1

Introduction to PLCs

The need for low-cost, versatile and easily commissioned controllers has resulted in the development of programmable logic controllers, which can be used quickly and simply in a wide variety of industrial applications.

The most powerful facility which PLCs have, is that they can be easily programmed to produce their control function, instead of having to be laboriously hard-wired, as is required in relay control systems.

However, the method of programming a PLC control system can nevertheless use relay ladder diagram techniques, which therefore enables the skills of an outdated technology to be still viable with that of the new.

The PLC was initially designed by General Motors of America in 1968, who were interested in producing a control system for their assembly plants and which did not have to be replaced every time a new model of car was manufactured.

The initial specification for the PLC was:

1. Easily programmed and reprogrammed, preferably in plant, to enable its sequence of operations to be altered.
2. Easily maintained and repaired.
3. More reliable in a plant environment.
4. Smaller than its relay equivalent.
5. Cost-effective in comparison with solid-state and relay systems, then in use.

1.1 Basic PLC units

The four basic units within the FX2N PLC units are:

1. The central processor unit (CPU)
   This is the main control unit for the PLC system, which carries out the following:
   (a) Downloads and uploads ladder diagram programs via a serial communications link.
   (b) Stores and executes the downloaded program.
   (c) Monitors in real time the operation of the ladder diagram program. This gives the impression that a real hardwired electrical control system is being monitored.
   (d) Interfaces with the other units in the PLC system.
2  Mitsubishi FX Programmable Logic Controllers

2. Input unit
   The input unit enables external input signals, i.e. signals from switches, push buttons, limit switches, proximity detectors, to be connected to the PLC System and then be processed by the CPU.

3. Output unit
   The output unit is connected to its externally operated devices, i.e. LED’s, indicator lamps, digital display units, small powered relays, pneumatic/hydraulic pilot valves.
   Each time the program is executed, i.e. after each program scan, then depending on the ladder diagram program and the logic state of the inputs, the outputs will be required to turn ON, turn OFF, or remain as they are.

4. Power supply
   The power supply is used to provide the following DC voltages from the 240 V mains supply:
   (a) 5 V DC supply for the internal electronics within all of the PLC units.
   (b) 24 V DC supply, which can be used to supply the input devices.
   (c) Alternatively, the 24 V DC can be supplied from an external DC power supply, which is used for both the input and the output devices.

1.2 Comparison of PLC and RELAY systems

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>PLC</th>
<th>Relay</th>
</tr>
</thead>
<tbody>
<tr>
<td>Price per function</td>
<td>Low</td>
<td>Low – if equivalent relay program uses more than ten relays</td>
</tr>
<tr>
<td>Physical size</td>
<td>Very compact</td>
<td>Bulky</td>
</tr>
<tr>
<td>Operating speed</td>
<td>Fast</td>
<td>Slow</td>
</tr>
<tr>
<td>Electrical noise immunity</td>
<td>Good</td>
<td>Excellent</td>
</tr>
<tr>
<td>Construction</td>
<td>Easy to program</td>
<td>Wiring – time-consuming</td>
</tr>
<tr>
<td>Advanced instructions</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Changing the control sequence</td>
<td>Very simple</td>
<td>Very difficult – requires changes to wiring</td>
</tr>
<tr>
<td>Maintenance</td>
<td>Excellent – PLCs rarely fail</td>
<td>Poor – relays require constant maintenance</td>
</tr>
</tbody>
</table>

1.3 PLC software

To be able to design a PLC program using a computer, it is essential for the software to have the following facilities:

1. Programs can be designed using conventional relay ladder diagram techniques.
2. Test if the program is valid for use on the chosen PLC.
3. Programs can be permanently saved either on a computer’s hard disk or on floppy disks.
4. Programs can be re-loaded from either the hard disk or the floppy disk.
5. Ladder diagram contacts and coils can be annotated with suitable comments.
6. Hard copy printouts can be obtained.
7. The program can be transferred to the PLC, via a serial link.
8. The program within the PLC can be transferred back to the computer.
9. The ladder diagram control system can be monitored in ‘real time’.
10. Modifications can take place, whilst the PLC is online.

