

INDUSTRIAL AUTOMATION USIN PLC

1.1 Introduction

1.1.1 Programmable logic controller

“Necessity is the mother of invention,” states a well-known quotation. In the past years, the manufacturing process was cumbersome and often the desired quantity and quality were not achieved. Since the relays and timers such as cam timers are considered mechanical devices, the lifetime of their functionality is limited and quite often they become cumbersome, especially in large applications where thousands of them are required. As the electrical relays have to be hard-wired, and as many relays have to be worked with, the trouble-shooting can become complicated.

The first programmable logic controller (PLC) project was created in 1968, by Bedford Associates, MA, USA, who had initiated the development of an electronic device called the “Modular Digital Controller” for controlling the operations in an automobile assembly line in General Motors (GM). This development proved to be successful and dramatically replaced the hard-wired electrical relay systems with an electronic controller.

This controller has made a significant contribution to the automation of factory assembly lines. Most of the relays and timers were built into a single controller. As of today, the programmable logic controllers deliver a wide range of functionality, including basic relay control, motion control, process control, and complex networking. They are also used in distributed control systems (DCSs).

1.2 PLC block diagram of components

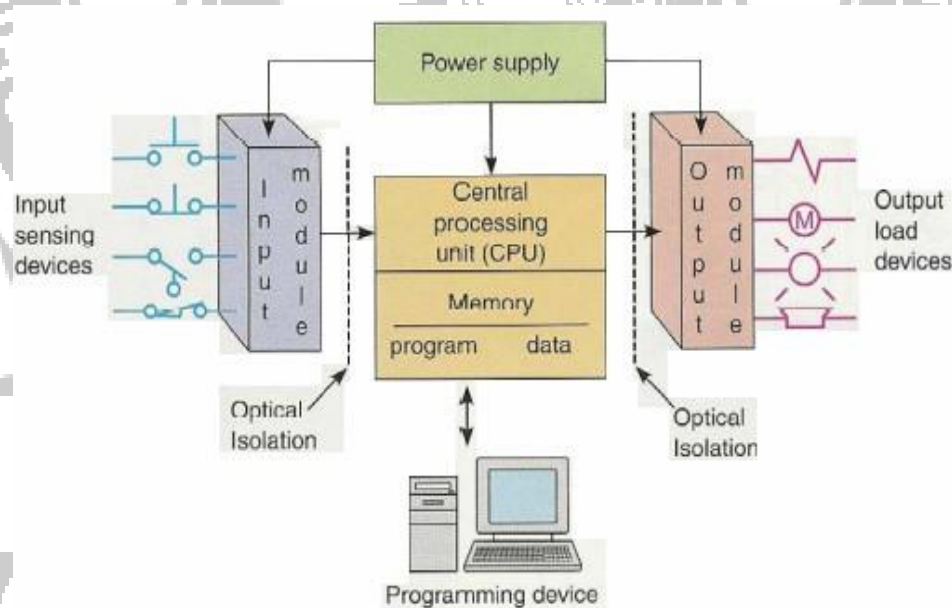


Figure 1.1
PLC block diagram

Figure 1.1 shows, in block form, the four major units of a PLC system and their interconnections which are briefly described here:

1. **Central processing unit (CPU)**

This is called the “Brain” of the PLC system, and has the following three sub- units

- (a) A microprocessor unit that carries out the mathematical and logical operations of the system.
- (b) A memory unit in which the system software and the user program data and

information are stored and retrieved.

- (c) Power supply, which is an electrical supply that converts the alternate current (AC) line voltage to various direct current (DC) operational values. In this process, the power supply is filtered and regulated to a DC voltage to ensure proper operation of the PLC system.

2. PLC programmer/monitor

A programming device is used to communicate with the circuits of the PLC. This may be a hand-held terminal, industrial terminal, or a personal computer.

3. I/O modules

- (a) The “I” is the input module, which has terminals into which outside process electrical signals, generated by sensors or transducers, are entered. These sensors or transducers can be thousands of meters away from the CPU.
- (b) The “O” is the output module, which has terminals into which output signals are sent to activate relays, solenoids, various solid-state switching devices, motors and displays. These output signaling elements may also be thousands of meters away from the CPU.

Sometimes, an electronic system for connecting I/O modules to remote locations can be added as it is necessary.

4. Racks and chassis

There is a rack on which the PLC parts are mounted and the enclosures on which the CPU, the PM, and the I/O modules are mounted.

5. Optional devices

- (a) Printer – it is a device using which the program in the CPU may be printed. In addition, operating information may be printed upon command.
- (b) Program recorder/player – PLCs use floppy disks, with hard disks for secondary storage. This recorder provides the backup and a way to download the program written-off from the PLC process system.
- (c) Master computers – they are often used to coordinate many individual, interconnected PLCs. These interconnected electrical buses are sometimes referred to as “Data Highways.”

1.2.1 Size of the PLC system

Programmable logic controllers are classified on the basis of their size:

- A small system is one with <500 analog and digital I/Os.
- A medium system has I/Os ranging from 500 to 5,000.
- A system with >5,000 I/Os is considered large.

1.2.2 Components of the PLC system

Figure 1.2 illustrates a sample PLC system and its components.

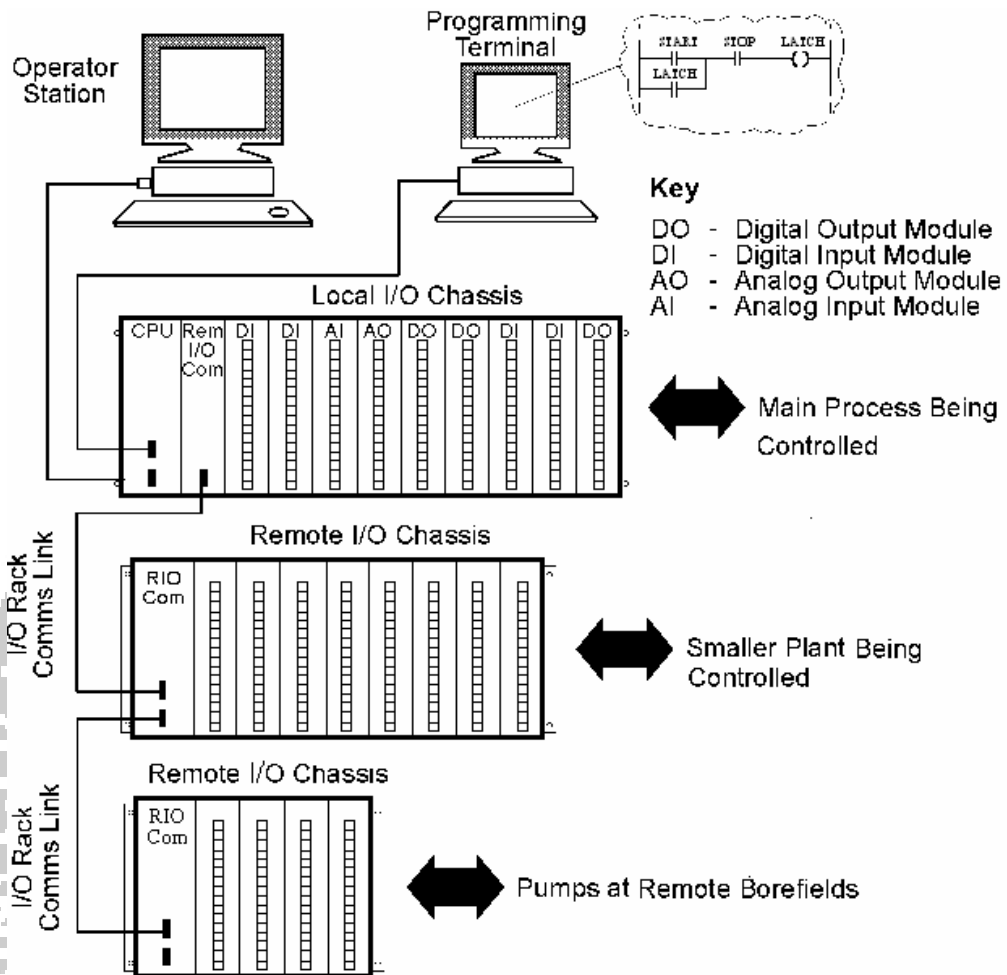


Figure 1.2
Typical PLC system components

This is the actual system. How does it look like? Does it seem difficult to understand it? Let us compare Figure 1.2, component by component, with Figure 1.3, which is its simplified version.

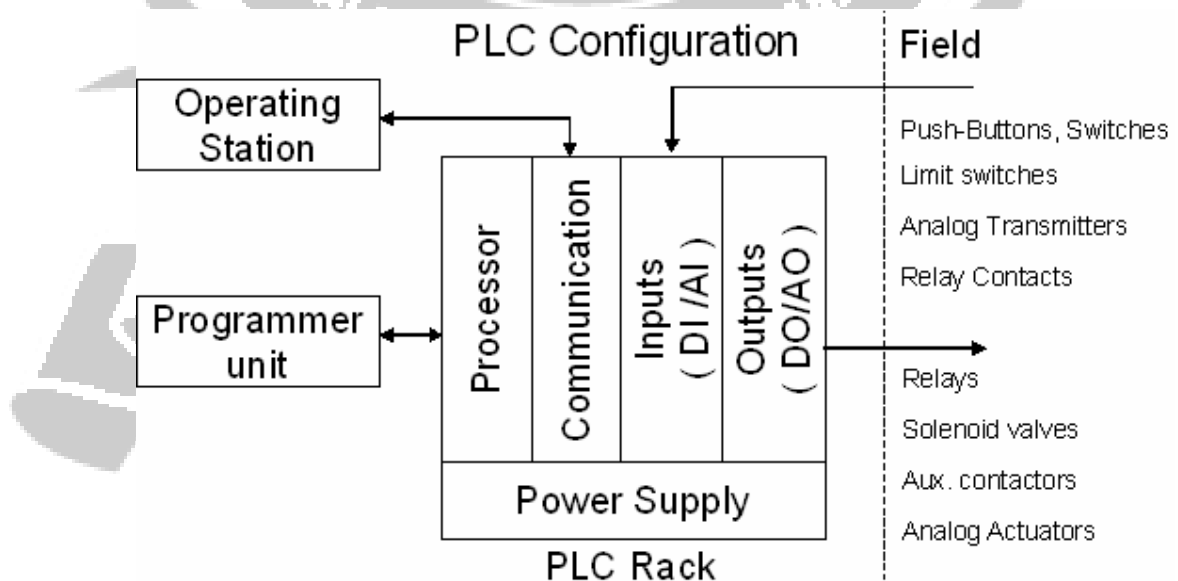


Figure 1.3
A typical PLC configuration

1.3 PLC power supply

A DC power supply is required by the PLC for low-level voltage used by the CPU, as well as for the I/O and communication modules. More often than not, a separate power supply module mostly supplies power. This is located beside the CPU unit or the external power supply, depending on the PLC vendor.

The power supply available in most plants in 220 V AC, 120 V AC (60 Hz), or 24 V DC and most PLCs operate on +5 V and -5 V DC. The conversion from 120 V AC to ± 5 V DC is accomplished by a built-in voltage-converting power supply. Figure 1.4 illustrates this.

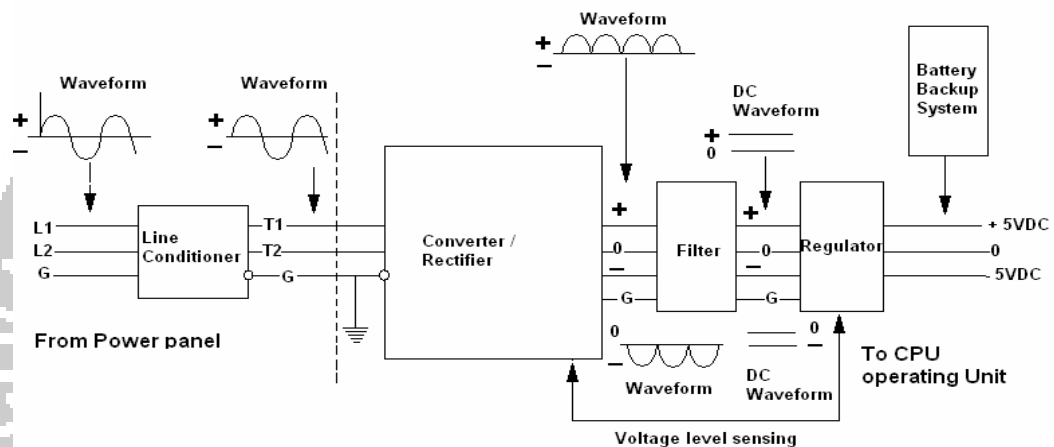


Figure 1.4
Power supply

As shown in Figure 1.4, there are five parts, including a switching system for the battery backup system:

1. **Line conditioner** – This is either included in the PLC CPU or separate external unit according to CPU current rating. This AC conditioner purifies the AC waveform, because sometimes due to external factors, the sine wave form may be distorted. The external factors are considered to be the sine wave distortion during switching or generation and by the electrical back surge from other electrical equipment in the plant.
2. **Converter/rectifier** – It changes the bidirectional AC to a pulsating, unidirectional DC waveform. Internally, a transformer steps down the voltage to an appropriate level. Then the bridge rectifier produces pulsating DC outputs. One output is +5 V and the other is -5 V. This dual voltage is required to operate many of the IC chips in the CPU.
3. **Filter** – A computer needs a constant input DC voltage for correct operation. The pulsating DC voltage is to be smoothened out. This is accomplished in the filter section.
4. **Regulator** – The regulator is always included in the circuit, to keep the voltage at or near the 5 V levels regardless of load (CPU) demands.
5. **Battery backup system** – The switch is set to switch the output from power supply to battery backup power quickly and automatically if the input power fails while disconnecting the CPU plug or the plant power fails. The continuity of power voltage keeps the user program from being lost. There is also some circuitry that converts battery DC (e.g., 24 V) to the two 5 V DC at required level.

The voltage required depends on the type of chips used within the system. If TTL ICs are used,

a 5 V DC power supply will be required. If a CMOS type of IC is utilized, then the power supply will be in the range of 3–18 V.

Power is also required for operating field devices and output loads so that they may operate. A separate external power supply is provided for this purpose. It is often referred to as the field interrogation power supply.

The latter is kept separate from the control power supply so that any power supply problems in the field are not echoed within the PLC.

1.4 PLC processor module and memory

The processor or CPU is the heart of a PLC system. It will be referred to as the CPU from now onward, for the sake of convenience. A typical processor card is shown in Figure 1.5.

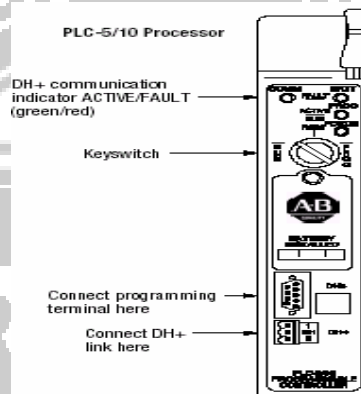


Figure 1.5

The processor of a PLC (Courtesy: Allen-Bradley)

The main processor (or CPU) is a microprocessor-based system that executes the control program, after reading the status of the field inputs. It, in turn, sends commands to the field outputs. Depending on the manufacturer, it is possible to find bit or word processors. If a bit processor is used, it will only be able to control logic bit operations. A word processor can control both bit and word operations such as processing numerical data, calculations, and analog values. Nowadays

most processors are found to be of the word type.

Does it appear as if something is missing? The CPU requires a power supply for its internal electronics, as well as for operating the signal exchange with the I/O modules.

That power supply is either derived from a separate external power supply, or some PLC units may have a power supply card installed beside the CPU card.

1.4.1 Features of the CPU

Normally, one will find the following common features in any PLC CPU card.

1. Operating key switches (mode)

These switches are included to enable the user to select different modes of operation of the PLC system.

- **Off/stop:** If this mode is selected, the PLC cannot run or be programmed.
- **Run:** The PLC will run or execute the program, but modifying or changing the program is not possible.
- **Program:** Program execution is stopped and modification or deletion of program is possible.

These features are generally present in each system, but may have minor differences.

2. Indications

In order to know the current status of the CPU, some indication lights are given on the front/face.

- **Power:** Indicates whether the CPU power supply is healthy.

- **Run:** Indicates whether a PLC is in run mode.
 - **Stop:** Indicates whether a PLC is in stop mode.
 - **Fault:** This will illuminate whenever there is any fault within the PLC – either in the software or in the hardware.
 - **Program:** Indicates the PLC has been selected in the program mode by means of the selector switch.
 - **Communication:** Depending on the communication options provided, this indicates the health of a communication link.
3. **Programming port**
A programming port is provided on the CPU to download any user program from a programming device, to the CPU. The programming port is either a nine-pin serial COM port or any other type depending on the vendor.
 4. **Communication port**
Communication ports are prerequisites in PLC units as the PLC must exchange data with other PLCs (or operator stations) to show the process information. For this purpose, different vendors provide different kinds of communication ports. As a common practice, you will probably find an Ethernet port.
 5. **Battery**
A 3.6 V DC battery is normally given in a compartment on the CPU itself for memory backup in case of a power failure.
 6. **Memory chip**
In some PLCs, such as those from Siemens, an external flash EEPROM card is provided in slot on the CPU for user program backup storage.
The CPU's memory contains the manufacturer's operating system and housekeeping functions, the program written by the user, and the data stored by the user, relating to the process or the equipment being controlled.
The memory chip is the main component of the PLC processor unit. It will be discussed in more detail in the next chapter.
These are the general features that can be found on the PLC's CPU cards. However, some CPUs may offer other additional features as well, relating to the working requirements.

1.4.2 Working of a PLC CPU

The operation of a CPU is very similar to the operation of the PLC itself. This is due to the fact that the CPU is the brain, where everything occurs.

Figure 1.6 will indicate this more clearly.

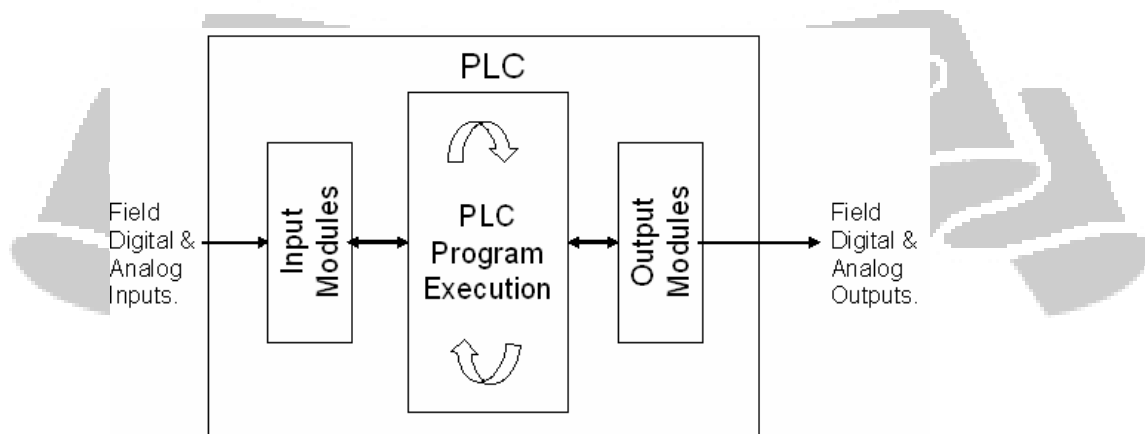


Figure 1.6

Working of a PLC CPU

A PLC uses input modules (analog or digital) for collecting field data. Then, during program execution (which goes on continuously), it generates output commands depending on the input field data. These output commands are sent to the field via output (analog or digital) modules.

In order to do this, the PLC has the following four stages of operation that are continuously repeated, many times per second (i.e., the CPU's scan rate).

- **Self-test:** This checks for hardware and software errors of the PLC.
- **Input scan:** This reads the status of inputs from the cards and transfers values to memory. It can be equated to taking snaps of the inputs. In some cases (such as with analog inputs), they are not stored in memory.
- **Logic solving:** A program is executed on the basis of the input status stored in the memory. Thus, the outputs are decided and transferred to the memory.
- **Output scan:** The outputs are transferred from the memory to the physical cards.

Why is an input or output scan required? Why can't the PLC take the status of inputs directly all the time and send this information directly to the cards?

Visualize a condition where an input (which is used or accessed in logic format at multiple locations) changes state, while the program is halfway through its execution. What's going to happen? This will invalidate the logic. To avoid this situation, input and output scans are done so that once the input status is copied in the memory it remains valid throughout that program execution cycle.

Other than this, it is important to note that data access with I/O modules is done through a communication data bus (back plane connector).

The CPU has a PG port. This is used to feed the PLC program by means of the programming device.

1.4.3 Memory systems

The memory system is an integral and very important part of any PLC system. There are two broad sections of PLC memory:

- Internal memory
- External memory

"Internal memory" is the memory within the PLC; that is, the user accessible memory (RAM). It is an integral part of each PLC.

"External memory" is the memory outside the PLC; that is, generally the EPROM or EEPROM. It is an optional part of any PLC, and is dependent on the vendor.

The functions of user-accessible memory and its various types will now be discussed in detail.

Internal or user accessible memory (RAM)

Internal or user accessible memory (RAM) has the following functions:

- Storing the user PLC program.
- Storing the status of inputs and outputs.
- Storing timer, counter, and register values. Figure

1.7 describes this section of memory.

Figure 1.7

Sections of PLC RAM memory

As shown in Figure 1.7, RAM is used for storing the "User PLC program," which occupies its major portion. It is also used for storing the status of inputs and outputs, storing timer, counter, and register values.

Based on these functions, PLC memory is broadly divided in two categories:

- Program memory
- Storage memory

1. Program memory

This is a portion of the memory used for storing the user PLC program. This program is actually stored in the memory, by means of a machine code format. Programming is usually done in ladder, statement list, or any PLC language. Following this, the program is downloaded to the PLC. As part of the download process, the program is converted into machine code and is stored in program memory.

The sequence of machine code instructions is very similar to the sequence of user programs that are just discussed.

The program memory occupies the largest portion of total memory usage. For example, a system with 16 K memory words may have program memory ranging from 4 to 12 K words, depending on the complexity of the program.

The complexity or size of the process decides the size/space of memory required in the PLC's CPU. This is a major factor in the selection of a CPU, as once the system is commissioned, it is very important that there should be enough space still left, for future program additions.

2. Storage memory

This portion of the memory stores the important information relating to program execution such as the present status of the inputs and outputs, timer, counter, register values, etc. It does not occupy much space, but dictates the maximum number of timers, counters, and registers that can be used in the program.

Storage memory can be described as storing the following information:

- Process input and output image. That is the online status of real-world analog and digital inputs, as well as outputs.
- Preset and accumulated values of timers and counters.
- Values of temporary storage bits and registers.
- Storing system-related data such as hardware configuration of the system, CPU-related diagnostic information, etc.

Please note that to prevent the loss of data in case of a power failure, it is very important to have battery backup as all the above-mentioned information are stored in the RAM.

Normally, all PLCs have a battery for memory backup. Along with it, as seen earlier, there is a "battery healthy" indication on the CPU as well.

External memory (EEPROM)

This is the optional memory that can be plugged externally into the slot provided on the PLC CPU.

It may generally be either an EPROM or EEPROM type of memory. As the EEPROM offers more flexibility (by means of easier program changes), it has become more popular of the two.

The functions of EEPROM are:

- storing the user PLC program permanently
- avoiding program loss in case of a power failure
- allowing the user to transfer the altered PLC program using standard programming devices.

A copy of the PLC program can be stored on the external memory. If this is done, there is no need to worry about power failures any more. Some PLCs offer an alternate option. For example, the program in the external memory may be copied automatically into the internal memory after a power failure. Such a feature is provided to safeguard the internal PLC program.

However, if a good battery backup is supplied for the RAM memory, then the external memory is not required.

1.4.4 Digital I/O interaction

Next, it is important to show how digital I/Os interact with the PLC, through the hardware as well as the software. Take the following example:

In a certain process, a tank heater can be started by a manual pushbutton. At the same time, once started, a temperature switch (provided to control the temperature of the liquid inside the tank) will take over control. It is assumed that the input and output are all 24 VDC.

Hardware things to do:

Field devices, such as the pushbutton and the temperature switch, will be hardwired to a 24 V DC digital I/P module.

Similarly, the heater coil's auxiliary contactor will be hardwired to 24 V DC digital O/P channel.

How would the PLC know which digital I/P is connected where, and where should it give the output so that a specific digital O/P is energized?

This introduces the concept of "Addressing." Just as we define our postal addresses, inputs and outputs have to be defined with unique addresses.

Addressing

Normally, 8-, 16-, or 32-channel digital I/P cards are used for accessing field inputs.

This means that, with a 16-channel I/P card, one can access/connect to 16 individual field inputs.

Each PLC vendor has a unique addressing format (Figure 1.8). Normally, you will find that the addressing for input or output is done in such a manner that the channel, slot, and rack address are easily projected.

Study the following example:

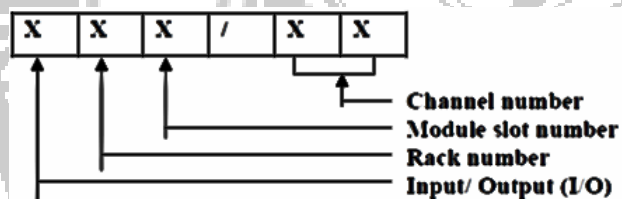


Figure 1.8

Addressing format

The input address I 014/03 indicates that the input channel is located at channel 3 of the slot 4 module, in rack 1.

