PROGRAMMABLE LOGIC CONTROLLERS

NQF LEVEL 3

OUTCOME 2
BASICS OF PLC TECHNOLOGY

This is set at the British Edexcel National level NQF 3

On completion of this tutorial you should be able to explain the criteria for selecting a PLC based on:

- The cost, versatility and scanning time
- The internal architecture
- The system hardware and software requirements
- The manufacturers' specification of input/output (I/O) units (digital and analogue)
- The power supply
- The use of operating system
- The configuration of inputs and outputs
- The input/output devices
- The mechanical switch relays (electromechanical and solid state)
- The transducers used in common applications

CONTENT

1. Introduction

The PLC has its origins in the motor manufacturing industries. Manufacturing processes were partially automated by the use of rigid control circuits, electrical, hydraulic and pneumatic. It was found that when ever a change had to be made, the system had to be rewired or reconfigured. The use of wiring boards on which connections could be changed by unplugging them and changing them around followed. With the development of micro-computers it was realised that if the computer could switch things on or off and respond to a pattern of inputs, then the changes could be made by simply reprogramming the computer and so the PLC was born.

There are still many applications of automated systems with permanent connections to perform a single control action. Often the system uses logic components to produce the correct action (electronic and pneumatic). The PLC mimics this process by performing the logical operations with the programme rather than with real components. In this way cost savings are produced as fewer components are needed and more flexibility is introduced as programmes can be changed more easily than reconfiguring a hard ware system. Programming is covered in Outcomes 2 and 3.

A Programmable Logic Controller is a mini computer specifically designed for industrial and other applications. Examples are:

- Automated machines (pneumatic, hydraulic and electric actuators).
- Robots (e.g. for assembly work, paint spraying, welding and so on).
- Production processes (e.g. machine tools).
- Signalling systems (e.g. traffic lights).
- Process Control (e.g. sugar refining and power stations).

2. *Architecture and Terminology*

The PLC activates its output terminals in order to switch things on or off. The decision to activate an output is based on the status of the system's feed-back sensors and these are connected to the input terminals of the PLC. The decisions are based on logic programmes stored in the RAM and/or ROM memory. They have a central processing unit (CPU), data bus and address bus. A typical unitary PLC is shown below.

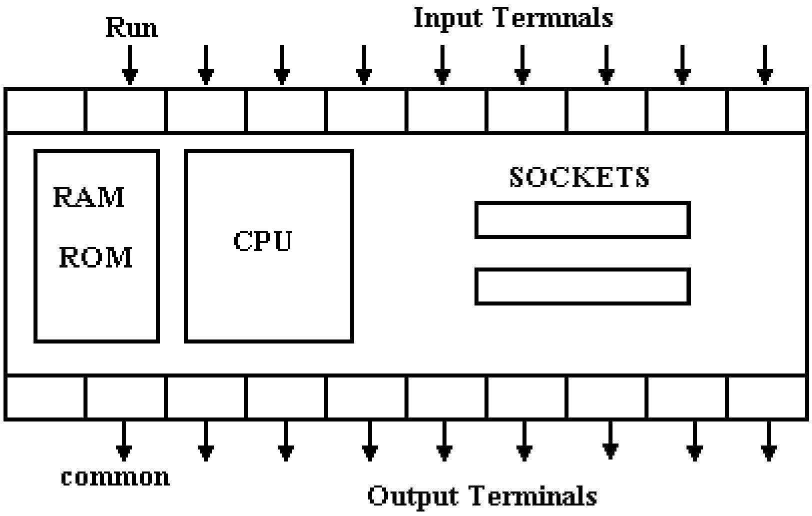

Figure 1

The next diagram shows a very oversimplified diagram of the structure. The Central processing Unit controls everything according to a programme stored in the memory (RAM or ROM). Everything is interconnected by two busses, the address bus and the data bus (shown as a single red line). The system must be able to communicate with external devices such as programmers, display monitors and Analogue/Digital converters.

