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*Here's a valuable PLC reference that you can use right now. This particular reference is taken from our award-winning textbook—**Programmable Controllers: Theory and Implementation, 2nd Edition**.*

*In it, you'll explore PLC installation as well as other factors that affect PLC operation, such as noise, heat, and voltage. There's also lots of examples and tables to help explain the topics.*

*Best yet, we've included the corresponding chapter from the companion workbook. Here you can look over the key points as well as see how much you learned by answering the review questions. And, yes, the answers are also included.*

*This PLC reference is just a sample of what the textbook and workbook have to offer. If you like it, we've included the product literature page with the order number.*

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# PLC Reference Book

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—Jeff Camp, United Control Corp.

**The biggest book on PLCs.** Written by industry experts, this book covers important, up-to-date, real-world programmable controller topics and applications. This new edition is completely revised and updated to give you the latest developments and insights from the field. At 5 pounds and 1,035 pages, it puts all the PLC information you need at your fingertips. And, since this is a generic PLC reference, it will help you with all of the different makes and models of PLCs in your facility.

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## 21 Chapters of PLC Know-How

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- 3: Logic Concepts
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- 20: PLC Start-Up and Maintenance
- 21: System Selection Guidelines



## • Valuable Maintenance Tips •

### SELECTION, INSTALLATION & SAFETY

- ✓ Follow our 11 major steps in selecting a PLC for an application and avoid using the wrong controller
- ✓ Install sinking and sourcing inputs and outputs properly—one wrong wire and it won't work
- ✓ Implement safety circuits correctly in PLC applications to protect people and equipment
- ✓ Prevent noise, heat, and voltage variations from ruining your PLC system
- ✓ Implement a step-by-step static and dynamic start-up checkout to guarantee smooth PLC system operation
- ✓ Design preventive safety and maintenance into your total control system

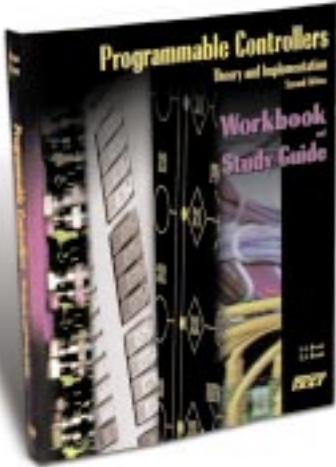
### TROUBLESHOOTING & MAINTENANCE

- ✓ Learn no-nonsense troubleshooting procedures to reduce downtime
- ✓ Troubleshoot analog I/O and avoid undesirable count jumps
- ✓ Learn 6 preventive maintenance procedures to keep your PLC system running fault free
- ✓ Learn a step-by-step procedure for finding hidden ground loops
- ✓ Learn how to deal with leaky inputs
- ✓ Identify vibration problems and use them for preventive engineering control
- ✓ Control excessive line voltage and avoid intermittent shutdowns

### PROGRAMMING

- ✓ Learn the number systems and codes used in PLC addressing
- ✓ Eliminate the confusion of ladder logic programming
- ✓ Master all types of timers and counters used in real-life applications
- ✓ Avoid ladder scan evaluation problems
- ✓ Implement a safe circuit with hardware and software interlocking

# Programmable Controllers: Workbook/Study Guide



“Sometimes you think you know it all, but after reading the questions, I often times had to refer back to the theory book.”

—Ernest Presto, Electrical Engineer, Polyclad Laminates, Inc.

Imagine having the answers to over 800 PLC problems at your fingertips. That's what you get with *Programmable Controllers: Workbook and Study Guide*. At 334 pages, it's the perfect companion to *Programmable Controllers: Theory and Implementation*, 2nd Edition.

This workbook provides not only valuable summaries of each of the text-book's twenty-one chapters, but also over 800 review questions. And each of the review questions includes a detailed answer and explanation. Use it on the job to brush up on the essentials and to solve any PLC problem.

Whether you're an expert or just learning about PLCs, you'll find plenty to put your skills to the test.

## You Will Learn:

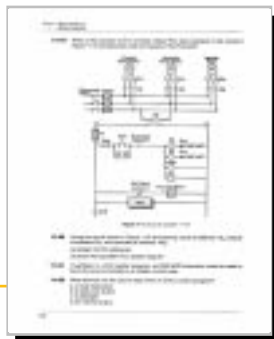
- Proper address assignment and interfacing
- Basic PLC ladder program implementation
- Data measurement
- Internal coil assignments
- Proper digital and analog interfacing procedures
- Advanced function block programming
- Network protocols
- Analog input and output data handling
- Correct PLC installation

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- Makes a great review tool
- Practice PLC addressing and programming
- Great on-the-job quick-reference guide
- Separate answer section makes quizzing easy
- Valuable chapter summaries

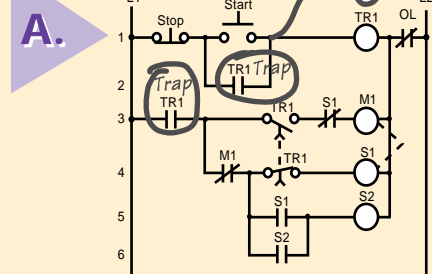
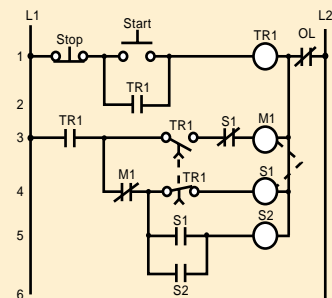
Sample pages from the workbook



## Sample Problem

A sample problem from Chapter 11 of the workbook:  
*System Programming and Implementation*

Q. Circle the locations where timer traps will be used in the PLC implementation of this reduced-voltage start motor circuit.



# PLC Start-Up and Maintenance

*If I had been present at the Creation, I would have given some useful hints for the better arrangement of the Universe.*

—Alfonso the Wise, King of Castille

## Key Terms

**Control program checkout**—a final review of a PLC's control program prior to starting up the system.

**Dynamic system checkout**—the process of verifying the correct operation of a control program by actually implementing it.

**Ground loop**—a condition in which two or more electrical paths exist within a ground line.

**Master control relay**—a hardwired or softwired relay instruction that de-energizes its associated I/O devices when the instruction is de-energized.

**Panel enclosure**—the physical enclosure that houses a PLC's hardware and components.

**Safety control relay**—a hardwired or softwired relay instruction that de-energizes its associated I/O devices when de-energized.

**System layout**—the planned approach to placing and connecting PLC components.

**Wire bundling**—the technique of grouping an I/O module's wires according to their characteristics.

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## HIGHLIGHTS

The design of programmable controllers includes a number of rugged features that allow PLCs to be installed in almost any industrial environment. Although programmable controllers are tough machines, a little foresight during their installation will ensure proper system operation. In this handbook, we will explore PLC installation, explaining the specifications for proper PLC component placement and environment. We will also explain other factors that affect PLC operation, such as noise, heat, and voltage. In addition, we will discuss wiring guidelines and safety precautions. Although proper PLC installation leads to good system operation, no programmable controller system is without faults. Therefore, we will investigate proactive maintenance techniques, as well as reactive troubleshooting processes. When you finish, you will understand the fundamentals of PLC start-up and operation.

