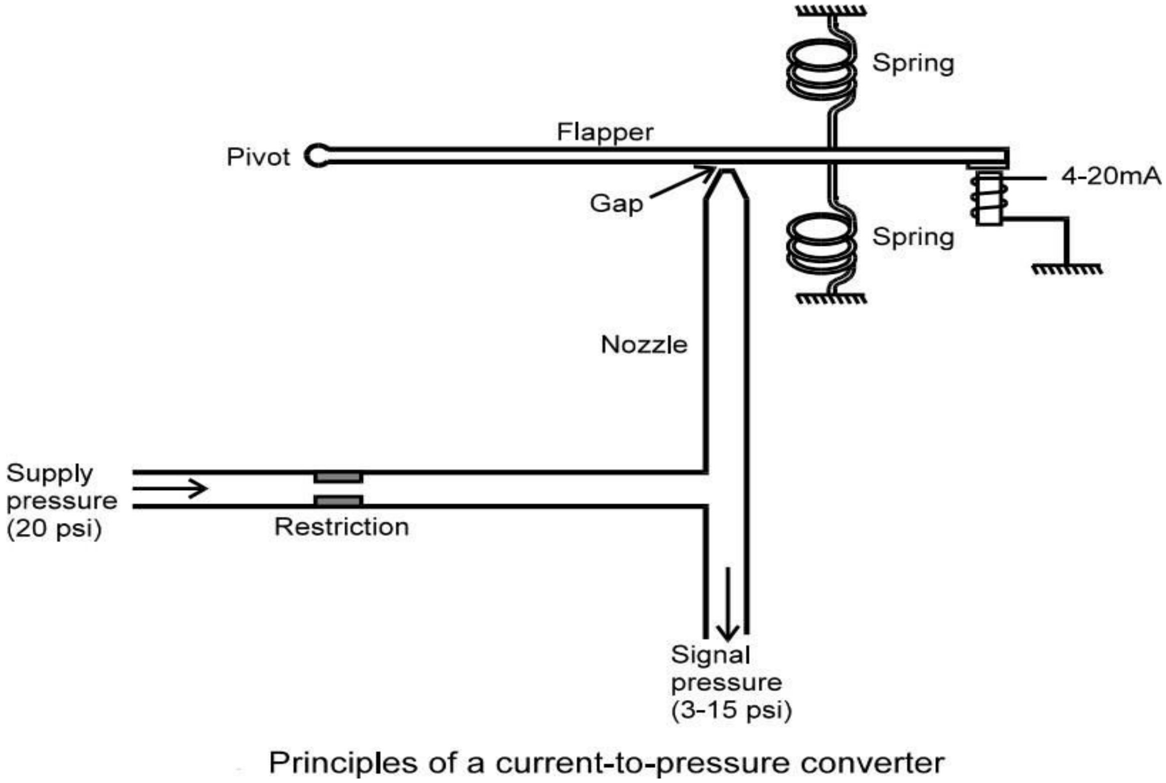

Fig-1.7: Current to pressure converter.

- In the Current to Pressure converter, we usually give input current signal as 4 – 20 mA. We also give a continuous supply of 20 P.S.I to the Flapper Nozzle assembly.
- As we give input current signal, Electromagnet gets activated.

- If the current is more, then the power of magnet will get increased. The Flapper of the Flapper-Nozzle instrument is connected to Pivot so that it can move up and down and a magnetic material was attached to other end of flapper and it is kept near the electromagnet.
- As the magnet gets activated. the flapper moves towards the electromagnet and the nozzle gets closed to some extent. So the some part of 20 P.S.I supplied will escape through nozzle and remaining pressure will come as output.
- If the current signal is high, then power of the magnet will increase, then flapper will move closer to the nozzle, so less pressure will escape through nozzle and output pressure increases.
- In this way the output pressure will be proportional to the input current.
- For the input current of 4 – 20 mA we can get the output pressure of 3 – 15 P.S.I

1.9.1 Choked Flow:

1) When an increase in pressure drop across the valve no longer has any effect on the flow rate through the valve.
2) When the velocity of the gas or vapor reaches sonic velocity at the vena contracta.

  - When liquid passes through a restriction, the velocity increases to a maximum and the pressure decreases to a minimum.
  - As the flow exits, velocity is restored to its previous value, while the pressure never completely recovers, thus creating a pressure differential across the valve.
  - If the pressure differential is sufficiently large, the pressure may, at some point, decrease to less than the vapor pressure of the liquid.
  - When this occurs, the liquid partially vaporizes and is no longer incompressible.
  - It is necessary to account for choked flow during the sizing process to ensure against undersizing a valve.
  - In other words, it is necessary to know the maximum flow rate that a valve can handle under a given set of conditions.
  - When selecting a valve, it is important to check the pressure recovery characteristics of valves for the thermodynamic properties of the fluid.

- High recovery valves, such as ball and butterfly, will become choked at lower pressure drops than low recovery valves such as globe which offer a more restricted flow path when fully open.

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UNIT – II –CONTROLLERS – SMRA 1401

2. Controller

A controller is a mechanism that seeks to minimize the difference between the actual value of a system (i.e. the process variable) and the desired value of the system (i.e. the setpoint). Controllers are a fundamental part of control engineering and used in all complex control systems.

Before we introduce you to various controllers in detail, it is very essential to know the uses of controllers in the theory of control systems. The important uses of the controllers include:

1. Controllers improve the steady-state accuracy by decreasing the steady state error.
2. As the steady-state accuracy improves, the stability also improves.
3. Controllers also help in reducing the unwanted offsets produced by the system.
4. Controllers can control the maximum overshoot of the system.
5. Controllers can help in reducing the noise signals produced by the system.
6. Controllers can help to speed up the slow response of an over damped system.

Different varieties of these controllers are codified within industrial automotive devices such as programmable logic controllers and SCADA systems. The various types of controllers are discussed in detail below.

2.1 Types of Controllers

There are two main types of controllers: continuous controllers, and discontinuous controllers.

In discontinuous controllers, the manipulated variable changes between discrete values. Depending on how many different states the manipulated variable can assume, a distinction is made between two position, three position, and multi-position controllers. Compared to continuous controllers, discontinuous controllers operate on very simple, switching final controlling elements.

The main feature of continuous controllers is that the controlled variable (also known as the manipulated variable) can have any value within the controller's output range. Now in the continuous controller theory, there are three basic modes on which the whole control action takes place, which are:

1. **Proportional controllers**.
2. **Integral controllers**.
3. **Derivative controllers**.

We use the combination of these modes to control our system such that the process variable is equal to the set point (or as close as we can get it). These three types of controllers can be combined into new controllers:

1. Proportional and integral controllers (PI Controller)
2. Proportional and derivative controllers (PD Controller)
3. Proportional integral derivative control (PID Controller)

Now we will discuss each of these control modes in detail below.

2.1.1 Proportional Controllers

All controllers have a specific use case to which they are best suited. We cannot just insert any type of controller at any system and expect a good result – there are certain conditions that must be fulfilled. For a **proportional controller,** there are two conditions and these are written below:

1. The deviation should not be large; i.e. there should not be a large deviation between the input and output.
2. The deviation should not be sudden.

Now we are in a condition to discuss proportional controllers, as the name suggests in a proportional controller the output (also called the actuating signal) is directly proportional to the error signal. Now let us analyze the proportional controller mathematically. As we know in proportional controller output is directly proportional to the error signal, writing this mathematically we have,

$$A(t) \propto e(t) \qquad \text{-----------------2.1}$$

Removing the sign of proportionality we have,

$$A(t) = K_p \times e(t) \qquad \text{--------------2.2}$$

Where K_p is proportional constant also known as controller gain.

It is recommended that K_p should be kept greater than unity. If the value of K_p is greater than unity (>1), then it will amplify the error signal and thus the amplified error signal can be detected easily.

Advantages of Proportional Controller

Now let us discuss some advantages of the proportional controller.

1. The proportional controller helps in reducing the steady-state error, thus makes the system more stable.
2. The slow response of the overdamped system can be made faster with the help of these controllers.

Disadvantages of Proportional Controller

Now there are some serious disadvantages of these controllers and these are written as follows:

1. Due to the presence of these controllers, we get some offsets in the system.
2. Proportional controllers also increase the maximum overshoot of the system.

Now, we will explain the Proportional Controller (P-controller) with a unique example. With this example reader's knowledge about 'Stability' and 'Steady State Error' will also enhance. Consider the feedback control system shown in Figure-1

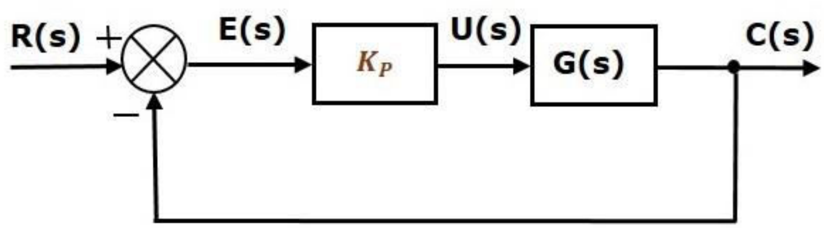

Figure- 2.1 A Feedback Control System with Proportional Controller

'K' is called a proportional controller (also called error amplifier).

2.1.2 Integral Controllers

As the name suggests in **integral controllers** the output (also called the actuating signal) is directly proportional to the integral of the error signal. Now let us analyze integral controller mathematically. As we know in an integral controller output is directly proportional to the integration of the error signal, writing this mathematically we have,

$$A(t) \propto \int_0^t e(t)dt \quad \text{----------------2.3}$$

Removing the sign of proportionality we have,

$$A(t) = K_i \times \int_0^t e(t)dt \quad \text{----------------2.4}$$

Where Ki is an integral constant also known as controller gain. The integral controller is also known as reset controller.

Advantages of Integral Controller

Due to their unique ability, Integral Controllers can return the controlled variable back to the exact set point following a disturbance that's why these are known as reset controllers.

Disadvantages of Integral Controller

It tends to make the system unstable because it responds slowly towards the produced error.

2.1.3 Derivative Controllers

We never use **derivative controllers** alone. It should be used in combinations with other modes of controllers because of its few disadvantages which are written below:

1. It never improves the steady-state error.
2. It produces saturation effects and also amplifies the noise signals produced in the system.

Now, as the name suggests in a derivative controller the output (also called the actuating signal) is directly proportional to the derivative of the error signal. Now let us analyze the derivative controller mathematically. As we know in a derivative controller output is directly proportional to the derivative of the error signal, writing this mathematically we have,

$$A(t) \propto \frac{de(t)}{dt}$$ ------------------2.5

Removing the sign of proportionality we have,

$$A(t) = K_d \times \frac{de(t)}{dt}$$ ----------------------2.6

Where, K_d is proportional constant also known as controller gain. The derivative controller is also known as the rate controller.

Advantages of Derivative Controller

The major advantage of a derivative controller is that it improves the transient response of the system.

2.1.4 Proportional and Integral Controller

As the name suggests it is a combination of proportional and an integral controller the output (also called the actuating signal) is equal to the summation of proportional and integral of the error signal. Now let us analyze proportional and integral controller mathematically. As we know in a proportional and integral controller output is directly proportional to the summation of proportional of error and integration of the error signal, writing this mathematically we have,

$$A(t) \propto \int_0^t e(t)dt + A(t) \propto e(t)$$ -------------------2.7

Removing the sign of proportionality we have,

$$A(t) = K_i \int_0^t e(t)dt + K_p e(t)$$ ------------------2.8

Where, K_i and k_p proportional constant and integral constant respectively.

Advantages and disadvantages are combinations of the advantages and disadvantages of proportional and integral controllers. Through the PI controller, we are adding one pole at origin and one zero somewhere away from the origin (in the left-hand side of complex plane).

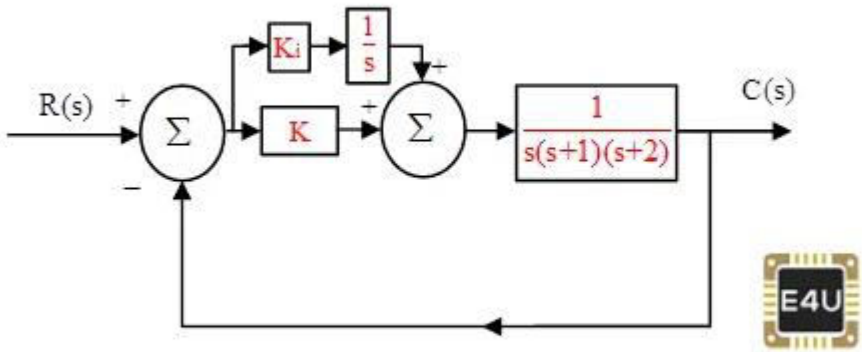

Fig 2.2 Proportional and Integral Controller

As the pole is at the origin, its effect will be more, hence PI controller may reduce the stability; but its main advantage is that it reduces steady-state error drastically, due for this reason it is one of the most widely used controllers. The schematic diagram of the PI controller is shown in Fig-6. Against step input, For the values of K=5.8, K_i=0.2, Its time response, is shown in Fig-7. At K=5.8 (As a P- controller, it was on the verge of instability, so just by adding the small value of an Integral part, it became unstable. Please note the Integral part reduces the stability, which does not mean that system will be always unstable. In the present case, we have added an integral part and the system became unstable).