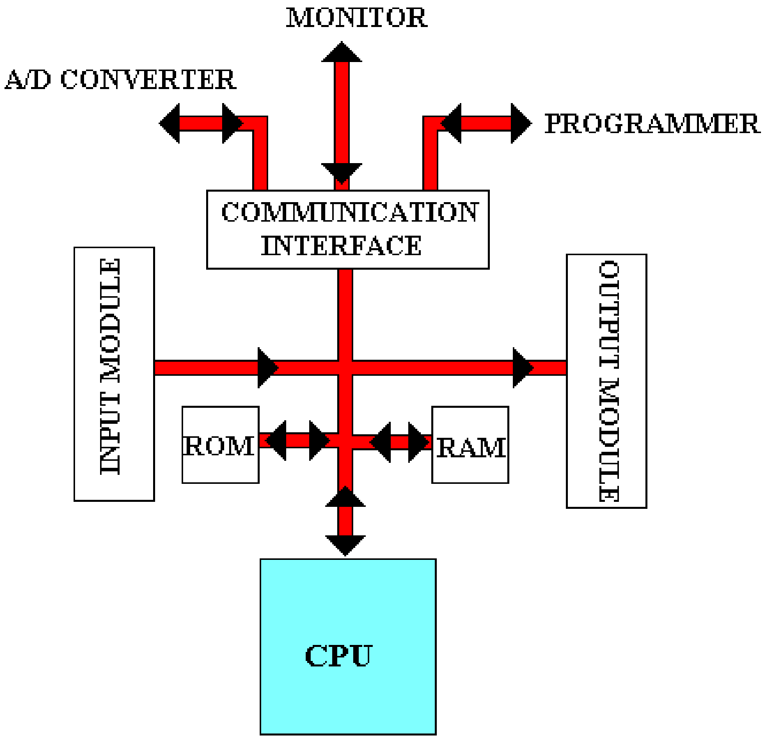

Figure 2

The CPU

The next diagram shows the internal structure of the Central Processing Unit in its simplest form. It usually contains (but sometimes it is external and separate) an Arithmetic Logic Unit (ALU). This is the part that performs operations such as adding, subtracting, multiplying, dividing and comparing. The Buffers act as switches that isolate the lines on either side if required. A, B and C are latches that passes the data from one side to the other when told to do so.

Digital data is passed around through busses. The busses were originally 4 parallel lines but as technology progressed this become 8, then 16 and now 32. Digital numbers and how they are put onto busses is explained in outcome 2.

The busses are connected to memory chips. In a memory chip, digital numbers are stored in locations. The number is the data and the location is the address. Data can be sent to or brought from memory locations by either writing it or reading. The lines labelled R and W are signal lines that makes the CPU read or write.

A ***Register*** is a temporary memory location where data is put to be manipulated and then taken away.

The ***Clock*** line is pulsed at a regular rate to synchronise the operations. Currently this has reached a rate measure in Giga Hertz (1000 million times a second).

The Reset line when activated resets the programme Counter to Zero.

The operations are carried out to a set of instruction (the programme) and these are decoded in the ID (Instruction Decoder)