## 1 PLC SYSTEM LAYOUT

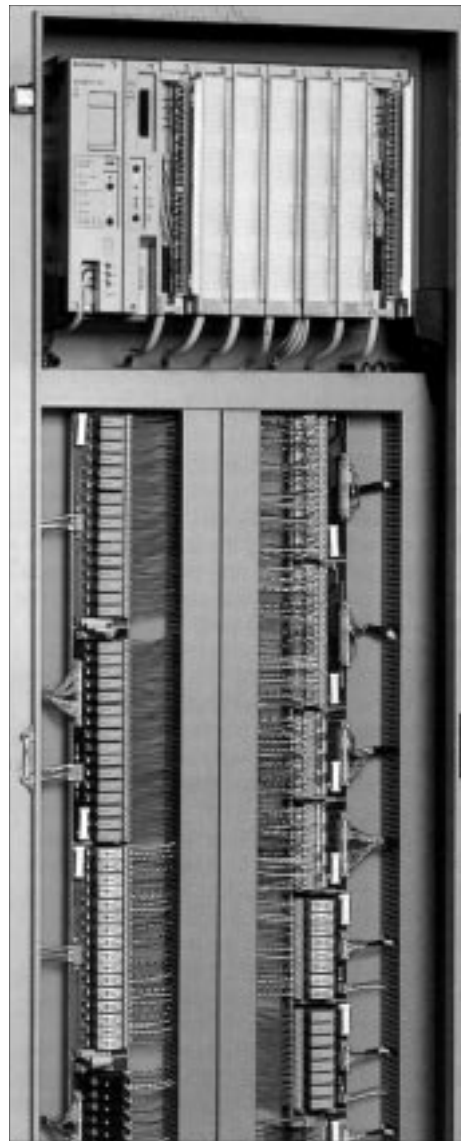
**System layout** is the conscientious approach to placing and interconnecting components not only to satisfy the application, but also to ensure that the controller will operate trouble free in its environment. In addition to programmable controller equipment, the system layout also encompasses the other components that form the total system. These components include isolation transformers, auxiliary power supplies, safety control relays, and incoming line noise suppressors. In a carefully constructed layout, these components are easy to access and maintain.

PLCs are designed to work on a factory floor; thus, they can withstand harsh environments. Nevertheless, careful installation planning can increase system productivity and decrease maintenance problems. The best location for a programmable controller is near the machine or process that it will control, as long as temperature, humidity, and electrical noise are not problems. Placing the controller near the equipment and using remote I/O where possible will minimize wire runs and simplify start-up and maintenance. Figure 1 shows a programmable controller installation and its wiring connections.

### PANEL ENCLOSURES AND SYSTEM COMPONENTS

PLCs are generally placed in a NEMA-12 **panel enclosure** or another type of NEMA enclosure, depending on the application. A panel enclosure holds the PLC hardware, protecting it from environmental hazards. Table 1 describes the different types of NEMA enclosures. The enclosure size depends on the total space required. Mounting the controller components in an





Courtesy of Siemens, Alpharetta, GA, and Phoenix Contact, Harrisburg, PA

**Figure 1.** Installation of a PLC-based system using modular I/O terminal blocks.

enclosure is not always required, but it is recommended for most applications to protect the components from atmospheric contaminants, such as conductive dust, moisture, and other corrosive and harmful airborne substances. Metal enclosures also help minimize the effects of electromagnetic radiation, which may be generated by surrounding equipment.

The enclosure layout should conform to NEMA standards, and component placement and wiring should take into consideration the effects of heat, electrical noise, vibration, maintenance, and safety. Figure 2 illustrates a typical enclosure layout, which can be used for reference during the following layout guideline discussion.

<b>NEMA Panel Enclosures</b>	
<b>Type 1 (Surface mount)</b>	For indoor use to protect against contact with the enclosed equipment in applications where unusual service conditions do not exist
<b>Type 1 (Flush mount)</b>	Used for the same types of applications as Type 1 surface-mounted enclosures in situations where installation in a machine frame or plaster wall is desired
<b>Type 3</b>	For outdoor use to protect against windblown dust, rain, sleet, and external ice formation
<b>Type 3R</b>	For outdoor use to protect against falling rain, sleet, and external ice formation
<b>Type 3R, 7, and 9 (Unilock enclosure for hazardous locations)</b>	Used for the same types of applications as Type 3R, 7, and 9 enclosures but provides a copper-free aluminum, bronze-chromated housing
<b>Type 4</b>	For indoor or outdoor use to protect against windblown dust and rain, splashing water, and hose-directed water
<b>Type 4X (Nonmetallic, corrosion-resistant, fiberglass-reinforced polyester)</b>	For indoor and outdoor use to protect against corrosion, windblown dust and rain, splashing water, and hose-directed water
<b>Type 6P</b>	For indoor and outdoor use to protect against the entry of water during prolonged submersion at a limited depth
<b>Type 7 (Hazardous gas locations bolted enclosure)</b>	For indoor use in applications using hazardous gases; capable of withstanding an internal explosion of specified gases and containing such an explosion to prevent the ignition of the surrounding atmosphere
<b>Type 9 (Hazardous dust locations)</b>	For indoor use in applications where hazardous dust is present; designed to prohibit the entry of dust as well as prevent the ignition of dust by enclosed heat-generating devices
<b>Type 12</b>	For indoor use to protect against dust, falling dirt, and dripping noncorrosive liquids
<b>Type 13</b>	For indoor use to protect against dust, spraying of water, oil, and noncorrosive coolants

**Table 1.** NEMA panel enclosure descriptions.

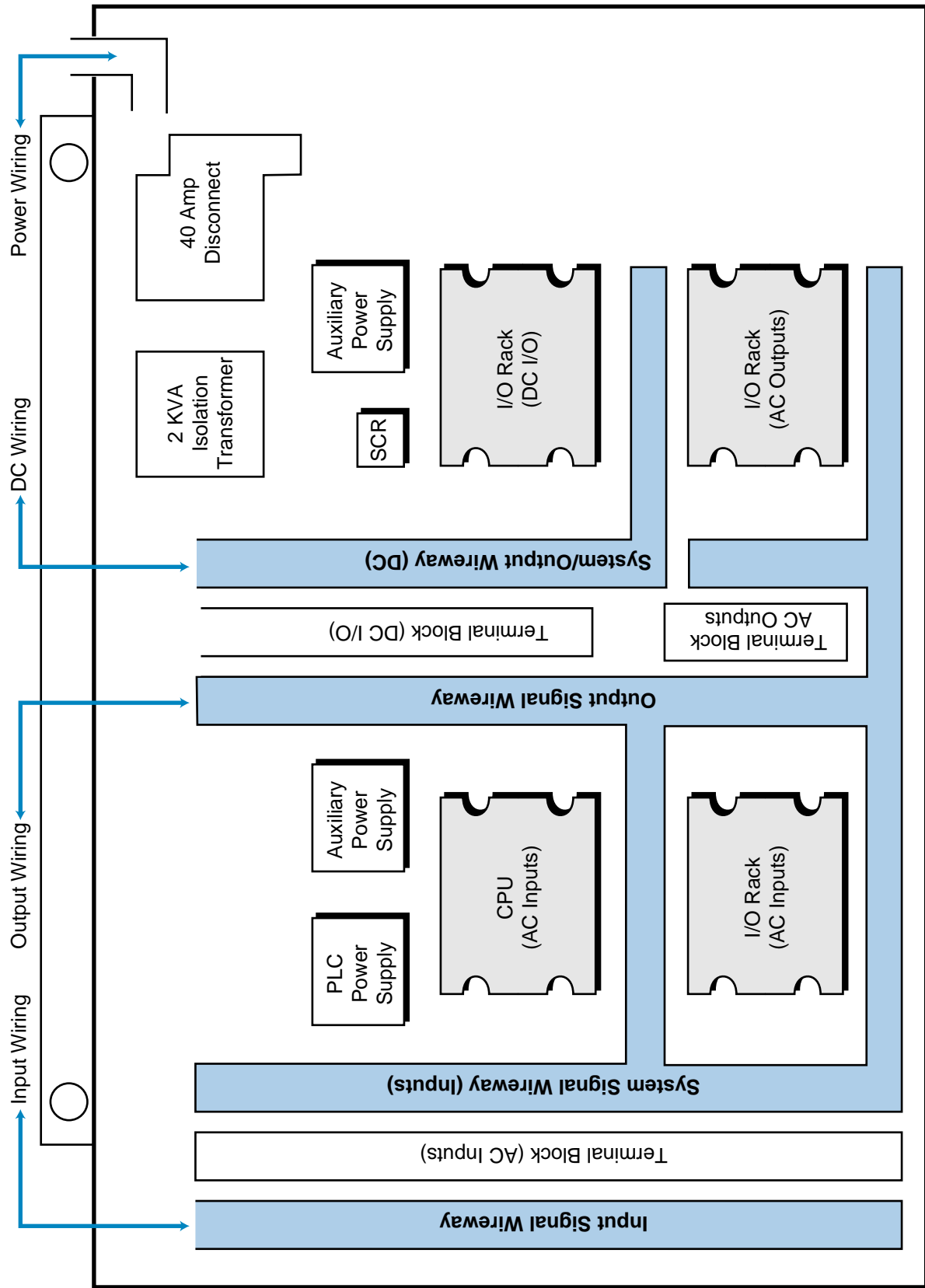


Figure 2. Enclosure layout.