Figure 1.9 shows the rack, slot, and channel locations.

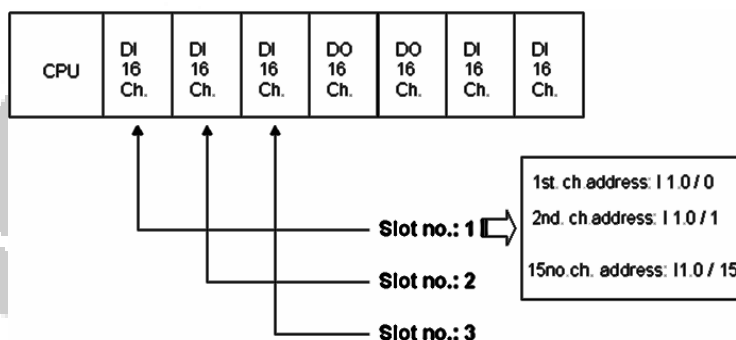


Figure 1.9

Digital I/O addressing

Input address I 1.0/3 indicates that the input channel is located at channel 3 of slot 1 module in rack 1.

Similarly, output addresses of 16 channels for slot 4 modules would be O 4.0/1 to O4.0/15.

Depending on different vendors, the I/O addressing may differ somewhat. However, the overall concept very much remains the same.

Input image table

As seen earlier, channels are identified in individual numbers, and the status of each individual channel is stored in each individual bit in a word defined in memory.

You now have a bit, on the input image table that corresponds exactly to the channel to which the input is connected, for each and every input connection.

Depending on the current status of the input, the corresponding bit on the input image table is updated.

Once you have the input bit on an image table, you can access it in the program either by specifying the address or assigning some symbolic name to each input address. By then, using the same symbolic name, it appears everywhere in the program where access to that input address is required. It is that simple. Exactly the same applies to the digital outputs as well.

Each output is well-defined with the same addressing method. For each connected output, there is a bit on the output image table that corresponds exactly to that channel.

At the end of the program execution, the corresponding bits are transferred from program to “output image table.” From there, they are transferred to a unique output channel.

1.4.5 Analog I/O interaction

Now, let's see how analog I/Os interact with the PLC through hardware as well as software.

For the sake of simplicity, take the following example:

In this process, a tank heater is used to control the temperature of the liquid in the tank.

Temperature feedback is given to the PLC through a temperature transmitter connected to the PLC. The PLC gives analog output 4–20 mA, which controls a valve supplying fuel to the heater.

Let us assume that the input and output is 4–20 mA.

Hardware things to do:

Field devices, such as a temperature transmitter giving 4–20 mA as output, will be hardwired to a 4–20 mA DC analog I/P module.

Similarly, a valve I/P converter requiring a 4–20 mA input will be hardwired to a 4–20 mA DC analog O/P module.

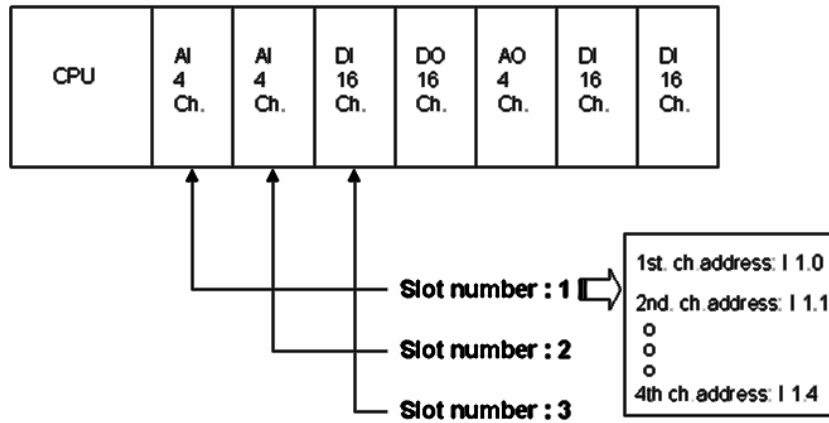
Addressing will be required by the PLC (e.g., the connection of the analog I/P) so that the PLC knows where to generate the required output.

A similar addressing concept is used for analog I/Os as was used for the digital example.

Addressing

Normally, four- and eight-channel analog I/P cards are used for accessing field inputs.

Figure 1.10 shows a PLC configuration with analog I/O modules.

**Figure 1.10***Analog I/O addressing*

Analog input address I-1.0 indicates that the module is located in the first slot and channel 0. Similarly, output addresses for the first analog output channel in slot 5 analog output module is O:5.0.

For accessing analog inputs and outputs, most PLCs prefer to access directly (as opposed to working through a process image table). Why would this be?

This is to ensure that a corresponding control action is executed immediately after any change in the analog input occurs.

Analog inputs and outputs are accessed instantaneously during the program execution.

An analog input module converts analog signals into digital value using the analog-to-digital converter (ADC). The ADC gives a 12-bit digital binary count that is exactly proportionate to the field signal.

There are some instructions or standard blocks available for accessing these digital counts, by using the unique addressing. Values are then scaled to the required engineering units. This can then be transferred in a register, if required.

Similarly, if an analog output must be sent out to the field, the control value (generated after program execution) is scaled into a 12-digit binary value using standard block or instructions.

The same digital value is then transferred to the required analog output channel by unique addressing.

According to the binary value, a proportional 4–20 mA DC or 0–10 V DC signal is generated depending on the analog output module type.

This same signal will, in turn, reach the control device connected to the PLC.

This is how analog input and output interactions take place.

1.5 PLC input/output modules

1.5.1 Basics of discrete I/O systems

Digital signals coming and going to discrete field devices have only two states: “On” or “Off.”

This “On” or “Off” signal is given to a PLC via the digital input modules. Program execution takes place based on the status of the input signals. At the end of the execution, appropriate “On” or “Off” output commands are given to discrete field devices through digital output modules.

Thus, this interaction between discrete field devices and the PLC takes place through DI and DO modules.

The DI/DO modules exchange signals with the field through hardwiring. However, signal exchange with the PLC takes place through the back plane connectors’ data bus.

DI/DO modules are plugged into the rack, which is the enclosure used for accommodating all the I/O modules. Depending on where the modules are plugged, the rack is broadly divided as:

1. Master or CPU rack

This is the rack into which the PLC CPU is plugged. This rack may [or may not] provide slots for plugging the I/O modules, depending on the vendor and the configuration. If the system is small, it may generally provide slots for I/O modules. There are no free slots for plugging I/O modules for the large systems.

2. Local rack

This rack lies just beside the master rack. It provides slots for plugging I/O modules. Data are exchanged with the CPU through a local rack communication processor. In most cases, you will find that the master rack works as a local rack.

3. Remote rack

This rack is placed at a remote location along with I/O modules. It exchanges data with the CPU through a remote communication processor.

1.5.2 Types of discrete field devices

Field devices that give only a “Yes” or “No” signal are discrete devices. That means, either the voltage is “present” or “not present” or the contact is “closed” or “open.”

Depending on the different types of digital inputs, voltage levels may be as follows:

- 24 V DC signal
- 48 V DC signal
- 110 V AC signal
- 230 V AC signal
- Isolated input

Most of these signals can be found somewhere in any plant.

Attention will now be focused on a brief look at these field devices, one at a time:

1. Selector switch, push button, and emergency stop switch

These are manually operated switches or buttons, which give a “Normally Open” or “Normally Closed” contact, as required, for a selected switch position.

2. Mechanically operated switch

In this category, there are switches that are operated mechanically due to changes in some or the other position. A good and very common example is a “Limit switch.” Limit switches are used in many applications to sense the position of any moving device. They also give “NO” or “NC” contact outputs.

3. Sensor type of switch

These sensors are used to sense various parameters and conditions of the process. They give a “Yes” or “No” signal to the PLC, corresponding to the presence of the process parameter condition. For example, a flow switch gives a clear indication of whether the flow is “Present” or “Not Present,” as a NO/NC contact to the PLC.

Similarly, a level switch gives change in NO/NC contact when the level of a process variable exceeds the limit of the level switch. More commonly used

examples of this type of switches include pressure, proximity, temperature, and vibration switches, and so on.

This is one of the easiest methods of collecting various process conditions and including them into the process.

Depending on the application and the manufacturer, some switches may also need a separate power supply to operate. A few of them give potential free contacts, while others provide a wet contact, such as 24 V DC or 230 V AC.

Depending on the type of field devices, appropriate PLC digital input modules should be selected to access these inputs.

1.5.3 Types of discrete input modules

Different digital input modules are available to access the different types of discrete field devices. They will now be discussed individually.

Discrete DC input module

These modules are widely used for their low-voltage level signals and compatibility with several discrete field devices.

Figure 1.11 shows the termination diagram, as well as a section of the internal circuit for most common types of 24 V DC digital input (sink-type) modules.

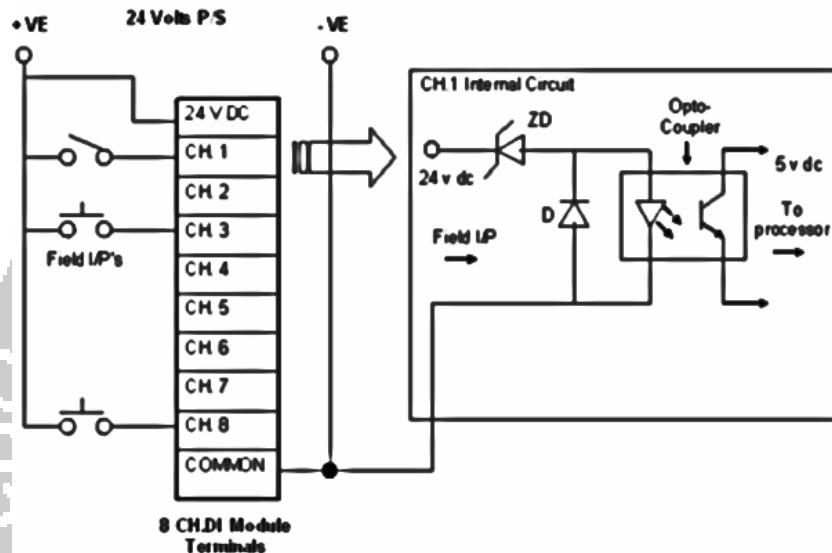


Figure 1.11
Digital DC input module

Source-type DI module

It is not uncommon for some PLC vendors to make use of the source-type DI modules. This is the opposite of the more commonly used “sink” type.

In the source-type DI modules, current flows from the module terminal to the field device, whereas with the sink-type DI module, just the reverse occurs.

What difference does this make in the wiring?

Instead of using a 24 V DC positive as common on the field, there will be 24 V DC negative as common.

Discrete AC input module

These are normally used for interfacing discrete AC field devices with the PLC. One will generally find that these modules are used for interfacing MCC signals with the PLC.

Figure 1.12 shows the termination diagram, as well the section of an internal circuit for a 230 V DC digital input module.

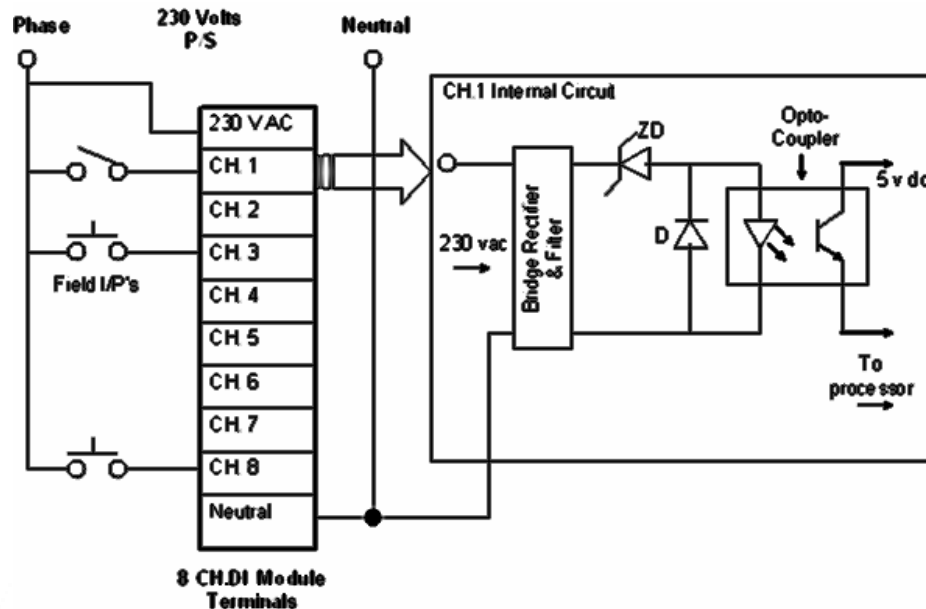


Figure 1.12
Digital AC input module

Other than the power section, everything else within a DI module remains the same for a channel internal circuit.

The power section includes a bridge rectifier and a noise filter unit. A bridge rectifier converts the 230 V AC signal into DC voltage. This voltage signal then passes through a filter circuit that filters out any noise in the incoming signal.

Following this, the DC level signal passes through a threshold detection circuit, which detects the “logic state” of the signal. After passing through the opto-isolator circuit, the logic “1” or “0” signal is passed to the internal circuit.

Fuse protection is provided for the power section. An LED indicator is used to indicate the state of the fuse, that is, whether it is healthy or not. LEDs are also provided for indicating the logical status of all incoming signals.

Isolated DC/AC input module

These modules are similar to the previous modules, except that each and every input has a separate common.

These are utilized when differing inputs are coming from multiple power circuits. From a power point of view, it is important that the common of each power circuit input is kept separate.

For this purpose, each input terminal is provided with a separate common terminal. Naturally, the number of channels available will be less than in those modules to accommodate common terminals for all the inputs.

These types of DI modules are rarely found in the industry.

1.5.4 Types of discrete output modules

Discrete output modules are, typically, some of the most commonly used modules in PLC applications.

Various discrete field devices (such as solenoids, auxiliary contactors, on/off valves, lights, alarms, and motor starters) are operated using these “discrete output modules” of the PLC.

Since many discrete field devices have various voltage requirements for operation, different types of discrete output modules are available. Generally, output voltage levels of modules may be indicated as follows:

- 12–30 V DC
- 110 V AC/DC
- 230 V AC/DC
- Isolated output

Some of the major discrete modules will now be discussed, individually.

Discrete DC output module

These cards are widely used due to their low-voltage level signals and, thus their compatibility with many discrete output devices.

Figure 1.13 shows the termination diagram as well as a section of the internal circuit for most common types of 24 V DC digital output (source type) cards.

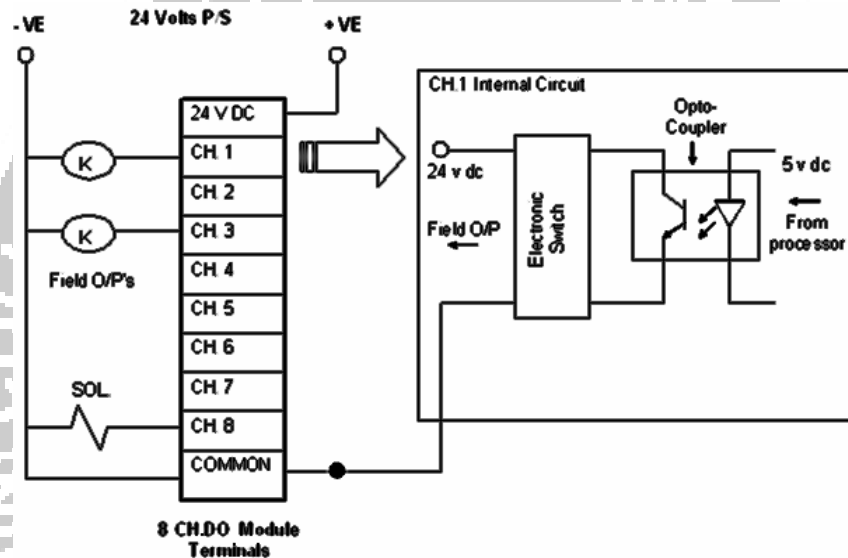


Figure 1.13

Digital DC output module

As shown in Figure 1.13, discrete field devices are connected via an eight-channel DO module (24 V DC source type). This module is supplied with a 24 V DC supply and a common terminal is provided as well.

The internal circuit of one channel can be seen in Figure 1.13, as well.

As discussed earlier, at the end of the program execution, each output bit status is transferred to an output image table. Depending on the bit status of the output image, a corresponding 5 or 0 V DC signal is provided.

An opto-isolator is provided in between for an isolation of the internal circuit from the field circuit. The opto-coupler provides noise immunity, as well as physical isolation between the field and the processor.

After the opto-coupler, the optically-isolated output signal activates an electronic switch, which provides a 24 V DC or 0 V signal (as is the case of the module used in the figure).

In many instances, the electronic switch is in the form of a power transistor that is used to switch the load. In many instances, a freewheeling diode may be provided across the load.

Depending on the type of the card, one may also find a fuse protection for the complete module and individual channels, to protect the power transistors from overload conditions. A fuse-blown LED indicator will be provided for a group of channels.

A typical digital output module will have an indication LED for each channel, to reveal the logic status of the output signal. If it glows (depending on the configuration), it may mean that the output signal is “True.”

Sink-type DO modules

Similar to DI modules, DO modules may be purchased (or wired up) in either the sink or source configuration.

In sink-type configurations of DO modules, current flows from a field device to a module

terminal, whereas in case of a source type of DO module, it is simply the reverse.

What difference is it going to make in the wiring?

Instead of 24 V DC negative as common in the field, there will be 24 V DC positive as common

Discrete AC output module

These modules are normally used for interfacing the AC discrete output field devices with the PLC. One will often find these modules generally used for interfacing the MCC signals with the PLC.

Figure 1.14 shows the termination diagram, as well as a section of the internal circuit for 230 V AC digital output card.

Other than a different power section, everything else inside a DO module remains the same for a channel internal circuit.

The power section now includes a Triac, instead of a power transistor, for switching the load along with an RC snubber circuit.

As discussed earlier, an isolated output signal coming from a processor is now used to drive a Triac switch. The Triac switch will be either “On” or “Off,” depending on the gate trigger signal.

Accordingly, the output load will also be either “On” or “Off.”

Fuse protection is also provided for the power section. An LED indicator is provided to reveal the status of the fuse. Similarly, an LED is provided for indicating the logical status of each outgoing signal.

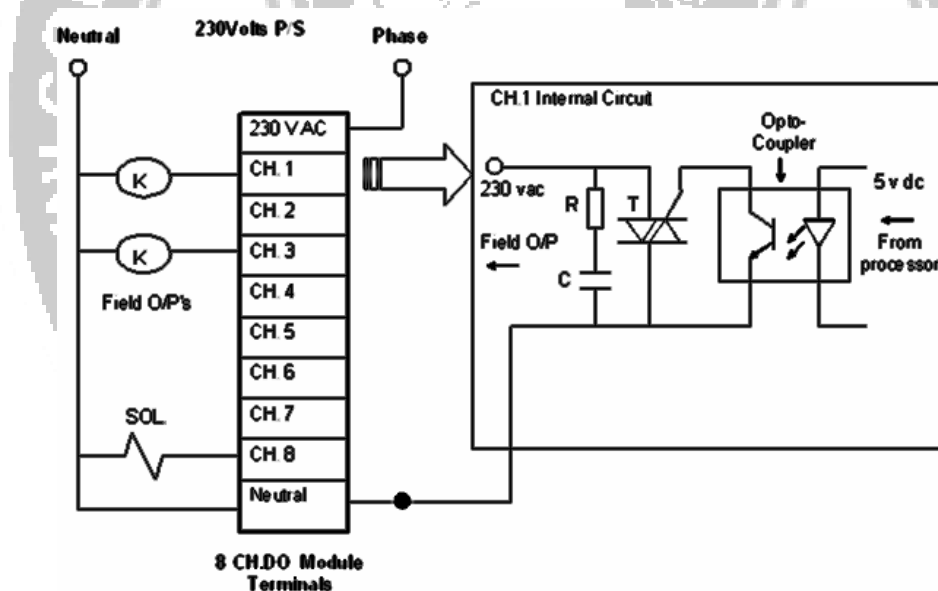


Figure 1.14

Digital AC output module

Isolated DC/AC output module

These modules are very similar to the modules just discussed, with the exception that each output has a separate common or return line.

They are normally required when outputs going to multiple power circuits, with different voltages, are involved. In these instances, it is important to keep the common of each power circuit output separate.

For that reason, each output terminal is provided with a separate common terminal. It stands to reason that the number of channels available will be less in these modules, to accommodate the extra terminals.

These types of DO modules are rarely used in the industry.

PLCs and Processing I/O

Introduction

After an introduction of PLCs in chapter one, various characteristics of the PLC need to be discussed. The purpose now is to discuss what parts constitute a modern PLC and how these parts interface. The topology of a PLC system is also discussed as to how PLCs are distributed in a manufacturing environment to best control a process efficiently.

Since each is electronic and operates using one or more microprocessors, a 5 volt power supply and CPU (central processing unit) are the core of the PLC. Included in the CPU is a computer with memory and communications hardware to communicate to a programming panel, the I/O, and to a network which is either peer-to-peer or a multimode network.

Many PLC vendors divide the work of the PLC between multiple microprocessors with coordination handled by a master microprocessor. One processor may be assigned to handle the I/O. Another may handle the networking and communication to the programming panel. A supervisory microprocessor handles the logic, scan, arithmetic, and other instructions solution of the program.

Inputs and outputs complete the PLC with inputs reporting the status of the system and outputs controlling the sequencing of the process. Inputs and outputs are of many types and forms. A simple switch can be an input. Also, a high-speed pulse input can be an input providing speed information from a motor. Inputs and outputs alike can be simple or complex in nature. Both the simple I/O as well as the more complex will be discussed in the chapter and through the rest of the book.

Overview of the PLC

Inputs form the portion of the PLC connecting switches, sensors, transducers and other devices to the processor. Typically, the input is tied to a screw terminal. The PLC program reads the status of the inputs and solves logic based on this status.

The CPU stores the program and controls communication with all peripherals including programming devices as well as the I/O. The CPU executes the programs in an orderly manner and guarantee that I/O responds per the program. The guarantee is not trivial if one is experienced with most computer operating systems.

Outputs are connected to devices that control the process. Relays, motors, solenoids and other outputs are some examples. A pulse wave PWM is one that controls stepper motors and positional movement. The PLC program can control the status of this output and thus control the motor speed and movement.

In the figures below, the simplified PLC is shown first followed by an expanded view of the PLC. Each view shows the importance of the CPU (Central Processing Unit) as well as the interconnection of the CPU to I/O (Inputs and Outputs). Other devices interact in such a way that the program executes and solves logic in a timely manner.

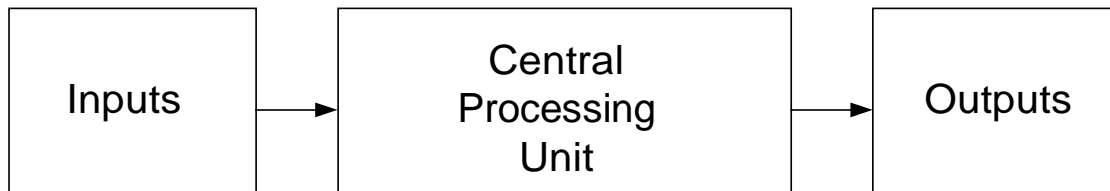


Fig. 3-1a Simplified View of the PLC

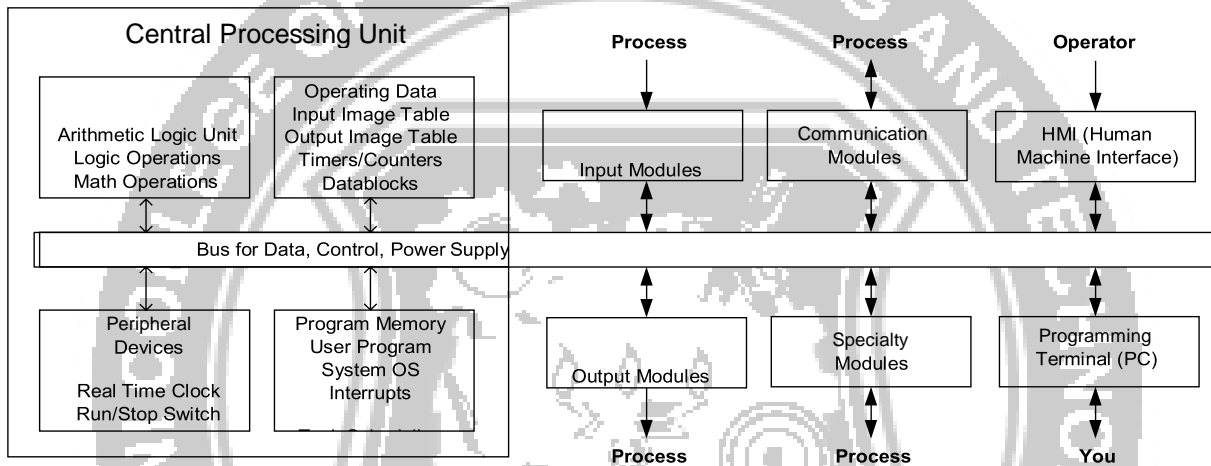


Fig. 3-1b Expanded View of the PLC

The second view gives a greater detail of data flow into and out of the PLC. As the devices and programs become more involved, the flow of data must both increase while being as secure as with simple systems. All systems may not use communication modules or specialty modules.