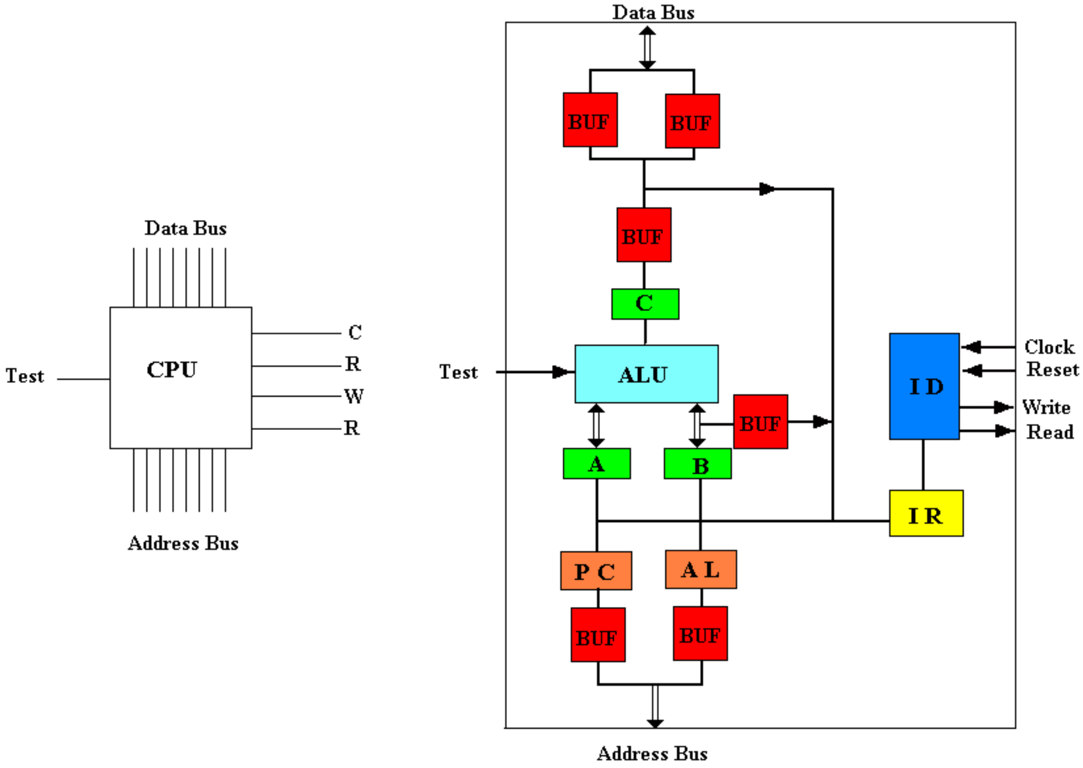

Figure 3

Input Module

The input module connects the input terminals to the rest of the system. The input voltage from the switching device is typically 24 V but manufacturers make them work on a range of voltages included 110V a.c. in some cases. Typically the inputs are electrically isolated from the internal electronics by *Opto Isolators*.

This is a way of passing on the status of the input (on or off) by use of a light emitting diode and phototransistor. A typical opto isolator is shown.

They have the advantage of reducing the effects of spurious pulses generated from electro magnetic sources. It is also a safety feature to prevent live voltages appearing on the input lines in the event of a fault.

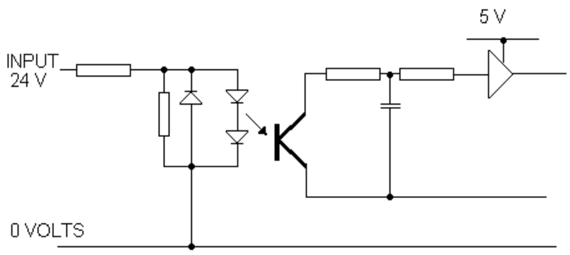

Figure 4

Output Module

The output module contains switches activated by the CPU in order to connect two terminals and so allow current to flow in the external circuit. This will activate devices such as pneumatic solenoid valves, hydraulic solenoid valves, motors, pipe line valves, heating elements and so on. Care must be taken not to overload the contacts. The switch may be a transistor or a relay. The diagram shows a typical output arrangement. The terminals are numbered and these numbers are used in the programme. The voltage and current that may be switched depends on the manufacturer's model.

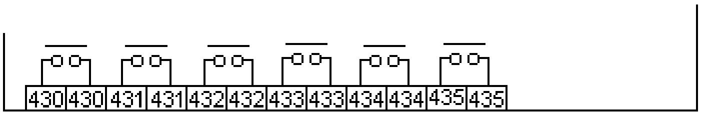

Figure 5

Memory

The PLC has RAM (Random Access Memory) and ROM (Read Only Memory). The programme, when written and entered, is stored in the RAM. The ROM contains permanent programmes such as that required to monitor the status of the inputs and outputs and to run diagnostic tests. Memory may be also classes as **volatile** or **non-volatile**. The contents of volatile memory are only retained so long as power is maintained to the memory chip and depends on a backup battery to maintain the data when the unit is switched off. This is most likely to be used for RAM. Non-volatile memory retains the data and is most likely to be used for ROM. It may not be possible to change the stored contents once the data is stored in this memory. For example magnetic storage devices and CD storage devices are non-volatile but in these units it is more likely to be flash memory chips. Volatile memory is faster to access and write to than non-volatile.