1.4 Gx-Developer software

The Gx-Developer software is a Windows-based package, which enables users to produce ladder diagram projects for use with the Mitsubishi range of PLCs.

It has been produced by Mitsubishi Electric to replace the DOS-based package, MEDOC.

Advantages – Gx-Developer

1. As the software uses drop-down menus, there is no need to remember keypress characters.
2. The drop-down menus are selected using a mouse.
3. All of the functions can be accessed using an icon, instead of the drop-down menus.
4. Ladder diagrams can be entered more quickly.
5. Modifications can be easily carried out.
6. Improved monitoring facilities, i.e. direct monitoring of the contents of a special unit’s buffer memory.
7. Fault-finding diagnostics.
8. Improved documentation, i.e. notes.

1.5 Hardware configuration

This section deals with configuring an FX2N system.

Since the main components of all FX PLCs, i.e. the CPU, inputs and outputs are all parts of the one unit instead of separate plug in modules, the FX range of PLCs are known as ‘Brick Type’ PLCs.

The main considerations that must be taken into account when configuring a system are:

1. External devices, inputs and outputs.
   (a) How many are required?
   (b) Is the supply from the Input devices to the PLC inputs from: volt-free contacts, 24 V DC, or 110 V AC?
   (c) Is the supply from the PLC outputs to the external loads from: volt-free contacts, 24 V DC, or 110 V AC?
   (d) Is a fast-switching operation required?
   (e) Are proximity detectors required (see Section 1.21)?

2. Power supply requirements.
   (a) Supply voltage.
   (b) Internal power supply.

3. Special function units.
   (a) How many can the system support?
   (b) Is an external power supply required?
1.6 Base unit, extension units and extension blocks

Figure 1.1 shows a base unit along with 2 \times extension blocks.

It is very important that confusion is avoided when these units are discussed.

The basic way to describe the difference between a base unit, an extension unit and an extension block is as follows:

1. A base unit is made up of four components, i.e. power supply, inputs, outputs and CPU.
2. An extension unit is made up of three components, i.e. power supply, inputs and outputs.
3. An extension block is made up of one or two components, i.e. inputs and/or outputs. It can be seen that the extension block does not have a power supply. It therefore obtains its power requirement from either the base unit or an extension unit. Hence it is necessary to determine how many of these un-powered units can be connected before the ‘On Board’ power supply capacity is exceeded. The tables in Sections 1.8 and 1.9 show how this can be worked out.

1.7 PLC voltage supplies

24 V DC supply

The FX2N has a 24 V internal power supply, which can be used for supplying current to input switches and sensors.

From the smaller FX2N table below, it can be seen that if no un-powered extension blocks have been used, then the maximum available current from the 24 V supply is 250 mA.

However, if one 16-input and one 16-output extension block were fitted, then the available current falls to 0 mA and a separate 24 V power supply would then be required for supplying the input switches and any sensors.

1.8 Smaller FX2N PLCs

A = Number of additional outputs
B = Number of additional inputs
C = Invalid configuration

<table>
<thead>
<tr>
<th>Available current (mA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
</tr>
<tr>
<td>16</td>
</tr>
<tr>
<td>8</td>
</tr>
<tr>
<td>0</td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>
Figure 1.1
1.9 Larger FX2N PLCs

A = Number of additional outputs  
FX2N 48M* - E** → FX2N-128M* - E**

B = Number of additional inputs  
FX2N 48E* - E**

C = Invalid configuration

1.10 5 V DC supply

The FX2N has a second power supply, of 5 V, which is not available to the user. Its function is to supply, via the ribbon cable bus connections, any special units connected to the system.

The table below details the current available from this supply.