**General.** The following recommendations address preliminary considerations for the location and physical aspects of a PLC enclosure:

- The enclosure should be located so that the doors can fully open for easy access when testing or troubleshooting wiring and components.
- The enclosure depth should provide adequate clearance between the closed enclosure door (including any print pockets mounted on the door) and the enclosed components and related cables.
- The enclosure's back panel should be removable to facilitate mounting of the components and other assemblies.
- The cabinet should contain an emergency disconnect device installed in an easily accessible location.
- The enclosure should include accessories, such as AC power outlets, interior lighting, and a gasketed, clear acrylic viewing window, for installation and maintenance convenience.

**Environmental.** The effects of temperature, humidity, electrical noise, and vibration are important when designing the system layout. These factors influence the actual placement of the controller, the inside layout of the enclosure, and the need for other special equipment. The following considerations help to ensure favorable environmental conditions for the controller:

- The temperature inside the enclosure must not exceed the maximum operating temperature of the controller (typically 60°C).
- If the environment contains "hot spots," such as those generated by power supplies or other electrical equipment, a fan or blower should be installed to help dissipate the heat.
- If condensation is likely, the enclosure should contain a thermostat-controlled heater.
- The enclosure should be placed well away from equipment that generates excessive electromagnetic interference (EMI) or radio frequency interference (RFI). Examples of such equipment include welding machines, induction heating equipment, and large motor starters.
- In cases where the PLC enclosure must be mounted on the controlled equipment, the vibrations caused by that equipment should not exceed the PLC's vibration specifications.

**Placement of PLC Components.** The placement of the major components of a specific controller depends on the number of system components and the physical design or modularity of each component (see Figure 3). Although



**Figure 3.** Placement of PLC components.

different controllers have different mounting and spacing requirements, the following considerations and precautions apply when placing any PLC inside an enclosure:

- To allow maximum convection cooling, all controller components should be mounted in a vertical (upright) position. Some manufacturers may specify that the controller components can be mounted horizontally. However, in most cases, components mounted horizontally will obstruct air flow.
- The power supply (main or auxiliary) has a higher heat dissipation than any other system component; therefore, it should not be mounted directly underneath any other equipment. The power supply should be installed at the top of the enclosure above all other equipment, with adequate spacing (at least ten inches) between the power supply and the top of the enclosure. The power supply may also be placed adjacent to other components, but with sufficient spacing.
- The CPU should be located at a comfortable working level (e.g., at sitting or standing eye level) that is either adjacent to or below the power supply. If the CPU and power supply are contained in a single PLC unit, then the PLC unit should be placed toward the top of the enclosure with no other components directly above it, unless there is sufficient space.
- Local I/O racks (in the same panel enclosure as the CPU) can be arranged as desired within the distance allowed by the I/O rack interconnection cable. Typically, the racks are located below or adjacent to the CPU, but not directly above the CPU or power supply.

- Remote I/O racks and their auxiliary power supplies are generally placed inside an enclosure at the remote location, following the same placement practices as described for local racks.
- Spacing of the controller components (to allow proper heat dissipation) should adhere to the manufacturer's specifications for vertical and horizontal spacing between major components.

**Placement of Other Components.** In general, other equipment inside the enclosure should be located away from the controller components, to minimize the effects of noise and heat generated by these devices. The following list outlines some common practices for locating other equipment inside the enclosure:

- Incoming line devices, such as isolation and constant voltage transformers, local power disconnects, and surge suppressors, should be located near the top of the enclosure and beside the power supply. This placement assumes that the incoming power enters at the top of the panel. The proper placement of incoming line devices keeps power wire runs as short as possible, minimizing the transmission of electrical noise to the controller components.
- Magnetic starters, contactors, relays, and other electromechanical components should be mounted near the top of the enclosure in an area segregated from the controller components. A good practice is to place a six-inch barrier between the magnetic area and the controller area. Typically, magnetic components are adjacent and opposite to the power supply and incoming line devices.
- If fans or blowers are used to cool the components inside the enclosure, they should be located close to the heat-generating devices (generally power supply heat sinks). When using fans, outside air should not be brought inside the enclosure unless a fabric or other reliable filter is used. Filtration prevents conductive particles and other harmful contaminants from entering the enclosure.

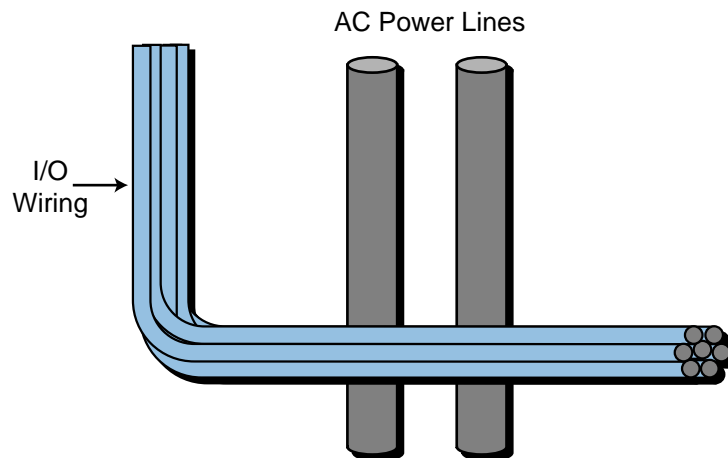
**Grouping Common I/O Modules.** The grouping of I/O modules allows signal and power lines to be routed properly through the ducts, thus minimizing crosstalk interference. Following are recommendations concerning the grouping of I/O modules:

- I/O modules should be segregated into groups, such as AC input modules, AC output modules, DC input modules, DC output modules, analog input modules, and analog output modules, whenever possible.
- If possible, a separate I/O rack should be reserved for common input or output modules. If this is not possible, then the modules should be

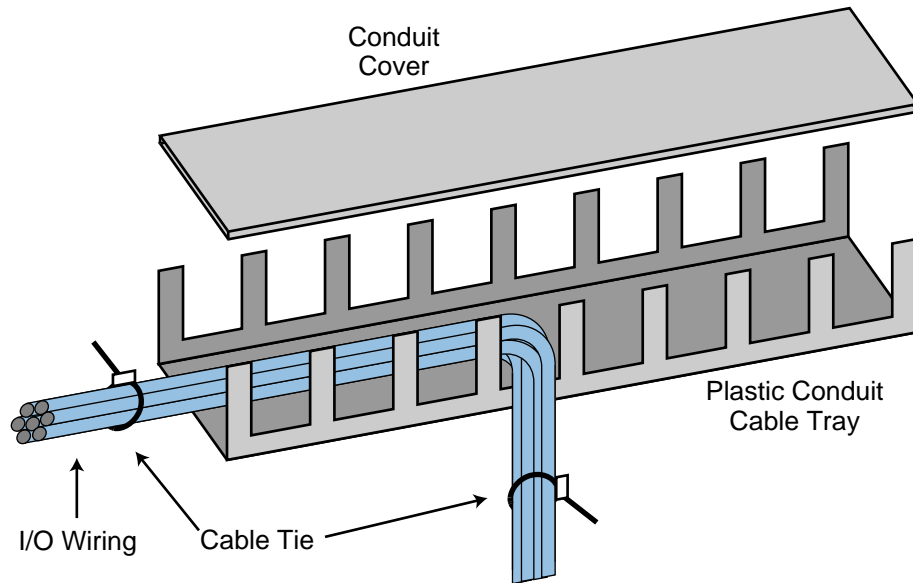
separated as much as possible within the rack. A suitable partitioning would involve placing all AC modules or all DC modules together and, if space permits, allowing an unused slot between the two groups.