Registers are a memory location containing a digital number. The difference between a register and any other memory location is that the bits may be manipulated under control of the programme by being shifted or rotated.

Flags are single bits in a register that are switched on to indicate the status of something.

Testing

The PLC has certain diagnostic, monitoring and testing facilities within the software. Light Emitting Diodes (LED) shows the status of the inputs and outputs. It is also possible to fix a bank of switches to the input side and test a programme by setting the switches to a certain state and seeing if the appropriate output action is taken. The most advanced method connects the PLC to a computer with appropriate software and runs a complete simulation of the system being controlled showing the status of everything.

Programming Methods

The P.L.C. is programmed with logical commands. This may be done through a programming panel or by connection to a computer. There are several types of programming panels varying in complexity from a simple key pad to a full blown hand held computer with graphics screen. Computers are able to run programming software with graphics, simulators, diagnostics and monitoring. This could be a laptop carried to the site or a main computer some distance away. Often the programme is developed and tested on the computer and the programme is transferred to the PLC. This could be by a communication link, by a magnetic tape, compact Disc or more likely with an EEPROM. The EEPROM is a memory chip to which the programme is written. The chip is then taken to the PLC and simply plugged in. The memory cannot be overwritten but it can be erased by exposure to UV light and reused.

3. Styles

The main styles are:

- *Unitary*
- *Modular*
- *Rack Mounting.*

Figure 6 A range of styles

Unitary

The Unitary PLC contains every feature of a basic system in one box. They are most likely located on or close to the machine being controlled.

Figure 7 Unitary PLCs

Modular

These use a range of modules that slot together to build up a system. The basic modules are the power supply, the main module containing the CPU, the input module and the output module. Other modules such as A/D converters may be added. The main advantage is that the number of input and output terminals can be expanded to cope with changes to the hardware system.

Modular PLCs may be designed to be fixed direct to a back panel. Usually they are arranged on a rack or rail and mounted inside a large cabinet for protection and security.

Figure 8 Modular PLCs

Rack Mounting

This is a similar concept to the modular design but the modules. They will be arranged in rows on racks inside cabinets. They do not plug into each other but plug into a standard communication slot in the rack. All the slots are connected by standard network or bus so that they all communicate with each other and with the external systems. This cuts down on the quantity of cable work needed. The system is flexible and expandable.

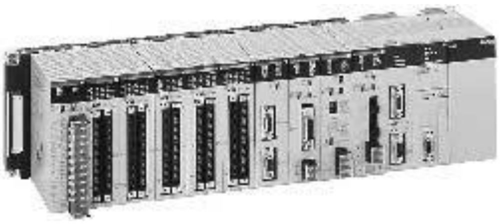

Figure 9 Rack Mounted System

4. Input Sensors

A range of sensors are needed to provide feed-back to the input terminals of the PLC. These measure or monitor many things such as:

- Position (linear and angular)
- Temperature
- Speed
- Pressure
- Weight
- Quantity
- Flow rate
- Depth
- Density
- Acidity
- Content (e.g. the carbon dioxide in a flue gas)
- Voltage
- Current
- Torque
- Power

Some of the sensors simply determine if something is on or off, such as:

- Simple switches (like start and stop)
- Micro switches
- Proximity switches
- Relays
- Voltage sensing relays
- Outputs of A/D converters

Figure 10 Range of Sensors

In order to control the position of actuators (electrical, hydraulic or pneumatic), sensors may be placed on them or on the machine that they move. These detect when the correct position has been reached (e.g. a switch to indicate that a guard is in place). If the control valves are electrically (solenoid) operated, simple mechanically operated electric switches may be used (micro switches).

Switches and valves may be normally open (NO) or normally closed (NC).