2.1.5 Proportional and Derivative Controller

As the name suggests it is a combination of proportional and a derivative controller the output (also called the actuating signal) is equals to the summation of proportional and derivative of the error signal. Now let us analyze proportional and derivative controller mathematically. As we know in a proportional and derivative controller output is directly proportional to the summation of proportional of error and differentiation of the error signal, writing this mathematically we have,

$$A(t) \propto \frac{de(t)}{dt} + A(t) \propto e(t)$$ ------------2.9

Removing the sign of proportionality we have,

$$A(t) = K_d \frac{de(t)}{dt} + K_p e(t)$$ ------------------2.10

Where, K_d and K_p proportional constant and derivative constant respectively. Advantages and disadvantages are combinations of advantages and disadvantages of proportional and derivative controllers.

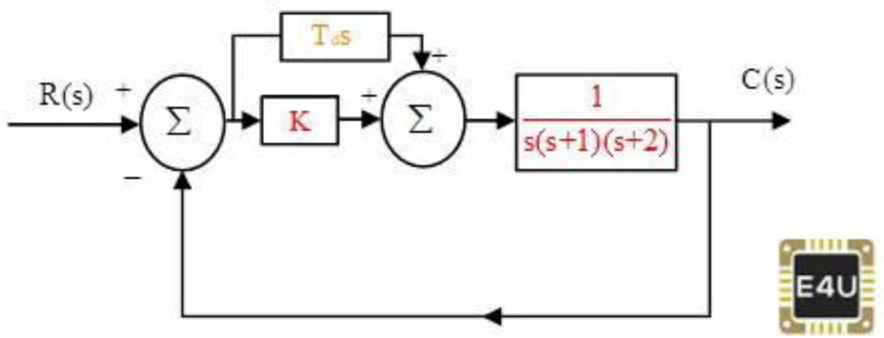

Fig 2.3 Proportional and Derivative Controller

Readers should note that adding ‘zero’ at the proper location in the open-loop transfer function improves stability, while the addition of pole in the open-loop transfer function may reduce the stability. The words “at proper location” in the above sentence are very important & it is called designing of the control system (i.e. both zero & pole should be added at proper points in the complex plane to get the desired result).

Inserting the PD controller is like the addition of zero in open-loop transfer function [G(s)H(s)]. Diagram of PD Controller is shown in Fig-8 In the present case, we have taken the values of K=5.8, Td=0.5. Its time response, against step input, is shown in Fig-9. You can compare Fig-9, with Fig-5 and can understand the effect of inserting the derivative part in the P-controller.

2.1.6 Proportional plus Integral plus Derivative Controller (PID Controller)

A PID controller is generally used in industrial control applications to regulate temperature, flow, pressure, speed, and other process variables.

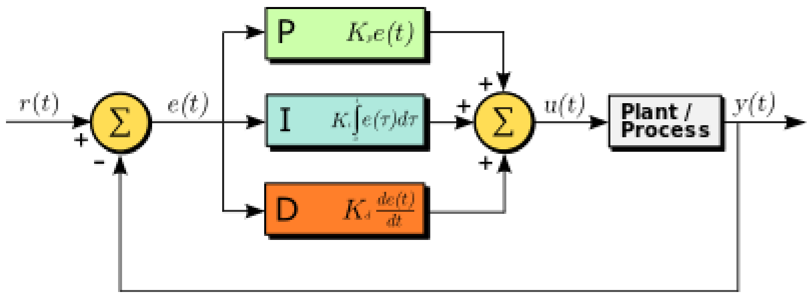

Figure 2.4 Proportional , Integral and Derivative Output

It can be observed that one pole at origin is fixed, remaining parameters T_d, K, and Ki decide the position of two zeros. In this case, we can keep two complex zeros or two real zeros as per the requirement, hence PID controller can provide better tuning. In the olden days, the PI controller was one of the best choice of control engineers, because designing (tuning of parameters) of the PID controller was a little difficult, but nowadays, due to the development of software designing of PID controllers have become an easy task.

Against step input, For the values of K=5.8, K_i=0.2, and T_d=0.5, Its time response, is shown in Fig-11. Compare Fig-11 with Fig-9 (We have taken values such that all the time response can be compared).

2.2 General Guidelines for Designing a PID Controller

When you are designing a PID controller for a given system, general guidelines to obtain the desired response are as follows:

1. Obtain the transient response of closed-loop transfer function and determine what needs to be improved.
2. Insert the proportional controller, Design the value of ‘K’ through Routh-Hurwitz or suitable software.
3. Add an integral part to reduce steady-state error.

4. Add the derivative part to increase damping (damping should be between 0.6-0.9). The derivative part will reduce overshoots & transient time.
5. Sisotool, available in MATLAB can also be used for proper tuning and to obtain a desired overall response.
6. Please note, above steps of tuning of parameters (designing of a control system) are general guidelines. There are no fixed steps for designing controllers.

SCHOOL OF MECHANICAL ENGINEERING

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UNIT – III – BASICS OF PROGRAMMABLE LOGIC CONTROLLER – SMRA 1401

Definition- overview of PLC systems - Input/ Output modules - Power supplies - I/O slots, General PLC programming procedures - programming on-off outputs, Auxiliary commands and functions - creating ladder diagrams from process control descriptions - Ladder logic for traffic light control system. PLC basic programming - digital logic Gates - Boolean algebra. Basic PLC functions-register basics - timer functions - counter functions.

3. **Definition**

A programmable logic controller (PLC) is a special form of micro-processor-based controller that uses a programmable memory to store instructions and to implement functions such as logic, sequencing, timing, counting and arithmetic in order to control machines and processes and are designed to be operated by engineers with perhaps a limited knowledge of computers and computing languages.

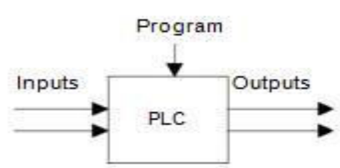

Figure 3.1 A programmable logic controller

PLCs have the great advantage that the same basic controller can be used with a wide range of control systems. To modify a control system and the rules that are to be used, all that is necessary is for an operator to key in a different set of instructions. There is no need to rewire. The result is a flexible, cost effective, system which can be used with control systems which vary quite widely in their nature and complexity. PLCs are similar to computers but whereas computers are optimised for calculation and display tasks, PLCs are optimised for control tasks and the industrial environment. Thus PLCs are:

1 Rugged and designed to withstand vibrations, temperature, humidity and noise.

2 Have interfacing for inputs and outputs already inside the controller.

3 Are easily programmed and have an easily understood programming language which is primarily concerned with logic and switching operations.

The first PLC was developed in 1969. They are now widely used and extend from small self-contained units for use with perhaps 20 digital inputs/outputs to modular systems which can be used for large numbers of inputs/outputs, handle digital or analogue inputs/outputs, and also carry out proportional-integral-derivative control modes.

3.1. The PLC System

Typically a PLC system has the basic functional components of processor unit, memory, power supply unit, input/output interface section, communications interface and the programming device. Figure 3.2 shows the basic arrangement.

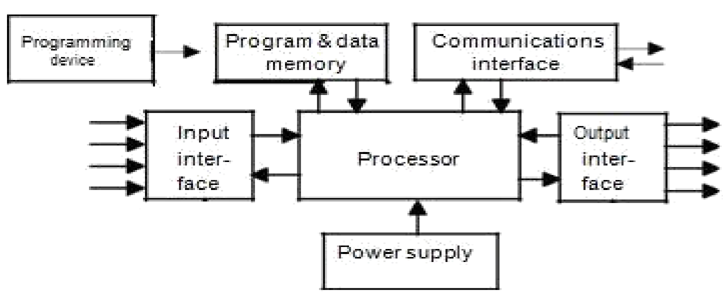

Figure 3.2 The PLC system

1 The processor unit or central processing unit (CPU) is the unit containing the microprocessor and this interprets the input signals and carries out the control actions, according to the program stored in its memory, communicating the decisions as action signals to the outputs.

2 The power supply unit is needed to convert the mains a.c. voltage to the low d.c. voltage (5 V) necessary for the processor and the circuits in the input and output interface modules.

3 The programming device is used to enter the required program into the memory of the processor. The program is developed in the device and then transferred to the memory unit of the PLC.

4 The memory unit is where the program is stored that is to be used for the control actions to be exercised by the microprocessor and data stored from the input for processing and for the output for outputting.

5 The input and output sections are where the processor receives information from external devices and communicates information to external devices. The inputs might thus be from switches or other sensors such as photo-electric cells, temperature sensors, or flow sensors, etc. The outputs might be to motor starter coils, solenoid valves, etc. Input and output devices can be classified as giving signals which are discrete, digital or analogue. Devices giving discrete or digital signals are ones where the signals are either off or on. Thus a switch is a device giving a discrete signal, either no voltage or a voltage. Digital devices can be considered to be essentially discrete devices which give a sequence of on− off signals. Analogue devices give signals whose size is proportional to the size of the variable being monitored. For example, a temperature sensor may give a voltage proportional to the temperature.

6 The communications interface is used to receive and transmit data on communication networks from or to other remote PLCs (Figure 3.3). It is concerned with such actions as device verification, data acquisition, synchronization between user applications and connection management.

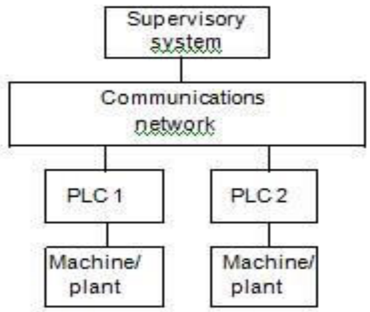

Figure 3.3 Basic communications model

3.1.1 Internal architecture

Figure 3.4 shows the basic internal architecture of a PLC. 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 with a frequency of typically between 1 and 8 MHz. This frequency determines the operating speed of the PLC and provides the timing and synchronisation 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.

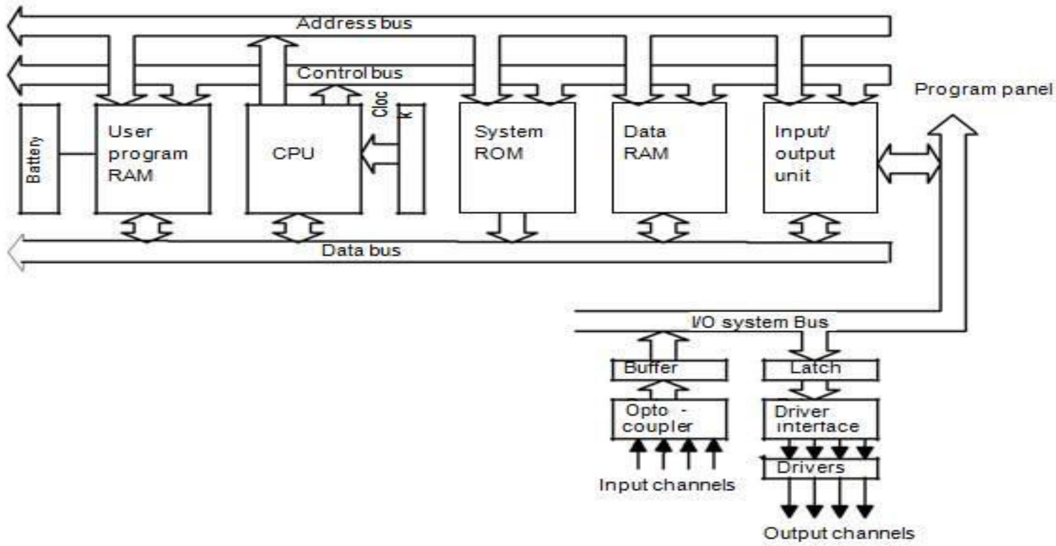

Figure 3.4 Architecture of a PLC

3.1.2 The CPU

The internal structure of the CPU depends on the microprocessor concerned. In general they have:

1 An *arithmetic and logic unit* (ALU) which is responsible for data manipulation and carrying out arithmetic operations of addition and subtraction and logic operations of AND, OR, NOT and EXCLUSIVE-OR.

2 Memory, termed *registers*, located within the microprocessor and used to store information involved in program execution.

3 A *control unit* which is used to control the timing of operations.

3.1.3 The buses

The buses are the paths used for communication within the PLC. The information is transmitted in binary form, i.e. as a group of *bits* with a bit being a binary digit of 1 or 0, i.e. on/off states.

The term *word* is used for the group of bits constituting some information. Thus an 8 -bit word might be the binary number 00100110. Each of the bits is communicated simultaneously along its own parallel wire. The system has four buses:

1 The *data bus* carries the data used in the processing carried out by the CPU. A microprocessor termed

as being 8-bit has an internal data bus which can handle 8-bit numbers. It can thus perform operations between 8-bit numbers and deliver results as 8-bit values.

2 The *address bus* is used to carry the addresses of memory locations. So that each word can be located in the memory, every memory location is given a unique *address*. Just like houses in a town are each given a distinct address so that they can be located, so each word location is given an address so that data stored at a particular location can be accessed by the CPU either to read data located there or put, i.e. write, data there. It is the address bus which carries the information indicating which address is to be accessed. If the address bus consists of 8 lines, the number of 8-bit words, and hence number of distinct addresses, is 28 = 256. With 16 address lines, 65 536 addresses are possible.

3 The *control bus* carries the signals used by the CPU for control, e.g. to inform memory devices

whether they are to receive data from an input or output data and to carry timing signals used to synchronise actions.