Some may use a great number. All will use some kind of programming terminal and “you” will be responsible for providing the program to run it.

Most PLCs also have a table reserved for health status of the cpu, the I/O, and the software. This table can be monitored to find if processor errors have occurred. Status tables may be ignored for the most part until something goes wrong. When an error occurs, their use is extremely important to the programmer and to the recovery of the processor. The programmer must monitor the status table in order to determine what went wrong and to restore the processor to running condition again.

Also along-side the PLC's cpu is a watch dog timer (WDT). The WDT monitors health throughout the PLC and shuts down the I/O and program if there is a danger that the program or hardware has caused a major breakdown of the PLC's integrity to process the program and control the process. The WDT is helpless to shut down the machine being controlled if the program in the PLC is not functioning correctly due to poor programming. Care must be taken to consider all possible conditions of a program. The proper control of the machine or process under all conditions and circumstances is critical.

What Happens Electrically

Figure 3-2 demonstrates the flow of current in a simple circuit. The battery provides power to the lamp but is blocked in Fig. 3-2b because the switch is open. With an open switch, no current flows and the circuit is incomplete. When the switch closes, however, current flows and the lamp is illuminated (Fig. 3-2c). As simple as this circuit is, it contains the fundamental principle of input and output flow in a control circuit and the PLC.

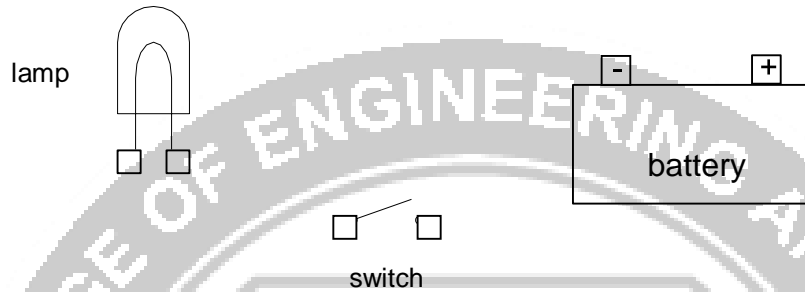


Fig. 3-2a Simple Electrical Components

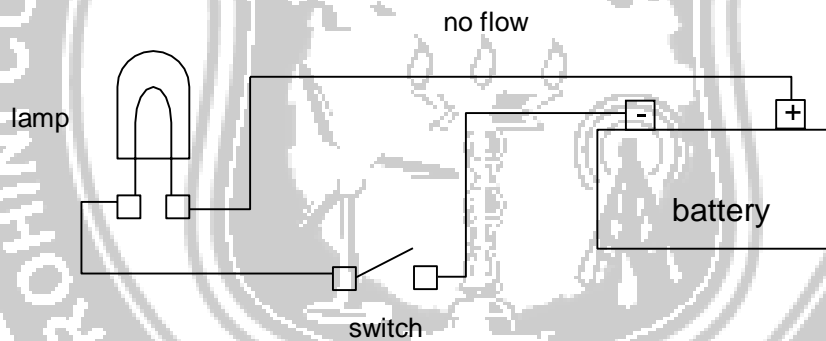


Fig. 3-2b Simple Electrical Circuit (Open, No Flow)

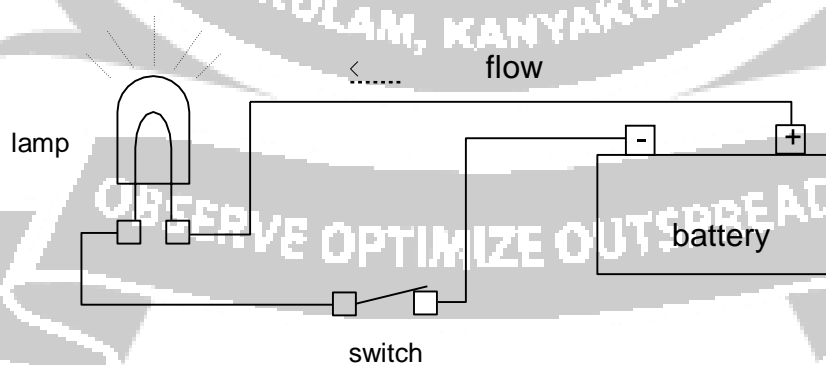


Fig. 3-2c Simple Electrical Circuit (Closed, Flow)

The schematic for these circuits resembles the circuit below (Fig. 3-2d). Symbols have replaced their physical devices but the functionality remains the same.

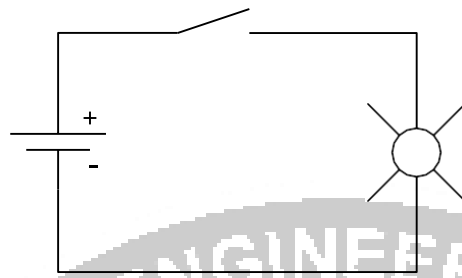


Fig. 3-2d Simple Electrical Schematic

Fig. 3-3 shows the PLC solving logic in a similar manner to the simple circuit above. The complication of additional circuits solving logic adds to the sophistication of the circuit. This allows much more sophistication in the defining of how a circuit will perform under all conditions.

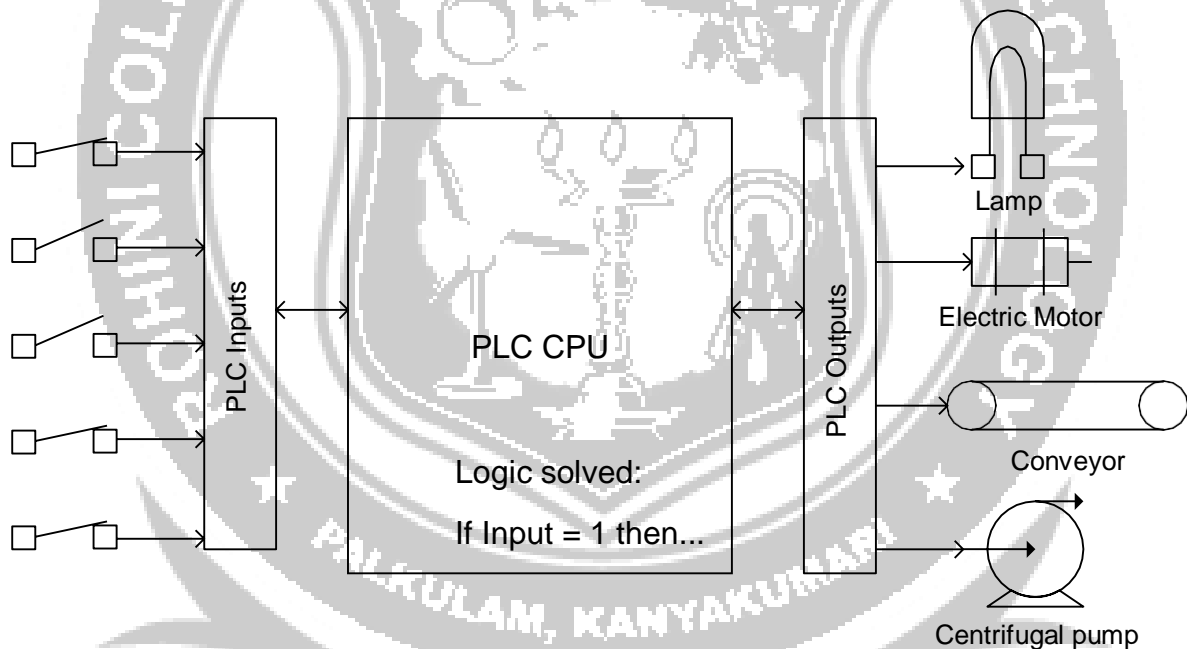


Fig. 3-3 Simple PLC Circuit with Real-World Devices

In addition to simple PLC networks such as that above, the PLC may contain network I/O allowing inputs and outputs to be communicated with at remote locations. Fig. 3-5 demonstrates this type of system.

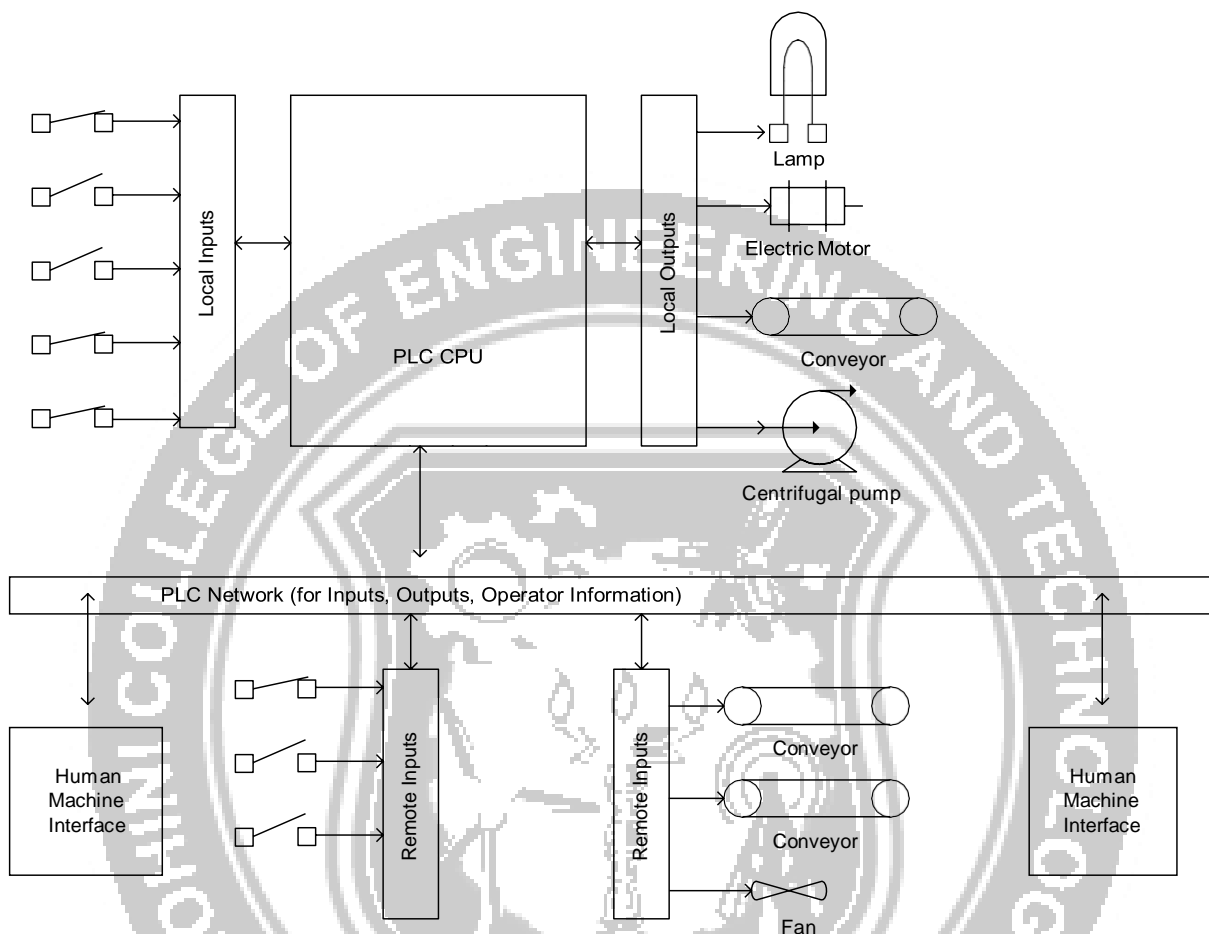


Fig. 3-4 PLC Circuit with Remote I/O

Inputs and outputs may even be communicated over wireless networks and this type of network is becoming increasingly more popular as wiring costs continue to rise and the equipment is designed for safe operation in all environments. Safe wireless networks are the latest advances in PLC equipment and offer expansion of logic into areas formerly off-limits to the PLC.

The PLC program is generated on a PC using the manufacturer's software, and temporarily stored there.

After the PC is connected with the TCP/IP interface of the PLC, the program can be transferred with a load function to the PLC's memory.

The PC is no longer needed for further program processing in the PLC except to monitor the online program observing the operation of the inputs, outputs and logic (program) linking the inputs to the outputs.

The Generic PLC

How does the PLC replace relay logic from a ladder logic diagram? Consider the following example. Pictured below is a simple generic PLC with four inputs and four outputs. One input is wired to a push button and one output is wired to an indicator light. While not exactly the same as our PLC processor, the steps of installing a program and wiring the PLC are the same.

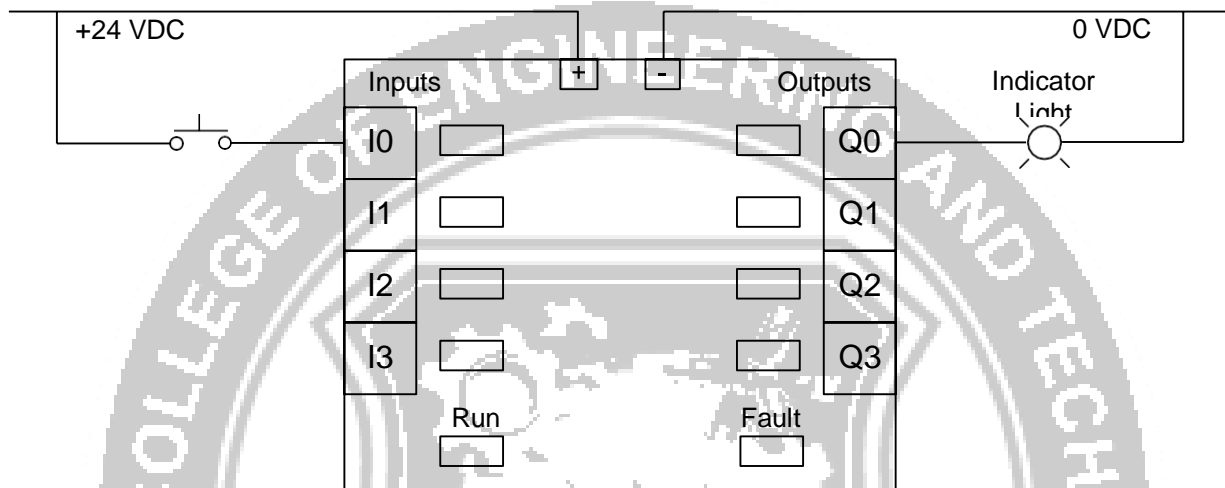


Fig. 3-5 Generic PLC Layout

Notice when wiring an input and energizing the button that the green indicator light for the input comes on:

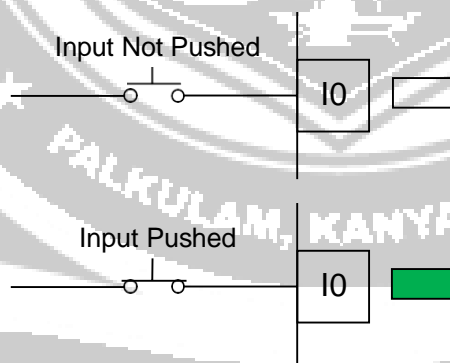


Fig. 3-6 PLC Inputs

In the program, contacts referring to the input conduct as shown below:

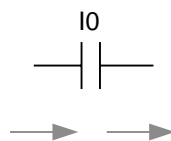


Fig. 3-7a Internal Logic

The program needed to create a circuit similar to the switch and light of Fig. 3-2d is shown below:

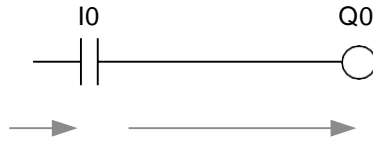


Fig. 3-7b Internal Logic

and the Run light is on:



then the output will turn on and the light will turn on.

When the program shows the output on, the output LED turns on and the output terminal energizes the light as shown:

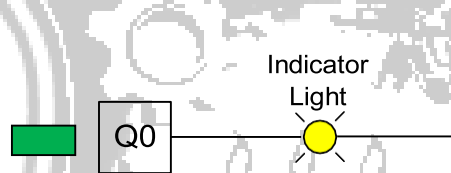


Fig. 3-8a Output Power On

When the program is turned from Run to Program, the output LED turns off and the output turns off. The outputs also turn off and the Run light goes off if a fault occurs.

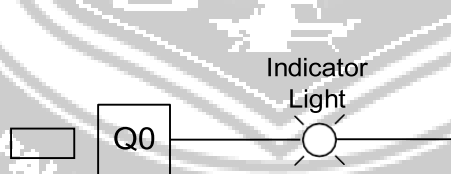


Fig. 3-8b Output Power Off

OBSERVE OPTIMIZE OUTSPREAD

How is the Program Processed in the PLC?

The program is processed in the PLC cyclically, in the following sequence:

1. First, the status is transferred from the process image of the outputs to the output terminals.
 2. The processor examines the individual inputs for high voltage or low voltage. Status of the inputs is stored in the process image of the inputs. For the inputs with the rated voltage a 1 or HIGH is stored, for those that don't the 0 or LOW is stored.
 3. This processor then processes the program stored in the program memory. The program consists of a list of logic operations and instructions that are processed one after the other. For the required input information, the processor accesses the input table entered previously and the result of the logic operation is written into a process image of the outputs. If necessary, the processor also accesses other memory areas during program processing; for example, for local data of sub-programs, data blocks and flags.
 4. Then, internal operating system tasks such as self-tests and communication are performed. Then we return to item 1.
1. Transfer the status from the output image to the outputs.
 2. Store the status of the inputs in the input image table.

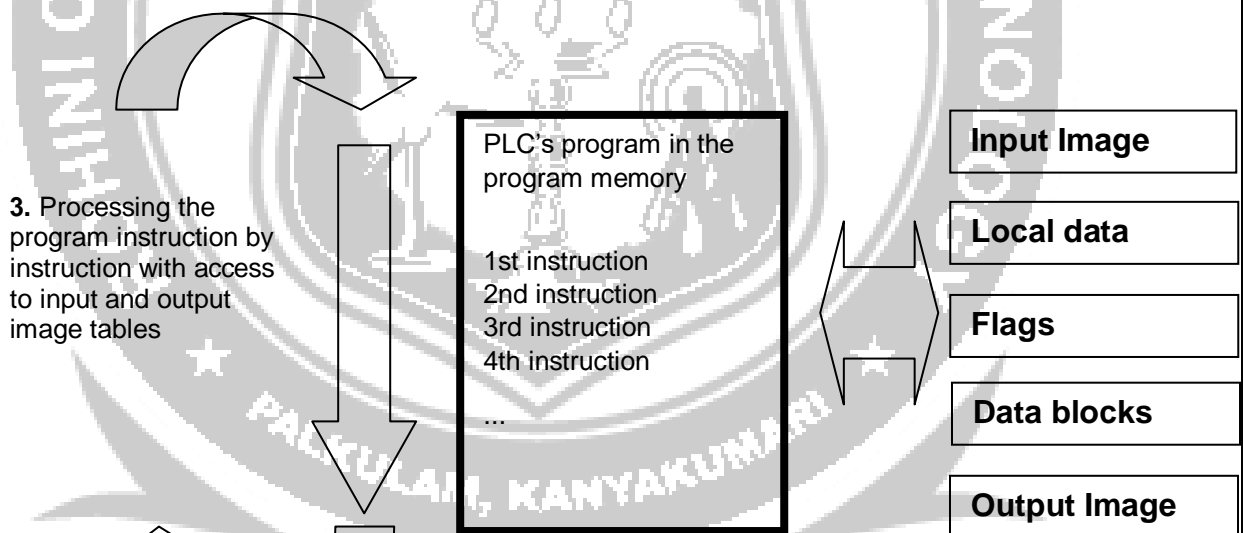


Fig. 3-9

Note: The time the processor needs for this sequence is called cycle time. In turn, the cycle time depends on the number and type of instructions and the processor capacity.

4. Perform internal operating system tasks (communication, self-test, etc...)

I/O

We need to discuss the types of inputs and outputs that constitute a valid PLC system. For inputs, we find:

From Liptak's Process Control: "Input Systems

Inputs are defined as real-world signals giving the controller real-time status of process variables. These signals can be analog or digital, low or high frequency, maintained or momentary.

Typically they are presented to the programmable controller as a varying voltage, current, or resistance value."

Analog signals include thermocouple and resistance temperature devices. Digital signals include on-off signals from relay contacts or push buttons. Signals such as flowmeters provide frequency input with the frequency varying with the flow.

Signals to the programmable controller are input from single wire devices or from parallel signals. A thumb-wheel switch or scale system can input a four-digit number from four BCD parallel digits. Many signals such as the scale system also require a synchronization signal before data can be read.

Inputs include the following types or attributes: DC

voltage

AC voltage, ranges of 50 Hz or 60 Hz available

True High or True Low DC voltages

Analog inputs, ranges 0-10V or 4-20 ma most popular BCD,

Binary Coded Decimal

Thermocouple

Scale/load cells/LVDT, weight and force sensors RTD,

Resistance Temperature Detector Latching

Isolated or Common Neutral

Intelligent (Smart with own CPU on board I/O card) Resolver

Encoder

Serial Communications Port

An example is the limit switch shown below:



Fig. 3-10 Picture of Limit Switch (Input)

From Liptak's Process Control:

“Outputs

There are three common categories of outputs: discrete, register, and analog. Discrete outputs can be pilot lights, solenoid valves, or annunciator windows (lamp box). Register outputs can drive panel meters or displays; analog outputs can drive signals to variable speed drives or to I/P (current to air) converters and thus to control valves.”

Output signals are similar to input signals in that signals can be either analog or digital. Digital signals can be either single data or a parallel arrangement of bits. Most modules are ordered in arrangements of 4, 8, 16, or 32 devices per card.

Both input and output signals are optically isolated in designs for the US market. This protects signals from entering the interior of the PLC and allows the designer to wire circuits less carefully than in circuits without optical isolation. One main design difference between US and European PLC design is the lack of optical isolation in the European design.

Outputs include the following types or attributes: DC

- voltage
- AC voltage, ranges of 50 Hz or 60 Hz available Isolated or Common Source
- True High or True Low DC voltages
- Analog Output
- Serial Communications Port
- Intelligent (Smart with own CPU on board I/O card) Servo Controller

While I/O modules vary in type and number, recent developments have caused even these general rules to change. Distributed I/O is an example of a small number of inputs and outputs isolated at a machine that control a portion of a machine remotely from the PLC. Typical remote I/O requires a rack, power supply and a large number of cards while distributed I/O is pre-configured for only a small number of inputs and outputs. A number of advantages occur with the use of distributed I/O in that the machine can be wired and tested in one facility, broken down and shipped to a second facility, and re-connected with very little change in the wiring. This leads to quicker start-ups and cheaper overall wiring costs. Typical distributed I/O is controlled over a communications network that is daisy-chained from device to device.

Some examples of PLC outputs include:



Fig. 3-11 Solenoid Valve (Output)



Fig. 3-12 Relay (Output)

The relay pictured may provide input contacts but is primarily used to turn on or off various other signals from the PLC and is connected to a PLC output to accomplish this task.

What is This?



From above, it resembles a light.



From the side, it still resembles a light but there are contacts that resemble those of a pushbutton.

Contacts for light to be connected are located here:



From the rear, it is clear that the contacts are for a pushbutton. NC refers to a normally closed and NO refers to a normally open contact.

And in fact, this is both a light and a pushbutton, commonly referred to as an illuminated pushbutton. Note that the pushbutton and light may be independent or wired to show when the button is pushed with a light on. We will in most programs

require that the button be independent from the light.

Fig.. 3-13 Combined Pushbutton/Pilot Light



Looking ahead in Ch. 5, we have an example of an Input/Output table. This table is organized to define the type of sensor or actuator, its function and the signal assignment. Signal assignments are made based on the condition of the program if the signal is compromised. If a wire falls off and the program responds poorly, then the signal assignment should be changed to the opposite type. Signal assignment of 1 is referenced as Normally Open and 0 referenced as Normally Closed.

The table below may be expanded to include the I/O address, ordering information, cost, and other pertinent information. This table has many uses and is important to the overall project's success.