<table>
<thead>
<tr>
<th>Available current (mA)</th>
<th>64</th>
<th>56</th>
<th>48</th>
<th>40</th>
<th>32</th>
<th>24</th>
<th>16</th>
<th>8</th>
<th>0</th>
</tr>
</thead>
<tbody>
<tr>
<td>48</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>40</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>32</td>
<td>85</td>
<td>35</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>24</td>
<td>160</td>
<td>110</td>
<td>60</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>16</td>
<td>235</td>
<td>185</td>
<td>135</td>
<td>85</td>
<td>35</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>8</td>
<td>310</td>
<td>260</td>
<td>210</td>
<td>160</td>
<td>110</td>
<td>60</td>
<td>60</td>
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<tr>
<td>0</td>
<td>385</td>
<td>335</td>
<td>285</td>
<td>235</td>
<td>185</td>
<td>185</td>
<td>135</td>
<td>35</td>
<td></td>
</tr>
<tr>
<td></td>
<td>460</td>
<td>410</td>
<td>360</td>
<td>310</td>
<td>260</td>
<td>210</td>
<td>160</td>
<td>110</td>
<td>60</td>
</tr>
</tbody>
</table>

B

The table on page 7 gives the current required by the most frequently used units along with the I/O requirements.

1.11 Special unit power supply requirements

Depending on the special units used, the current consumption from the 5 V supply and the 24 V supply must be taken into account.

The table on page 7 gives the current required by the most frequently used units along with the I/O requirements.
### 1.12 Part number

The part number describes the type of PLC and its functionality. The part number can be broken down as in Figure 1.2

![Part number diagram](image)

**Figure 1.2**

### 1.13 Serial number

Also found on the unit is a serial number (Figure 1.3), from which the construction date can be determined.

![Serial number diagram](image)

**Figure 1.3**
1.14 PLC inputs

All PLC inputs are isolated by photocouplers to prevent operational errors due to contact chattering or other electrical noise that may enter via the input.

For this very reason ON/OFF status changes will take approximately 10 msec. This time should be taken into account when programming, as it will have a direct effect on the way the program will operate.

For the input device to actually register on the PLC it will have to draw a minimum of 4 mA for the PLC input to switch. Anything less than 4 mA, will result in the PLC input not turning on.

The current into a PLC input must not exceed 7 mA; anything in excess of this could result in the input being damaged.

The input signals can come from a wide variety of devices, i.e.

1. Push buttons.
2. Rotary switches.
3. Key switches.
4. Limit switches.
5. Level sensors.
6. Flow rate sensors.
7. Photo-electric detectors.
8. Proximity detectors (inductive or capacitive).

The inputs ‘1’–’7’ connect to the PLC via a pair of no-voltage contacts, which can be either normally open or normally closed.

However, the proximity detectors usually provide a transistor output which can be either an NPN or a PNP transistor.

1.15 AC inputs

110 V AC Inputs are also available.

It is recommended that the same supply voltage to the PLC is used as for the inputs, i.e.(100–120 V AC).

This minimises the possibility of an incorrect voltage being connected to the inputs. With AC versions the S/S terminal is not used (see Section 1.18).

Note

1. In normal operation, use of inputs should be restricted to 70% at any one time.
2. Except for inputs concerned with safety (refer page 76 and Chapter 10) input devices such as ON/OFF switches, push buttons, foot switches and limit switches are usually wired to the PLC through the normally open contacts of the device.
1.16 PLC outputs

There are three different types of output for the FX range of PLCs, these are:

1. Relay.
2. Triac (solid-state relay – SSR).
3. Transistor.

**Relay**

This is the most commonly used type of output. The coils and the contacts of the output relays enable electrical isolation to be obtained between the internal PLC circuitry and the external output circuitry. Dependent on a number of factors, i.e. the supply voltage, the type of load, i.e. resistive, inductive or lamp, the contact life, the maximum-switched current per individual output is 2 A. The PLC will provide groups of 4, 8 or 16 outputs each with a common. The commons are logically numbered COM1, COM2, etc. and are electrically isolated from one another. When the ‘END’ instruction in the ladder diagram is executed, the PLC will REFRESH the outputs from the output latch memory to turn the appropriate output relay either ON or OFF. The response time for the operation of an output relay is approximately 10 msec.

**Triac**

The TRIAC is an AC switch, which basically consists of two thyristors connected ‘back to back’.

Since the TRIAC output is solid state, the lifetime of a TRIAC output is far longer than that of the relay output. The voltage range of these devices is 85–240 V AC and each output can switch up to a maximum of 0.35 A. As with all other output configurations, the physical output is isolated by a photocoupler. The response of the TRIAC when turning ON is faster than the Relay, i.e. 1 msec but the OFF times are identical, i.e. 10 msec. Care should be taken when configuring the system so that the output circuitry is not overloaded. Care should also be taken concerning leakage current in a TRIAC output circuit. This current is far greater than that of a relay circuit and may cause any externally connected miniature relays to remain energised.