4 The *system bus* is used for communications between the input/output ports and the input/output unit.

3.1.4 Memory

There are several memory elements in a PLC system:

1 System read-only-memory (ROM) to give permanent storage for the operating system and fixed data used by the CPU.

2 Random-access memory (RAM) for the user's program.

3 Random-access memory (RAM) for data. This is where information is stored on the status of input and output devices and the values of timers and counters and other internal devices. The data RAM is sometimes referred to as a data table or register table. Part of this memory, i.e. a block of addresses, will be set aside for input and output addresses and the states of those inputs and outputs. Part will be set aside for preset data and part for storing counter values, timer values, etc.

4 Possibly, as a bolt-on extra module, erasable and programmable read-only-memory (EPROM) for ROMs that can be programmed and then the program made permanent.

The programs and data in RAM can be changed by the user. All PLCs will have some amount of RAM to store programs that have been developed by the user and program data. However, to prevent the loss of programs when the power supply is switched off, a battery is used in the PLC to maintain the RAM contents for a period of time. After a program has been developed in RAM it may be loaded into an EPROM memory chip, often a bolt-on module to the PLC, and so made permanent. In addition there are temporary buffer stores for the input/output channels. The storage capacity of a memory unit is determined by the number of binary words that it can store. Thus, if a memory size is 256 words then it can store 256* 8 = 2048 bits if 8-bit words are used and 256 □ 16 = 4096 bits if 16-bit words are used. Memory sizes are often specified in terms of the number of storage locations available with 1K representing the number 210, i.e. 1024. Manufacturers supply memory chips with the storage locations grouped in groups of 1, 4 and 8 bits. A 4K % 1 memory has 4 % 1 % 1024 bit locations. A 4K % 8 memory has 4 % 8 % 1024 bit locations. The term byte is used for a word of length 8 bits. Thus the 4K % 8 memory can store 4096 bytes. With a 16-bit address bus we can have 2 16 different addresses and so, with 8-bit words stored at each address, we can have 2 16 % 8 storage locations and so use a memory of size 216 % 8/210 = 64K % 8 which we might be as four 16K % 8 bit memory chips.

3.1.5 Input/output unit

The input/output unit provides the interface between the system and the outside world, allowing for connections to be made through input/output channels to input devices such as sensors and output devices such as motors and solenoids. It is also through the input/output unit that programs are entered from a program panel. Every input/output point has a unique address which can be used by the CPU. It is like a row of houses along a road, number 10 might be the 'house' to be used for an input from a particular sensor while number '45' might be the 'house' to be used for the output to a particular motor.The input/output channels provide isolation and signal conditioning functions so that sensors and actuators can often be directly connected to them without the need for other circuitry. Electrical isolation from the external world is usually by means of optoisolators (the term optocoupler is also often used). Figure 1.5 shows the principle of an optoisolator. When a digital pulse passes through the light-emitting diode, a pulse of infrared radiation is produced. This pulse is detected by the phototransistor and gives rise to a voltage in that circuit. The gap between the light-emitting diode and the phototransistor gives electrical isolation but the arrangement still allows for a digital pulse in one circuit to give rise to a digital pulse in another circuit.

Infrared radiation

Light-emitting diode

Photo-transistor

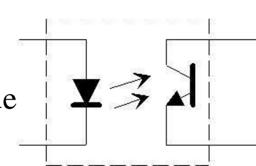

Figure 3.5 Optoisolator

3.1.6 Programming Procedure

As an introduction to ladder diagrams, consider the simple wiring diagram for an electrical circuit in Figure 3.6. The diagram shows the circuit for switching on or off an electric motor. We can redraw this diagram in a different way, using two vertical lines to represent the input power rails and stringing the rest of the circuit between them. Figure 3.10(b) shows the result. Both circuits have the switch in series with the motor and supplied with electrical power when the switch is closed. The circuit shown in Figure 3.10(b) is termed a *ladder diagram*.

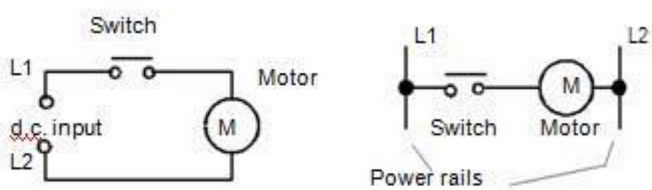

Figure 3.6 Ways of drawing the same electrical circuit

With such a diagram the power supply for the circuits is always shown as two vertical lines with the rest of the circuit as horizontal lines. The power lines, or rails as they are often termed, are like the vertical sides of a ladder with the horizontal circuit lines like the rungs of the ladder. The horizontal rungs show only the control portion of the circuit, in the case , it is just the switch in series with the motor. Circuit diagrams often show the relative physical location of the circuit components and how they are actually wired. With ladder diagrams no attempt is made to show the actual physical locations and the emphasis is on clearly showing how the control is exercised.

Figure 3.11 shows an example of a ladder diagram for a circuit that is used to start and stop a motor using push buttons. In the normal state, push button 1 is open and push button 2 closed. When button 1 is pressed, the motor circuit is completed and the motor starts. Also, the holding

contacts wired in parallel with the motor close and remain closed as long as the motor is running. Thus when the push button 1 is
released, the holding contacts maintain the circuit and hence the power to the motor. To stop the motor, button 2 is pressed. This disconnects the power to the motor and the holding contacts open. Thus when push button 2 is released, there is still no power to the motor. Thus we have a motor which is started by pressing button 1 and stopped by pressing button 2.

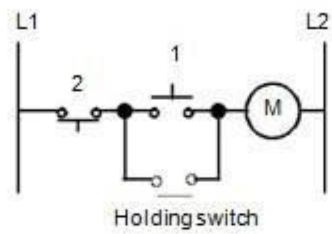

Figure 3.7 Stop-start switch

3.2 PLC ladder programming

A very commonly used method of programming PLCs is based on the use of *ladder diagrams*. Writing a program is then equivalent to drawing a switching circuit. The ladder diagram consists of two vertical lines representing the power rails. Circuits are connected as horizontal lines, i.e. the rungs of the ladder, between these two verticals.

In drawing a ladder diagram, certain conventions are adopted:

1 The vertical lines of the diagram represent the power rails between which circuits are connected.

2 Each rung on the ladder defines one operation in the control process.

3 A ladder diagram is read from left to right and from top to bottom, Figure 1.12 showing the scanning motion employed by the PLC. The top rung is read from left to right. Then the second rung down is read from left to right and so on. When the PLC is in its run mode, it goes through the entire ladder program to the end, the end rung of the program being clearly

denoted, and then promptly resumes at the start This procedure of going through all the rungs of the program is termed a cycle. The end rung might be indicated by a block with the word END or RET for return, since the program promptly returns to its beginning.

4 Each rung must start with an input or inputs and must end with at least one output. The term input

is used for a control action, such as closing the contacts of a switch, used as an input to the PLC. The term output is used for a device connected to the output of a PLC, e.g. a motor.

5 Electrical devices are shown in their normal condition. Thus a switch which is normally open

until some object closes it, is shown as open on the ladder diagram. A switch that is normally closed is shown closed.

6 A particular device can appear in more than one rung of a ladder. For example, we might have a

relay which switches on one or more devices. The same letters and/or numbers are used to label the device in each situation.

7 The inputs and outputs are all identified by their addresses, the notation used depending on the PLC manufacturer. This is the address of the input or output in the memory of the PLC

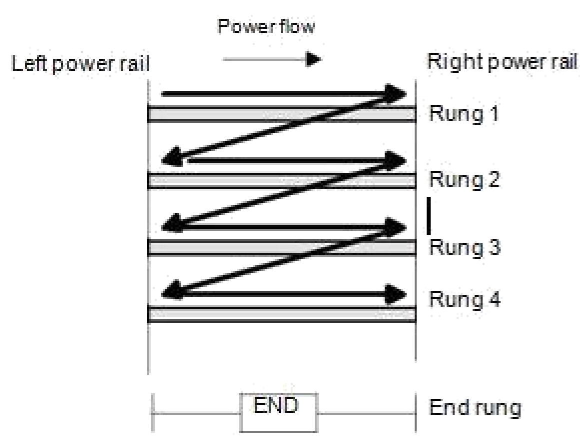

Figure 3.8 scanning the ladder program

Figure 3.8 shows standard IEC 1131-3 symbols that are used for input and output devices. Some slight variations occur between the symbols when used in semi-graphic form and when in full graphic. Note that inputs are represented by different symbols representing normally open or normally closed contacts. The action of the input is equivalent to opening or closing a switch. Output coils are represented by just one form of symbol. Further symbols will be introduced in later chapters.

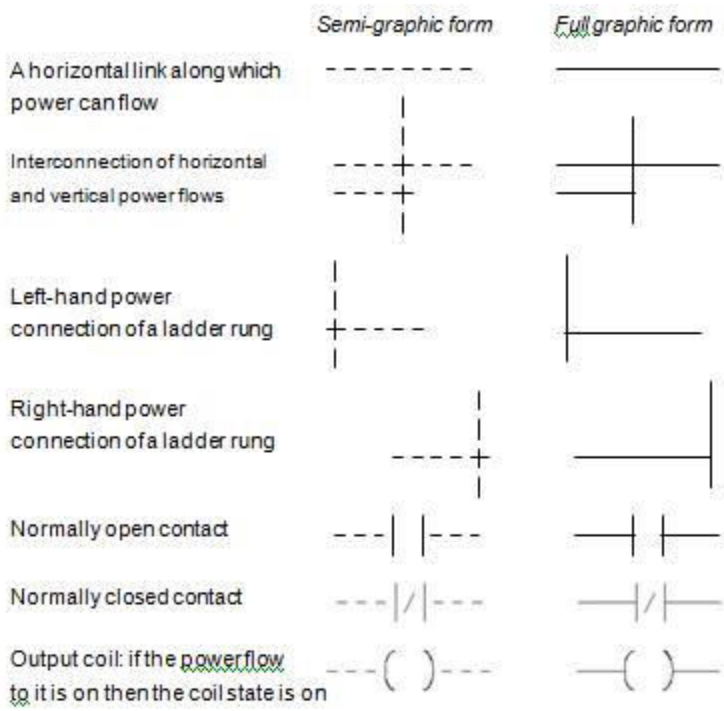

Figure 3.9 Basic symbols

To illustrate the drawing of the rung of a ladder diagram, consider a situation where the energising of an output device, e.g. a motor, depends on a normally open start switch being activated by being closed. The input is thus the switch and the output the motor. Figure 1.14(a) shows the ladder diagram.

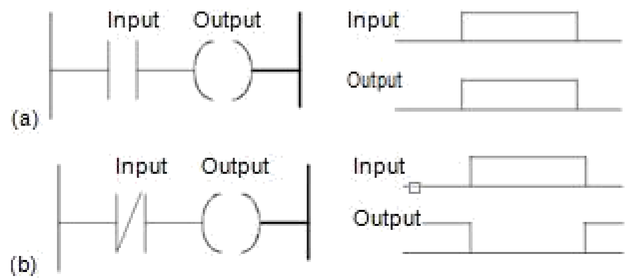

Figure 3.10 A ladder rung

Starting with the input, we have the normally open symbol | | for the input contacts. There are no other input devices and the line terminates with the output, denoted by the symbol ( ). When the switch is closed, i.e. there is an input, the output of the motor is activated. Only while there is an input to the contacts is there an output. If there had been a normally closed switch |/| with the output (Figure 3.14(b)), then there would have been an output until that switch was opened. Only while there is no input to the contacts is there an output.

In drawing ladder diagrams the names of the associated variable or addresses of each element are appended to its symbol. Thus Figure 3.15 shows how the ladder diagram would appear using (a) Mitsubishi, (b) Siemens, (c) Allen-Bradley, (d) Telemecanique notations for the addresses. Thus Figure 3.11(a) indicates that this rung of the ladder program has an input from address X400 and an output to address Y430. When wiring up the inputs and outputs to the PLC, the relevant ones must be connected to the input and output terminals with these addresses.

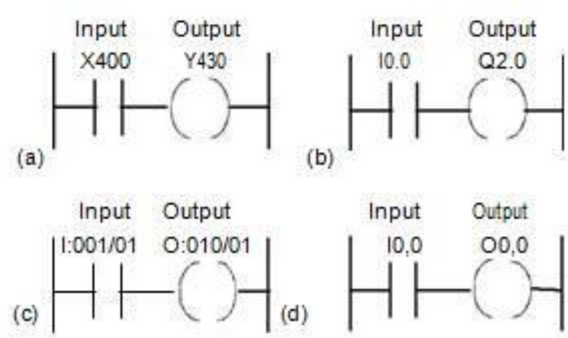

Figure 3.11 Notation: (a) Mitsubishi, (b) Siemens, (c) Allen-Bradley, (d) Telemecanique

3.3 Logic functions

There are many control situations requiring actions to be initiated when a certain combination of conditions is realised. Thus, for an automatic drilling machine , there might be the condition that the drill motor is to be activated when the limit switches are activated that indicate the presence of the workpiece and the drill position as being at the surface of the workpiece. Such a situation involves the AND logic function, condition A and condition B having both to be realised for an output to occur. This section is a consideration of such logic functions.

