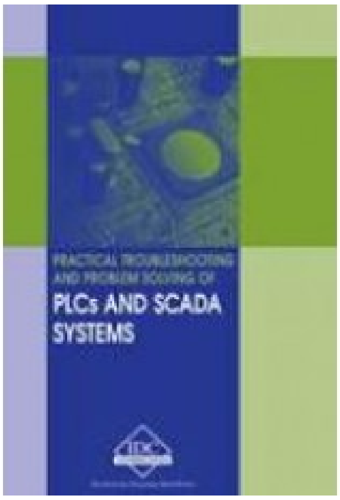
SK-E - Practical Troubleshooting and Problem Solving of PLCs and SCADA Systems



Price: $139.94

Ex Tax: $127.22

Short Description

The objective of this manual is to help you troubleshoot, identify, prevent and fix common PLC and SCADA problems. The emphasis is on practical hard hitting information that goes beyond typical theory, focusing unerringly on providing you with the necessary skills to solve your problems whether it is a PLC, SCADA system, or indeed communications system linking the two together. The automation system on your plant underpins your entire operation. It is thus critical that you have the knowledge and tools to quickly identify and fix problems as they occur to ensure you have a safe, secure and productive system. No compromise is obviously possible here. This manual distils all the tips and tricks learnt over many years.

Description

The objective of this manual is to help you troubleshoot, identify, prevent and fix common PLC and SCADA problems. The emphasis is on practical hard hitting information that goes beyond typical theory, focusing unerringly on providing you with the necessary skills to solve your problems whether it is a PLC, SCADA system, or indeed communications system linking the two together. The automation system on your plant underpins your entire operation. It is thus critical that you have the knowledge and tools to quickly identify and fix problems as they occur to ensure you have a safe, secure and productive system. No compromise is obviously possible here. This manual distils all the tips and tricks learnt over many years.

Table of Contents
Download Chapter List

Table of Contents

First Chapter
Chapter 1: Introduction to PCL and SCADA Systems

1

Introduction to PLC and SCADA Systems

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 fluffy 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
- 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 not 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 V DC.

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 to16 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. **Local 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 gives “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 DC 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 sourceconfiguration.

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.

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 a 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 ± 10% 50 Hz or 12/24/48 V DC ± 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.

SNR = 10 log *S/N* (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

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 mm^2 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 mm^2 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 V DC)

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 ± 2%).

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 coverts 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
- Level 2 – Medium susceptibility-analog signals> 50 V and switching circuits.
- Level 3 – Low susceptibility-awitching signals> 50 V, analog signals >50 V, regulating signals of 50 V with currents
- 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 commentating 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 un-fused 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.)

Table 1.2
Tray-conduit spacing (in.)

Table 1.3
Conduit spacing (in.)

*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 (

A PLC system p