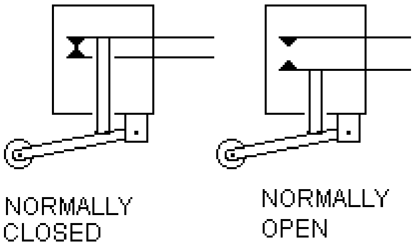

Figure 11

In many cases it is best to fit the sensor to the actuator. Cylinders are often fitted with reed switches, which are activated by a magnet fixed in the piston. These only work if the barrel is made of non-magnetic material such as aluminium.

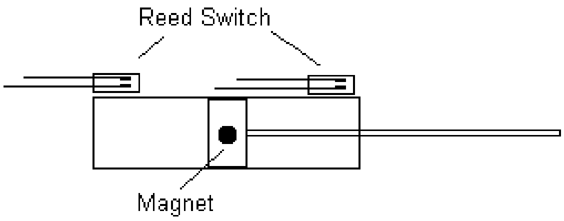

Figure 12

There are ranges of devices, which switch on when something comes close to them. These are called ***Proximity*** switches. They work on various electronic principles. The switching signal is turned on or off when the sensor is activated. Some will detect any material, some will only detect iron, and some will only detect metals in general. In this way, for example, it is possible to detect if the object is metal or plastic).

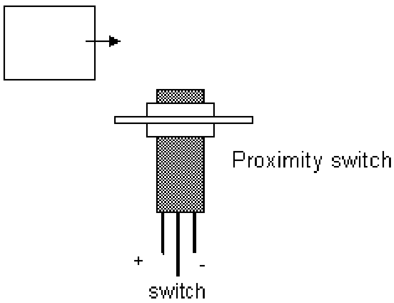

Figure 13

A similar sensor uses light beams and sensors. Often the light used in infrared. These sensors switch on or off when the light beam is interrupted. These might be used for detecting an item passing on a conveyor belt and activate a cylinder accordingly. They are widely used for counting the number of objects passing by.

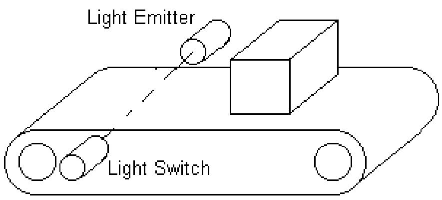

Figure 14

Voltage Sensing Relays

These are used with analogue devices that produce a voltage representing the variable (e.g. a DC tachometer for measuring speed). The unit is adjusted to trip a relay when a certain point is reached (e.g. to indicate a motor has reached its correct speed). Typically 24 V is applied to the PLC input. Another example is a level measuring device that produces a voltage proportional to level and when the level reaches a certain depth, the voltage sensing relay trips and activates the PLC input.

Input Voltages

Typical input voltages are 12V and 24V but sometimes they can be as low as 5V (the normal computer bus voltage) or as high as 110 or 240 V (normal mains a.c. levels). They may accept d.c. or a.c. No two PC's are the same so you must take care to check the input rating.

5. Output Devices

Output devices are switched on by the PLC. This can be anything electrical such as the following.

- D.C. motor (e.g. to start a conveyor belt).
- A.C. motor (e.g. to start a pump).
- Linear electric actuator
- Solenoid valve in hydraulic or pneumatic systems.
- Solenoid valves on plant systems (e.g. to open a pipe line valve or allow steam into a heater).
- Lights (e.g. traffic lights)
- Alarms (e.g. fire alarm or oil level alarm).
- Heating elements (e.g. heater in a hydraulic tank)

Typical switching voltages are 12V, 24V, 110 and 240 V. In many cases, the PLC cannot switch the device directly because of the high voltage or current needed. In this case power switching relays or transistors are used.