3.3.1 AND

Figure 3.12(a) shows a situation where an output is not energised unless two, normally open, switches are both closed. Switch A and switch B have both to be closed, which thus gives an AND logic situation. We can think of this as representing a control system with two inputs A and B (Figure 3.12(b)). Only when A and B are both on is there an output. Thus if we use 1 to indicate an on signal and 0 to represent an off signal, then for there to be a 1 output we must have A and B both 1. Such an operation is said to be controlled by a logic gate and the relationship between the inputs to a logic gate and the outputs is tabulated in a form known as a truth table. Thus for the AND gate we have:

Inputs A	Inputs B	Output
0	0	0
0	1	0
1	0	0
1	1	1

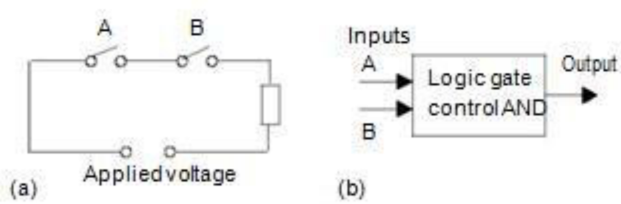

Figure 3.12 (a) AND circuit, (b) AND logic gate

An example of an AND gate is an interlock control system for a machine tool so that it can only be operated when the safety guard is in position and the power switched on.

Figure 3.13(a) shows an AND gate system on a ladder diagram. The ladder diagram starts with | |, a normally open set of contacts labelled input A, to represent switch A and in series with it | |, another normally open set of contacts labelled input B, to represent switch B. The line then terminates with O to represent the output. For there to be an output, both input A and input B have to occur, i.e. input A and input B contacts have to be closed (Figure 3.13(b)). In general:

On a ladder diagram contacts in a horizontal rung, i.e. contacts in series, represent the logical *AND operations*.

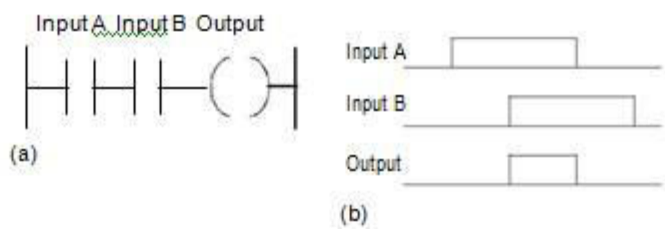

Figure 3.13 AND gate with a ladder diagram rung

3.3.2 OR

Figure 3.18(a) shows an electrical circuit where an output is energised when switch A <u>or</u> B, both normally open, are closed. This describes an OR logic gate (Figure 1.18(b)) in that input A <u>or</u> input B must be on for there to be an output. The truth table is:

Inputs		Output
A	B	
0	0	0
0	1	1
1	0	1
1	1	1

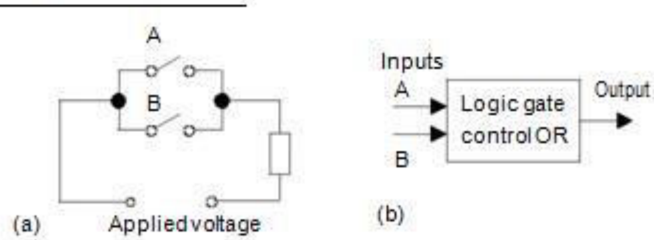

Figure 3.14 (a) OR electrical circuit, (b) OR logic gate

Figure 3.14 (a) shows an OR logic gate system on a ladder diagram. The ladder diagram starts with | |, normally open contacts labelled input A, to represent switch A and in parallel with it | |, normally open contacts labelled input B, to represent switch B. Either input A or input B have to be closed for the output to be energised (Figure 3.14(b)). The line then terminates with O to represent the output. In general:

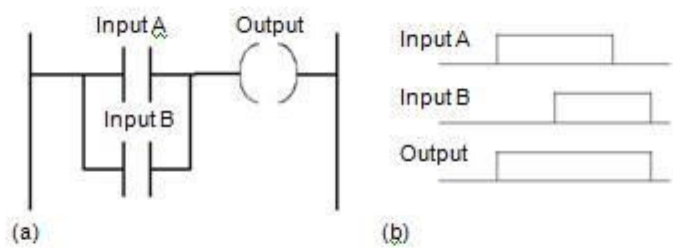

Figure 3.15 OR gate

3.3.3 NOT

Figure 3.16 (a) shows an electrical circuit controlled by a switch that is normally closed. When there is an input to the switch, it opens and there is then no current in the circuit. This illustrates a NOT gate in that there is an output when there is no input and no output when there is an input (Figure 3.16 (c)). The gate is
sometimes referred to as an *inverter*. The truth table is:

Input A	Output
0	1
1	0

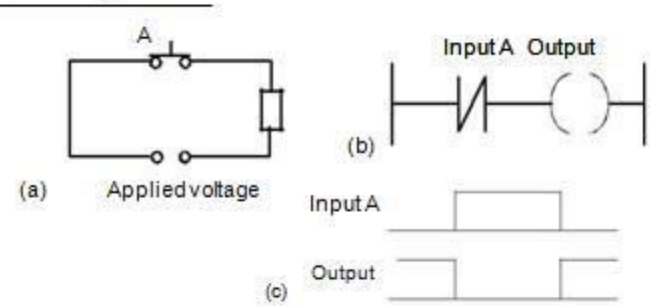

Figure 3.16 (a) NOT circuit, (b) NOT logic with a ladder rung, (c) high output when no input to A

Figure 3.16 (b) shows a NOT gate system on a ladder diagram. The input A contacts are shown as being normally closed. This is in series with the output ( ). With no input to input A, the contacts are closed and so there is an output. When there is an input to input A, it opens and there is then no output.

An example of a NOT gate control system is a light that comes on when it becomes dark, i.e. when there is no light input to the light sensor there is an output.

3.3.4 NAND

Suppose we follow an AND gate with a NOT gate (Figure 1.21(a)). The consequence of having the NOT gate is to invert all the outputs from the AND gate. An alternative, which gives exactly the same results, is to put a NOT gate on each input and then follow that with OR (Figure 1.21(b)). The same truth table occurs, namely:

Inputs		Output
A	B	
0	0	1
0	1	1
1	0	1
1	1	0

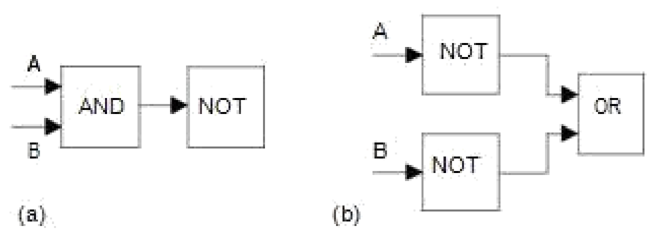

Figure 3.17 NAND gate

Both the inputs A and B have to be 0 for there to be a 1 output. There is an output when input A and input B are not 1. The combination of these gates is termed a NAND gate.

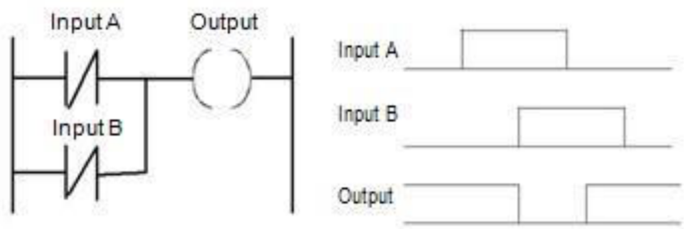

Figure 3.18 A NAND gate

Figure 3.21 shows a ladder diagram which gives a NAND gate. When the inputs to input A and input B are both 0 then the output is 1. When the inputs to input A and input B are both 1, or one is 0 and the other 1, then the output is 0. An example of a NAND gate control system is a warning light that comes on if, with a machine tool, the safety guard switch has not been activated and the limit switch signalling the presence of the workpiece has not been activated. Suppose we follow an OR gate by a NOT gate (Figure 3.22(a)). The consequence of having the NOT gate is to invert the outputs of the OR gate. An alternative, which gives exactly the same results, is to put a NOT gate on each input and then an AND gate for the resulting inverted inputs (Figure 3.22(b)). The following is the resulting truth table:

Inputs		Output
A	B	
0	0	1
0	1	0
1	0	0
1	1	0

The combination of OR and NOT gates is termed a NOR gate. There is an output when neither input A or input B is 1.

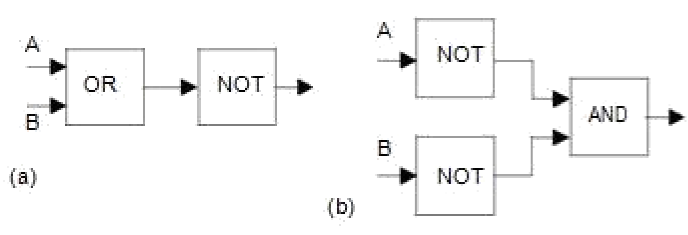

Figure 3.19 NOR gate

Figure 3.23 shows a ladder diagram of a NOR system. When input A and input B are both not activated, there is a 1 output. When either X400 or X401 are 1 there is a 0 output.

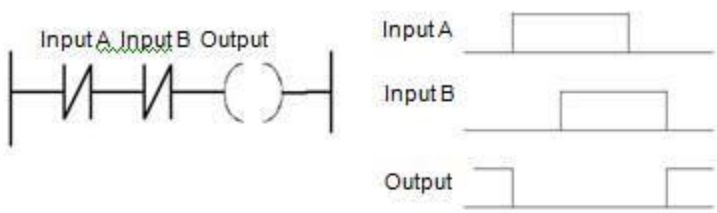

Figure 3.20 NOR gate

3.3.5 Exclusive OR (XOR)

The OR gate gives an output when either or both of the inputs are 1. Sometimes there is, however, a need for a gate that gives an output when either of the inputs is 1 but not when both are 1, i.e. has the truth table:

Inputs		Output
A	B	
0	0	0
0	1	1
1	0	1
1	1	0

Such a gate is called an *Exclusive* OR or XOR gate. One way of obtaining such a gate is by using NOT, AND and OR gates as shown in Figure 3.20

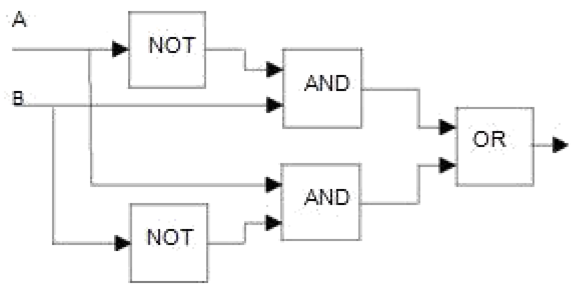

Figure 3.21 ***XOR gate***

Figure 3.21 shows a ladder diagram for an XOR gate system. When input A and input B are not activated then there is 0 output. When just input A is activated, then the upper branch results in the output being 1. When just input B is activated, then the lower branch results in the output being 1. When both input A and input B are activated, there is no output. In this example of a logic gate, input A and input B have two sets of contacts in the circuits, one set being normally open and the other normally closed. With PLC programming, each input may have as many sets of contacts as necessary.

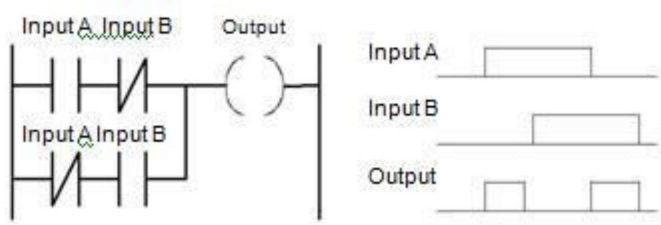

Figure 3.22 XOR gate

3.4 Latching

There are often situations where it is necessary to hold an output energised, even when the input ceases. A simple example of such a situation is a motor which is started by pressing a push button switch. Though the switch contacts do not remain closed, the motor is required to continue running until a stop push button switch is pressed. The term latch circuit is used for the circuit used to carry out such an operation. It is a self-maintaining circuit in that, after being energised, it maintains that state until another input is received.

An example of a latch circuit is shown in Figure3.23 When the input A contacts close, there is an output. However, when there is an output, another set of contacts associated with the output closes. These contacts form an OR logic gate system with the input contacts. Thus, even if the input A opens, the circuit will still maintain the output energised. The only way to release the output is by operating the normally closed contact B.

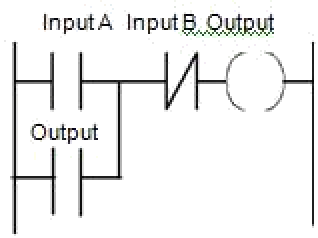

Figure 3.23 Latched circuits

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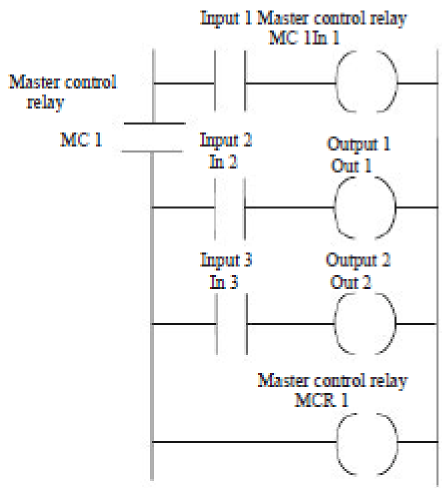
UNIT – IV – PLC INTERMEDIATE FUNCTIONS – SMRA 1401

4.1 MASTER CONTROL RELAY

When large numbers of outputs have to be controlled, it is sometimes necessary for whole sections of ladder diagrams to be turned on or off when certain criteria are realized. This could be achieved by including the contacts of the same internal relay in each of the rungs so that its operation affects all of them. An alternative is to use a master control relay.