Sensor	Function/State	Signal Assignment
Start Button	Start	1
High Level Switch	Level exceeded	0
Half Level Switch	Level exceeded	1
Temperature Switch	80° C exceeded	0

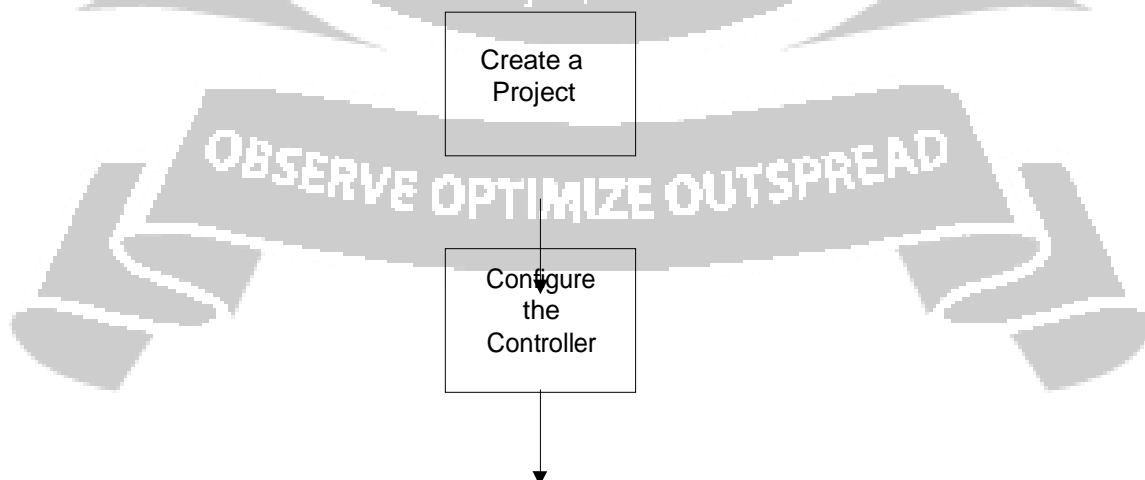
Table 3-1 (5-2a) Input Definitions

Actuator	Function/State	Signal Assignment
Agitator motor	Stirring/running	1
Fill Valve V-2	Fill tank	1
Flush Valve V-1	Empty tank	1
Heat	Heat juice	1
Done/Ready Indicator	Illuminated	1

Table 3-1 (5-2b) Output Definitions

How to Run a PLC program:

The steps to run a program in the plc is common to all plc manufacturers. It in general follows the following steps:



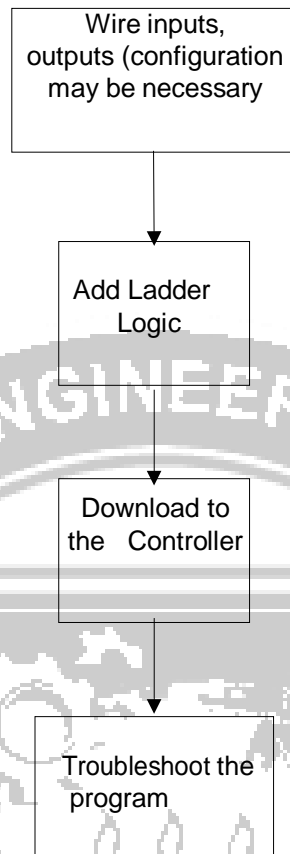


Fig. 3-14 Flow Chart of Program Development

Next we study the major brands of PLCs and begin the process of setting them up for use as a relay simulator and much more. This is the study of how to program a process and the PLC can do so much more than relays could. This is part of what will be explored.

The SIMATIC S7-1200

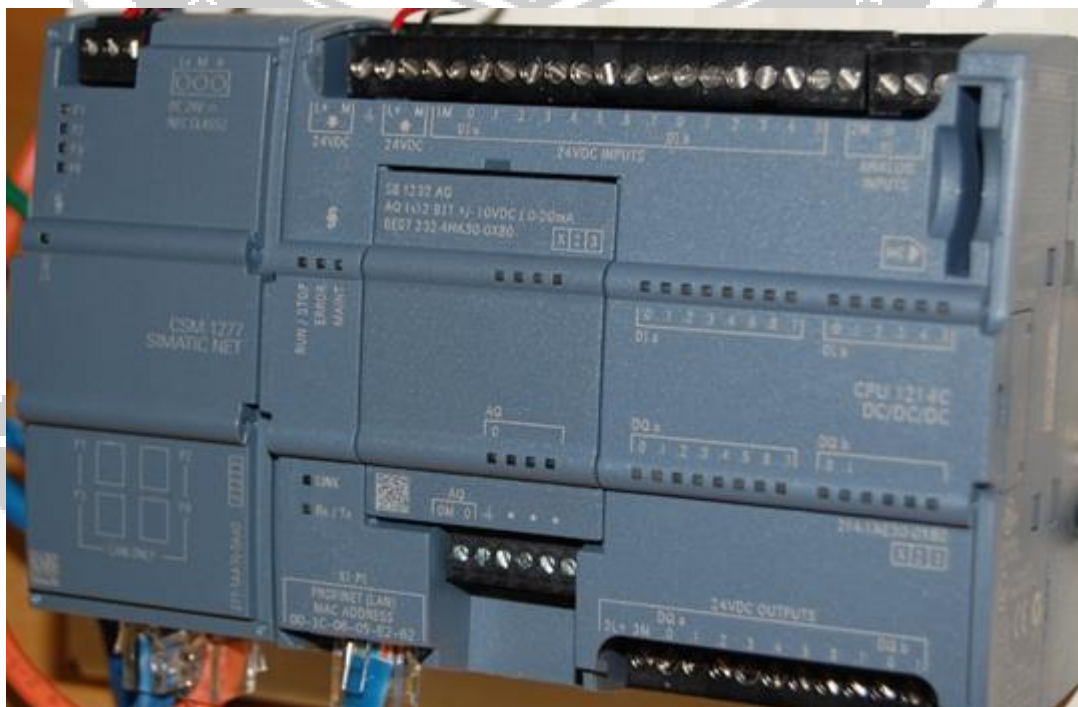


Fig. 3-15 Siemens S7-1200

Pictured below is a S7-1200 PLC from Siemens. It is a powerful new controller with many capabilities only available in more expensive models until recently.

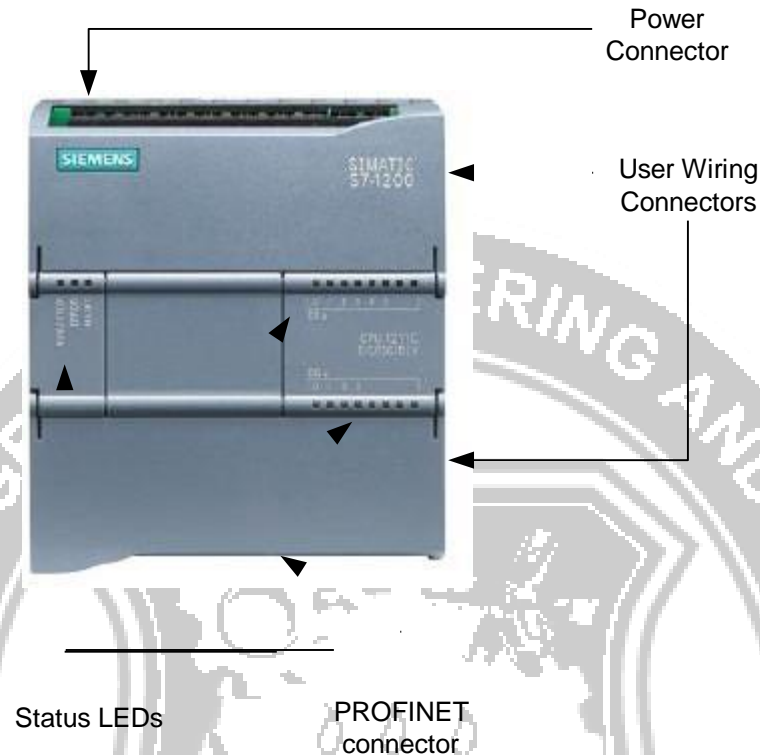


Fig. 3-16 New S7-1200 PLC from Siemens

The S7-1200 is referred to as a micro PLC and is programmed in **STEP 7 Basic**, the newest software offering from Siemens. The processor has capabilities of adding additional I/O to the basic unit shown above. The processor communicates to a programming panel through an Ethernet port referred to as the PROFINET interface found on the bottom of the unit. This port offers access to other controllers, a programmer's console and various HMI (Human Machine Interface) units.

Capabilities of this model – the CPU 1214C - include:

User Memory	-	Work memory	50 Kbytes
		Load memory	2 Mbytes
		Retentive memory	2 Kbytes
On-board digital I/O	14 inputs		
	10 outputs		
On-board analog I/O	2 inputs		
Process image size	Inputs	1024 bytes	
	Outputs	1024 bytes	
Bit memory (M)		8192 bytes	
SM modules		8 SMs max	
expansion			
SB expansion		1 SB max	
CM expansion		3 CMs max	
High-speed counters		6 total	
	Single phase	3 at 100 kHz and 3 at 30 kHz	
	Quadrature phase	3 at 80 kHz and 3 at 20 kHz	
Pulse outputs		2	
Pulse catch inputs		14	

Time delay/cyclic interrupts

4 total with 1 ms resolution

Edge interrupts

12 rising and 12 falling

Real time clock

accuracy

+/- 60 sec/month



Execution speed	boolean	0.1
	Move Word	microsec/instruction
	Real Math	12 µsec/instruction
Communication		18 µsec/instruction
		1 Ethernet port
	Data rate	10/100Mb/s
	Isolation	xfrmr isolated
	Cable type	CAT5e shielded
Connections	HMI	3
	PG	1
	User program	8
	CPU to CPU	3

Specifications of the PLC include:

Digital Inputs	Number of inputs	14
	Type	Sink/Source
	Rated voltage	24 VDC at 4 mA, nominal Continuous permissible 30 VDC, max
	Surge voltage	35 VDC for 0.5 sec
	Logic 1 min.	15 VDC
	Logic 0 max.	5 VDC
	Isolation	500 VAC for 1
min. High Speed Clock kHz	Single phase rate	100 kHz and 30
Analog Inputs	Number	2 Voltage (single-ended)
	Range	0 to 10 V
	Full-scale range	0 to 27648
	Overshoot range	27649 to 32511
	Overflow	32512 to 32767
	Resolution	10 bits
	Max withstand voltage VDC	35
	Smoothing	None, weak, medium or strong
	Noise rejection	10, 50, or 60 Hz
	Impedance	>= 100 KΩ
	Isolation	None
	Accuracy	3.0% - 3.5%
	Common mode rejection	40 dB, DC to 60 Hz
	Operational signal range	Signal plus common mode voltage less than 12V and greater than -12 V
	Cable length	100 m, twisted and shielded

Descriptions of S7-1200 Modules:

- Central modules CPU with different capacity, integrated inputs/outputs and PROFINET interface (for example, CPU1214C)



Fig. 3-17a S7-1200 (CPU 1214C)



- Signal boards SB for adding analog or digital inputs/outputs; whereby the size of the CPU does not change

(signal boards can be used with the CPUs 1211C/1212C and 1214C)



Fig. 3-17b Signal Board of S7-1200 (Analog I/O)

- SIMATIC memory cards 2MB or 24MB for storing program data and simple CPU replacement for maintenance



Fig. 3-17c Memory Card of S7-1200

Note: For this module M01, any CPU with integrated digital inputs and digital outputs is sufficient.

The SIMATIC Memory Card (MC) stores the program, data, system data, files and projects. It can be used for the following:

- Transferring a program to several CPUs
- Firmware update of CPUs, signal modules SM and communication modules CM



Fig. 3-17d Memory Card being installed

You may want to have this card on hand when you upgrade your software since the version of firmware onboard the PLC must be upgraded at the same time or you may be unable to properly link the PLC to the software in the programming terminal.

Allen-Bradley's CompactLogix L23E Programmable Automation Controllers

The following processor is the 1769-L23E-QBFC1B:



Fig. 3-18 Front View of CompactLogix L23E



Fig. 3-19 View of CompactLogix L23E with Wiring Exposed

CompactLogix programmable automation controllers (PACs) offer the benefits of the Logix Control Platform—common programming environment, common networks, and common control engine—in a smaller footprint for machine-level control applications. The new CompactLogix L23 extends these benefits into even smaller applications. The CompactLogix L23 controllers include the Logix control engine, power supply and two of the most common I/O configurations, lowering costs and simplifying configuration. Each CompactLogix L23 PAC offers 512Kb of memory, up to three tasks, four programs and embedded EtherNet/IP capabilities for ease of use. Up to two local Compact I/O or communication cards can also be added for additional flexibility.

1769-L23E-QBFC1B

Embedded Communication Ports	Isolated Serial (DF1 or ASCII) Ethernet/IP with (MSG + I/O)
EtherNet/IP Connections	8 TCP/IP – 32 CIP
Memory	512 KB
Embedded I/O	16 DC in, 16 DC out, 4 Analog in, 2 Analog out, 4 High-Speed Counters (250 kHz)
Expansion	2 Additional 1769 I/O Modules or 1 1769 Communication Module
Tasks	3-Continuous, Periodic or Event
Programs	4
Routines	Unlimited
Languages	LD, FBD, ST, and SFC
Alarms & Events	Supported
PhaseManager	Supported
Add-on Instructions	Supported
Dimension	130x293x90mm
Power Requirements	19.2 – 31.2 VDC – 50VA

Table 3-2 CompactLogix L23E Capabilities

CompactLogix L16ER and the newer S7-1200 Processors



Fig. 3-20 L16ER in Rack

Allen Bradley's CompactLogix 5370 controllers expand the scalability of the Logix family of controllers, offer a wider variety of options, and provide best-fit alternatives for your specific application requirements. Coupled with Kinetix® 350, the controllers provide high performance in a compact and affordable integrated motion package for a variety of machine applications, all on one common network – EtherNet/IP. The L16ER Compact Logix processor, part of this family is shown above along with the newer Siemens S7-1200 processor. While the Siemens processor is similar to the earlier one, the A-B processor is very different. Some of the characteristics of this processor are:

The CompactLogix 5370 system provides:

- Two EtherNet/IP ports
- One USB port
- Support for local expansion modules
- Control of local and distributed I/O modules
- Use of 1784-SD1 or 1784-SD2 secure digital (SD) card for nonvolatile flash memory
- Internal energy storage solution eliminating the need for a battery

Characteristics

The CompactLogix 5370 L1 controller comes with a built-in 24V DC power supply and embedded digital I/O (16 DC inputs, 16 DC outputs). Up to eight 1734 POINT I/O expansion modules are supported. The following list the characteristics of this processor:

Characteristic	1769-L16ER-BB1B
User Memory	384 kB
Secure Digital Memory Card	1 GB (standard)
	2 GB (optional)
Communication Ports	DualPort Ethernet DLR, USB
Embedded I/O	• 16 DC inputs
	• 16 DC outputs
Module expansion capacity	6 expansion modules and 4 Ethernet nodes

Network

Both A-B and Siemens have various requirements for connecting their processor to the Ethernet cable.

For the PC and the SIMATIC S7-1200 to communicate with each other, it is important that the IP addresses of both devices match.

First, we show you how to set the computer's IP address.

1. From the System control, call the Network connections. Then, select the Properties of the LAN connection (→ Start → Settings → System control → Network connections → Local Area Connection → Properties)
2. Select the Properties from the Internet Protocol (TCP/IP) (→ Internet Protocol (TCP/IP) → Properties)
3. You can now set the IP address and the Subnet screen form, and accept with OK (→ Use the following IP address → IP address: 192.168.0.99 → Subnet screen form 255.255.255.0 → OK → Close)

MAC address:

The MAC address consists of a permanent and a variable part. The permanent part ("Basic MAC Address") identifies the manufacturer (Siemens, 3COM, ...). The variable part of the MAC address differentiates the various Ethernet stations and should be assigned uniquely world-wide. On each module, a MAC address is imprinted specified by the factory.

Value range for the IP-address:

The IP address consists of 4 decimal numbers from the value range 0 to 255, separated by a period. For example, 141.80.0.16

Value range for the subnet screen form:

This screen form is used to recognize whether a station or its IP address belongs to the local subnetwork, or can be accessed only by means of a router.

The subnet screen form consists of four decimal numbers from the value range 0 to 255, separated by a period. For example, 255.255.0.0

In their binary representation, the 4 decimal numbers of the subnet screen form have to contain - from the left- a series of gapless values "1" and from the right a series of gapless values "0". The values "1" specify the area of the IP address for the network number. The values "0" specify the area of the IP address for the station address.

Example:

Correct values: 255.255.0.0 Decimal = 1111 1111.1111 1111.0000 0000.0000 0000 binary
 255.255.128.0 Decimal = 1111 1111.1111 1111.1000 0000.0000 0000 binary
 255.254.0.0 Decimal = 1111 1111.1111 1110.0000 0000.0000.0000 binary

Wrong value: 255.255.1.0 Decimal = 1111 1111.1111 1111.0000 0001.0000 0000 binary

Value range for the address of the gateway (Router):

The address consists of 4 decimal numbers from the value range 0 to 255, separated by a period. For example, 141.80.0.1.

Example:

You entered the following: for the subnet screen form 255.255.255.0, for the IP address 141.30.0.5 and for the router address 141.30.128.1.

The IP address and the gateway address must have a different value only in the 4th decimal number. However, in the example, the 3rd position already differs.

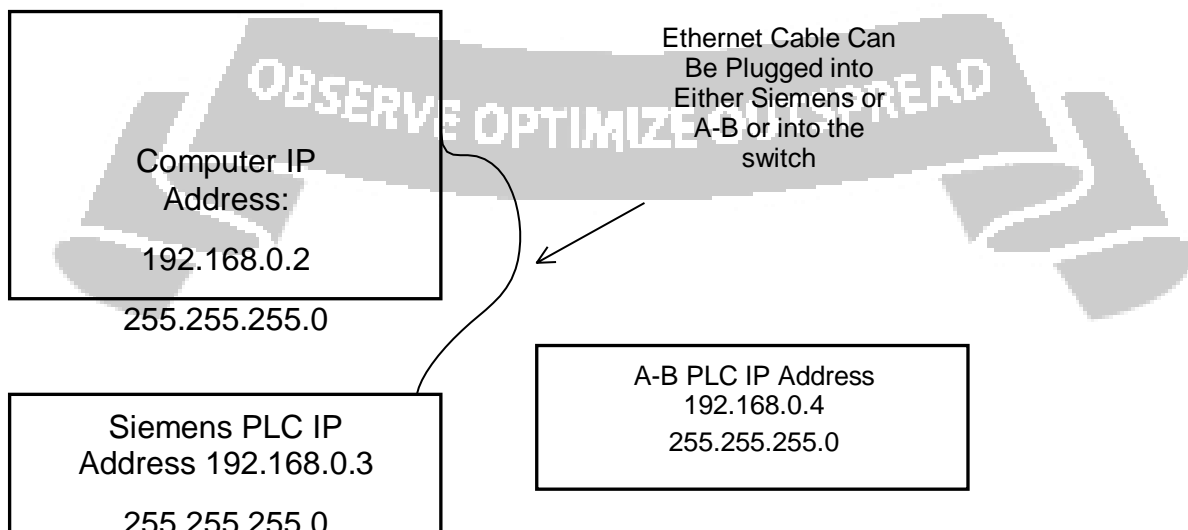
That means, in the example you have to change alternatively:

- the subnet screen form to: 255.255.0.0 or
- the IP address to: 141.30.128.5 or
- the gateway address to: 141.30.0.1

For setup of the A-B IP address, their BOOTP instructions on the internet give a good layout. Once the instructions for setup have been completed, the IP address is easily found using RSLinx Classic.

Once the hardware of an automation system is defined, the next step in the project cycle is to create a program. But before you start programming, it helps a whole lot if you understand the basic "structure" of the S7 PLC. This section will provide the necessary details of the CPU memory model, address areas and uses, how to add elements to a program, program structure, and what tools are available within the program editor for testing.

For our systems, the following local area network has been set up and will allow communication between PLCs and the computer:



Starting a Project and Logging onto the S7-1200

First, find the TIA V14 Button and click:



View the following:

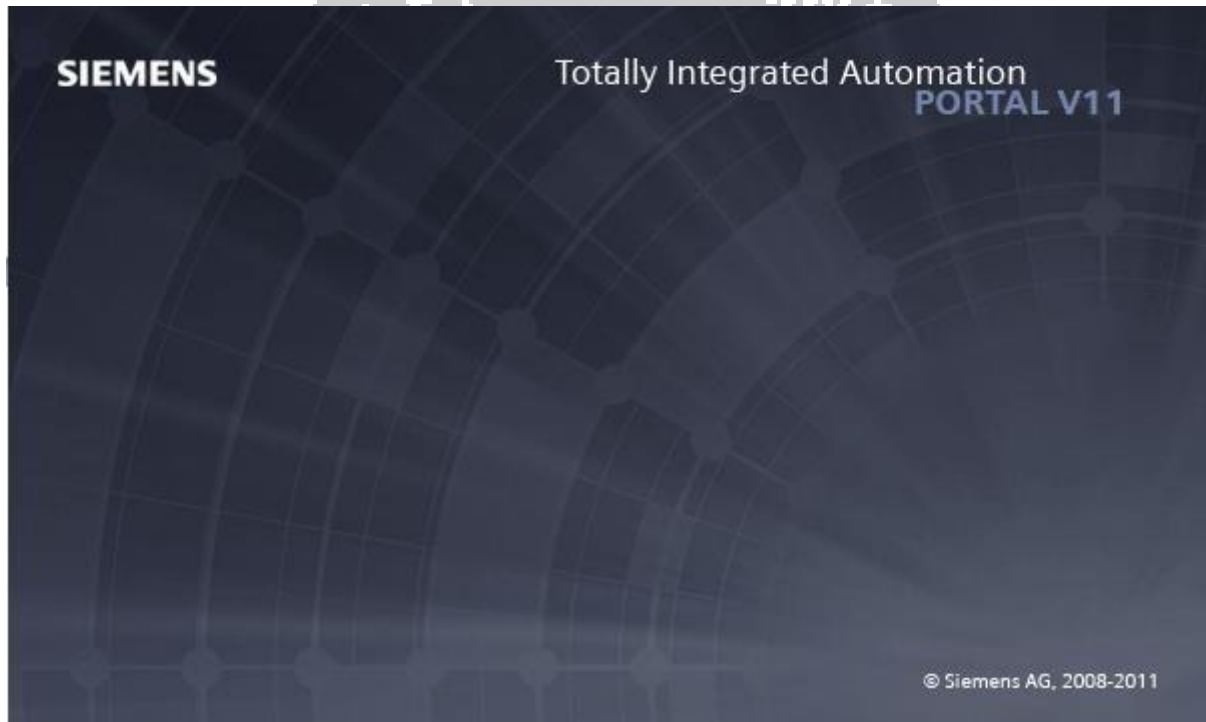


Fig. 3-21a The Siemens Portal

Select a name of your project. Be aware that you will need to address the project from the H drive or from a stick drive.

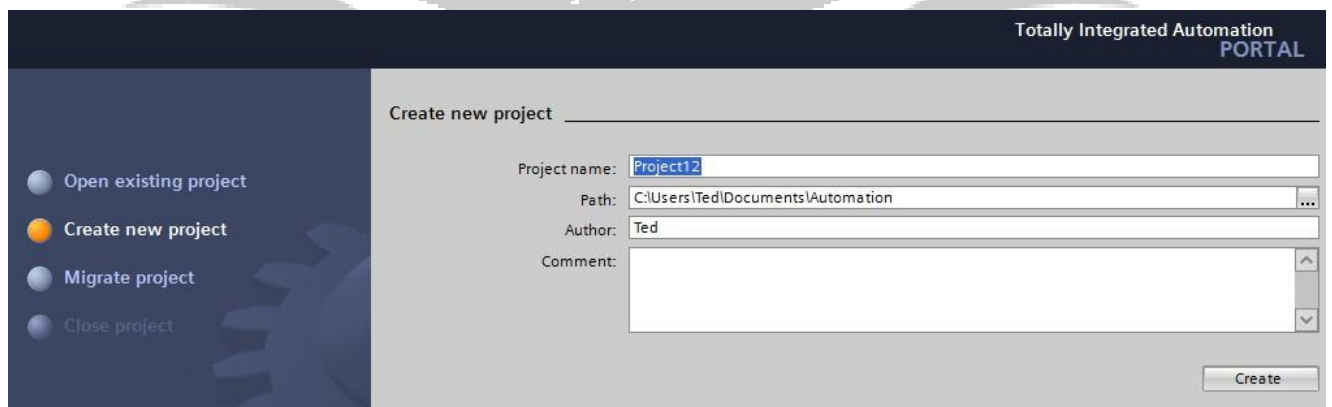


Fig. 3-21b Continuation of the Portal Screen

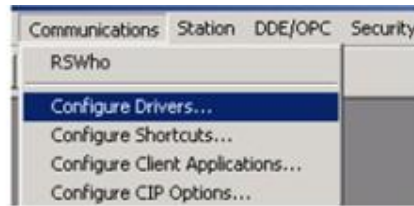
Additional instruction is found on the video accompanying this text. Since the instructions vary from processor to processor, please view this video as a first step in logging on and programming the Siemens program.

Starting a Project and Logging onto the L23E-QBFC1B and L16ER Processors

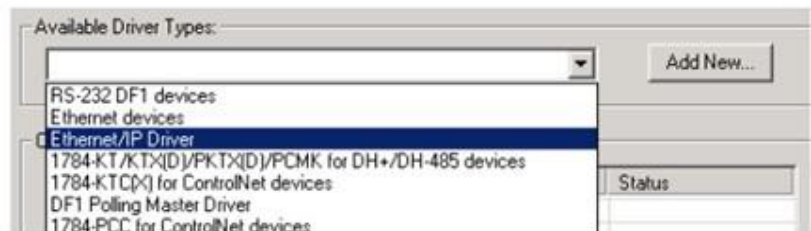
First, use RSLinx to configure the EtherNet/IP Driver:

Fig. 3-22

Choose 'Communications', then 'Configure Drivers'.