**Duct and Wiring Layout.** The duct and wiring layout defines the physical location of wireways and the routing of field I/O signals, power, and controller interconnections within the enclosure. The enclosure's duct and wiring layout depends on the placement of I/O modules within each I/O rack. The placement of these modules occurs during the design stage, when the I/O assignment takes place. Prior to defining the duct and wiring layout and assigning the I/O, the following guidelines should be considered to minimize electrical noise caused by crosstalk between I/O lines:

- All incoming AC power lines should be kept separate from low-level DC lines, I/O power supply cables, and I/O rack interconnection cables.
- Low-level DC I/O lines, such as TTL and analog, should not be routed in parallel with AC I/O lines in the same duct. Whenever possible, keep AC signals separate from DC signals.
- I/O rack interconnection cables and I/O power cables can be routed together in a common duct not shared by other wiring. Sometimes, this arrangement is impractical or these cables cannot be separated from all other wiring. In this case, the I/O cables can either be routed with low-level DC lines or routed externally to all ducts and held in place using tie wraps or some other fastening method.
- If I/O wiring must cross AC power lines, it should do so only at right angles (see Figure 4). This routing practice minimizes the possibility of electrical noise pickup. I/O wiring coming from the conduits should also be at right angles (see Figure 5).



**Figure 4.** I/O wiring must cross AC power lines at a right angle.



**Figure 5.** I/O wiring from a conduit.

- When designing the duct layout, the separation between the I/O modules and any wire duct should be at least two inches. If terminal strips are used, then the terminal strip and wire duct, as well as the terminal strip and I/O modules, should be at least two inches apart.

**Grounding.** Proper grounding is an important safety measure in all electrical installations. When installing electrical equipment, users should refer to National Electric Code (NEC) Article 250, which provides data about the size and types of conductors, color codes, and connections necessary for safe grounding of electrical components. The code specifies that a grounding path must be permanent (no solder), continuous, and able to safely conduct the ground-fault current in the system with minimal impedance. The following grounding practices have significant impacts on the reduction of noise caused by electromagnetic induction:

- Ground wires should be separated from the power wiring at the point of entry to the enclosure. To minimize the ground wire length within the enclosure, the ground reference point should be located as close as possible to the point of entry of the plant power supply.
- All electrical racks/chassis and machine elements should be grounded to a central ground bus, normally located in the magnetic area of the enclosure. Paint and other nonconductive materials should be scraped away from the area where the chassis makes contact with the enclosure. In addition to the ground connection made through the mounting bolt or stud, a one-inch metal braid or size #8 AWG wire (or the manufacturer's recommended wire size) should be used to connect each chassis to the enclosure at the mounting bolt or stud.



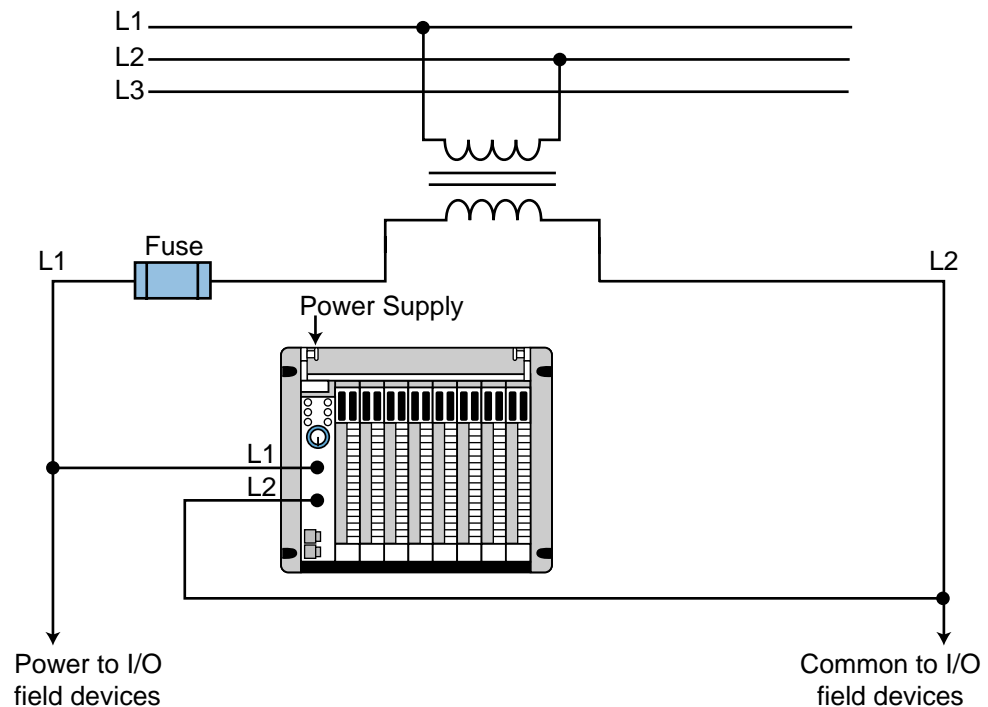
- The enclosure should be properly grounded to the ground bus, which should have a good electrical connection at the point of contact with the enclosure.
- The machine ground should be connected to the enclosure and to the earth ground.

## 2 POWER REQUIREMENTS AND SAFETY CIRCUITRY

The source for a PLC power supply is generally single-phase and 120 or 240 VAC. If the controller is installed in an enclosure, the two power leads (L1 hot and L2 common) normally enter the enclosure through the top part of the cabinet to minimize interference with other control lines. The power line should be as clean as possible to avoid problems due to line interference in the controller and I/O system.

### POWER REQUIREMENTS

**Common AC Source.** The system power supply and I/O devices should have a common AC source (see Figure 6). This minimizes line interference and prevents faulty input signals stemming from a stable AC source to the power supply and CPU, but an unstable AC source to the I/O devices. By keeping both the power supply and the I/O devices on the same power source, the user can take full advantage of the power supply's line monitoring feature.



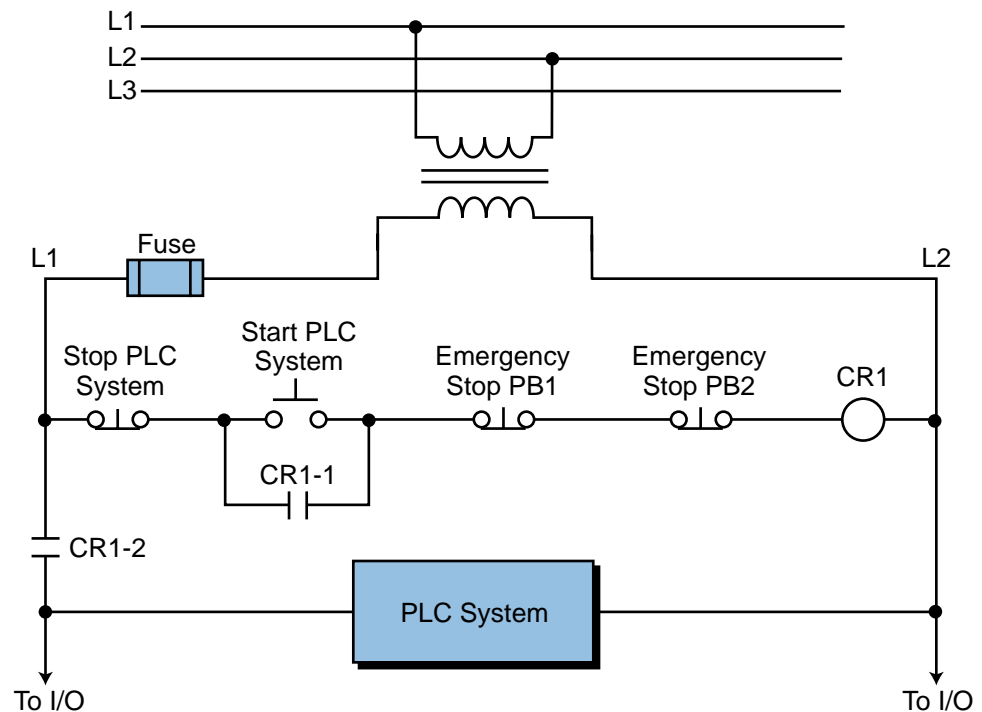
**Figure 6.** System power supply and I/O devices with a common AC source.