Figure illustrates the use of such a relay to control a section of a ladder program.



Principle of use of a master control relay.

Fig 4.1 Principle of use of Master control relay

With no input to input In 1, the output internal relay MC 1 is not energized, and so its contacts are open. This means that all the rungs between where it is designated to operate and the rung on which its reset MCR or another master control relay is located are switched off.

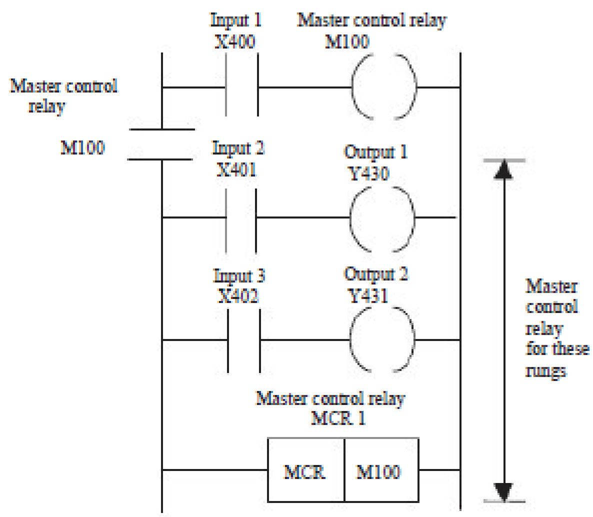
Assuming that it is designated to operate from its own rung, we can imagine it to be located in the power line in the position shown, and so rungs 2 and 3 are off. When input

In 1 contacts close, the master relay MC 1 is energized. When this happens, all the rungs between it and the rung with its reset MCR 1 are switched on. Thus outputs Out 1 and Out 2 cannot be switched on by inputs In 2 and In 3 until the master control relay has been switched on. The master control relay MC 1 acts only over the region between the rung it is designated to operate from and the rung on which MCR 1 is located. With a Mitsubishi PLC, an internal relay can be designated as a master control relay by programming it accordingly. Thus to program an internal relay M100 to act as a master control relay, the program instruction is:MC M100

To program the resetting of that relay, the program instruction is: MCR M100

Thus for the ladder diagram shown in Figure which is Figure with Mitsubishi addresses, the program instructions are:

LD X400 OUT M100 MC M100 LD X401 OUT Y430 LD X402 OUT Y431 MC M100

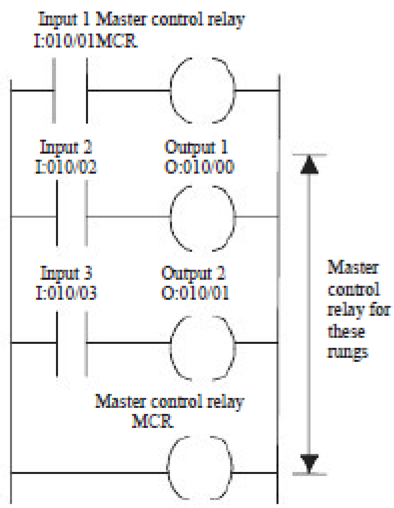


MCR with Mitsubishi PLC.

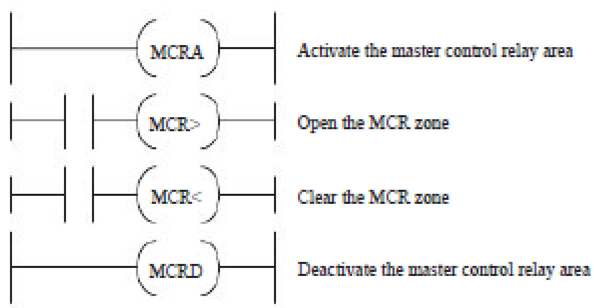
Figure 4.2 MCR with Mitsubishi PLC

Figure shows the format used by Allen-Bradley. To end the control of one master control relay (MCR), a second master control relay (MCR) is used with no contacts or logic preceding it. It is said to be programmed unconditionally.

The representation used for MCRs in Siemens ladder programs is shown in Figure.



An MCR with Allen-Bradley PLC.



Siemens representation of master control relays.

Fig 4.3 Master control relays

An area in which an MCR is to operate is defined by the activate master control area and deactivate master control relay functions. Within that area, the MCR is enabled when the MCR> coil is activated and disabled when the MCR< coil is enabled.

A program might use a number of MCRs, enabling various sections of a ladder program to be switched in or out. Figure shows a ladder program in Mitsubishi format involving two MCRs. With M100 switched on but M101 off, the sequence is: rungs 1, 3, 4, 6, and so on.

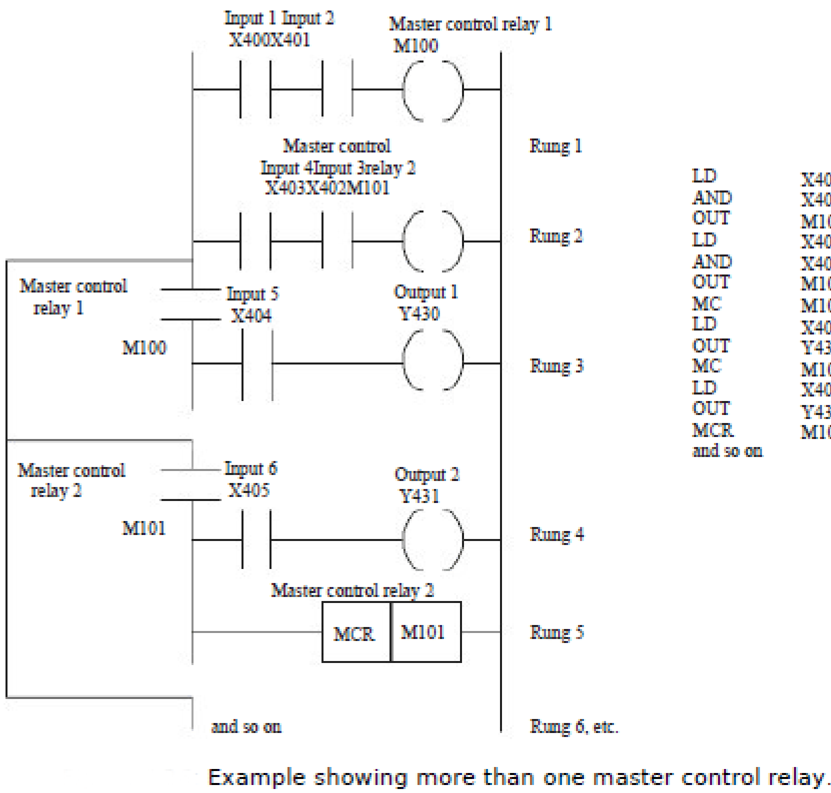


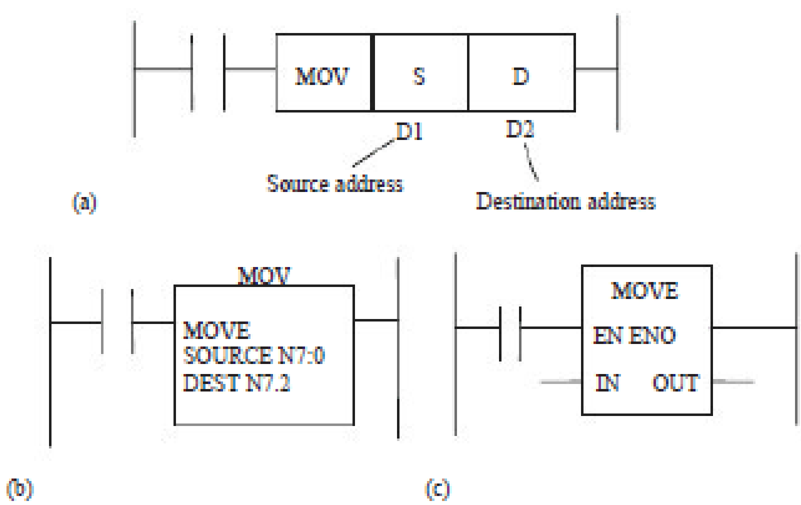
Fig 4.4 More than one MCR

The end of the M100 controlled section is indicated by the occurrence of the other MCR, M101. With M101 switched on but M100 off, the sequence is: rungs 2, 4, 5, 6, and so on. The end of this section is indicated by the presence of the reset. This reset has to be used since the rung is not followed immediately by another MCR. Such an arrangement could be used to switch on one set of ladder rungs if one type of input occurs and another set of ladder rungs if a different input occurs.

4.2 DATA MOVEMENT

The structured text program entry for a MOVE operation is :- with the destination address given first and then after :- the value to be moved to the destination, i.e.With ladder programs, Figure 12.2 illustrates a common practice of using one rung of a ladder program for each move operation, showing the form used by three manufacturers, Mitsubishi, Allen-Bradley, and Siemens. For the rung shown, when there is an input to | | in the rung, the

Data transfers might be to move a preset value to a timer or counter, or a time or counter value to some register for storage, or data from an input to a register or a register to output. Figure 12.3 shows the rung, in the Allen-Bradley format, that might be used to transfer a number held at address N7:0 to the preset of timer T4:6 when the input conditions for that rung are met. A data transfer from the accumulated value in a counter to a register would have a source address of the form C5:18.ACC and a destination address of the form N7:0. A data transfer from an input to a register might have a source address of the form I:012 and a destination address of the form N7:0. A data transfer from a register to an output might have a source address of the form N7:0 and a destination address of the form O:030.



Data movement: (a) Mitsubishi, (b) Allen-Bradley, and (c) Siemens.

Fig 4.5 Data Handling

4.4 TIMERS

PLC timers are instructions that provide the same functions as on-delay and off-delay mechanical and electronic timing relays. A PLC timer provides a preset delay to the control actions.

In general, there are three types of PLC timer delays, ON-delay timer, OFF-delay timer and retentive timer on.

The terms represented in the timer block in the PLC are a Preset value which means the delay period of the timer, an Accumulated value which is the current delay of the timer.

A timer begins the counting on time-based intervals and continues until the accumulated value equals the preset value. When the accumulated value equals the preset time the output will be energized. Then the timer sets the output.

4.5.1 TON timer or ON delay timer

An ON delay timer is used where we need a time delay before the time delay before an instruction becomes true.

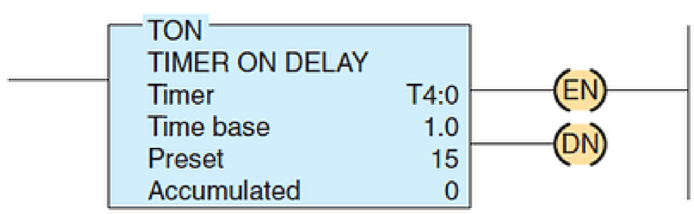


Fig 4.6 Basic Timer Circuit

A representation TON timer is shown above, which contains, *Timer number:* The timer file name *Time base:* which is shown in seconds, *Preset value:* Numeric valve set as the delay required to the timer. *Accumalated value:* The values are counting is displayed from zero. Value becomes zero whenever the timer is reset

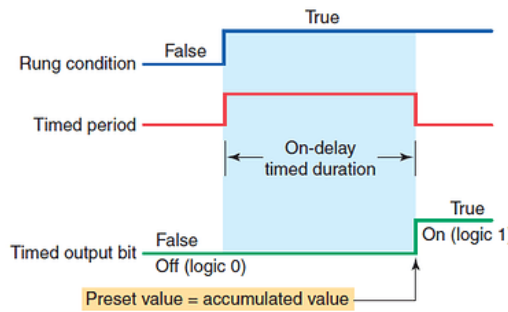


Fig 4.7 Timer Output

- The timer starts operating when the rung condition becomes true. The timer delay starts counting when the rung condition starts to accumulate.
- When the Preset value becomes equal to the accumulated value, the output is made true.
- The timed output becomes true sometime after the timer rung becomes true; hence, the timer is said to have an on-delay.
- The length of the delay can be adjusted by setting the preset value.

*4.5.2 TOFF timer or OFF delay timer***:**

A TOFF timer will keep the output energized for a preset time after the rung signal has gone false.

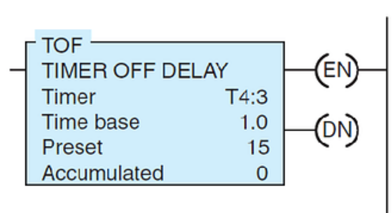


Fig 4.8 Timers

The TOFF timer will have all the contents as in the TON timer, with the similar function.

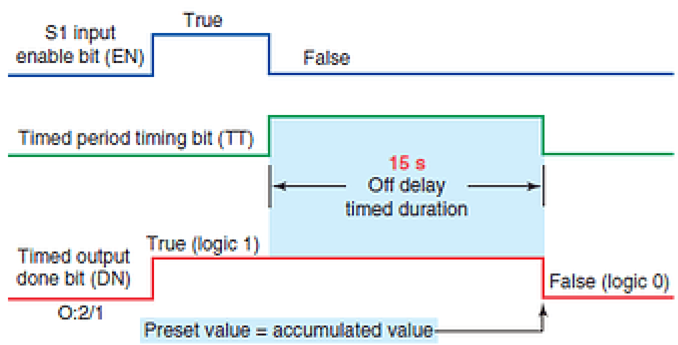


Fig 4.9 Timers Output

When the rung timer is true, the output will be true without any delay. When the rung signal becomes false the timer starts operating.

