5 Ladder and functional block programming

Programs for microprocessor-based systems have to be loaded into them in *machine code*, this being a sequence of binary code numbers to represent the program instructions. However, *assembly language* based on the use of mnemonics can be used, e.g. LD is used to indicate the operation required to load the data that follows the LD, and a computer program called an assembler is used to translate the mnemonics into machine code. Programming can be made even easier by the use of the so-called *high level languages*, e.g. C, BASIC, PASCAL, FORTRAN, COBOL. These use pre-packaged functions, represented by simple words or symbols descriptive of the function concerned. For example, with C language the symbol & is used for the logic AND operation. However, the use of these methods to write programs requires some skill in programming and PLCs are intended to be used by engineers without any great knowledge of programming. As a consequence, *ladder programming* was developed. This is a means of writing programs which can then be converted into machine code by some software for use by the PLC microprocessor.

This method of writing programs became adopted by most PLC manufacturers, however each tended to have developed their own versions and so an international standard has been adopted for ladder programming and indeed all the methods used for programming PLCs. The standard, published in 1993, is IEC 1131-3 (International Electrotechnical Commission). The IEC 1131-3 programming languages are ladder diagrams (LAD), instruction list (IL), sequential function charts (SFC), structured text (ST), and function block diagrams (FBD).

This chapter is an introduction to the programming of a PLC using ladder diagrams and functional block diagrams, with discussion of the other techniques in the next chapter. Here we are concerned with the basic techniques involved in developing ladder and function block programs to represent basic switching operations, involving the logic functions of AND, OR, Exclusive OR, NAND and NOR, and latching. Later chapters continue with further ladder programming involving other elements.

5.1 Ladder diagrams

As an introduction to ladder diagrams, consider the simple wiring diagram for an electrical circuit in Figure 5.1(a). 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 5.1(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 5.1(b) is termed a *ladder diagram*.

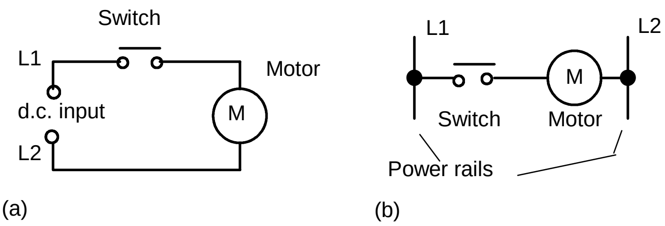

Figure 5.1 *Ways of drawing the same electrical circuit*

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 of Figure 5.1 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.

1. **Normal State:**
   - Push button 1 is open.
   - Push button 2 is closed.
   - The motor circuit is open.
2. **Starting the Motor:**
   - When push button 1 is pressed, the motor circuit is completed, and the motor starts.
   - Holding contacts wired in parallel with the motor close and remain closed as long as the motor is running.
   - When push button 1 is released, the holding contacts maintain the circuit, and power to the motor is sustained.
3. **Stopping the Motor:**
   - To stop the motor, push button 2 is pressed.
   - This action disconnects the power to the motor.
   - The holding contacts open when button 2 is pressed.
4. **After Releasing Button 2:**
   - When push button 2 is released, there is still no power to the motor because the circuit is open.

Figure 5.2 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.

Holding contacts, which are wired in parallel with the motor, close when the motor starts. These holding contacts act as auxiliary contacts associated with the motor's relay.

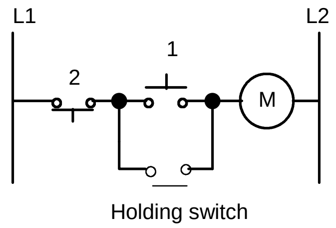

Figure 5.2 *Stop-start switch*

5.1.1 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. The power flow is taken to be from the left-hand vertical across a rung.
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 5.3 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 (see Section 4.4). 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.