If line conditions fall below the minimum operating level, the power supply will detect the abnormal condition and signal the processor, which will stop reading input data and turn off all outputs.

**Isolation Transformers.** Another good practice is to use an isolation transformer on the AC power line going to the controller. An isolation transformer is especially desirable when heavy equipment is likely to introduce noise into the AC line. An isolation transformer can also serve as a step-down transformer to reduce the incoming line voltage to a desired level. The transformer should have a sufficient power rating (in units of volt-amperes) to supply the load, so users should consult the manufacturer to obtain the recommended transformer rating for their particular application.

## SAFETY CIRCUITRY

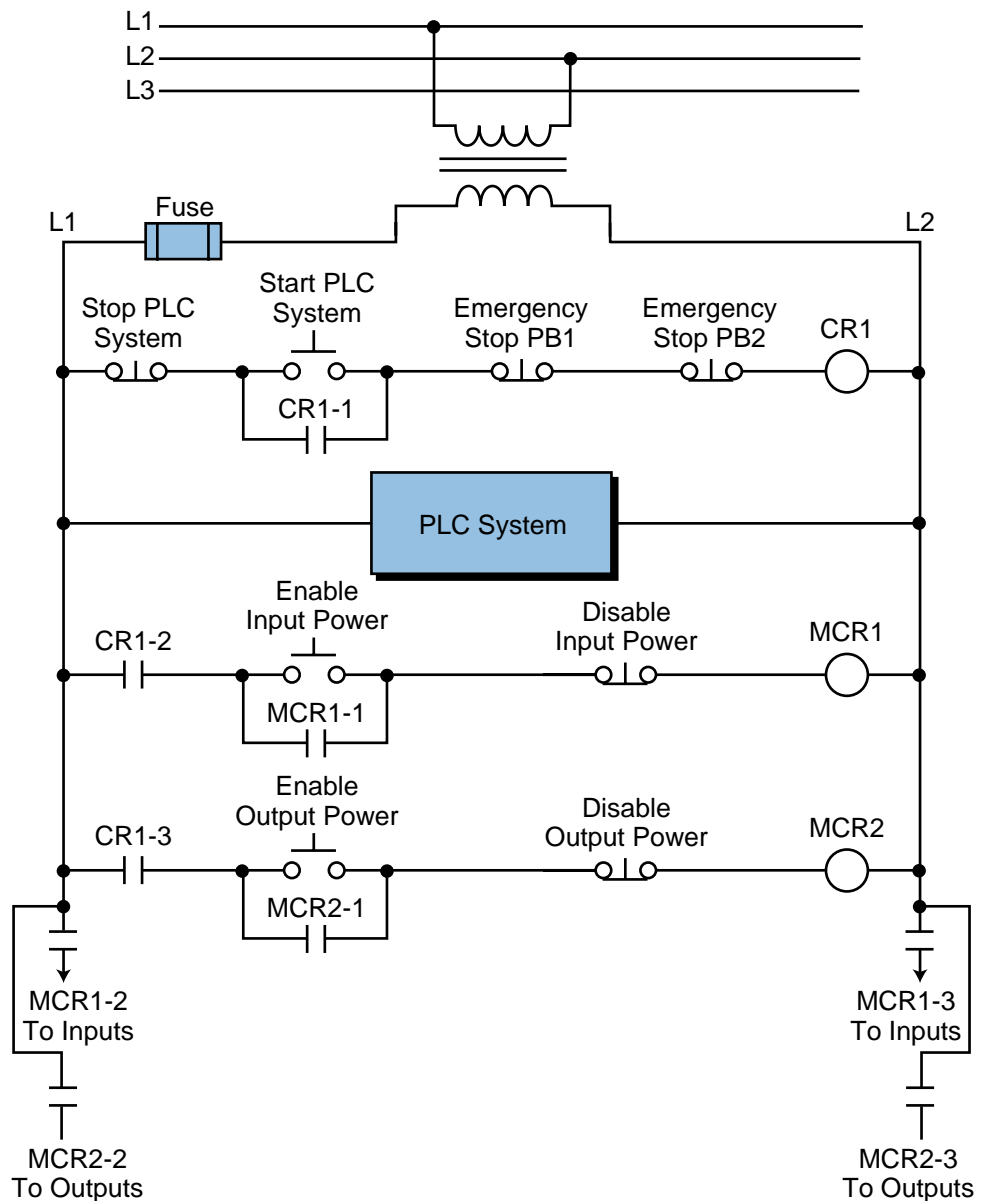
The PLC system should contain a sufficient number of emergency circuits to either partially or totally stop the operation of the controller or the controlled machine or process (see Figure 7). These circuits should be routed outside the controller, so that the user can manually and rapidly shut down the system in the event of total controller failure. Safety devices, like emergency pull rope switches and end-of-travel limit switches, should bypass the controller to operate motor starters, solenoids, and other devices directly. These emergency circuits should use simple logic with a minimum number of highly reliable, preferably electromechanical, components.



**Figure 7.** Emergency circuits hardwired to the PLC system.

**Emergency Stops.** The system should have emergency stop circuits for every machine directly controlled by the PLC. To provide maximum safety, these circuits should not be wired to the controller, but instead should be left hardwired. These emergency switches should be placed in locations that the operator can easily access. Emergency stop switches are usually wired into master control relay or safety control relay circuits, which remove power from the I/O system in an emergency.

**Master or Safety Control Relays.** Master control relay (MCR) and safety control relay (SCR) circuits provide an easy way to remove power from the I/O system during an emergency situation (see Figure 8). These control relay circuits can be de-energized by pushing any emergency stop switch

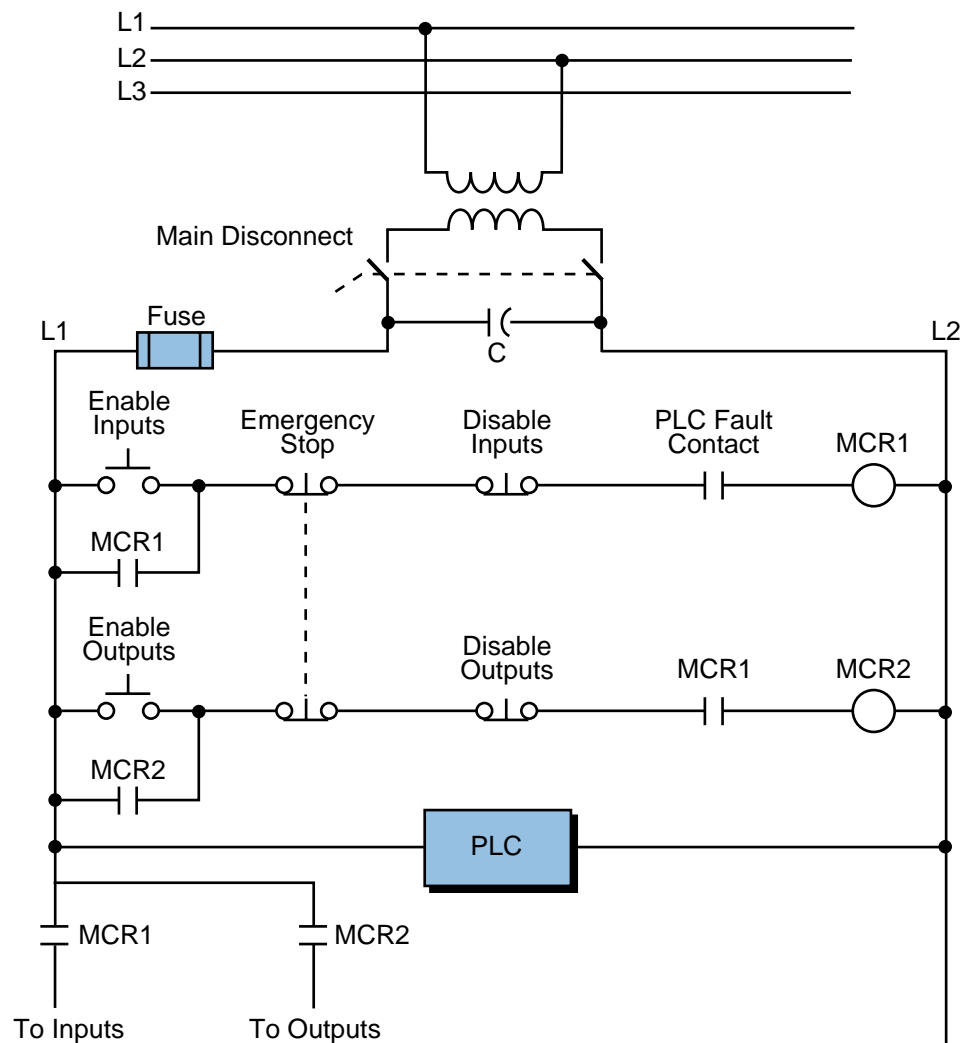


**Figure 8.** Master start control for a PLC with MCRs enabling input and output power.

connected to the circuit. De-energizing the control relay coil removes power to the input and output devices. The CPU, however, continues to receive power and operate even though all of its inputs and outputs are disabled.