- The timer starts accumulating times when the rung condition becomes true, until the accumulated value becomes equal to the Preset value.
- The output turns off when the output will turn false when the accumulated value equals the preset value.

4.5.3 Retentive timer:

A retentive timer is used when you want to retain accumulated time value through the power loss or the change in the rung state.

A retentive timer accumulates time whenever the device receives power, and it maintains the current time should power be removed from the device

Loss of power to the timer after reaching its preset value does not affect the state of the contacts. The retentive timer must be intentionally reset with a separate signal for the accumulated time to be reset

An example logic is shown above.

- When the push bottom PB1 is pressed, the timer starts working and the reading starts accumulating.
- When we push the PB1 button then rung become false and the timer stops working. Consider we are switching ON the push after a time, the timer starts counting from the previous value before the timer is stopped.
- We have to add another switch PB2 to reset the values in the timers.

4.6 COUNTERS

A **counter** is a PLC instruction that either increments (counts up) or decrements (counts down) an integer number value when prompted by the transition of a bit from 0 to 1 (“false” to “true”).

4.6.1 Counter instructions come in three basic types:

1. up counters,
2. down counters, and
3. up/down counters.

Both “up” and “down” counter instructions have single inputs for triggering counts, whereas “up/down” counters have two trigger inputs: one to make the counter increment and one to make the counter decrement.

4.6.2 PLC Counter Instructions

To illustrate the use of a counter instruction, we will analyze a PLC-based system designed to count objects as they pass down a conveyor belt:

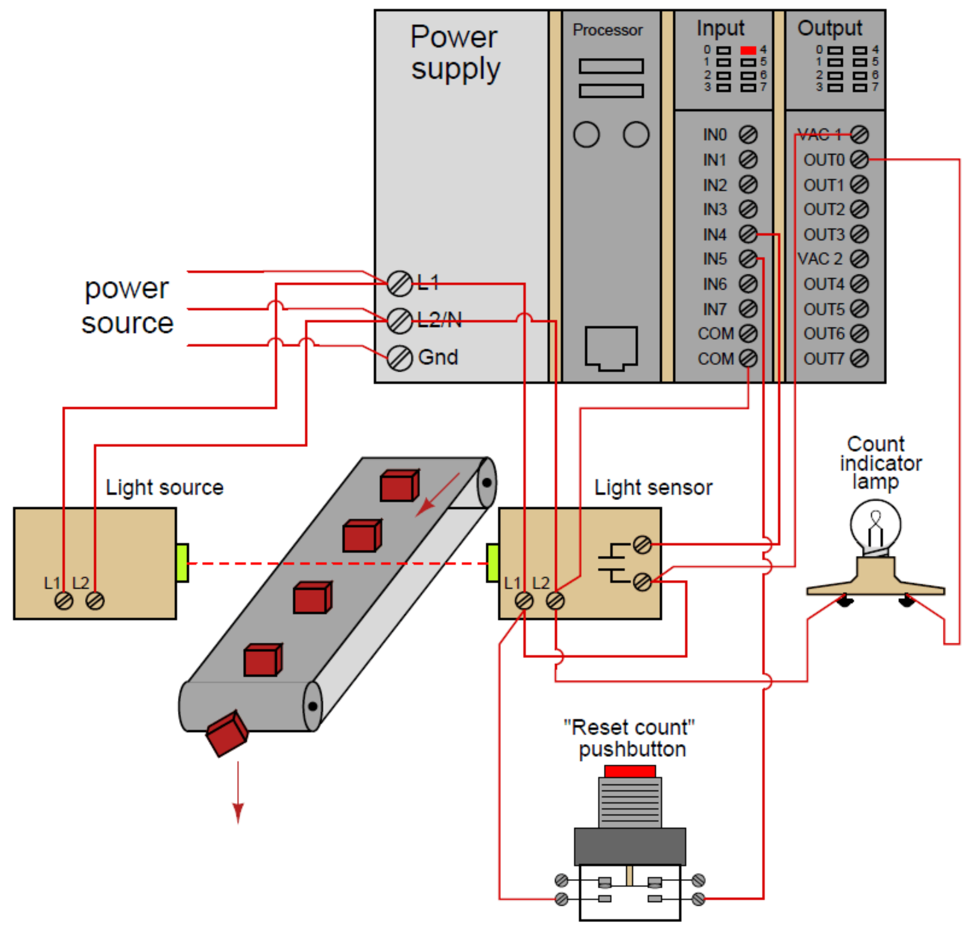


Fig 4.10 Counters Assembly

In this system, a continuous (unbroken) light beam causes the light sensor to close its output contact, energizing discrete channel IN4.

When an object on the conveyor belt interrupts the light beam from source to sensor, the sensor's contact opens, interrupting power to input IN4.

A push-button switch connected to activate discrete input IN5 when pressed will serve as a manual "reset" of the count value.

An indicator lamp connected to one of the discrete output channels will serve as an indicator of when the object count value has exceeded some pre-set limit.

We will now analyze a simple Ladder Diagram program designed to increment a counter instruction each time the light beam breaks.

4.7 SHIFT REGISTERS

The Shift Register (SR) instruction shifts data through a predefined number of BIT locations. These BIT locations can be a range of BITs, a single Word or DWord, or a range of Words or DWords. The instruction has three inputs. Data, Clock and Reset. The data input will load the beginning bit with a '1' if it is on or '0' if it is not. The clock input is used to shift the data through the shift register. In our example, we will be using the encoder on the conveyor to track the reject container. So each pulse of the clock represents a distance on the conveyor. The last input is the reset. It will place '0' in all of the bits within the shift register.

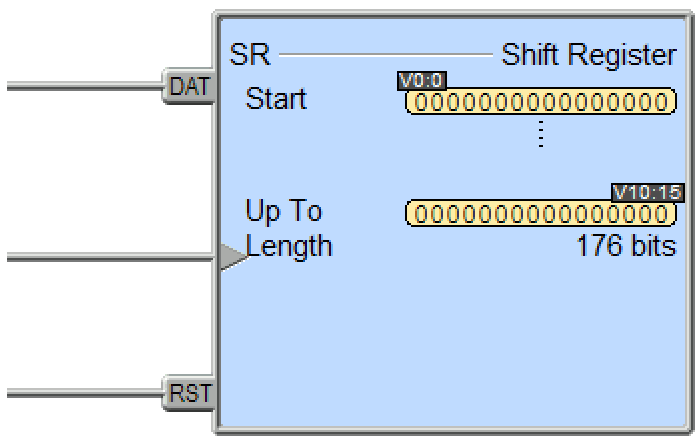


Fig 4.11 Shift Registers

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DEPARTMENT OF MECHANICAL ENGINEERING

UNIT – V –APPLICATIONS OF PLC – SMRA 1401

5.1 Field Bus and HART Protocol

Field bus: Introduction ,Concept of Field bus technology and layers, International field bus standards,
Field bus for use in industrial control, HART protocol: method of operation, Structure of HART protocol, Operating conditions , Industrial Applications.

5.1.1 HART Communication Protocol

HART (Highway Addressable Remote Transducer) is a smart (intelligent) instrumentation protocol provides digital communication to analog process control instruments. It is designed for applications where actual data is collected from instruments, sensors, and actuators by digital communication techniques. It was the first bi-directional digital communication scheme for process transmitters that didn't disturb the analog signal. The process could be left running during communication.
The range of HART applications is broadened due to the recent HART development, the Device Description Language (DDL), provides a universal software interface to new and existing devices.

5.1.2 HART in a Process Control system

In a process control system the function of process transmitter is to transmit the changes in the process variable in terms of 4-20mA signal to the controller. The controller detects this current variation by measuring the voltage across the current sense resistor.

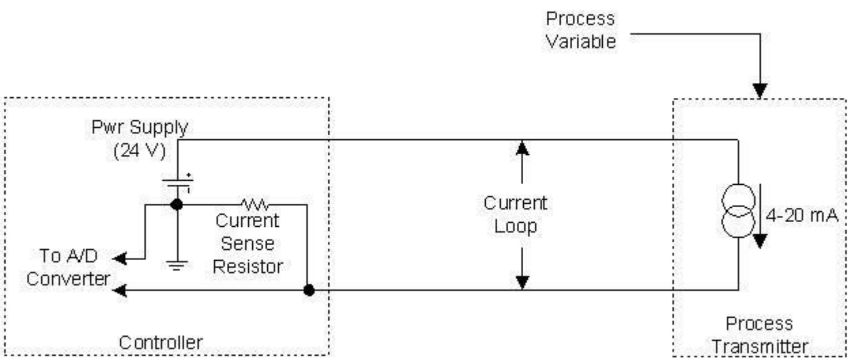
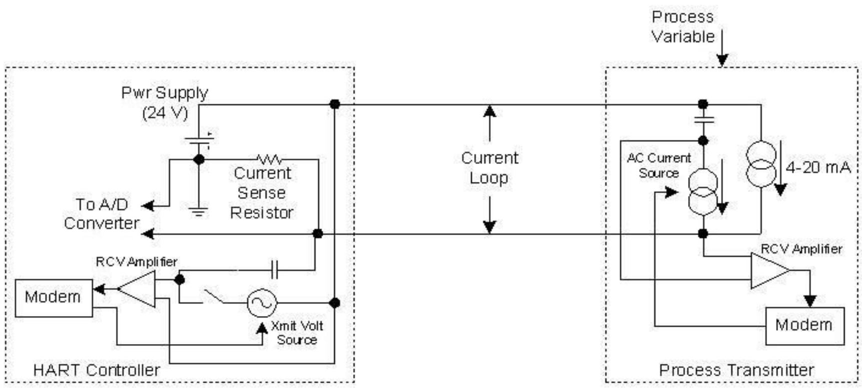


Figure 5.1 Simple Process Control Loop



Process Loop With HART Added

Figure 5.2 Process Control Loop with HART added

Figure above shows a process control system with HART added. Both the transmitter and the receiver has now include a “modem” and a "receive amplifier". The process transmitter also has an AC-coupled current source, and the controller an AC-coupled voltage source. The switch in series with the voltage source in the HART controller is normally open.

To send a HART message, the process transmitter turns ON its AC-coupled current source. When it is turned ON it superimposes a high-frequency carrier current of about 1 mA onto the normal transmitter output current. The current sense resistor at the controller converts this variation into a voltage. The voltage is sensed by the controller's receive amplifier and fed to the controller's modem which demodulates the signal. To send a HART message in the other direction ie., from the controller to the process transmitter, the HART Controller closes its transmit switch. This can be achieved by superimposing a voltage of about 500 mV to the controller signal.

The most important performance features of the HART protocol include:

- proven in practice, simple design, easy to maintain and operate
- compatible with conventional analog instrumentation
- simultaneous analog and digital communication
- option of point-to-point or multi-drop operation
- flexible data access via up to two master devices
- supports multivariable field devices
- sufficient response time of approx. 500 ms
- open de-facto standard freely available to any manufacturer

or user Devices which support the HART protocol is grouped into

- master (host) and
- slave (field) devices.

Master devices include handheld terminals as well as PC-based work places, e.g. in the control room. HART slave devices, on the other hand, include sensors, transmitters and various actuators.

The HART data is superimposed on the 4 to 20 mA signal via a FSK modem. This enables the devices to communicate digitally using the HART protocol, while analog signal transmission takes place at the same time HART communication is often used for such simple point-to-point connections.

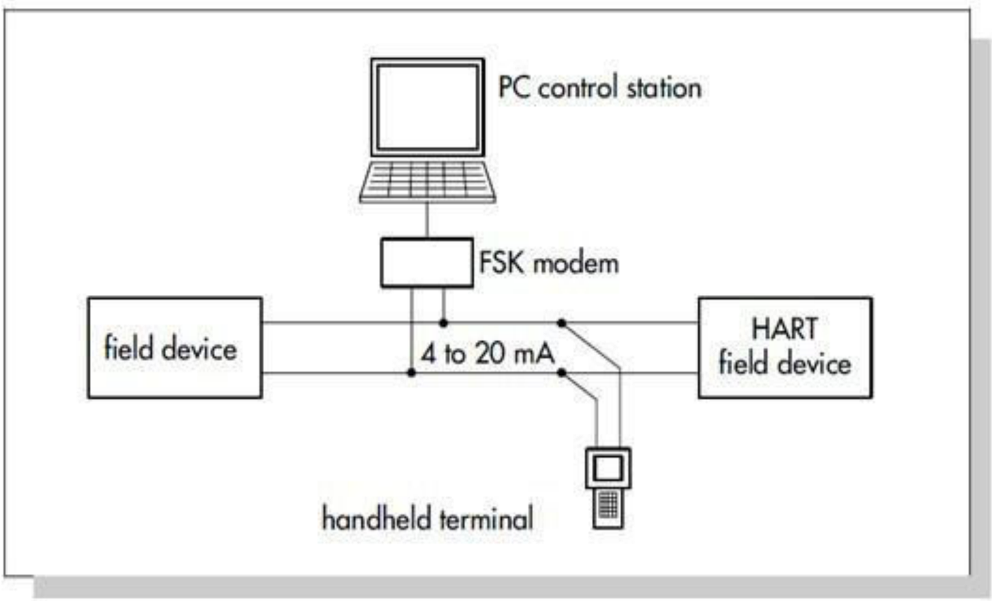


Figure 5.3 Connection of HART Devices

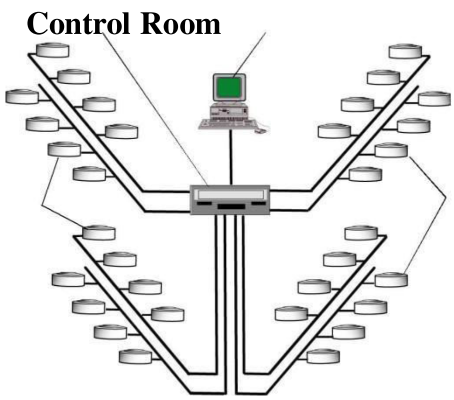
5.2 INDUSTRIAL APPLICATIONS OF HART PROTOCOL

5.2.1 Hart multidrop network for tank level and inventory management

Accurate measurements for inventory management are essential in all industries. The HART communication protocol enables companies to make sure inventory management is as efficient, accurate, and low cost as possible. Tank level and inventory management is an ideal application for a HART multidrop network . The HART network digital update rate of two PVs per second is sufficient for many tank-level applications. A multidrop network provides significant installation savings by reducing the amount of wiring from the field to the control room as well as the number of I/O channels required. In addition, many inexpensive process-monitoring applications are commercially available to further cut costs. A HART multiplexer is used to digitally scan field devices for level-measurement and status information. The information is forwarded to the host application using the Mod bus communication standard. Multivariable instruments further reduce costs by providing multiple process measurements, such as level and temperature, which reduces the wiring and number of process penetrations required.