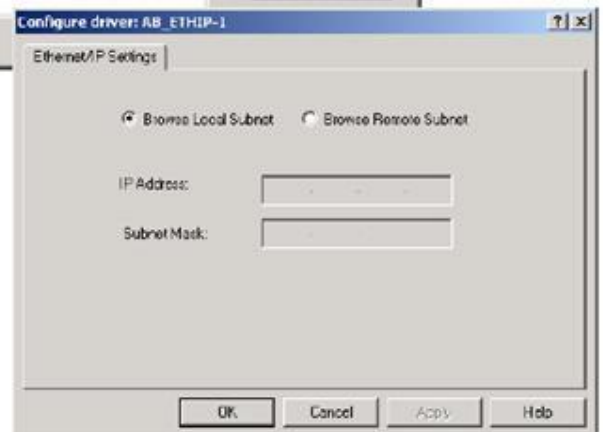
From the list of Available Driver Types, choose 'Ethernet/IP'.



Click 'Add New...' and then 'OK'.



Check 'Browse Local Subnet' and then click 'OK'.



Verify that the driver is 'Running'. Close the 'Configure Drivers' window.

Verify that Ethernet/IP is 'seeing' the PLC by clicking 'RSWho'.



and expanding the Ethernet link to see the specific CompactLogix processor



When launching Studio 5000, have the icon on your desktop or launch using Logix software. When launched, the following will appear:

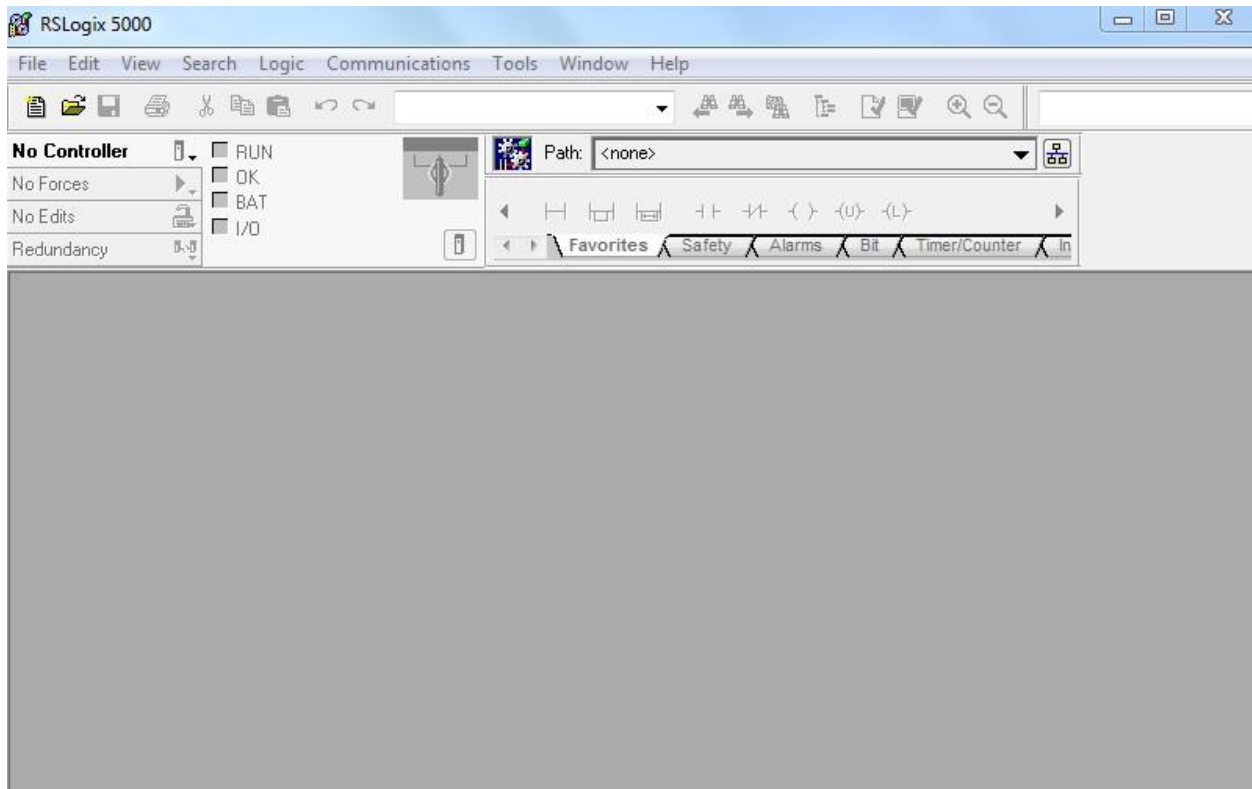


Fig. 3-23

When starting with no program, choose New from the File menu. The New Controller dialog appears. Choose our controller,

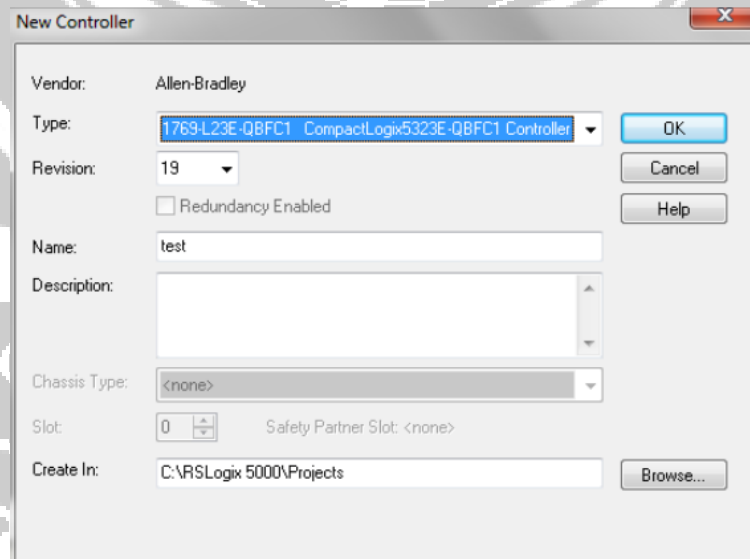


Fig. 3-24

the 1769-L23E-QBFC1 controller, add the revision level, 31 at present, add a name (text) in this example and click OK

Congratulations! You have a PLC that can do absolutely nothing. There is no tag database and no program stored yet.

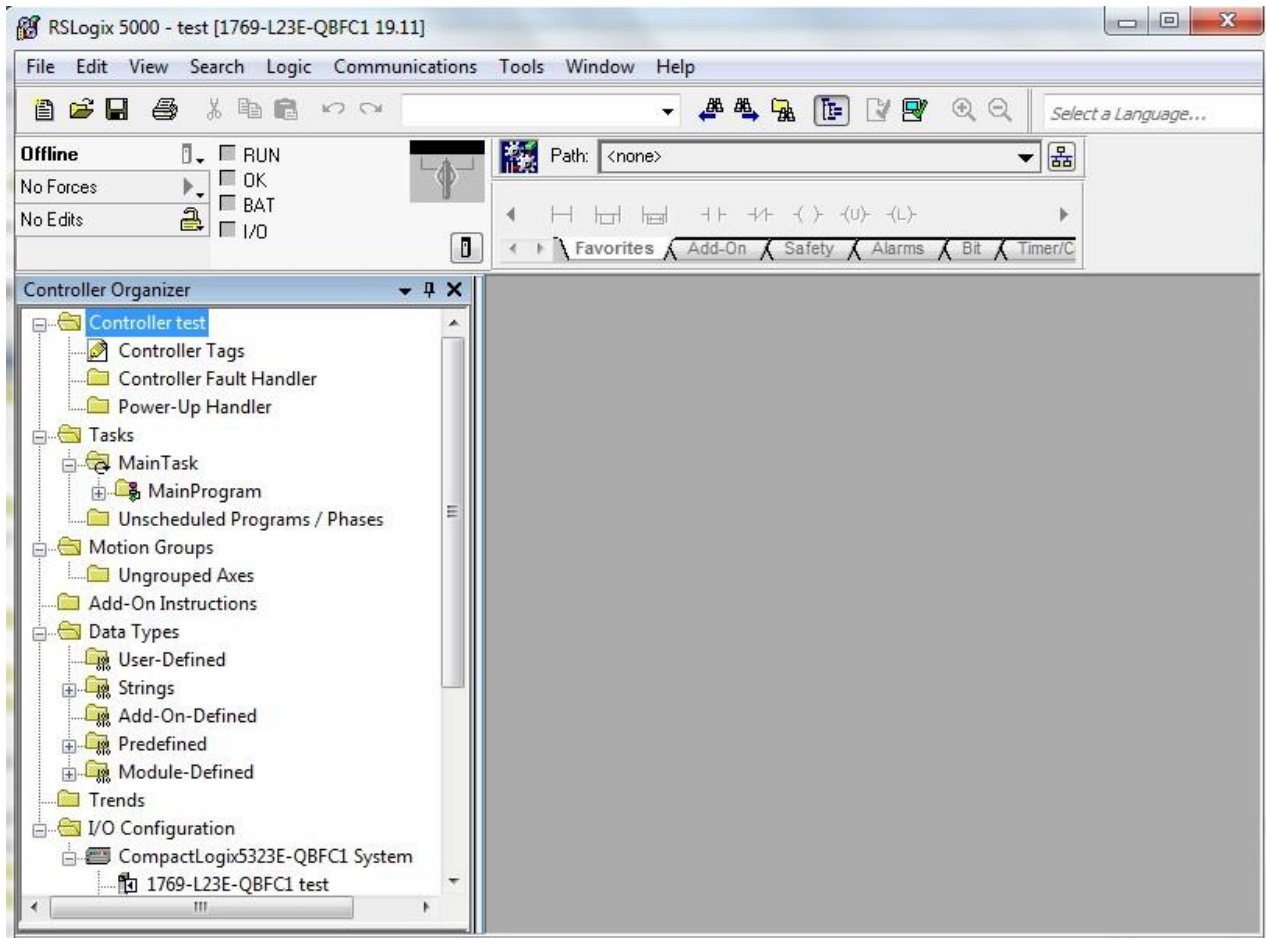


Fig. 3-25 Basic Programming Page of RSLogix 5000

There is, however, an I/O Configuration prepared. It includes the L23E, an Ethernet Port and some Embedded I/O. Note that there is also room for expansion I/O to the right of the processor.

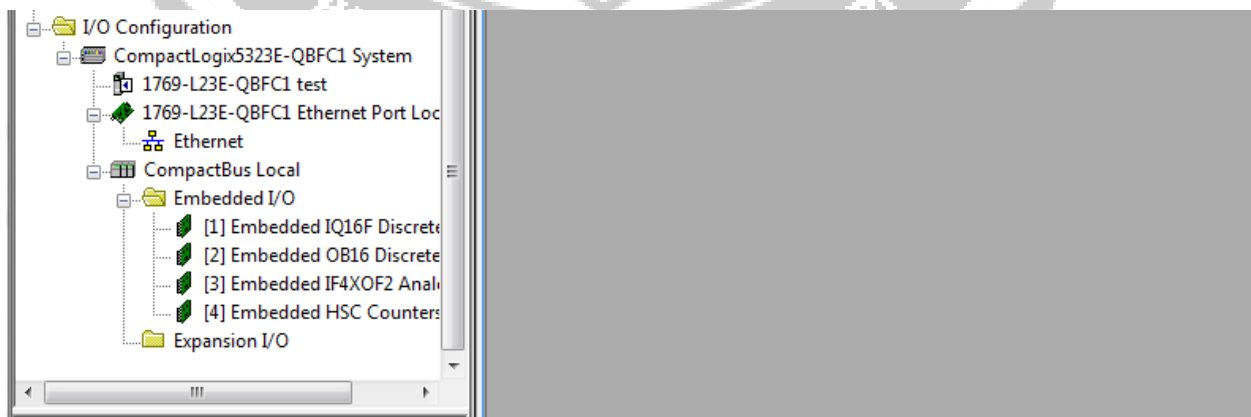


Fig. 3-26 I/O Configuration for L23E

On the left is a tree of folders. These show the controller, its tasks, any trends, data tables and the I/O configuration.

Click **MainProgram** and then **MainRoutine** to show the figure below. You are ready to program a rung of logic. Above the **MainRoutine** logic is the Ladder Instruction toolbar. From this toolbar, you can choose the type of contact to place in the rung of logic.

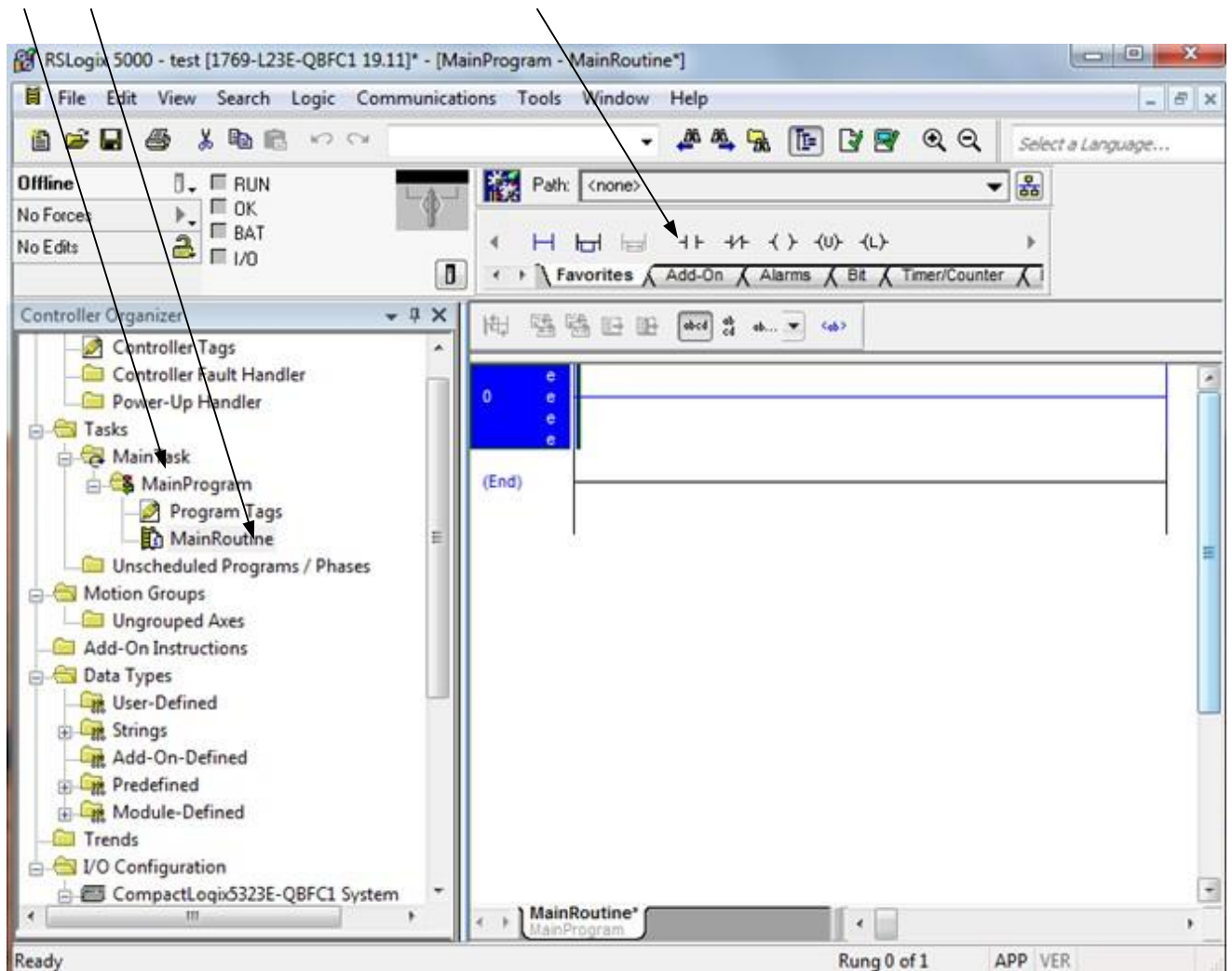


Fig. 3-27 Programming Area for RSLogix 5000

PALKULAM, KANYAKUNARI

OBSERVE OPTIMIZE OUTSPREAD

The embedded I/O may need to be configured. For instance, the 16 point input section has the following configuration screens:

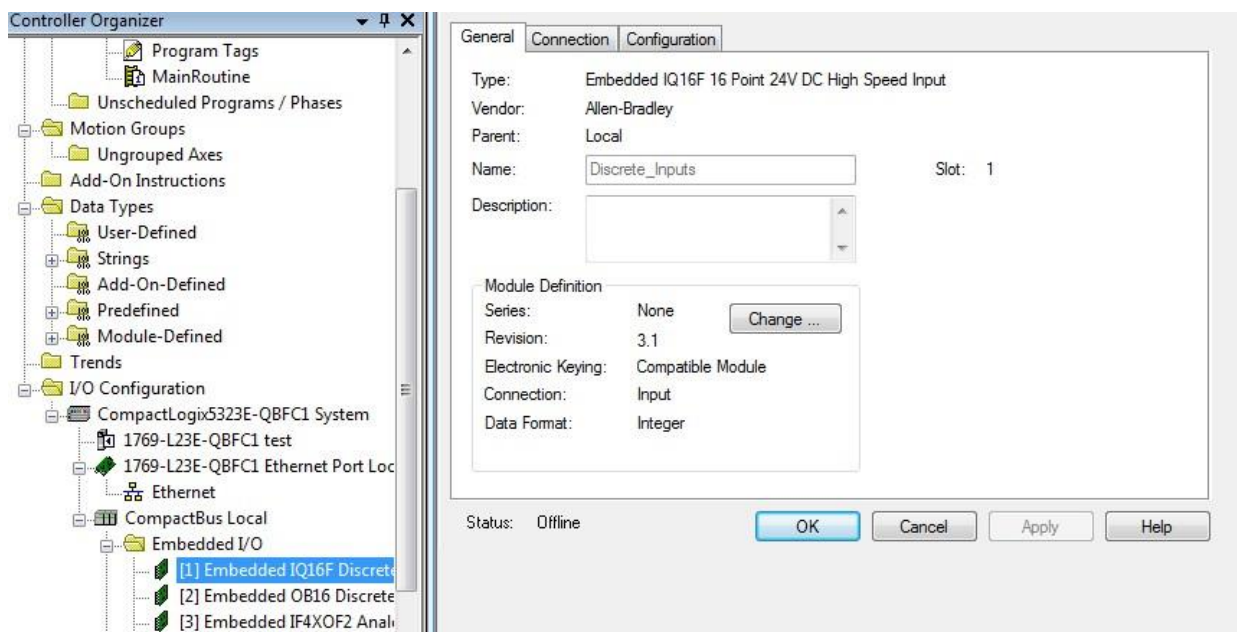


Fig. 3-28 Imbedded I/O Configuration Screen

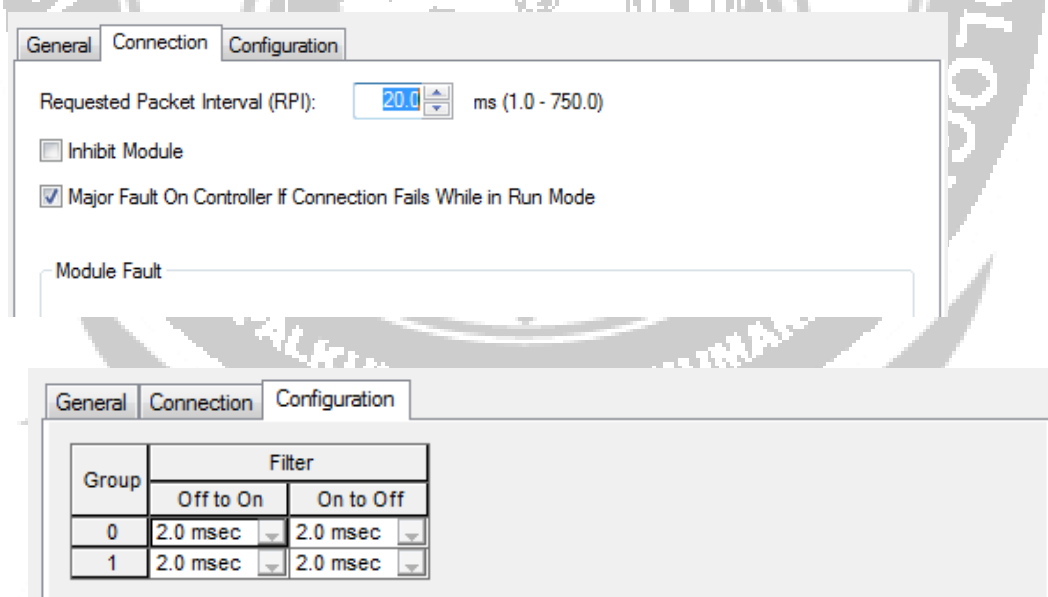


Fig. 3-29 Filter Times for Imbedded Input Group

It is important that the student practice the programming steps outlined above to be able to start a new project, download a project to the Siemens 1200 PLC and start and stop the processor. The ability to do this will pay dividends in later labs.

The embedded I/O is addressed automatically in the 'Controller Tags' entry. This resembles the following:

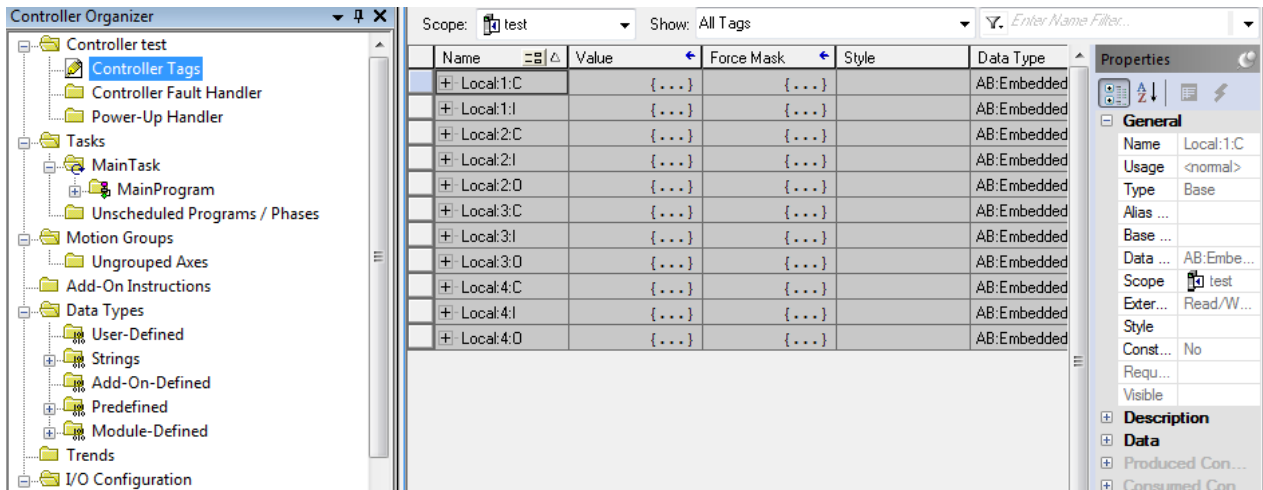


Fig. 3-30 Embedded I/O Addressing

The 16 inputs from the input card section are addressed as follows:

Local:1:I.Data.0 (bit 0)

...

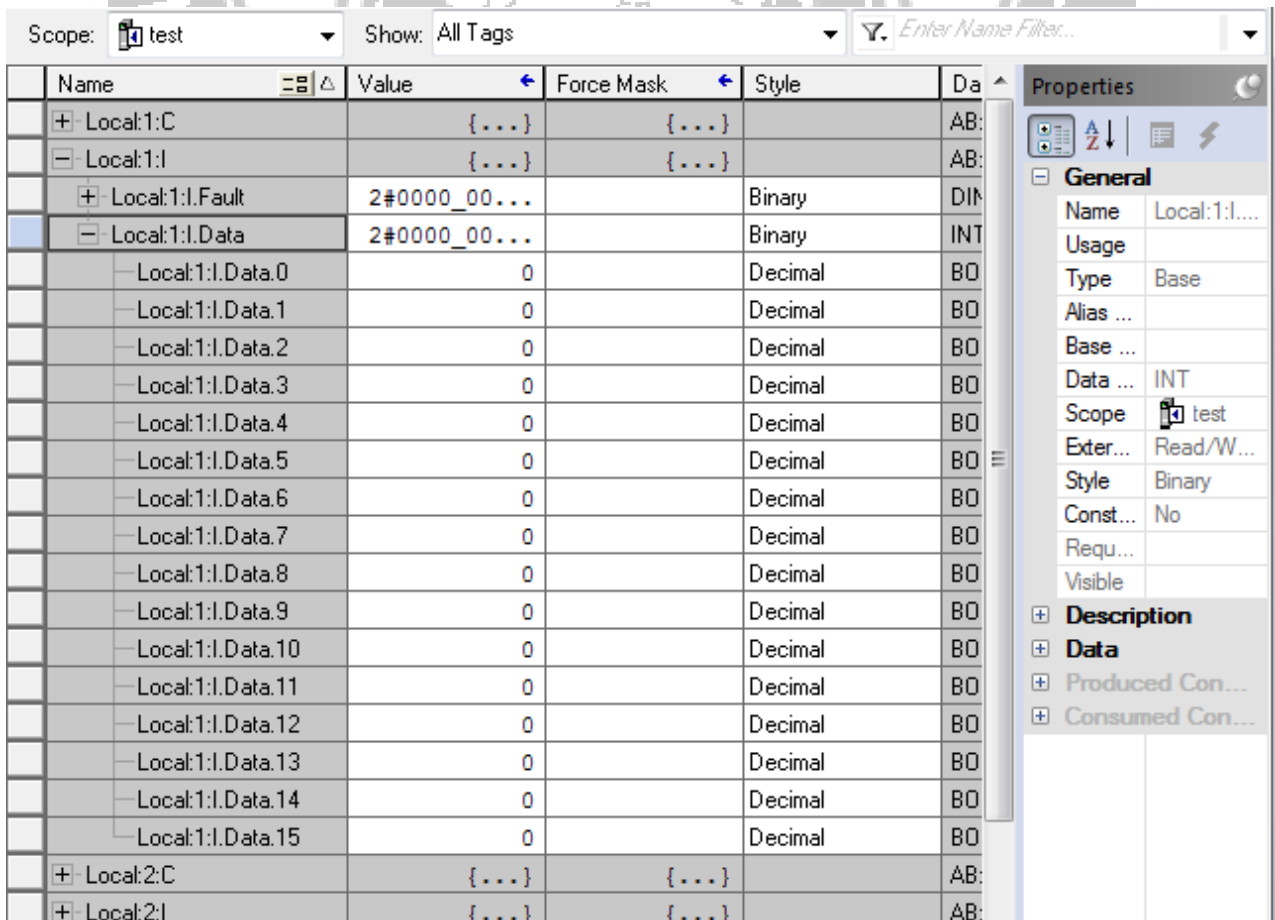


Fig. 3-31 Embedded I/O Addressing Expanded

Again, it is important to view the video for instructions about logging on and programming the A-B.