An MCR circuit may be extended by placing a PLC fault relay (closed during normal PLC operation) in series with any other emergency stop condition. This enhancement will cause the MCR circuit to cut the I/O power in the case of a PLC failure (memory error, I/O communications error, etc.). Figure 9 illustrates the typical wiring of a master control relay circuit.

**Emergency Power Disconnect.** The power circuit feeding the power



**Figure 9.** Circuit that enables/disables I/O power through MCRs and PLC fault contact detection.

supply should use a properly rated emergency power disconnect, thus providing a way to remove power from the entire programmable controller system (refer to Figure 9). Sometimes, a capacitor (0.47  $\mu$ F for 120 VAC, 0.22  $\mu$ F for 220 VAC) is placed across the disconnect to protect against an

*outrush* condition. Outrush occurs when the power disconnect turns off the output triacs, causing the energy stored in the inductive loads to seek the nearest path to ground, which is often through the triacs.

### 3 NOISE, HEAT, AND VOLTAGE REQUIREMENTS

Implementation of the previously outlined recommendations should provide favorable operating conditions for most programmable controller applications. However, in certain applications, the operating environment may have extreme conditions that require special attention. These adverse conditions include excessive noise and heat and nuisance line fluctuations. This section describes these conditions and provide measures to minimize their effects.

**Excessive Noise.** Electrical noise seldom damages PLC components, unless extremely high energy or high voltage levels are present. However, temporary malfunctions due to noise can result in hazardous machine operation in certain applications. Noise may be present only at certain times, or it may appear at widespread intervals. In some cases, it may exist continuously. The first case is the most difficult to isolate and correct.

Noise usually enters a system through input, output, and power supply lines. Noise may also be coupled into these lines electrostatically through the capacitance between them and the noise signal carrier lines. The presence of high-voltage or long, closely spaced conductors generally produces this effect. The coupling of magnetic fields can also occur when control lines are located close to lines carrying large currents. Devices that are potential noise generators include relays, solenoids, motors, and motor starters, especially when operated by hard contacts, such as push buttons and selector switches.

Analog I/O and transmitters are very susceptible to noise from electromechanical sources, causing jumps in counts during the reading of analog data. Therefore, motor starters, transformers, and other electromechanical devices should be kept away from analog signals, interfaces, and transmitters.

Although the design of solid-state controls provides a reasonable amount of noise immunity, the designer must still take special precautions to minimize noise, especially when the anticipated noise signal has characteristics similar to the desired control input signals. To increase the operating noise margin, the controller must be installed away from noise-generating devices, such as large AC motors and high-frequency welding machines. Also, all inductive loads must be suppressed. Three-phase motor leads should be grouped together and routed separately from low-level signal leads. Sometimes, if the noise level situation is critical, all three-phase motor leads must be suppressed (see Figure 10). Figure 11 illustrates line-filtering configurations used for removing input power noise to a controller or transmitter.

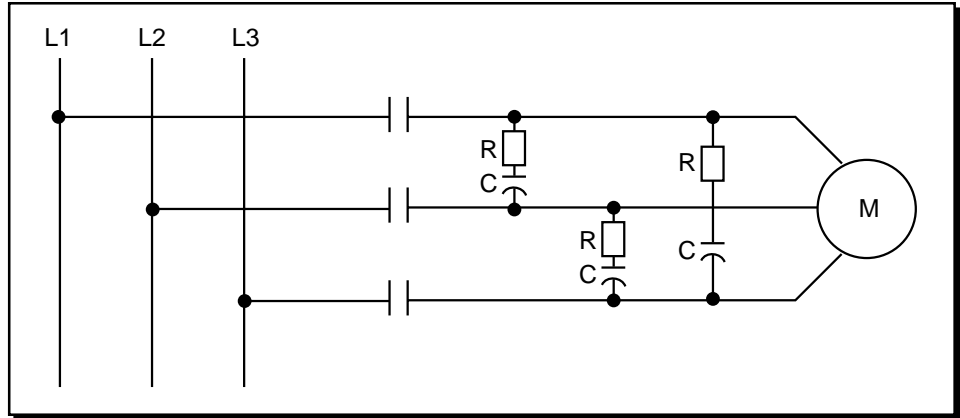
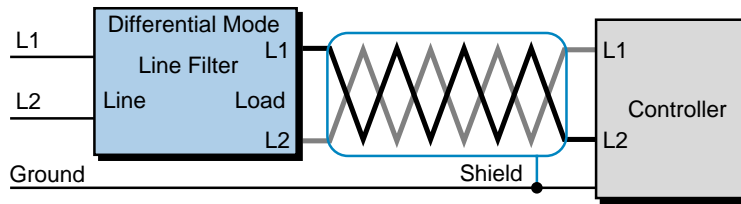
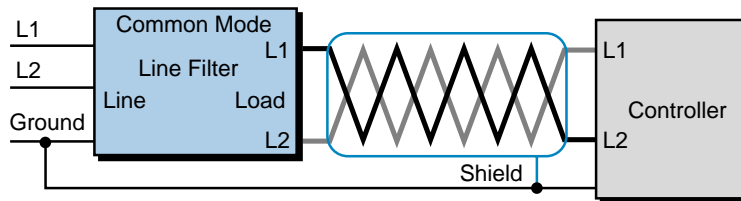


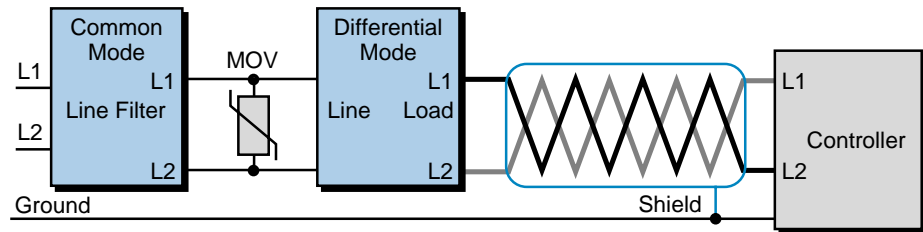
Figure 10. Suppression of a three-phase motor lead.



(a) Differential mode filter diagram



(b) Common mode filter diagram



(c) Combination differential/common mode filter diagram

Note 1: Keep line filters 12 inches or less from the controller. Minimize the line distance where noise can be introduced into the controller.

Note 2: To prevent ground loops, do not tie the common mode line metal case filters with other metal that is at ground potential. Doing so will reduce the filters' effectiveness.

Courtesy of Wailow Electric Co., St. Louis, MO

Figure 11. Power noise reduction using one of three line-filtering configurations.

**Excessive Heat.** Programmable controllers can withstand temperatures ranging from 0 to 60°C. They are normally cooled by *convection*, meaning that a vertical column of air, drawn in an upward direction over the surface of the components, cools the PLC. To keep the temperature within limits, the cooling air at the base of the system must not exceed 60°C.