5.2.2 MULTIDROP FOR TANK FARM MONITORING

In one tank farm application, 84 settlement tanks and filter beds on a very large site (over 300,000 m2) are monitored using HART multidrop networks. The HART architecture required just eight cable runs for 84 tanks, with 10–11 devices per run . Over 70 individual runs of over 500 m each were eliminated. Cable savings were estimated at over $40,000 when compared to a conventional installation. RTU I/O was also reduced, which resulted in additional hardware and installation savings. The total installed cost was approximately 50% of a traditional 4–20 mA installation.



Tank Farm Monitoring with Multidrop

Figure 5.4 Multi drop for tank farm monitoring

5.2.3 WASTEWATER TREATMENT PLANT UPGRADE

A Texas wastewater treatment plant replaced stand-alone flow meters and chart recorder outstations that required daily visits for totalization with a HART system. HART-based magnetic flow meters were multi dropped into HART RTUs to create a cost - effective SCADA network. The use of HART technology reduced system and cable costs, enhanced measurement accuracy, and eliminated time-consuming analog calibration procedures. A system of 11 HART multi drop networks was used to connect 45 magnetic flow meters from different plant areas. Each flow meter communicated flow rate and a totalized value over the HART network. Multi drop networks eliminated the need for additional hardware and PLC programming while providing a more accurate totalized value. Complex and costly system integration issues were also avoided—for example, there was no need for synchronization of totals between the host and field PLCs. Multi drop networking further reduced the installation cost by reducing the required number of input cards from the traditional 45 (for point -to-point installations) to 11. Maintenance was simplified because of access to instrument diagnostic and status data.

5.2.4 REMOTE REZEROING IN A BREWERY

The benefits of remote monitoring and rezeroing of smart transmitters using the HART protocol are dramatically illustrated in this example of two smart transmitters that control the fluid level in lauter tubs in a brewhouse application. Similar benefits would be realized in any application involving a closed vessel. Two smart transmitters are installed on each lauter tub—one on the bottom of the tank and the other about nine inches from the bottom. The bottom transmitter is ranged ±40 in
water; the upper transmitter is ranged 0–30 inH2O. As the lauter tub is filled, the bottom transmitter senses level based on pressure. When the level reaches the upper transmitter, that point is marked as the new zero-level point, and the upper transmitter becomes the primary sensing instrument for the lauter-tub level. The nine-inch zero-level offset from the bottom of the tank is necessary to accommodate loose grain that settles in the bottom of the tank.

Transmitters that are coordinated and working together control fluid level in each lauter tub to within a few barrels. However, the upper transmitter requires periodic maintenance or replacement and rezeroing. An undetected false upper-transmitter level reading can cause a tank level error of up to 40 gallons.The usual procedure for transmitter rezeroing takes about 95 minutes and has been required as frequently as twice a day. Rezeroing a transmitter using configuration software and PLC interface modules eliminates the need to locate and identify the problem at the site as well as the need for verification by control-room personnel and greatly reduces the chance for inadvertent errors. Estimated total time to rezero each transmitter is reduced to 15 minutes.Through the configuration software's instrument-status and diagnostic capabilities, a false level indication can be automatically detected while a lauter tub fill is in progress. The affected transmitter can then be automatically rezeroed by programming logic in the programmable controller to issue the appropriate command to the instrument.

5.3 FIELD BUS

5.3.1 Introduction to Fieldbus Systems

Fieldbus is consisting of two terms, Field and Bus [Fieldbus Introduction]. To start, the meaning of Field, as defined in industrial world, is a geographical or contextual limited area. From the industry point of view the Field is an abstraction of the plant levels. As for the term Bus is a well-known word in computer science as a set of common line that electrically (or even optically) connects various units (circuits) in order to transfer the data among them.

The origin of the fieldbus was to replace any point-to-point links between the field devices (Field Devices are simply the Sensors and Actuators of the plant) and their controllers (PLC's) by a digital single link on which all the information is transmitted serially and multiplexed in time. We will see that the fieldbus transfers, in most cases, this information in small-sized packets in serial manner. Choosing the serial transmission has many merits in comparison with other kinds of transmission like parallel transmission. For instance, the sequential or serial transmission reduces the total required number of the connecting lines over greater distances than that of the point-to-point or even parallel transmissions.

A set of rules must be defined in order to accomplish data transfer between the units along the bus. This set of rules is called Communication Protocol or just the Protocol. This is unlike the case of the ordinary point-to-point transmission where any two connected entities send and receive data from each other whenever the data is available. The protocol is responsible for two important rules on the bus, the mechanism that any unit can acquire or size the bus, and the synchronization between those multi-units on the bus.

5.3.2 Concept of Field bus technology and layers

The seven layers of the OSI model are

1- **Application layer** which provides the services that are required by specific applications.
2- **Presentation layer** is responsible for the data interpretation, which allows interoperability among different equipments.
3- **Session layer** is concerned with execution of any remote actions.
4- **Transport layer** is responsible for the end-to-end communication control.
5- **Network layer** is concerned with logical addressing process of nodes and routing schemes.
6- **Datalink layer** is responsible for the access to the communication medium, and for the logical transfer of the data.
7- **Physical layer** is concerned with the way that the communication is done.

Any communication system that is based on the OSI seven layers will provide higher flexibility and compatibility with products from different vendors. Modification to the **MAP** project was necessary as the node implementation become more complex in order to support all the services of the OSI reference model. The modification allowed the short length control data packets, which occurs at high rates, to be directly transmitted through the application layer to the data link layer. The resulting field bus is referred to as a 3-layered Architecture. These layers are: the Application layer, the Datalink layer, the Physical layer.

One may assume that the other four layers of the OSI model that are not available in the fieldbus hierarchy have disappeared along with their own functions and services. The main function of the presentation layer is to support the interoperability between different equipments which is currently done by the application layer in the field bus. The assembling and disassembling of data packets which was the function of the transport layer is done now by the datalink layer in the fieldbus network. If routers to be used in some fieldbus networks, then the routing service, which was assigned to the network layer, is done by the application layer in most cases in the fieldbus.

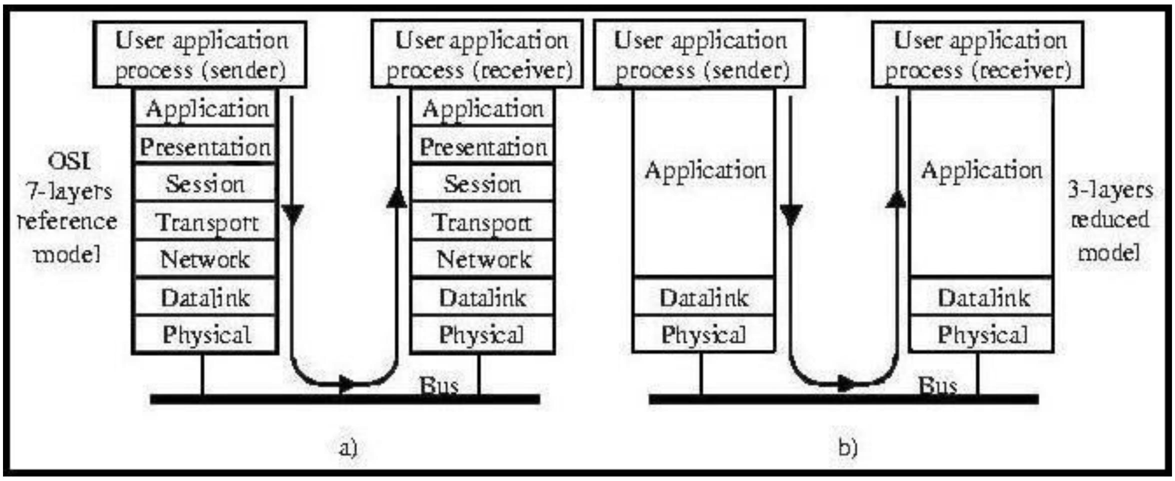


Figure 5.5 The OSI 7-layers reference model (a), and the reduced fieldbus 3-layer structure (b)

There are several protocols and services that are laid in the 3-layerd hierarchy of the fieldbus network. This will lead to a great difficulty in evaluating one and unique international fieldbus standard. There are several fieldbus protocols in the world. The designer of the DCCS communications system has multi -option solutions to fulfill his system requirements. These requirements are varied from one situation to another. In many situations the quality of services and the system throughput are the common requirements in all the DCCS systems. Also a fast response time is usually required by the real-time computer controlled networks designers.

5.3.4 Different Types of Fieldbuses

The fieldbus technology started at the early beginnings of the 80's in many countries. For example, the Factory Instrumentation Protocol (FIP), the Controller Area Network (CAN), and the Process Field Bus (PROFIBUS), the Process Network (P-NET) protocol, are all appeared in the same time period at the beginning of the 1980's.

5.3.5 CERN Recommendations on Fieldbuses

CERN is the European Organization that was established in 1954 to mainly serve the research of physics. But with the time passed the CERN became more interested in other aspects that may have some relationship with the physics. For example, the CERN involved in computer networking as the World Wide Web (**WWW**) was first developed at CERN in the beginnings of the 1990's.Now-a-days CERN is engaged in a large scale project of LHC experiments where fieldbuses is used to control and monitor the equipments of these LHC experiments. The working group finally found out that recommending one fieldbus may not satisfy all the users, so instead they had recommended three Fieldbuses. These are:

1- Controller Area Network (**CAN**).
2- Process Field Bus (**PROFIBUS**).
3- World Factory Instrumentation Protocol (**WorldFIP**).

5.3.6 Controller Area Network (CAN)

The **CAN** protocol is a priority-based bus network using a Carrier Sense Multiple Access with Collision Avoidance (**CSMA/CA**) medium access scheme. In this protocol any station can access the bus whenever it becomes idle. The collision resolution mechanism is very simple and is supported by the frame structure, or more specifically by its twelve leading bits, denoted as start bit and identifier fields. This identifier field serves for two different purposes. On one hand it is used to identify any message stream in a CAN network. Take for example a sequence of messages concerning the remote reading of a specific process variable. On the other hand, it is a priority field, which enables the collision resolution mechanism to schedule the contending messages.

This collision resolution mechanism in CAN works as follows: when the bus becomes idle, every station with pending messages will start to transmit. Due to its open-collector nature, the CAN bus acts as a big AND-gate, where each station is able to read the bus status. During the transmission of the identifier field, if a station is transmitting a "**1**" and reads a "**0**", it means that there was a collision with at least one higher-priority message, and this station aborts the message transmission at once. Thus the highest-priority message being transmitted will proceed without encountering any collision, and thus will be successfully transmitted to its destination. Obviously, each message stream must be uniquely identified.The collision resolution mechanism that is used by the CAN protocol imposes certain limitations to the bus length and its transmission data rate. For example, considering a bus length of 40m, the maximum data rate is 1Mbps.

5.3.7 Process Field Bus (PROFIBUS)

The ProfiBus communication model used to combine the distributed application processes into a common process, using communications relationships. All objects of a real device that can be communicated, such as variables, programs, data ranges are called communication objects. The process in a field device that is reachable for communication is called a virtual field device (VFD). The VFD contains the communication objects that may be manipulated by the services of the application layer.

The PROFIBUS protocol is based on a token passing procedure used by master stations to grant the bus access to each other, and a master-slave procedure used by master stations to communicate with slave stations. The PROFIBUS token passing procedure uses a simplified version of the Timed-token protocol. The medium access functions which are implemented at the layer-2 of the OSI reference model, is called Fieldbus Data Link (FDL). In addition to controlling the bus access and the token cycle time, the FDL is also responsible for the provision of data transmission services for the application layer. PROFIBUS supports four data transmission services which are: Send Data with No-Acknowledge (SDN); Send Data with Acknowledge (SDA); Request Data with Reply (RDR) and Send and Request Data (SRD). The SDN is an unacknowledged service used for broadcasts from a master station to all other stations on the bus. An important characteristic of other services is that they are immediately answered, with a response or an acknowledgement. This feature, also called "immediate-response", is particularly important for the real-time bus operation.