Wiring the Processor

Both Siemens and A-B require the inputs and outputs be wired properly to have a program accepted as working. Yes, there is a simulator for both but the actual wiring of the project adds a step that most will eventually appreciate the full scope of a PLC project.

Pictured first is a Siemens S7-1200 processor wired for an input and output.

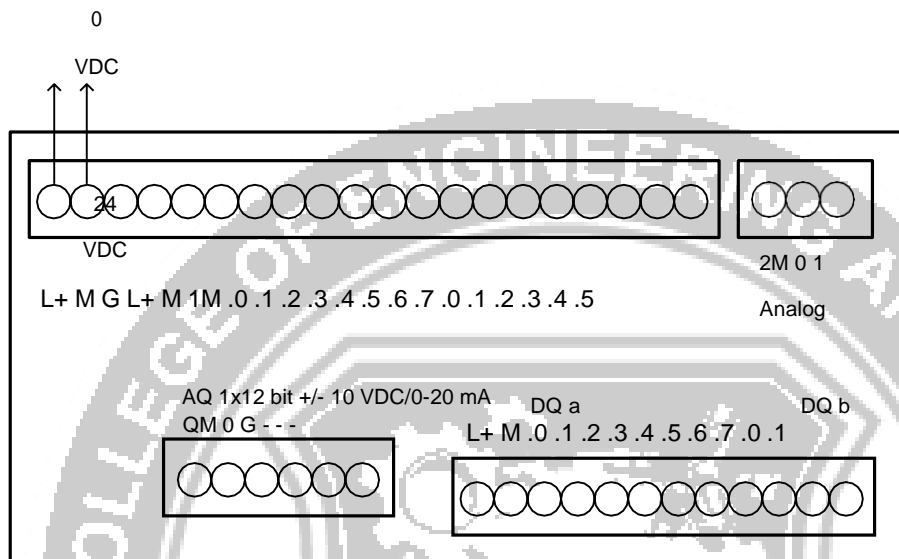


Fig. 3-32

Wire PB input to I0.2

Fig. 3-34 Wiring Layout of Siemens PLC

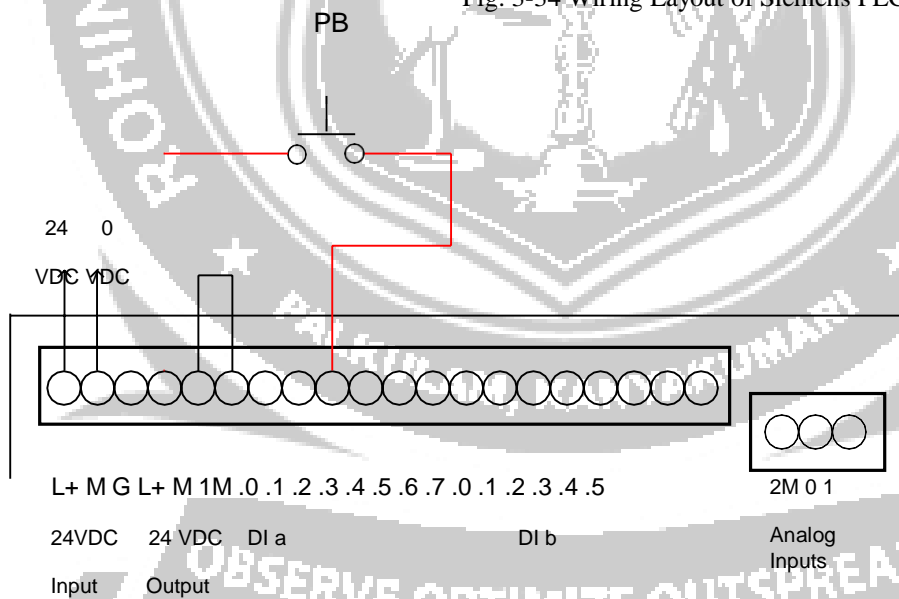


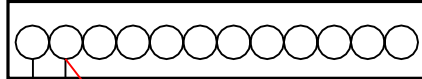
Fig. 3-33

Wire Lite to output Q0.5

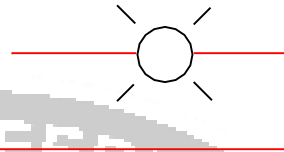
DQ a

DQ b

L+ M .0 .1 .2 .3 .4 .5 .6 .7 .0 .1



24 0



Next is an A-B L23E-QBFC1B processor wired for inputs and outputs:

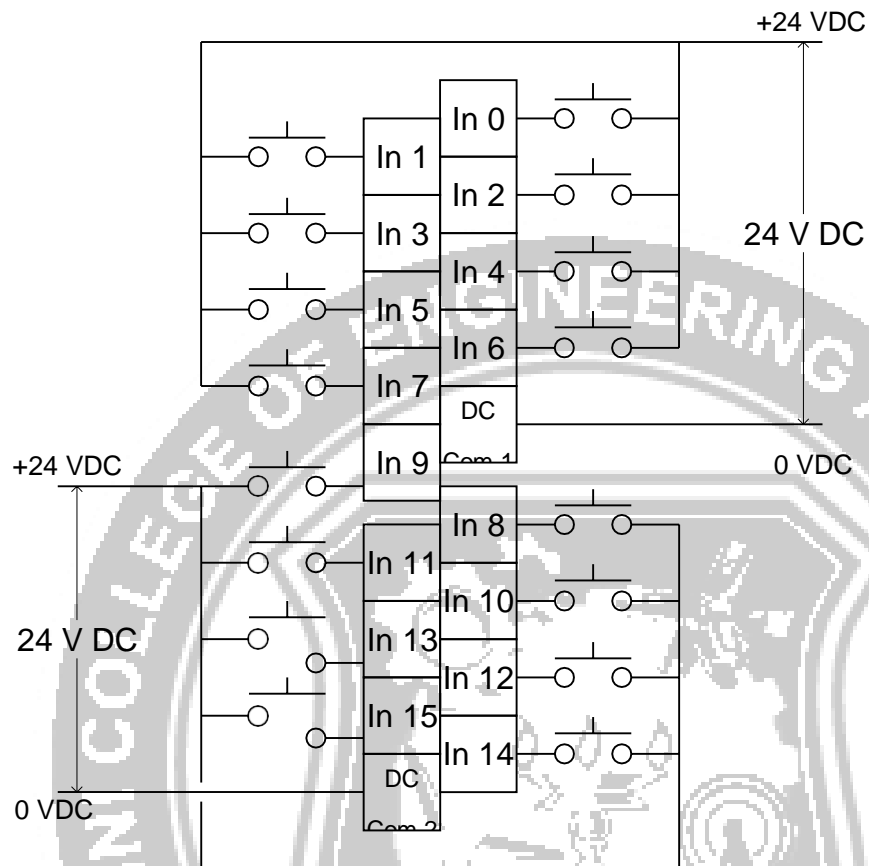
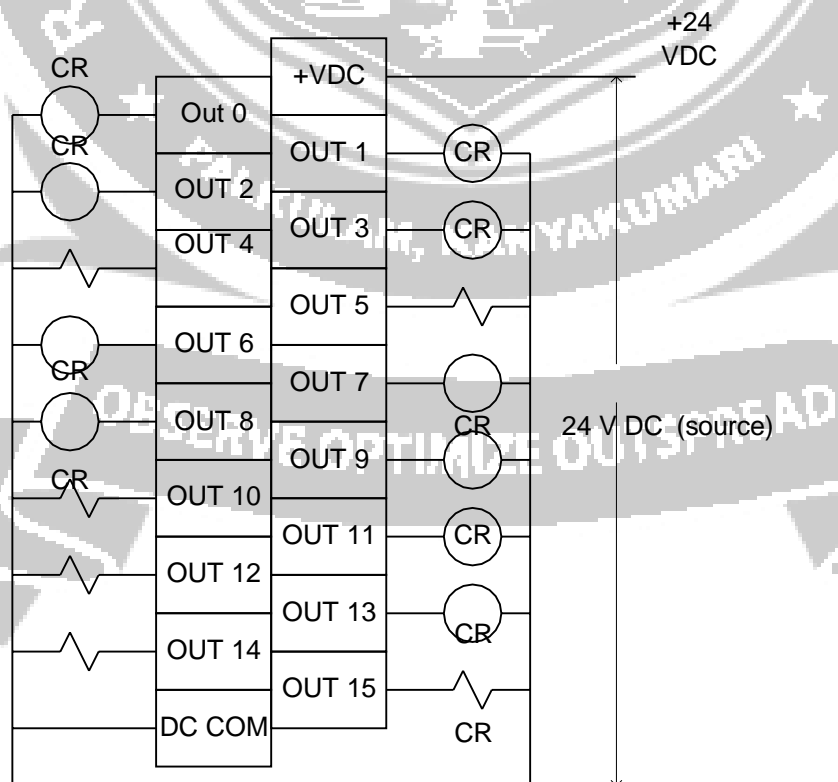


Fig. 3-34 A-B Sample Input Wiring



0 VDC

Fig. 3-35 A-B Sample Output Wiring



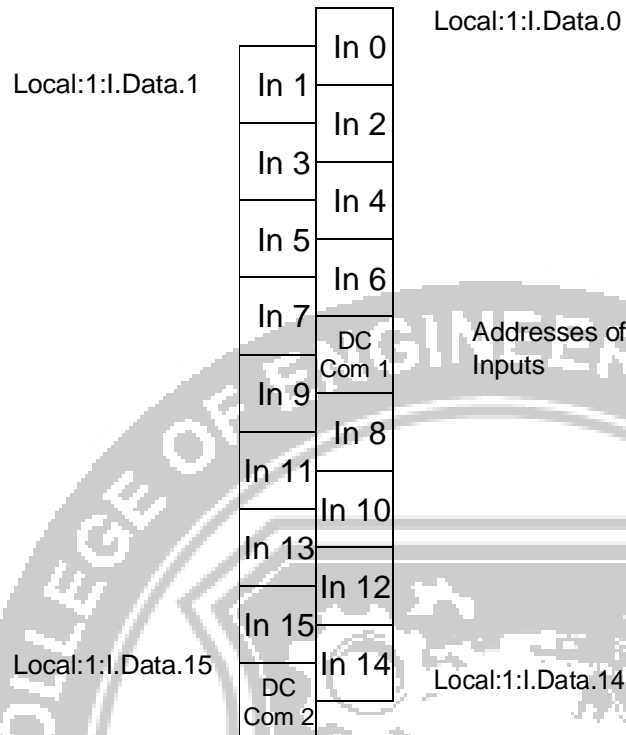


Fig. 3-36

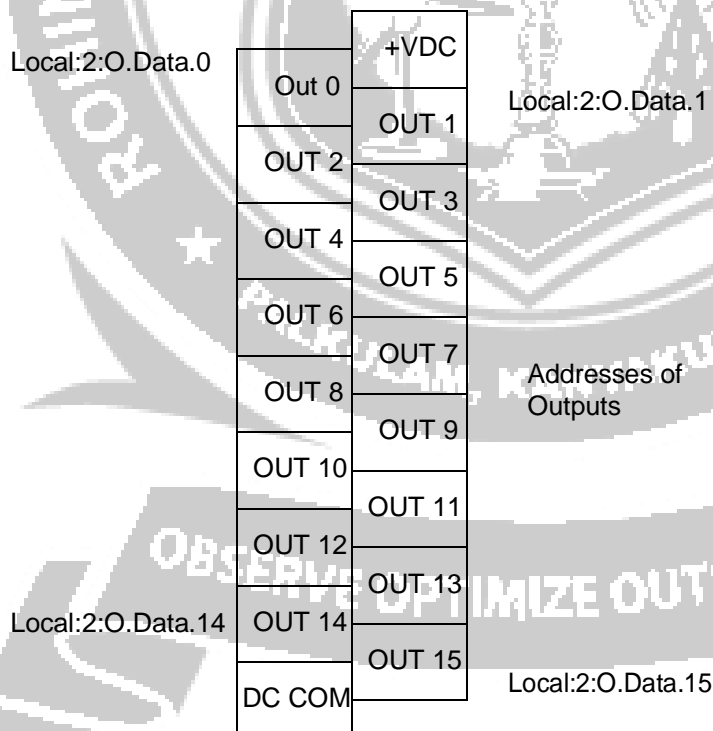
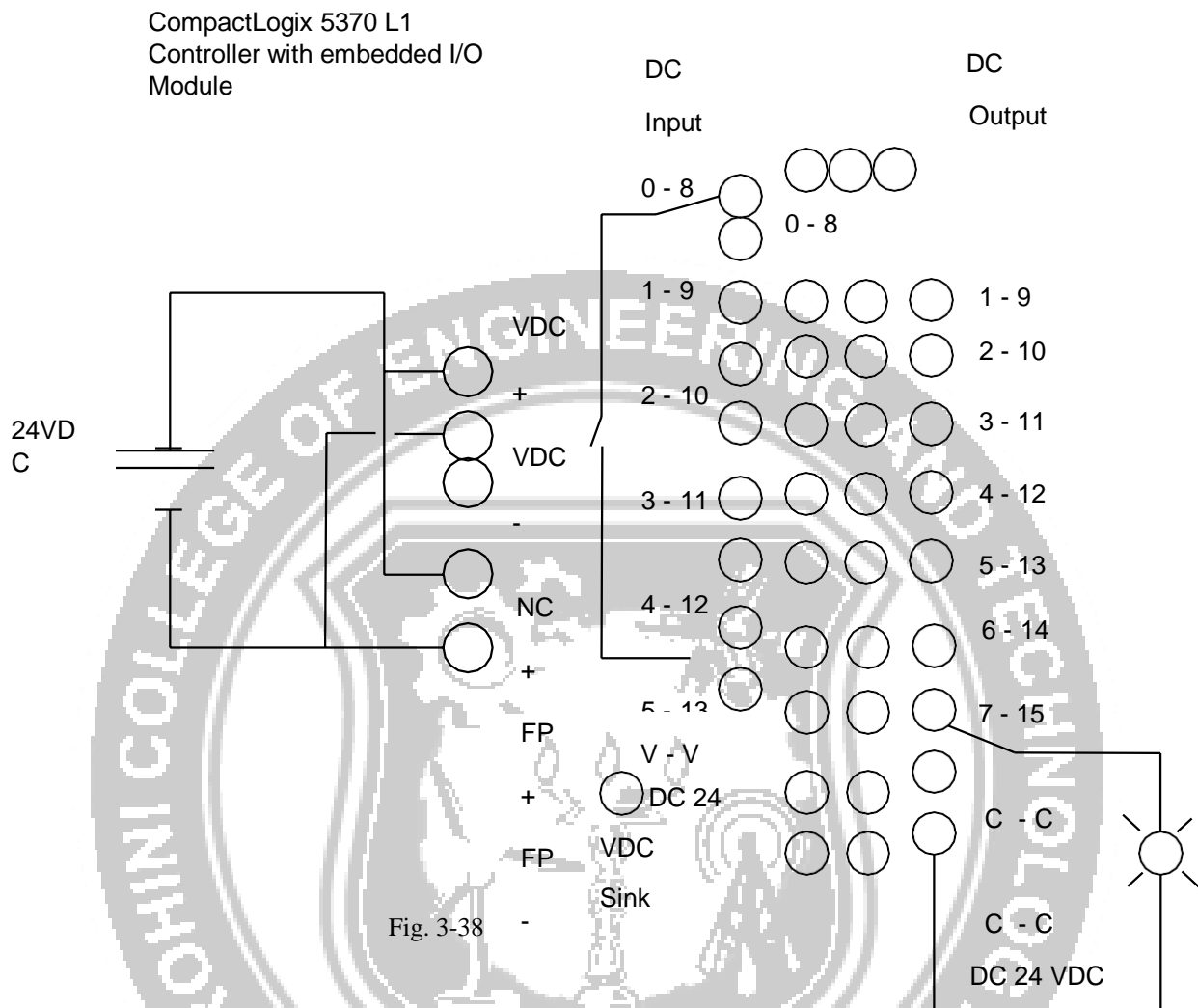


Fig. 3-37

Finally an A-B L16ER processor wired for inputs and outputs:



Operating Modes of the CPU

The CPU has the following operating modes:

- In the operating mode **STOP**, the CPU does not execute the program, and you can load a project.
- In the operating mode **STARTUP**, the CPU performs a startup.
- In the operating mode **RUN**, the program is executed cyclically. Projects can not be loaded in the CPU's RUN mode.

The CPU does not have a physical switch for changing the operating mode. The operating mode (**STOP** or **RUN**) is changed by using the button on the operator panel of the software STEP7 Basic. In addition, the operator panel is provided with the button **MRES** to perform a general memory reset and displays the status LEDs of the CPU.

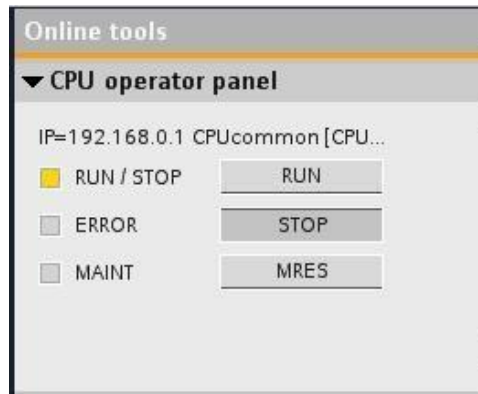


Fig. 3-39 Controlling Run/Stop Mode of CPU

The color of the **status** LED RUN/STOP on the front of the CPU indicates its current operating mode.



- **Yellow** light indicates the **STOP** mode.
- **Green** light indicates the **RUN** mode.
- **Blinking** light indicates the **STARTUP** mode.

Fig. 3-40 Location of Run/Stop LEDs

In addition, there are the LEDs **ERROR** to indicate errors and **MAINT** to indicate that maintenance is required.

All the processors of Allen Bradley CompactLogix PLC have a key switch of **RUN-REM-PROG** with the following functionality. Mode of **RUN** allows no edits. **REM** PLC in the processor remote mode control allows remote programming with RSLogix 5000. Program mode or **PROG** PLC will stop the processor and allow downloads

Download vs Upload

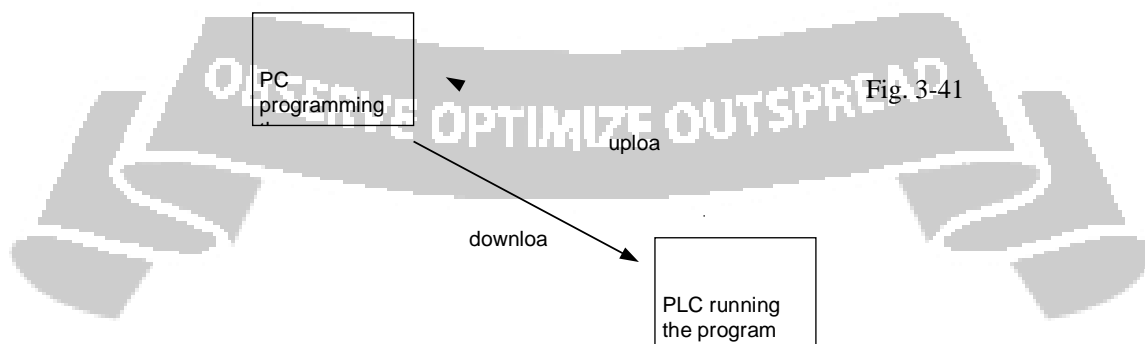


Fig. 3-41

The Earliest Programming Panel

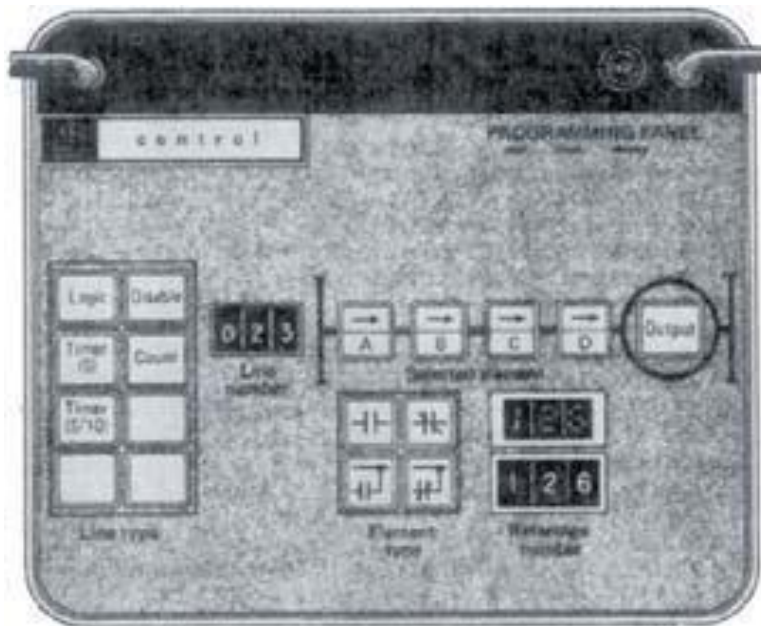


Fig. 3-42 Modicon 084 Programming Panel

The programming panel above is of the first PLC, the Modicon 084. There was a very limited group of Boolean expressions available for the programmer. All other expressions were required to be broken into a number of rungs that together represented the original Boolean expression.

The four buttons for normally open, normally closed, parallel normally open and parallel normally closed were the only choices. The parallel branches were tied back to the left power bus.

The figure below shows the limited choices for each of the four contacts and how the combinations of these expressions forced the engineer to break up most logic into a number of rungs or lines of logic.

This cryptic first PLC's restrictions seem very limiting. They are. To be blunt, all PLC's force the user to make compromises with an original schematic drawing. Electricity flows in any direction but the PLC manufacturers forced power to flow left to right and never in the reverse direction. Power could flow up or down but never right to left. This compromise is still in place with all PLC manufacturers (with ladder). With the FBD programming format, lines can be drawn in any fashion and connections flow in any direction.

From Steve Jones, SHJCo, Oct 12, 2017, Control Design, "A walk down automation programming memory lane"

I first "cut my teeth" on PLCs at Rochester Products Division of General Motors in Rochester, New York, when I was asked to modify logic in some of its manufacturing machines in 1977. The first one I was given was an in-line machining center that performed drilling and tapping at various angles on automotive carburetor housings in stages. There were 65 stations in this one system controlled by four Modicon 084 programmable logic controllers (PLCs).

If you are not familiar with the 084 PLCs, these dinosaurs had core memory of about 1 k of toroid donuts per card, with one bit per donut; and the logic consisted of four contacts and a coil for every rung. The contacts could be normally open (NO) or normally closed (NC) and could be logically ORed (or not) with the left power rail. It was programmed using a Zero case enclosed programming panel using thumb wheels, push buttons and indicator lights.

We “saved” the programs by calling the central computer room and then connecting the phone to a modem, using a different Zero case, where the computer room would capture the program with a DEC PDP-8 minicomputer and then punch a paper tape for storage on a shelf. We had to hand- draw all of the logic on D-size sheets and update the drawings when the logic was changed.”