The PLC components must be properly spaced when they are installed to avoid excess heat. The manufacturer can provide spacing recommendations, which are based on typical conditions for most PLC applications. Typical conditions are as follows:

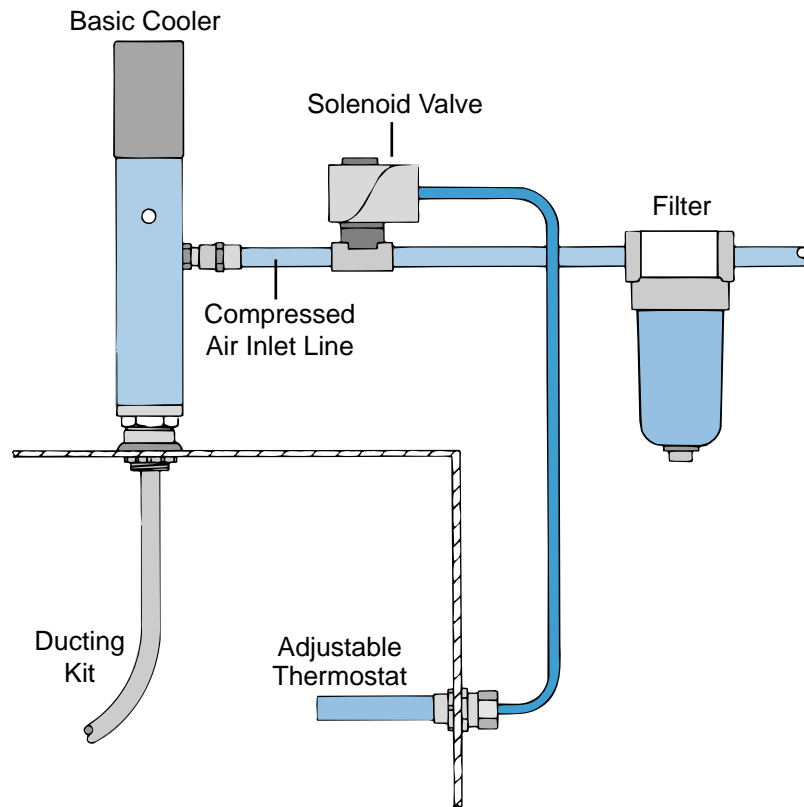
- 60% of the inputs are ON at any one time
- 30% of the outputs are ON at any one time
- the current supplied by all of the modules combined meets manufacturer-provided specifications
- the air temperature is around 40°C

Situations in which most of the I/O are ON at the same time and the air temperature is higher than 40°C are not typical. In these situations, spacing between components must be larger to provide better convection cooling. If equipment inside or outside of the enclosure generates substantial amounts of heat and the I/O system is ON continuously, the enclosure should contain a fan that will reduce hot spots near the PLC system by providing good air circulation. The air being brought in by the fan should first pass through a filter to prevent dirt or other contaminants from entering the enclosure. Dust obstructs the components' heat dissipation capacity, as well as harms heat sinks when thermal conductivity to the surrounding air is lowered. In cases of extreme heat, the enclosure should be fitted with an air-conditioning unit or cooling control system that utilizes compressed air (see Figures 12 and 13). Leaving enclosure doors open to cool off the system is not a good practice, since this allows conductive dust to enter the system.



Courtesy of ITW Vortec, Cincinnati, OH

**Figure 12.** Vortex cooler used in cooling systems.



Courtesy of ITW Vortec, Cincinnati, OH

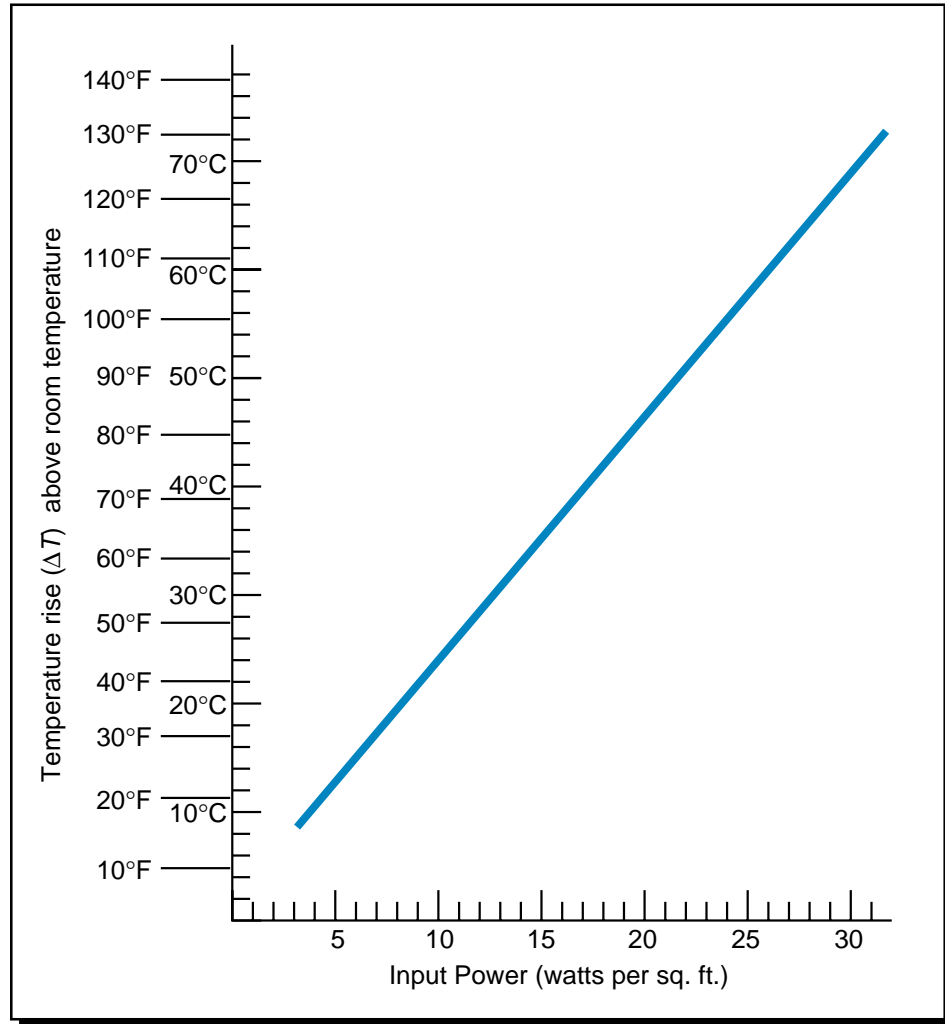
**Figure 13.** Compressed air cooling system.

There are methods available to calculate the temperature rise and heat dissipation requirements of an enclosure based on its size and equipment contents. Temperature rise is the temperature difference between the air inside an enclosure and the outside air temperature (ambient air temperature). Hoffman Engineering Co., a manufacturer of control system enclosures, has developed temperature rise graphs for use with their panels and enclosures. Figure 14 illustrates a temperature rise graph for a NEMA 12-type enclosure. The following example illustrates how to calculate temperature rise and required airflow using the graph.

#### EXAMPLE 1

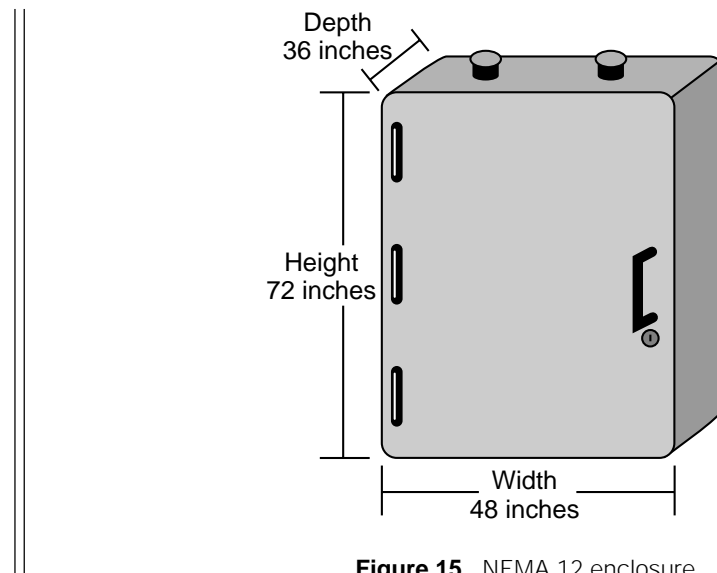
The NEMA 12 enclosure shown in Figure 15 contains a programmable controller with a power supply transformer, power supplies for an analog transmitter and other equipment, and various electromechanical equipment. The combined power dissipation of the equipment, found by adding each element's power dissipation, is 1011 watts. The ambient temperature of the enclosure is 90°F (32.2°C). Find **(a)** the temperature rise for this enclosure and **(b)** the required airflow.