**Transistor**

The transistor outputs are used, where a very fast switching time is required. The switching time of the transistor outputs, whether they are Sink or Source outputs, is < 0.2 msec with a 24 V DC, 100 mA load. As with all other output configurations, the physical output is isolated by a photocoupler.
1.17 Source–sink inputs

The term source–sink refers to the direction of current flow into or out of the input terminals of the PLC.

**Source input**

When the PLC is connected for source inputs, then the input signal current flows into the X inputs (Figure 1.4).

![Source Input Diagram](image1.png)

Figure 1.4

**Sink input**

When the PLC is connected for Sink inputs, then the input signal current flows out of the X inputs (Figure 1.5).

![Sink Input Diagram](image2.png)

Figure 1.5
1.18 The source/sink – S/S connection

The S/S connection is the common terminal for all of the internal input circuits of the PLC.

It enables the user to decide the direction in which the input devices will supply current to the PLC inputs, i.e. source or sink.

1.19 Source inputs – block diagram

To ensure that all of the input devices will supply the source input current, the user connects the S/S terminal to the 0 V terminal, as shown in Figure 1.6.

![Figure 1.6](image)

**Direction of source current flow**

When the push button is closed, the direction of current flow will be as follows:

1. From the +24 V terminal of the internal power supply, the +24 V PLC terminal, and then through the push button and into the X0 input terminal, i.e. source current.
2. Through the input resistor network circuit and then through the second LED.
3. With current flowing through the LED it will emit light, which in turn will cause the photo-transistor to turn ON.
4. The function of the photo-transistor is to isolate the 24 V input circuit from the 5 V PLC logic circuit and hence increase the noise immunity of the input.
5. With the photo-transistor turning ON, this will cause a signal to be sent to the input image table, to store the information that the input X0 is ON.
6. The input current now flows to the S/S terminal, through the user-connected link to the PLC 0 V terminal and then back to the negative (–) terminal of the internal power supply.
To ensure that all of the input devices will sink the current from the PLC inputs, the user now connects the S/S terminal to the +24 V terminal, as shown in Figure 1.7.

**Direction of sink current flow**

When the push button is closed, the direction of current flow will be as follows:

1. From the +24 V terminal of the internal power supply, through the user-connected link to the S/S terminal.
2. Through the first LED and then through the input resistor network circuit to the X0 input terminal.
3. With current flowing through the LED, it will emit light, which in turn will cause the same photo-transistor to turn ON.
4. With the photo-transistor turning ON, this will cause a signal to be sent to the input image table, to store the information that the input X0 is ON.
5. The input current now flows out of the X0 input terminal, i.e. sink current.
6. It then flows through the push button to the PLC 0 V terminal and then back to the negative terminal of the internal power supply.

**1.21 Proximity sensors**

There are two types of proximity sensors i.e. inductive and capacitive, and the supply voltages to these sensors are normally 24 V DC.

There are also two standard outputs for both proximity sensors, which are:

1. PNP (source)
2. NPN (sink)

Once selected, only that output type can be used for supplying the inputs to the PLC. They *cannot* be mixed.
If PNP proximity detectors are used, then every one of the PLC inputs become source inputs.
If NPN proximity detectors are used, then every one of the PLC inputs become sink inputs.
To configure the PLC to accept either a PNP or an NPN sensor, the S/S terminal has to be linked to either the 0 V line or the 24 V DC line respectively, as shown in the Figure 1.8.
Care must be taken to ensure that the S/S terminal is correctly connected, as failure to do this will result in the input not working.

1.22 S/S terminal configurations

PNP (source)  \hspace{1cm} \text{NPN (sink)}

![Diagram of S/S terminal configurations]

Figure 1.8

1.23 PLC ladder diagram symbols

\textbf{Inputs X}

\textit{Normally open contact}

X1

When an external source, e.g. an external switch, push button, relay contact, etc., operates, then the corresponding ladder diagram normally open contact or contacts, will close.
The X1 indicates that the external input is connected to input X1 of the PLC.
Normally closed contact

\[ X_2 \]

When the external input connected to the PLC is operated, then the corresponding ladder diagram contact or contacts will open.