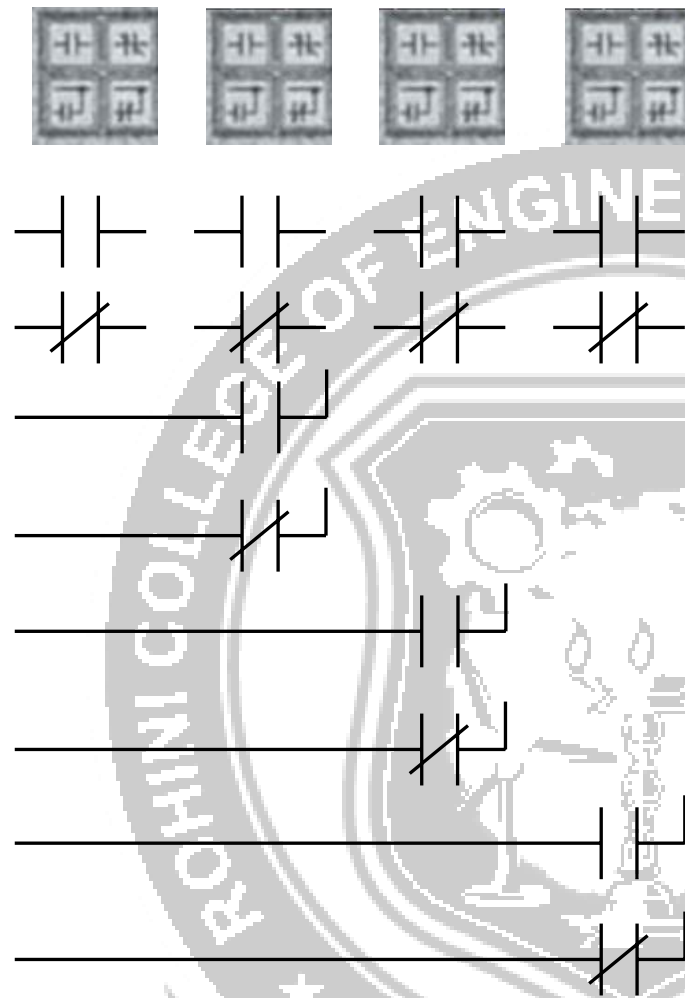


Fig. 3-43 Modicon 084
Programming Panel
Boolean Logic Choices

An example program is shown in the figure below showing how the original circuit was broken into a number of simpler circuits following the restrictions outlined above.

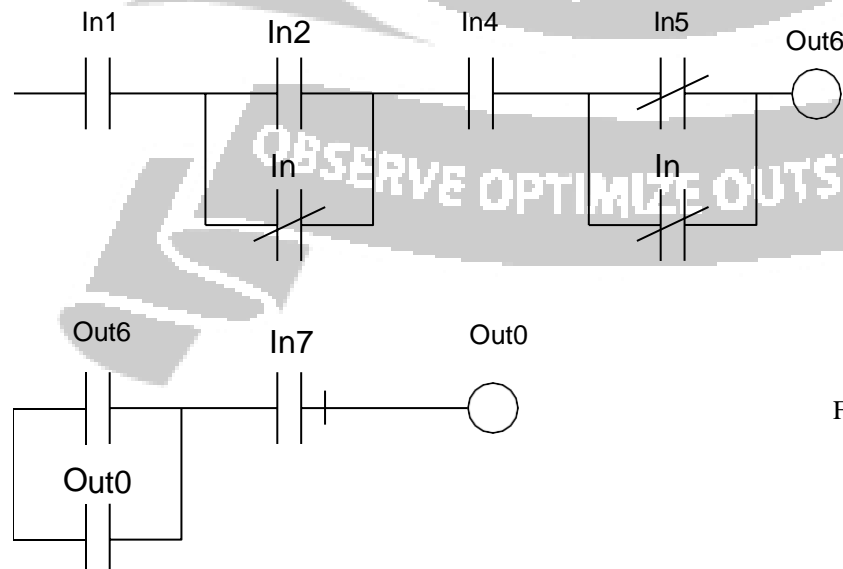


Fig. 3-44

The circuit at above is the circuit required but the programming panel above allows only four contacts and each contact after the first is either NO, NC or parallel NO or NC back to the left power bar.

The circuit above is broken down into the circuits below.

1.6 SCADA hardware

Supervisory control and data acquisition (SCADA) is not a specific technology, but a type of application that gets data about a system to control that system in a SCADA application.

A SCADA system consists of a number of remote terminal units (RTUs) collecting field data and sending that data back to a master station (HMI), via a communication system. The master station displays the acquired data and allows the operator to perform remote control tasks.

In the early days of data acquisition, relay logic was used to control production and plant systems. In modern manufacturing and industrial processes, mining industries, public and private utilities, and leisure and security industries, telemetry is often needed to connect equipment and systems separated by large distances. This can range from a few meters to thousands of kilometers. Telemetry is used to send commands and programs, and receives monitoring information from these remote locations.

Supervisory control and data acquisition refers to the combination of telemetry and data acquisition (Figure 1.15). It encompasses collecting information, transferring it back to the central site, carrying out any necessary analysis and control, and then displaying that information on a number of operator screens or displays. The required control actions are then conveyed back to the process.

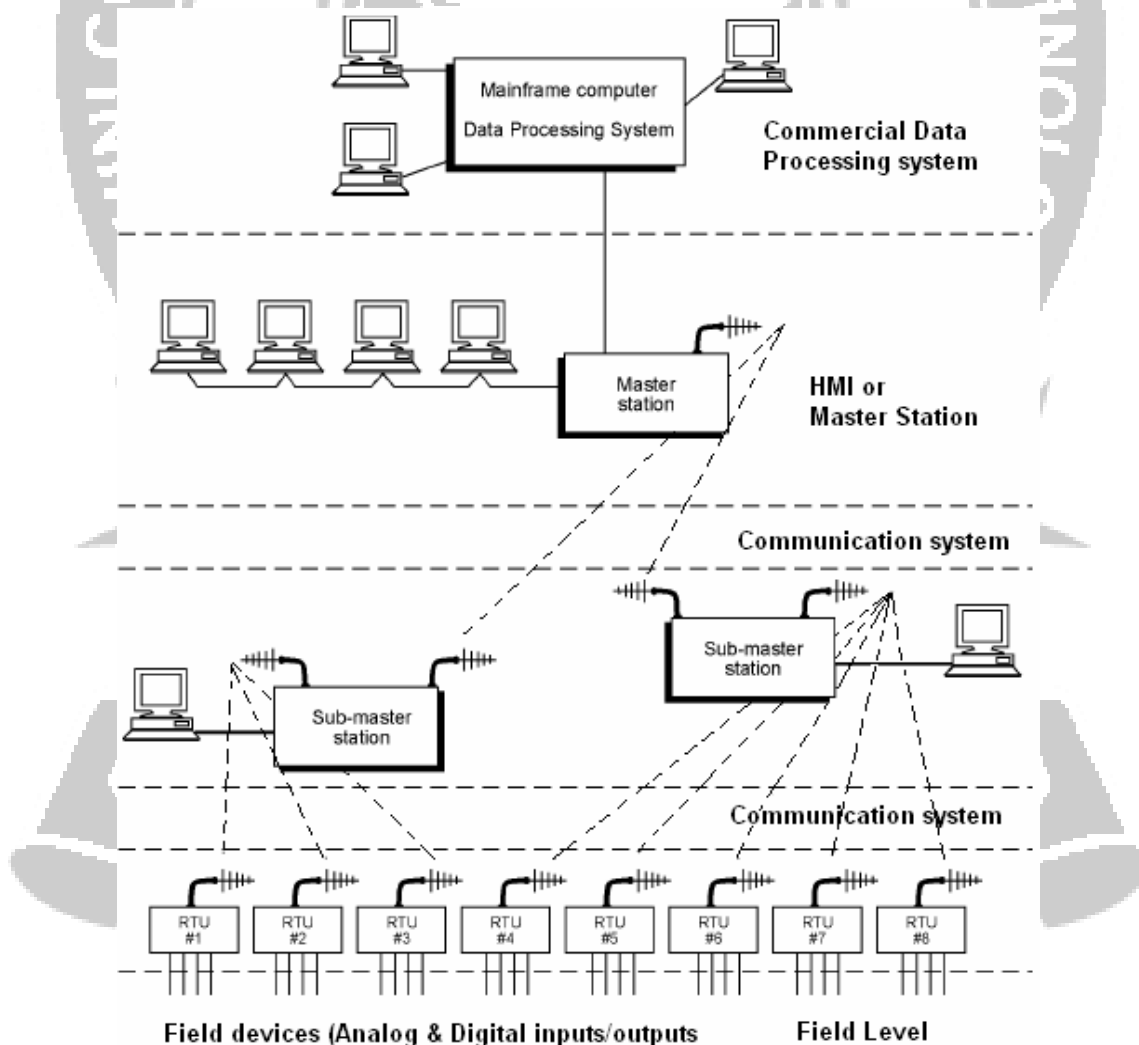


Figure 1.15

SCADA system hierarchies

A SCADA application has two elements:

1. The process/system/machinery you want to monitor and control – this can be a power plant, a water system, a network, a system of traffic lights, or anything else.
2. A network of intelligent devices that interfaces with the machinery process and system through sensors and control outputs. This network, which is the SCADA system, gives you the ability to measure and control specific elements of machinery process and system.

How SCADA systems work?

A SCADA system performs the following four functions:

1. data acquisition
2. networked data communication
3. data presentation
4. control

These functions are performed by four kinds of SCADA components:

1. Sensors (either digital or analog) and control relays – These directly interface with the managed system.
2. Remote telemetry units (RTUs) – These are small computerized units deployed in the field at specific sites and locations. They serve as local collection points for gathering reports from sensors and delivering commands to control relays.
3. SCADA master units or HMI – These are larger computer consoles that serve as the central processor for the SCADA system. Master units provide a human interface to the system and automatically regulate the managed system in response to sensor inputs.
4. The communications network – It connects the SCADA master unit to the RTUs in the field.

Power supply for RTU

The RTU should be able to operate from 110/240 V AC $\pm 10\%$ 50 Hz or 12/24/48 V DC $\pm 10\%$ typically. Batteries that should be provided are lead acid or nickel cadmium. Typical requirements here are for 20-hour standby operation and a recharging time of 12 hours for a fully discharged battery at 25°C.

The power supply, the battery, and the associated charger are normally contained in the RTU housing.

Important power supply monitoring parameters that should be transmitted back to the central site/master station are:

- analog battery reading
- alarm for battery voltage outside normal range
- mains voltage failure

Cabinets for batteries are normally rated to IP 52 for internal mounting and IP 56 for external mounting.

1.7 Good installation practice

1.7.1 Introduction

Proper installation of any electronic system is necessary for its reliable and safe working. Let us first learn some of the concepts relating to the PLC installation procedures.

Interference and noise

Interference or noise is an important factor to consider in the overall design and installation of the PLC system. Noise can be defined as the random generated undesired signal that corrupts (or

interferes with) the original (or desired) signal. The ratio of signal voltage to noise voltage determines the signal strength in relation to the noise. This is called the signal-to-noise ratio (SNR) and is an important consideration while designing electronic systems where electrical interference can be a problem.

The SNR is usually expressed in decibels (dB), which is the logarithmic ratio of the signal voltage to the noise voltage.

$$\text{SNR} = 10 \log S/N \text{ (measured in decibels)}$$

Sources and types of noise

Noise is normally introduced into the signal circuits through electrostatic (capacitive) coupling, magnetic (inductive) coupling, and resistance coupling. Arguably, a fourth category of noise is electromagnetic interference due to radio interference.

As this is mainly manifested as a near-field phenomenon (such as electrostatic and magnetic coupling), this will not be considered. The reduction of these noise signals takes the form of shielding and twisting of signal leads, proper grounding, and separation.

Shielding: By definition, it is the protection of the signal wires from noise of unwanted signals (Figure 1.16).

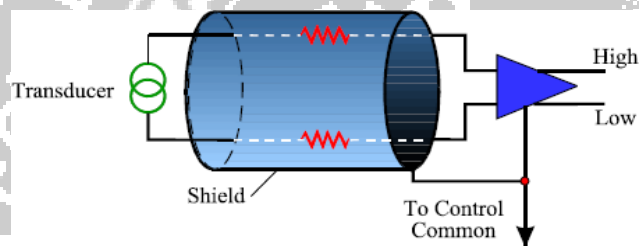


Figure 1.16

A typical shield

The purpose of the shield is to reduce the magnitude of the noise coupled into the low-level signal circuits by electrostatic or magnetic coupling. This has brushed up the above-mentioned concepts up to some extent. Let us focus once again on the installation requirements for different sections of a PLC system.

We will refer to the following typical PLC system schematic for understanding the installation requirements (Figure 1.17).

We will divide up the installation requirements of a PLC system in the following areas:

- PLC modules
- PLC rack
- PLC panel internal wiring
- PLC panel power supply
- Cabling between the PLC and the field devices
- Cabling between the PLC and the control room computers
- PLC earthing
- Specific PLC installation requirements
- Control room requirements

Now, we will discuss the installation requirements in each area.

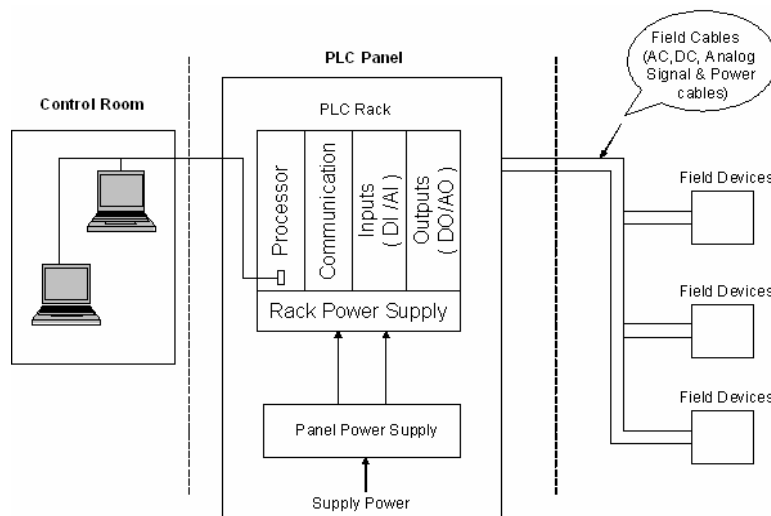


Figure 1.17

A typical PLC system

1.7.2 PLC modules

While installing PLC modules, a good amount of care should be taken because it is the most delicate part in the entire system. For non-floating inputs and output modules, connect terminal M of the load power supply to PE ground conductor of the control circuit. Similarly, the following installation features can be employed.

Keying of module

This is an important technique to avoid a situation in which the maintenance personnel replace an I/O module that has failed with the wrong module. Installing some form of keying mechanism (which is unique to each type of module supplied by the particular manufacturer) on the back plane prevents inadvertent errors of this nature.

Handling memory chips

Special care should be taken in handling memory chips for the PLC. They are very sensitive to static electricity and are easily damaged. The following installation rules should be followed:

- prior to handling the RAM chips, avoid handling any materials that can build up static charges (such as cellophane covered items)
- always wear an anti-static wrist strap that has been securely grounded
- ground all tools before contacting the RAM chip
- keep relative humidity in the work area between 40% and 60% RH
- eliminate all carpeted areas in the workplace that can build up static
- do not touch the chip pins (touch only the chip base)
- ensure careful alignment of the pins before installation of the memory chip into the chip socket
- if there is any valuable data on the chips, back up this information onto floppy or hard disk

Selecting voltages for I/O modules

This refers to the voltages used for the PLC to perform its actual digital input and output control (and its interface to the various items of equipment).

Typical considerations for selection of voltages to use in a PLC installation are:

Standardization

If an area of the factory or the plant is already standardized on the voltage (such as 110 V AC), then it makes sense from maintenance and spares point of view to continue with this approach.

Voltage range of input/output module

It may be the case that a particular PLC has already been selected and only supports a particular voltage level.

Minimization of power consumption/heat generation

A low voltage such as 24 V DC may be preferable when the power dissipation of an I/O module has to be minimized, as less current will be used here.

Leakage current/earthing and grounding problems

If the wiring is of such a poor standard that the ground loops are forming, the voltage used should be of such a level that they are well above spurious voltage and currents that may develop in the circuit due to these problems.

Voltage range

Ensure that the particular voltage selected is matched to the range of the I/O modules and there is a margin of safety. For example, if the range is 0–48 V DC and the input module selected has a range of 0–50 V DC, this will be inadequate if 48 V DC is sourced from a lead-acid battery system, which, when fully charged, has a voltage of 51 V.

Indeterminate state

When using certain sensors, there may be some leakage current even when the device is off. This can tend to bias the input channel into the ON condition even though the device has been switched off. An example of devices exhibiting this problem is proximity detectors. The voltage range should be checked to see whether this is a problem for a particular input with its associated sensor.

Loop powering of field devices

Some field devices require an external voltage source to power them. This voltage is often derived from the modules and should be compatible (e.g., 24 V DC).

It should be noted that in today's world, from an analog point of view, there is not much argument about using 4–20 mA for the interface. The low impedance 4–20 mA analog signal is relatively noise immune when compared with the high-impedance voltage signal systems.

Some of the older standards may still be 0–10 V/10–50 mA or 0–20 mA, but they are not as common as the 4–20 mA standard.

Sometimes, a voltage interface standard may have certain advantages over the 4–20 mA standard (such as lower power requirements). The zero of the range is selected to be 4 mA and is useful as anything <4 mA indicates that there is a problem (such as a broken wire). Interestingly, a 4–20 mA is related and associated with the older pneumatic standard 3–15 psi by having the same ratio (1:5).

1.7.3 PLC rack

Since all modules get their power supply from either backplane connectors or slots on the rack, their grounding and earthing are important. For every PLC rack, a grounding screw is normally provided on the rack enclosure.

The same should be connected with copper conductors of at least 10 mm² cross section radially by the shortest possible route to a central grounding point to protect against stray noise.

For non-grounded operation, connect the mounting rack of the PLC through a capacitor to the ground potential (to divert the radio frequency interference).

In addition, any electromagnetic interference coupled into the PLC via signal and supply lines are dissipated by connecting to the central grounding point on the rack.

Connect the central grounding point using a copper conductor of at least 10 mm² cross section to the PE protective ground conductor by the shortest possible route.

Connect the PE conductor of the supply line of the rack to the PE terminal on the rack if provided.

1.7.4 PLC panel internal wiring

Generally, in a typical PLC panel, we will find cables used for the following lines:

- supply line for PLC and load power supply units
- digital input/output signal lines for AC (110 V/230 V or else)
- digital input/output signal lines for DC (24 V/110 V or else)
- analog signal lines (4–20 mA, 0–5 V DC, or else 0–10 VDC)

The following rules should be followed with wiring arrangement inside the cabinet:

- analog output signal lines and digital signal lines can run unshielded in the same cable duct
- only shielded analog input signal lines can run with digital signal lines in the same cable duct
- neither digital signal lines for DC (24 V DC or else) nor analog signals (4–20 mA, 0–5 V DC, 0–10 V DC) should run with AC lines in the same cable duct
- all shields of signal cables must be grounded on module terminals provided
- use metal enclosures for mounting all PLC equipment. This provides a medium of screening from sources of electrical noise

1.7.5 PLC panel power supply

The PLC panel power supply is used for the following purposes:

- to supply power to PLC rack consisting modules
- to supply power to load power supplies (field interrogation power supply)
- to supply power to lighting and other utilities inside the panel

Generally, separate miniature circuit breakers (MCBs) are provided for individual units so that in the event of a breakdown of an individual equipment, only that equipment gets isolated from the main power supply.

Ensure that the AC power source for the PLC system is isolated (through a constant voltage transformer (CVT) or isolation transformer if possible) from any sources of electrical noise.

For PLC installations near sources of electrical interference, an isolation transformer is a recommended approach (Figure 1.18). Note that the output devices being controlled should draw power from the original source of the voltage unless the secondary of the isolation transformer (which is supplying the computers) has been specifically rated for these additional devices.

Where the AC power source has variations, a CVT can stabilize the voltage for short periods of time, thus minimizing shutdowns. It is worth noting here that CV transformers are very sensitive to variations in mains frequency and will not operate successfully with unstable mains frequency supplies.

For both the CVT and the isolation transformer, the operating frequency and the operating voltage should be carefully specified (e.g., 240 V AC +10 –15% or 50 Hz \pm 2%).

OBSERVE OPTIMIZE OUTSPREAD

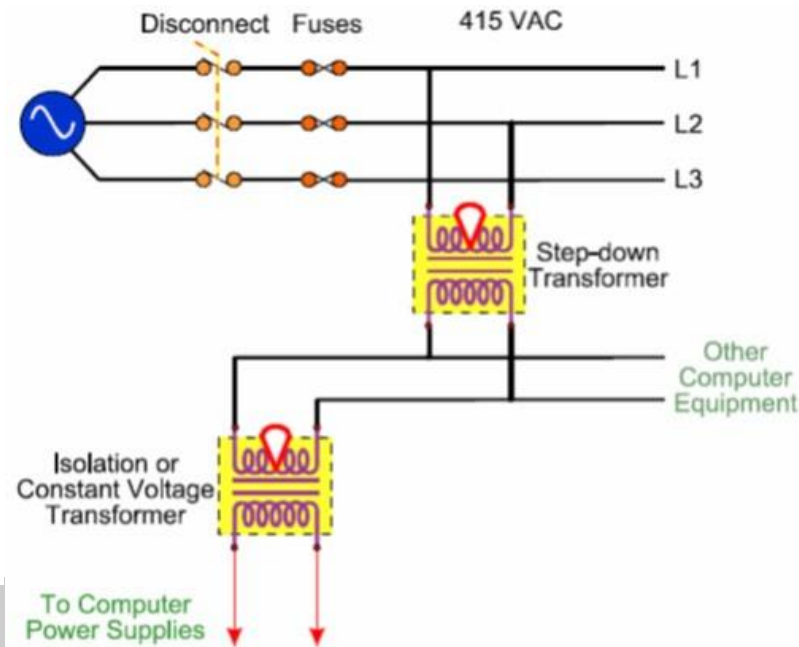


Figure 1.18

An isolation transformer

It is important to size transformers correctly for the following reasons:

- if the transformer is too small, it will clip the peaks off the sine wave (due to saturation) resulting in a lower RMS value of the voltage. The power supply could sense this as a low voltage and shut down. The transformer may also overheat and burn out.
- excessively large transformers do not provide as much isolation as a correctly sized transformer due to higher capacitive coupling

Where the power supply is variable in frequency, or is unreliable, or where the PLC requires high power supply security, the uninterruptible power supply (UPS) is often selected. Its size in KVA rating is decided as per the system load.

An online UPS converts raw AC power into DC voltage by first using a rectification unit and then converts the same DC voltage into AC using an inverter unit and feeds the same to the load. In the event of power failure of raw AC, it starts taking the DC voltage through batteries and converts into AC, and feeds the same to the load. Useful techniques to reduce the electromagnetic interference and switching transients are given in Figure 1.19.

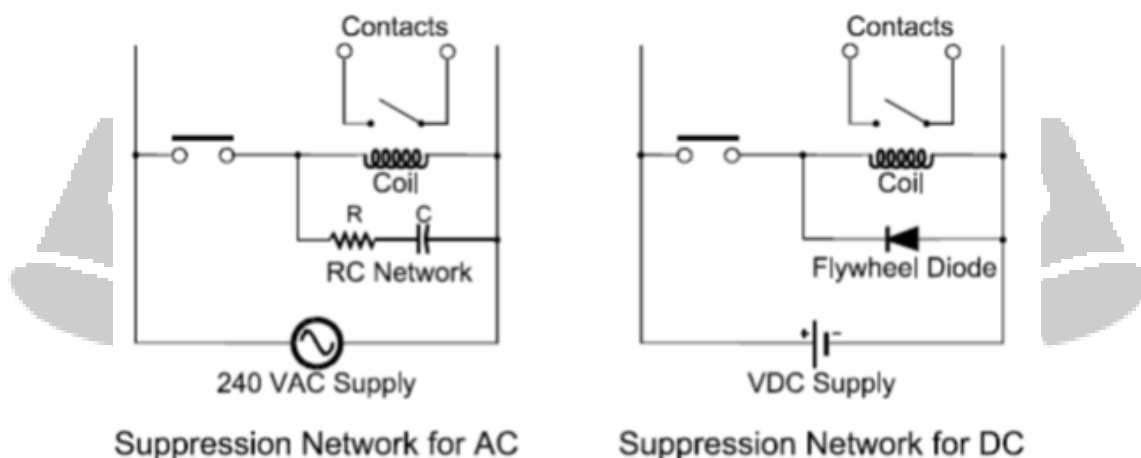


Figure 1.19

Techniques for reducing electromagnetic interference and surges

1.7.6 Cabling between PLC and field devices

The following thumb rules must be followed for cabling between the PLC and the field devices:

- analog output signal lines and digital signal lines must run in separate cables
- if you expect a higher interference, then run the digital AC, digital DC, and analog signal cables in separate cable ducts
- maintain a clearance of at least 10 cm between signal and power cables over 500 V

Shielding wire

It is theoretically possible to almost eliminate both electric and magnetic field noises (and hence, the need for shielding) by using twisted pair signal cables. Magnetic interference reduction can vary from a factor of 14 for 4-in. lay (or three twists per foot) to 141 for 1-in. lay (or 12 twists per foot).

Electrostatic coupling can be reduced by a factor of 103 for copper braid (with 85% coverage) to aluminum mylar tape with a factor of 6,610. These shielded wires are normally ineffective for magnetic coupling; hence, twisting of the pairs is also desirable within a shield.

It is important that the shield is earthed (or grounded) only at one point so that all ground loops are eliminated. This means that the shield envelope should have an insulated jacket so as to prevent multiple grounds.

Ground loops in signal wires can be eliminated by decoupling the input amplifier or using optically isolated signals (Figure 1.20). This is sometimes referred to as Galvanic Isolation.