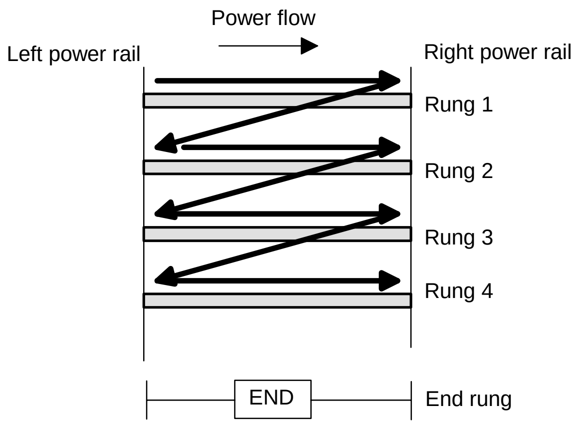

Figure 5.3 *Scanning the ladder program*

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 (see Section 4.6).

Figure 5.4 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.

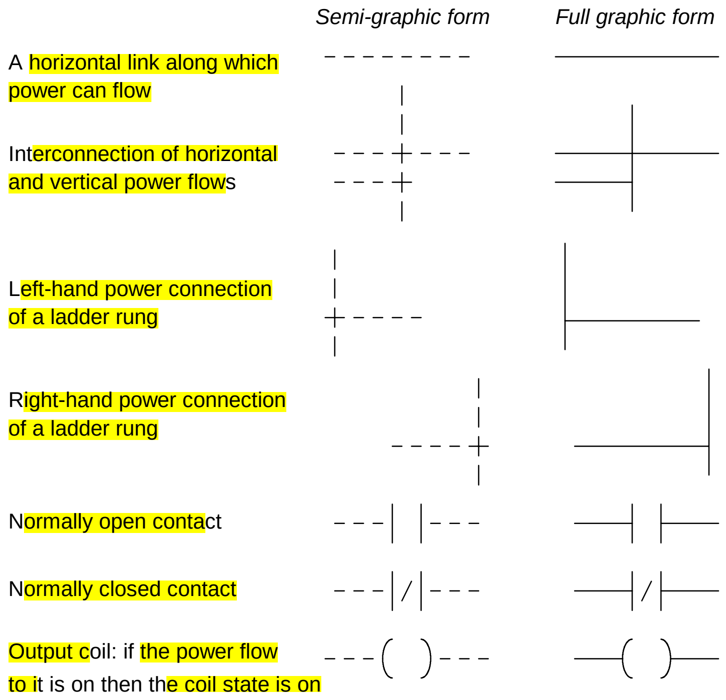

Figure 5.4 *Basic symbols*

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 5.5(a) shows the ladder diagram.

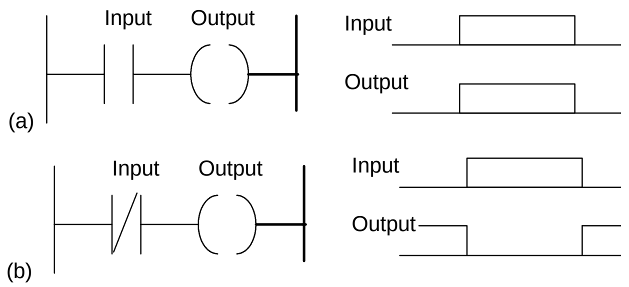

Figure 5.5 *A ladder rung*

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 5.5(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 5.6 shows how the ladder diagram of Figure 5.5(a) would appear using (a) Mitsubishi, (b) Siemens, (c) Allen-Bradley, (d) Telemecanique notations for the addresses. Thus Figure 5.6(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.

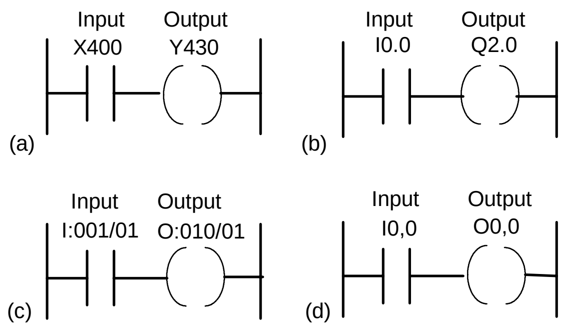

Figure 5.6 *Notation: (a) Mitsubishi, (b) Siemens, (c) Allen-Bradley, (d) Telemecanique*

5.2 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 (as illustrated in Figure 1.1(a)), 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.

5.2.1 AND

Figure 5.7(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 5.7(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