Relays

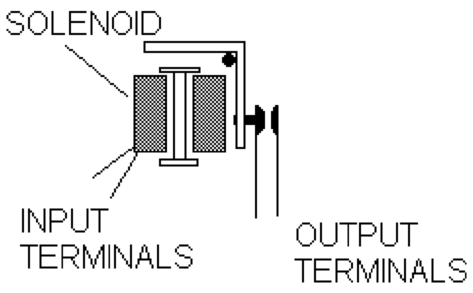

Figure 15

Some output switches are not able to switch high currents directly and the module would be damaged by high currents. They have to be interfaced to the hard ware by relays. A relay is used to allow a small current to operate devices with high current ratings. The relay is a mechanical switch and the contacts are moved by a solenoid.

Smart Devices

On modern PC's when you connect to a modern device such as a printer, expansion port, monitor, keyboard, mouse, memory card, digital camera … , it is identified and appropriate drivers are installed automatically to enable the device to work. The device may even enable messages about errors to be screened (e.g. printer out of paper).

S.M.A.R.T. devices used in industry are sensors and other periphery devices that have built in digital processors and communicate with the PLC digitally rather like the process described above. These are not only able to measure the variable but also process it at source and report additional information such as self diagnostics.

*6. **Selection Criteria***

You must consider many things when selecting a PLC system. Here are some of them.

Safety
We should never forget safety as the major concern and the PLC must be safe to operate in the environment (e.g. is there a possibility of an explosive atmosphere). Safety may also involve reliability and back up.

Function
If you were given the task of choosing a PLC for a specific application, you would need to choose one that is capable of performing all the functions you need it to do.

Communication and Compatibility
You must consider how the PLC will communicate with the larger system. Clearly all equipment must be compatible. It is likely that a company would use a favoured manufacture for all their PLC requirements so that operators will not have to be trained on a range of different systems. This would include the programming equipment which would be common to all the installations.

Environment
The PLC must be suitable for the working environment (heat, dust, vibration, moisture, electrical interference, magnetic fields).

Reliability
The application may require the PLC to have exceptional reliability. For example controlling an industrial process where a break down would be expensive or dangerous. It is likely that back up systems would be used where this is very important (e.g. nuclear power installation).

Cost
The syllabus mentions cost criteria but a PLC itself is not an expensive item compared to the hardware that will be used with it. Clearly a single unitary PLC for controlling a basic automated machine would be much cheaper than a major rack mounted system for controlling a whole industrial process.

You would need to consider the following.

- Is the application complex or basic?
- How many inputs and outputs devices will be used?
- What are the types of input and output devices to be used?
- What are the power and voltage requirements?
- Do you see the system requiring expansion in the future?
- Is the controlled process complex or simple?
- Will the units communicate with other units or computers?
- What sort of communication will you use?
- What sort of programming system will you use?
- What is the environment in which the PLC will be used?

SELF ASSESSMENT EXERCISE

PART 1

1. Explain the difference between a normal memory location and a register.

2. What do the following initials stand for? CPU, ALU, ROM, RAM

3. Describe the purpose 'flags'.

4. Which kind of memory would be most likely used for ROM, volatile or non-volatile?

5. What is the purpose of opto isolators in a PLC?

6. Explain the basic difference between an ordinary sensor and a 'smart' sensor

PART 2

1. A pneumatic machine is used to load a small steel plate from a magazine into a clamp, drill a hole in it and then eject it into a bin. This is a stand alone machine and does not communicate with any other system.

   There are switches used to control the following input functions producing a signal of 5V when on.

   ON/OFF
   Magazine empty
   Component in Clamp
   Clamp closed/Open
   Drill Down
   Drill Up

   There are the following output functions all using electric solenoids energised directly by the PLC. The electrical requirements are shown.

   Drill ON/OFF (2 Amperes at 12V)
   Raise/Lower Drill
   Close/Open Clamp
   Eject

   Using any catalogues/internet sites that you can find, select a PLC to do this job. Write a short essay explaining the reasons for your selection.

2. An industrial process involves several items of plant each with a complex control function and many sensors and controlled devices (motors, relays, solenoids etcetera). The processes involve explosive vapours. Everything is to be operated by a PLC system. The entire process is to be monitored and overall control made from a central control room.

   List the things that you think are important in deciding the PLC system to be chosen and outline how it will all be connected together.