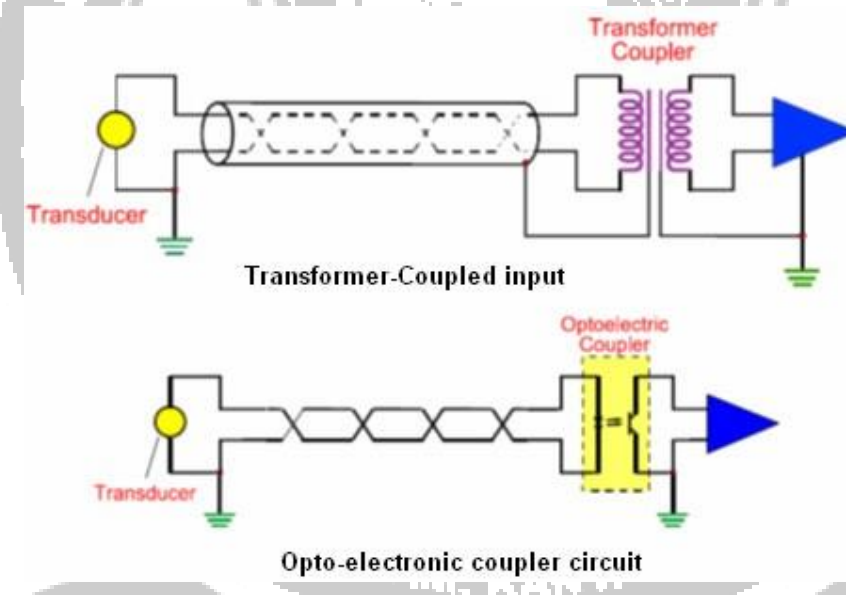


Figure 1.20

Ground loop in signal wire elimination

Cable spacing

In the practical world, with many different cabling systems in a particular plant, a system has been developed to classify all wirings in a certain class of susceptibility to interference and to group the classes in an orderly manner as indicated below.

Some points to emphasize when installing cabling are listed below:

- calculate the actual distance the cable is being run; that is, both the horizontal and vertical distances. Select the shortest possible path away from sources of noise
- route the cables well away from potential sources of electrical interference, harsh chemicals, excessive heat, wet environments, and sources of physical damage
- ensure that no one will walk or drive on the cable

- ensure that the cable is not put under undue tension (such as hanging between two points)
- do not bend the cable excessively in the installation process
- if the cable is likely to run a considerable distance, a calculation should be made of the IR drop along the wire to determine whether it is excessive

Hence, a higher voltage may be required if the cable resistance is high or the distance over which the cable is run is fairly lengthy.

Wiring levels

There are four basic levels or classes of wiring that can be identified. The IEEE 518 standard defines the following four levels:

- Level 1 – High susceptibility-analog signals of <50 V and digital signals of <15 V.
- Level 2 – Medium susceptibility-analog signals >50 V and switching circuits.
- Level 3 – Low susceptibility-switching signals >50 V, analog signals >50 V, regulating signals of 50 V with currents <20 A, and AC feeders <20 A.
- Level 4 – Power-AC and DC power buses of 0–1,000 V with currents of 20–800 A.

Wiring class codes

Within a level, conditions may exist that require specific cables and regrouping is not allowed. This condition may be identified by a class coding system, similar to the following:

- A – analog inputs, outputs
- B – pulse inputs
- C – contact and interrupt inputs
- D – decimal switch inputs
- E – output data lines
- F – display outputs, contact outputs
- G – logic input buffers
- S – special handling of special levels may require special spacing of conduits and trays, such as signals from communicating field and line resistors, or signals from line shunts to regulators, or power >1,000 V or >800 A, or both
- U – high voltage potential unfused greater than 600 V DC

Tray spacing

The tables from the IEEE 518 are given below. Tables 1.1–1.3 indicate the minimum distance in inches between the top of one tray and the bottom of the tray above, or between the sides of adjacent trays.

Table 1.1 Tray spacing (in.)

LEVEL	1	2	3	3S	4	4S
1	0	11	6	6	26	26
2	11	0	6	6	18	26
3	6	6	0	0	18	12
3S	6	6	0	0	8	18
4	26	18	18	8	0	0
4S	26	26	12	18	0	

Table 1.2

Tray-conduit spacing (in.)

LEVEL	1	2	3	3S	4	4S
1	0	1	4	4	18	18
2	1	0	4	4	12	18
3	4	4	0	0	0	2
3S	4	4	0	0	6	12
4	18	12	0	6	0	0
4S	18	18	8	12	0	0

Table 1.3

Conduit spacing (in.)

LEVEL	1	2	3	3S*	4	4S*
1	0	1	3	3	12	12
2	1	0	3	3	9	12
3	3	3	0	0	0	6
3S	3	3	0	0	6	9
4	12	9	0	6	0	0
4S	12	12	6	9	0	0

*Level 3S & 4S can be run in a common tray, but should be separated by a barrier

Cabling between PLC and control room computers

Cabling between the PLC and the control room generally involves communication cables (data exchange) and power supply cables.

Communication cables are special cables selected as per the mode of communication (e.g., PROFIBUS, MODBUS, Ethernet RJ45, fiber-optic cable, etc.).

Since they are special, delicate cables carrying low-level signals, they should be installed carefully as per the following rules:

- run the communication cable and power cable in separate cable ducts
- select the shortest possible route that is away from the sources of noise
- route cables well away from potential sources of electrical interference, harsh chemicals, excessive heat, wet environments, and sources of physical damage
- ensure that no one will walk or drive on the cable
- ensure that the cable is not put under undue tension (such as hanging between two points)
- do not bend the cable excessively in the installation process
- if possible, take the cable through a metallic conduit of suitable size, with the conduit grounded at one point

1.7.7 PLC earthing

The earth (or ground) is defined as a common reference point for all signals in the equipment situated at zero potential. Below 10 MHz, the principle of a single-point earthing system is the optimum solution.

Ensure that hardware is securely earthed. The earth electrode is the central point for all electrical equipment and the AC power within the facility. Use maximum size copper wire (e.g., 8 AWG) for the earth.

Three types of earthing systems are indicated in Figure 1.21. The series single point is perhaps the more common, while the parallel single point is the preferred approach with a separate earthing subsystem for groups of signals:

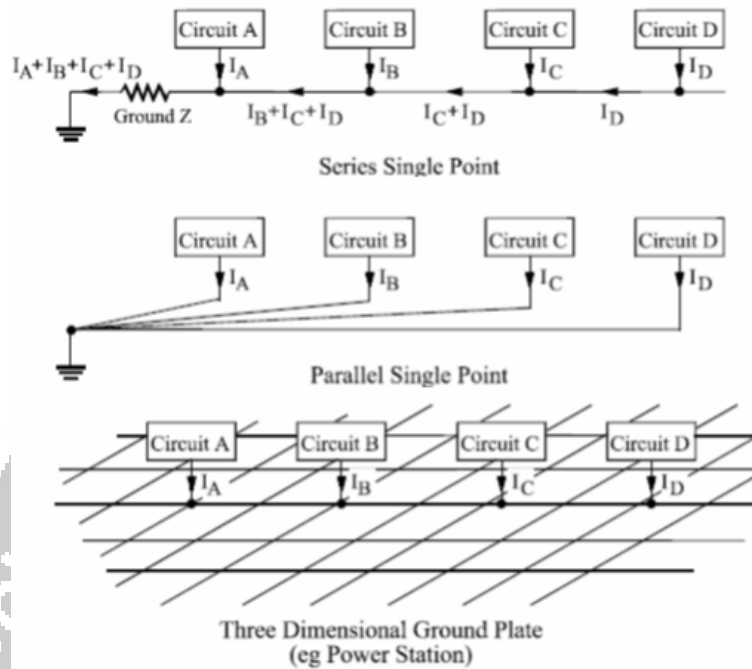


Figure 1.21

Various earthing configurations

- Safety or power earth
- Low-level signal (or instrumentation) earth
- High-level signal (motor controls) earth
- Building earth

Particularly when a PLC system is improperly grounded, it can behave erratically and may get destroyed.

The problem of ground loops arises when different devices are earthed at different earthing points (see Figure 1.22).

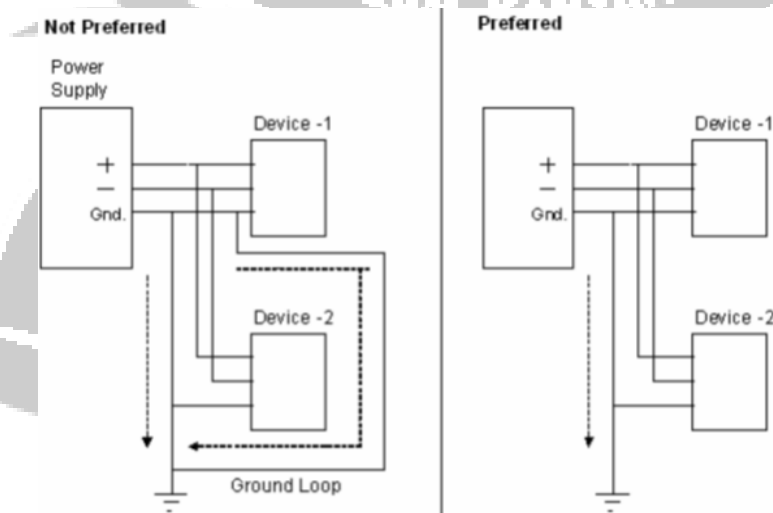


Figure 1.22

Ground loop

To avoid this, a tree-type configuration is preferred where all the separate components are connected to a common line first, and then that common line is connected with the earth point.

To avoid ground loops:

- each PLC module chassis should be grounded with the main PLC chassis
- the PLC chassis or rack should be grounded in turn to the back plate or to the ground connection
- ensure that the panel enclosure is connected to the ground point
- the ground connection should have least resistance value ($<0.1 \Omega$)

A PLC system particularly has a panel earth, an instrumentation signal shield earth, and a power supply earth.

The instrumentation earth and the power earth should be taken from separate earth pits. All signal shields must be grounded at one end in the case of digital and analog signal cables.

The shield must be grounded at both the ends for other data cables such as:

- connecting cables between the central PLC rack and the extension racks
- bus cables
- cables to peripherals

As discussed in earlier individual sections, grounding has to be provided for all necessary equipment.

1.7.8 Specific PLC installation requirements

There are a few specific requirements for the installation of PLC systems. For inductive loads such as electromagnetic relays, it draws an excess amount of current when it is turned on and there is a power surge when it is turned off. Surge suppressor can protect equipment from voltage spikes caused by inductive loads. These are discussed in the following sections.

Reed relays, electromechanical relays, and solenoids (DC only)

Direct current relays are often used in PLC panels nowadays for isolating PLC digital inputs or digital outputs from field devices. As the actuator mechanism of these loads is an electromagnetic coil with a large inductance, it is a good practice to use a freewheel or shunt diode across the relay control terminals when de-energizing the coil by switching off the digital output. When the coil current is removed, the back EMF generated by the energy in the coil is dissipated on the diode's current path. Otherwise, the back EMF builds up on the digital control line and may damage the digital output. Some relays have built-in freewheel diodes.

Similarly, if the relay is driving an inductive load, it is a good practice to protect the relay contacts from arcing and being damaged by the back EMF from the load by placing a freewheel or a shunt diode (and possibly, a resistance to dissipate energy) across it.

Other than open collector outputs, digital lines are not generally capable of driving relays. Buffering them with a driver chip is thus necessary. For example, a ULN 2003 may be used (see Figure 1.23).



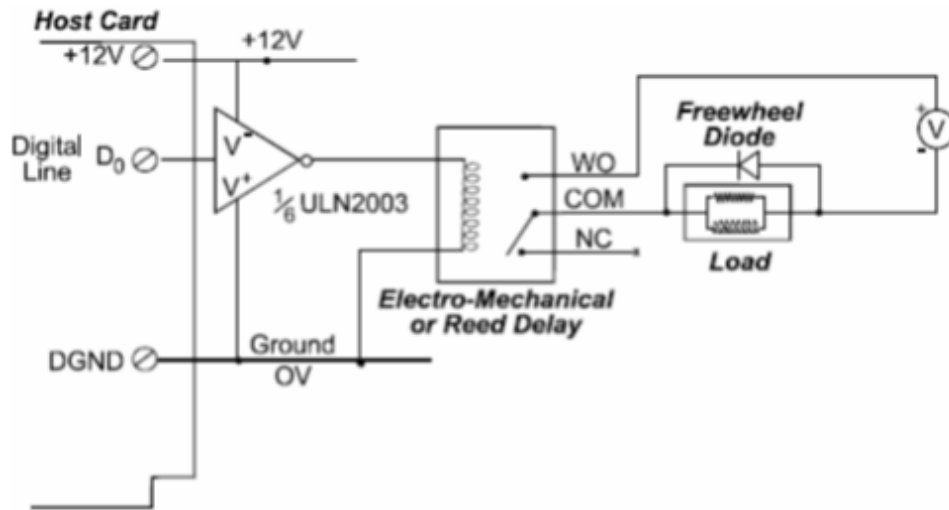


Figure 1.23

Driving relays and preventing back EMF damage

Solid-state relays

These are relays where the output switch is fabricated from power semiconductor devices and the control inputs behave like transistors. The control input may need buffering if the current requirements exceed the digital drive available, but there are no back EMF problems to deal with.

Back EMF from an inductive load may be reduced by a snubber network as shown in Figure 1.24.

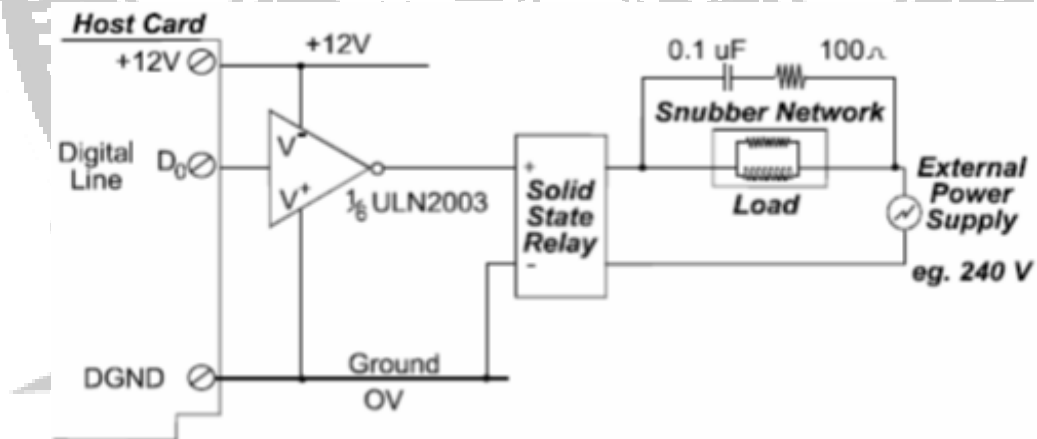


Figure 1.24

Driving solid-state relays

Switch inputs

As switches are passive devices with no power source, one side of the switch must be pulled up or down (with a suitable resistor) to the logic level (+5 V usually is normally available from the host card) or the ground and the switch position is read by the digital input.

Two such connections are shown in Figure 1.25. The first should give better noise immunity and has the advantage that one terminal is connected straight to the ground – useful if the system is made from a conducting metal and is at the ground potential – one does not need to have a ground return wire from the switch.

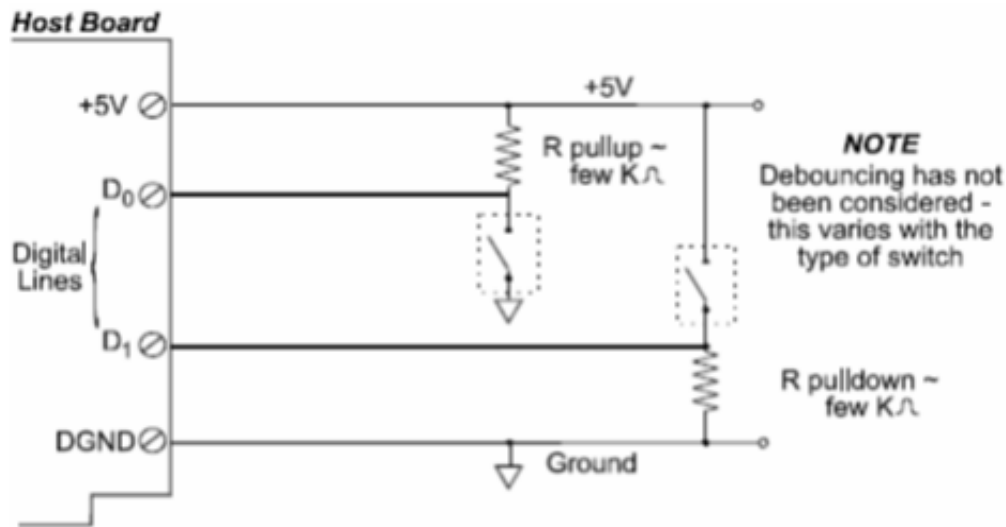


Figure 1.25

Reading the position of a switch

Fuses

It is always a good practice to fuse the output module channels. This ensures that if the normal load or in-rush currents are exceeded, the output channels are protected from damage. The manufacturers select fuses with certain current/time characteristics for use only with their output modules. These fuse types should be used. A good indication as to whether a fuse has blown on some output module is an individual “blown fuse” light.

Most good output modules will have an individual “blown fuse” light for each circuit.

Interposing relays

These are useful in circumstances where the load to be controlled has far greater current requirements than the output module can deliver. For example, we would use an interposing relay to control a larger relay, which is rated for the load’s voltage and current.

This may be preferable to use a higher rated output card of a different model with an attendant extra cost for a few circuits.

Safety circuit

The National Electrical Manufacturing Association (NEMA) and other authorities recommend the use of emergency stop function hardware to be independent of the PLC software and solid state electronic construction.

Two of the biggest areas of concern as far as safety is concerned are: one, the behavior of the software (especially during preliminary commissioning) and two, and the solid state output devices. Many solid state output devices fail in the shorted condition.

Control room requirements

The majority of tasks in a computer control room can be broken down into the following:

- monitoring of the system
- control adjustments
- alarm/emergency procedures
- staying awake

A few issues to assess in the design of the control room are:

Environmental considerations

The environment in which the system is installed must be appropriate to the computer system and the associated electronics systems. Typical environmental conditions that are considered suitable for the standard and the industrial environment are listed in Table 1.4.

Obviously, the environment in a control room should not have these extremes. The equipment should be rated for these ranges. Typical control room environmental ranges are discussed under ergonomic requirements. Industrial computer systems may be mounted in a less stringent environment than in the standard air-conditioned control room.

Table 1.4 Environmental conditions

ENVIRONMENTAL CONDITION	RECOMMENDED RANGE	
	INDUSTRIAL	STANDARD
Operating Temperature	0°C to 60°C	0°C to 50°C
Storage Temperature	-40°C to 85°C	-10°C to 60°C
Relative Humidity	5 to 95% RH	5 to 90% RH

Should the operational personnel believe that there could be problems with the environment having excessive dust, corrosive vapors, moisture or oil, and the best approach is to mount the computer system in an enclosure? This will provide the necessary protection for the processor.

Special consideration may have to be given to issues such as vibration and it may be necessary to mount the computer in the enclosure on shock mountings to absorb some of the vibrations.

Ensure that the enclosure doors can be easily opened and heat is allowed to dissipate.

Note that hot air rises and there can be a build-up of air inside the top of the enclosure and a fan may be needed to circulate the air.

Typical control room layout

A typical layout is given in Figure 1.26.

The “Horseshoe control room” layout is designed so that anyone in a center can see all the screens. Operators at any of the operator displays should be able to view the entire control room’s screens without undue difficulty as well.

Although the focus in a control room is normally on the equipment and computers, the amount of space for the operators should be maximized to avoid congestion (particularly when there is a changeover of shifts). Operators will spend a considerable amount of time in front of their consoles and the layout should ensure that the operator can see anyone coming into the control room and not have people peering over their shoulders.

Similar areas in the system that are being monitored should be situated close together to avoid unnecessary movement by the operators to see what is going on.

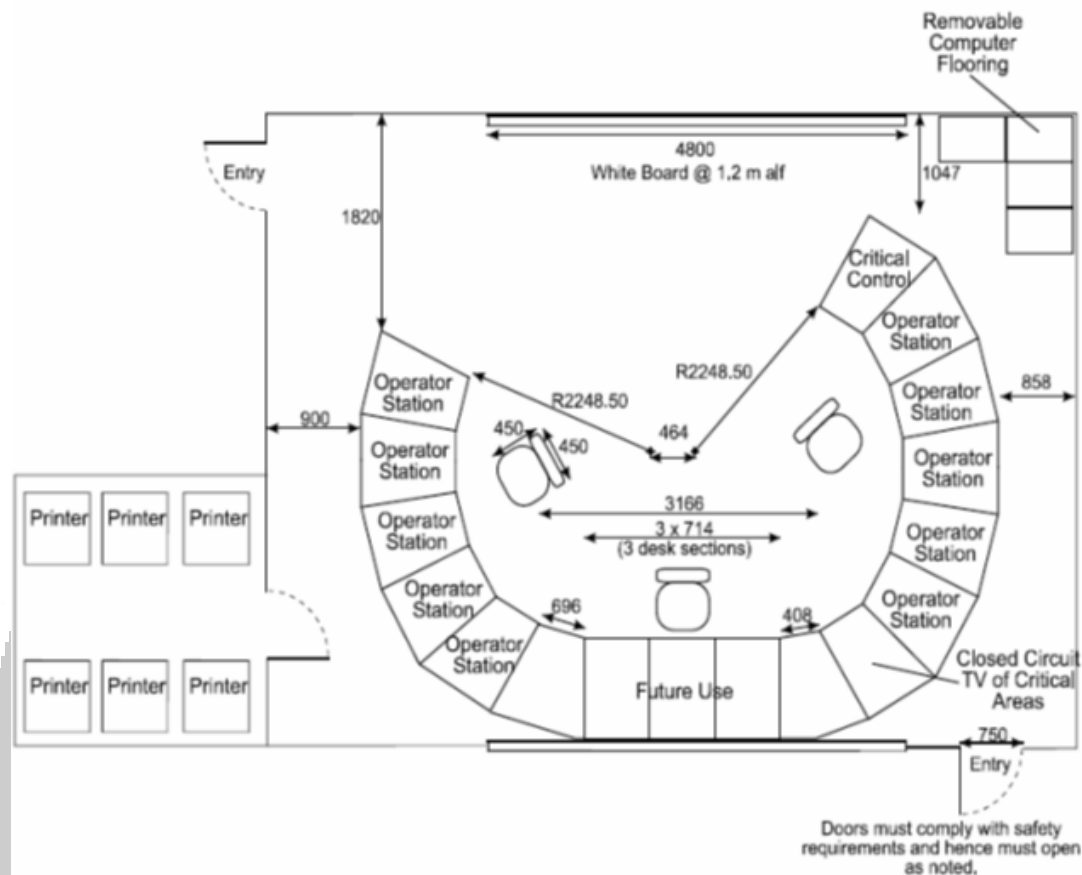


Figure 1.26

Typical control room

The voice communications system (either radio or telephone) should be situated as close as possible to the operators and for other persons entering the control room. For the control room indicated in the diagram, at least three internal telephones should be provided for easy access (with frequently used numbers programmed into the system).

The amount of desk space should not be compromised. Space should be allowed for manuals and other items to be left on the desk without unnecessary clutter.

Printers for the system are situated in a separate room to isolate the operators from the associated (rather, repetitive) noise. The associated inconvenience of having to walk to the printer room to view alarms can be minimized by providing on-screen alarm reports.

A “separate meeting room” should be provided to avoid holding meetings in the control room, which is of no interest to the operator but which disrupts his/her work.

The following specific issues should also be considered in the design of the computer control room.

Lighting

Tungsten halogen light sources produce warm lighting, while the light life of 2,000–4,000 hours is reasonable. They are not diffused and can produce significant shadowing.

If longer life is required, tubular fluorescent lamps have a life of 5,000–10,000 hours, but may have variable color rendering and variable apparent color if the correct color tube is not chosen.

The luminaries should be fixed overhead and provide direct lighting. Desk lighting can be installed to provide localized lighting over the keyboard.

A general level of lighting of 400 lux is recommended throughout the control room with a personal level of 200–600 lux set by the operator.

An average reflectance level of 30–60% is recommended for the walls. The ceiling should have a reflectance of at least 75%, with floors having an average of 40%.

Sound environment

A maximum noise level of 54–59 dB (A) is recommended.

Ventilation

The air temperature should be between 20°C and 26°C with relative humidity range of 40–60%. Fresh air should flow at the rate of 7 l/s per person throughout the control room.

Colors of equipment

Colors for walls and equipment should have a matt finish (i.e., no shiny surfaces) to avoid irritating reflections from the operator displays.

Strong contrasts in color should also be avoided to minimize glare. Matt or “orange peel” finish help to disguise inevitable blemishes and ripples on flat sheet metal surfaces.

A glossy “contours d’elegance” finish will cost extra and is unlikely to survive rigors of transport from factory to job site.

Where the general light level is low (<300 lux) warm color schemes are more acceptable than those in which cold colors predominate. A pleasant color scheme can be achieved with warm colors backed up with cool secondary colors.

These are typical installation requirements that should be taken care of. Further additions for improvisation are still possible.