Outputs Y

\[ (Y_0) \]

An external output device, for example, a power relay, a motor starter, an indicator, can be connected to the output terminals of the PLC, in this case output Y0. When the PLC operates output Y0, then the output device will be energised.

Auxiliary memory coils M

\[ (M_0) \]

An Auxiliary Memory Coil can be used in PLC programs for a variety of reasons.

1. To operate when the set of inputs, which are connected to the M Coil, are correct.

The inputs corresponding to the normally open contacts have been operated, i.e. X0, X1, X3, X6. The inputs corresponding to the normally closed contacts have not been operated, i.e. X2, X4, X5. This information can then be used throughout the ladder diagram by simply using the contacts of the memory coil, i.e. M0 instead of having to repeat all of those input contacts, which caused the M coil to initially operate.

2. As part of a latch circuit.
3. As part of a shift register circuit.
1.24 PLC address ranges

The following range of addresses are those used for the FX2N 48 I/O base unit.

**Inputs**
- X0–X27 (octal) 24 inputs.
- Expandable inputs 4–24.

**Outputs**
- Y0–Y27 (octal) 24 outputs.
- Expandable outputs 4–24.

**Timers**
- T0–T199 0.1 sec–3276.7 sec
- T200–T245 0.01 sec–327.67 sec
- T246–T249 0.001 sec–32.767 sec
- T250–T255 0.01 sec–3276.7 sec

**Counters**
- C0–C99 general-purpose (16 bit)
- C100–C199 battery-backed (latched 16 bit)
- C200–C219 bi-directional (32 bit)
- C220–C234 bi-directional and battery-backed
- C235–C255 high-speed counters

**Auxiliary relays**
- M0–M499 general-purpose
- M500–M3071 battery-backed
- M8000–M8255 special-purpose

**State relays**
- S0–S999 general-purpose
- S500–S999 battery-backed
- S900–S999 annunciator

**Data registers**
- D0–D199 general-purpose
- D1000–D7999 file registers
- Selectable from battery backup range
- D200–D7999 battery-backed
- D8000–D8255 special-purpose
- V and Z index registers
- V0–V7 and Z0–Z7 (16 bit)

1.25 Basic operation of a PLC system

To explain the basic operation of a PLC system, consider the following two lines of program:
1. When Input X1 closes, this operates internal memory coil M0.
2. The normally open contact of M0 on closing will cause output Y1 to become energised.

### 1.26 Block diagram – basic operation of a PLC system

![Block Diagram](image)

**Figure 1.9**

*Mitsubishi FX Programmable Logic Controllers*
1.27 Principle of operation

Input processing
The PLC initially reads the ON/OFF condition of all of the inputs used in the program. These conditions are then stored into the input image memory.

Program processing
1. The PLC then starts at the beginning of the PLC program, and for each element of the program, it READS the actual logic state of that element, which is stored in either the input image memory or the output image memory.
2. If the required logic state is correct, i.e. X1 is ON, the PLC will move on to the next element in the rung, i.e. M0.
3. If X1 is ON, then a logic 1 will be WRITTEN into the output image memory in the location reserved for M0.
4. If X1 is OFF, then a logic 0 is WRITTEN into the M0 memory location.
5. After an output instruction has been processed, the first element on the next line is executed, which in this example is a normally open contact of M0.
6. Hence the logic state of the M0 memory location is this time READ from, and if its logic state is at logic 1 indicating that the M0 coil is energised, this effectively means all M0 normally open contacts will now close. The contact of M0 being closed, will cause a Logic 1 to be WRITTEN to the memory location reserved for the output Y1.
7. However, if the contents of the M0 memory location are at logic 0, i.e. M0 is not energised, then a Logic 0 is WRITTEN to the Y1 memory location.

Output processing
1. Upon completion of the execution of all instructions, the contents of the Y memory locations within the output image memory are now transferred to the output latch memory and the output terminals.
2. Hence, any output, which is designated to be ON, i.e. Y1, will become energised.