In addition to these services, industrial applications sometimes require the use of periodical transmission methods. A FDL-controlled polling method may be used to scan field devices, such as sensors or actuators.

5.3.8 World Factory Instrumentation Protocol (WorldFIP)

A WorldFIP network interconnects stations with two types; either a bus arbitration station or production/consumption stations. At any given time instant, only one station can be the bus arbitration station. Hence, in WorldFIP, the medium access control is centralized, and performed by the active bus arbitrator which is known as the BA. WorldFIP supports two basic types of transmission services: exchange of identified variables and exchange of messages. In WorldFIP, the exchange of identified variables is based on a Producer/Consumer model, which relates producers and consumers within a distributed system. In order to manage any transactions associated with a single variable, a unique identifier is associated with each variable. The WorldFIP Data Link Layer (DLL) is made up of a set of produced and consumed buffers, which can be locally accessed or remotely accessed through network services. In WorldFIP networks, the bus arbitrator table (BAT) regulates the scheduling of all buffer transfers. There are two types of buffer transfers that can be considered in WorldFIP. These are: periodic and aperiodic . The BAT imposes the schedule of the periodic buffer transfers, and also regulates the aperiodic buffer transfers in the times that there are no periodic buffer transactions.

5.3.9 Industrial application of field bus

In compliance with hazardous area requirements, such as low power and intrinsic safety, the use of the RS485 interface with its high transmission rates is also possible in and Ex zone. This intrinsically safe bus is obtained by using an RS485 IS Coupler. The SIEMENS Fieldbus isolating transformer provides this functionality, requires no programming, and has a repeater to amplify the signal data on the bus line. Figure 1 shows the various topologies possible with RS485 IS network.

In the MBP-IS version, this transmission technology is especially suitable for use in hazardous areas in Process Automation, and is therefore widely used in applications of the chemical, oil and gas industries. Explosion protection is implemented via limiting power in the incoming bus supply or more frequently in the installation components in the field. Working on field devices during active operation is made possible, for example, by means of intrinsically safe ignition protection. Linear and tree structures and combinations of both are thus possible. In practice, the "trunk & spur topology" (Fig 2) has established itself as the de-facto standard, as it is especially clear and well-laid-out.

5.4 Conveyor belt control

Consider a program that is used to count the number of items put onto a conveyor belt from work cells and give an alert when the number reaches 100. This program might be part of a bigger program used to control a production unit. A proximity sensor can be used to sense when an item is put on the conveyor so that each time a 1 signal is produced. The program might thus be as shown in Figure 14.16, the Allen-Bradley format being used.

A further possibility in the above conveyor belt problem is that too many items must not be put on the belt at any one time. A program that might achieve this is to institute a time delay after an item is put on the belt before the next item can be loaded onto the belt. Figure 14.17 shows the program elements for that. When an item passes the proximity sensor, the timer-on-delay is started and only when that is completed will a furtheritem be able to be loaded.

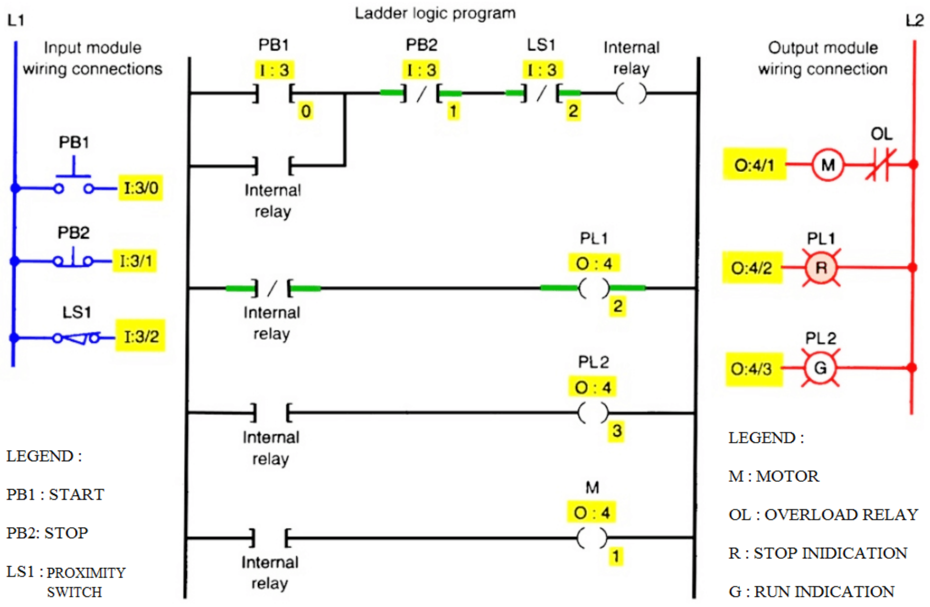


Fig 5.5 Conveyor Belt Control

Consider a production line problem involving a conveyor being used to transport bottles to a packaging unit, the items being loaded onto the conveyor, checked to ensure they are full, capped and then the correct number (4) of bottles being packed in a container. The required control actions are thus: if a bottle is not full the conveyor is stopped; activation of the capping machine when a bottle is at the required position, the conveyor being stopped during this time; count four bottles and activate the packing machine, the conveyor being stopped if another bottle comes to the packing point at that time; sound an alarm when the conveyor is stopped.

The detection of whether a bottle is full could be done with a photoelectric sensor which could then be used to activate a switch (X402/I0.2 input). The presence of a bottle for the capping machine could also be by means of a photoelectric sensor (X403/I0.3 input). The input to the counter to detect the four bottles could be also from a photoelectric sensor (X404/I0.4 input). The other inputs could be start (X400/I0.0 input) and stop (X401/I0.1 input) switches for the conveyor and a signal (X405/I0.5 input) from the packaging machine as to when it is operating, having got four bottles and so is not ready for any further caps.

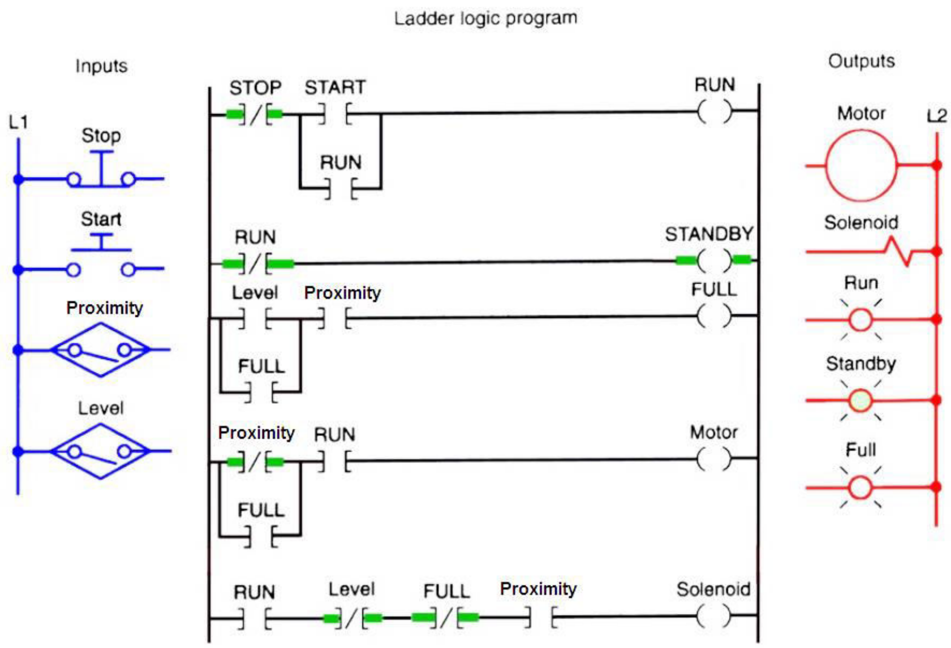


Fig 5.7 Bottle Packing program

5.5 Control of a process

The following is an illustration of the use of a sequential flow chart for programming. The process (Figure 5.8) involves two fluids filling two containers: when full their contents are then emptied into a mixing chamber, from where the mixture is then discharged. The whole process isthen repeated.

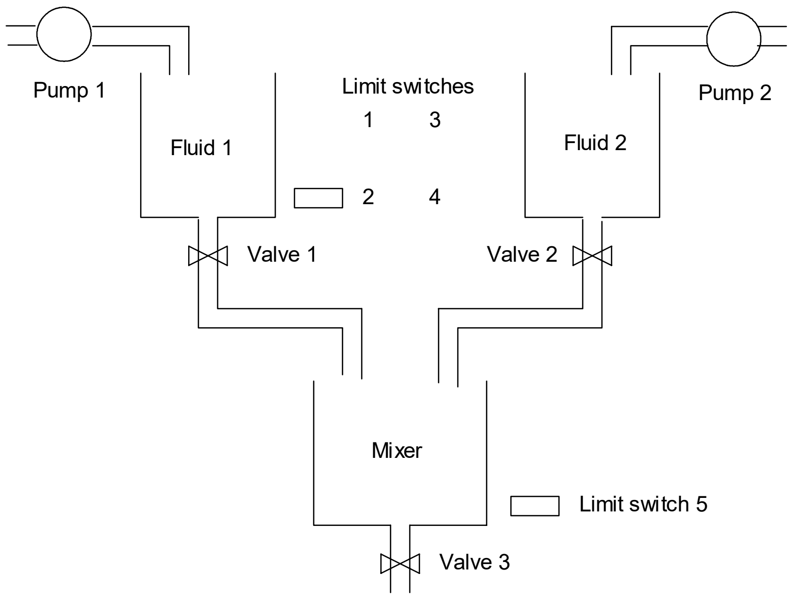


Figure 5.8 The mixing operation

Figure 5.8 shows the type of valve that might be used in such a process. It is solenoid operated to give flow through the valve and then, when the solenoid is not activated, a spring returns the valve to the closed position.

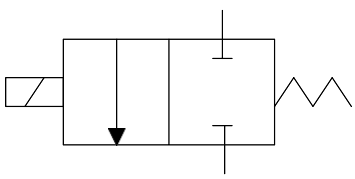


Figure 5.9 Valve

Figure 5.9 shows the sequential function chart program. When the start switch is activated, Fill 1 and Fill 2 occur simultaneously as a result of the actions of pumps 1 and 2 being switched on. When limit switch 1 is activated then Fill 1 ceases, likewise when limit switch 3 is activated Fill 2 ceases. We then have the containers for fluid 1 and fluid 2 full. The action that occurs when both limit switch 1 and 3 are activated is that the containers start to empty, the action being the opening of valves 1 and 2. When limit switches 2 and 4 are activated then the containers are empty. The next stage, the mixing of the liquids is then determined when limit switch 2 and limit switch 4 are both activated. After a time of 100 s the moxing ceases and the mixed liquids empty through valve 3. When limit switch 5 is activated the program reaches the end of its cycle and the entire sequence is then repeated.

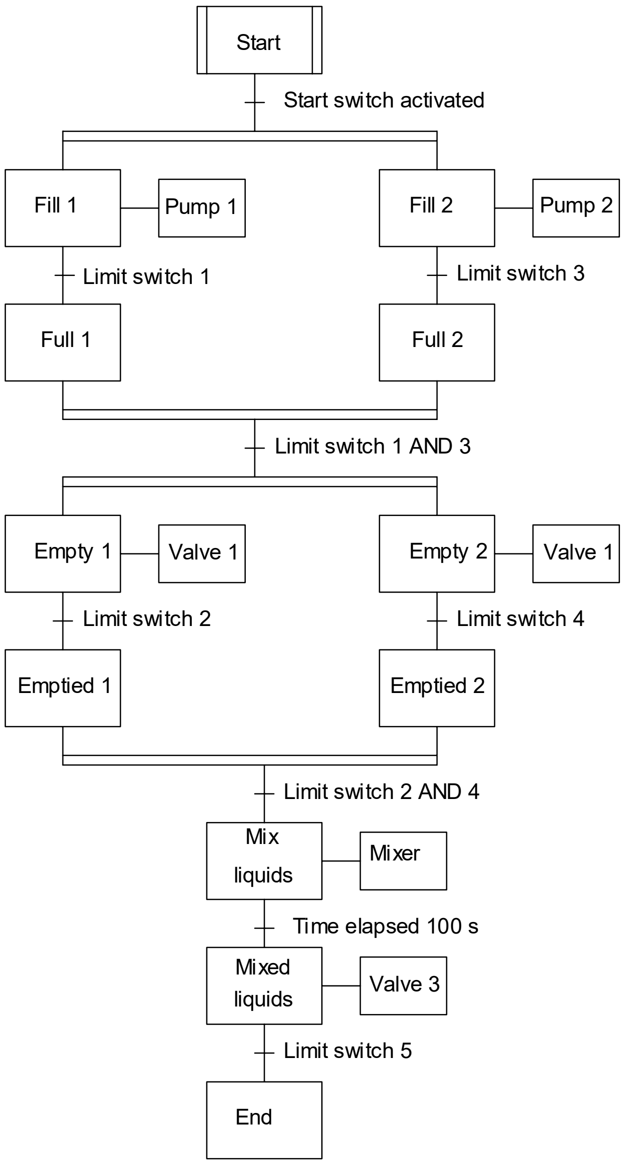


Figure 5.10 The mixing operation program