Courtesy of Hoffman Engineering Co., Anoka, MN

**Figure 14.** Temperature rise graph for a NEMA 12 enclosure.



**Figure 15.** NEMA 12 enclosure.

## SOLUTION

**(a)** To calculate the temperature rise, first calculate the total area (square feet) of the exposed sides of the enclosure. Assuming that the back and bottom sides of the enclosure are not exposed, the area of each exposed side equals:

$$\begin{aligned}\text{Front area} &= (\text{Height})(\text{Width}) \\ &= (6 \text{ ft})(4 \text{ ft}) \\ &= 24 \text{ ft}^2\end{aligned}$$

$$\begin{aligned}\text{Side area} &= (\text{Height})(\text{Depth}) \\ &= (6 \text{ ft})(3 \text{ ft}) \\ &= 18 \text{ ft}^2\end{aligned}$$

$$\begin{aligned}\text{Top area} &= (\text{Depth})(\text{Width}) \\ &= (3 \text{ ft})(4 \text{ ft}) \\ &= 12 \text{ ft}^2\end{aligned}$$

Therefore, the total area for heat dissipation, taking into account that there are two sides, is:

$$\begin{aligned}\text{Total area} &= 24 \text{ ft}^2 + 2(18 \text{ ft}^2) + 12 \text{ ft}^2 \\ &= 72 \text{ ft}^2\end{aligned}$$

So, 1011 watts of total power in the enclosure is distributed over a total surface area of 72 ft<sup>2</sup>, resulting in a power dissipation per square foot of 14.04 watts:

$$\begin{aligned}\text{Power dissipation} &= \frac{1011 \text{ watts}}{72 \text{ ft}^2} \\ &= 14.04 \text{ watts/ft}^2\end{aligned}$$

From the temperature rise curve for a NEMA 12 enclosure, we can find that the temperature rise is approximately 32°C or 57.5°F. Therefore, this system will experience a final temperature (ambient + rise) of approximately 64.2°C (32.2°C + 32°C) or 147.5°F (90°F + 57.5°F). This temperature exceeds the PLC's maximum operating temperature of 60°C, meaning that a malfunction could occur because of the high temperature inside the enclosure. This system, therefore, requires proper ventilation or cooling.

**(b)** The required airflow inside the enclosure is based on the maximum operating temperature of the components (e.g., 60°C for a PLC).

Assuming that all inside components can withstand up to 60°C (140°F), the permissible temperature rise ( $\Delta T$ ) in °F of the cooling air is:

$$\begin{aligned}\Delta T &= \text{Max temp of enclosure} - \text{Max temp of components} \\ &= 179.6^\circ\text{F} - 140^\circ\text{F} \\ &= 39.6^\circ\text{F}\end{aligned}$$

The required airflow  $Q_{\text{air}}$  is given by the equation:

$$Q_{\text{air}} = \frac{(3160)(\text{KW of enclosure})}{\Delta T}$$

where the term 3160 is a constant, KW is the kilowatt heat of the enclosure (in this case 1.011 KW) and  $\Delta T$  is the permissible temperature. Therefore, the airflow requirement is:

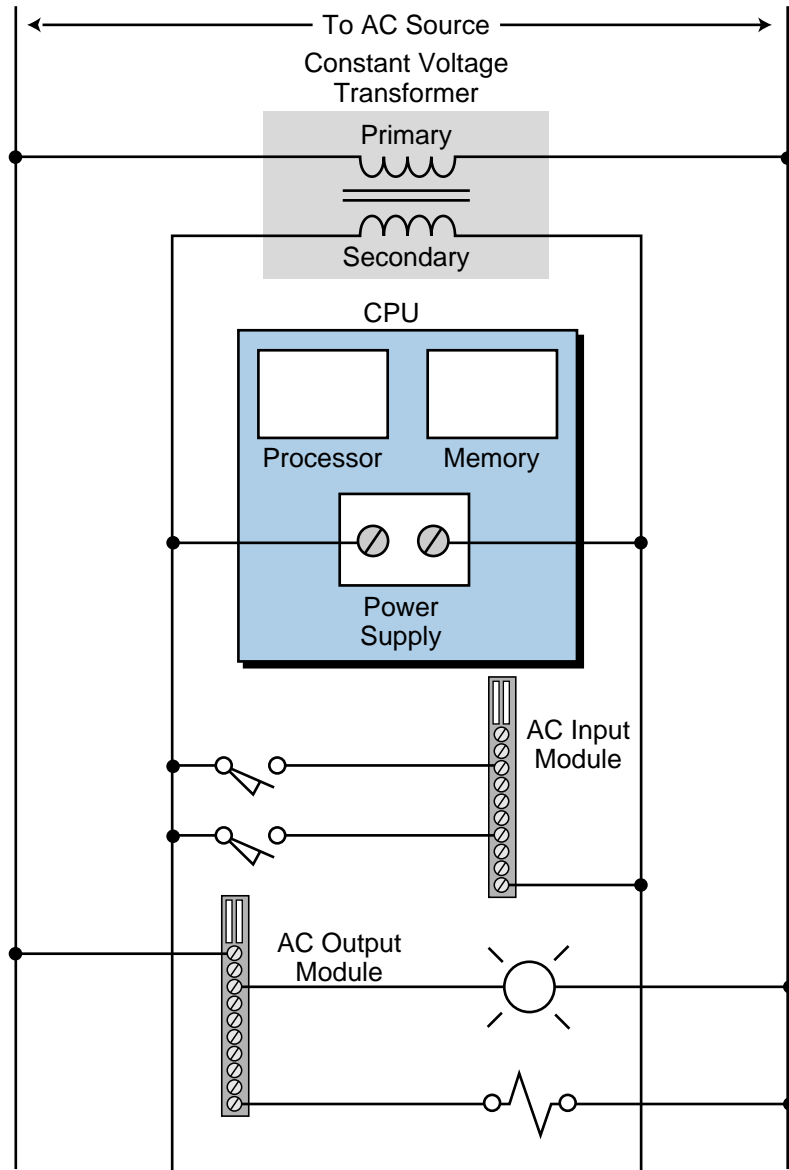
$$\begin{aligned}Q_{\text{air}} &= \frac{(3160)(1.011)}{39.6} \\ &= 80.68 \text{ ft}^3/\text{min}\end{aligned}$$

Thus, a minimum airflow of 80.68 ft<sup>3</sup>/min is required to dissipate the heat in the enclosure.

**Excessive Line Voltage Variation.** The power supply section of a PLC system can sustain line fluctuations and still allow the system to function within its operating margin. As long as the incoming voltage is adequate, the power supply provides all the logic voltages necessary to support the processor, memory, and I/O. However, if the voltage drops below the minimum acceptable level, the power supply will alert the processor, which will then execute a system shutdown.

In applications that are subject to “soft” AC lines and unusual line variations, the first step towards a solution is to correct any possible feeder problem in the distribution system. If this correction does not solve the problem, then a constant voltage transformer can be used to prevent the system from shutting down too often (see Figure 16). The constant voltage transformer stabilizes the input voltage to the power supply and input field devices by compensating for voltage changes at the primary to maintain a steady voltage in the secondary. When using a constant voltage transformer, the user should check that its power rating is sufficient to supply the input devices and the power supply. Also, the user should connect the output devices in front of the constant voltage transformer, rather than behind it, so that the transformer is

not providing power to the outputs. This arrangement will lessen the load supported by the transformer, allowing a smaller transformer to be used. The manufacturer can provide information regarding power rating requirements.



**Figure 16.** Constant voltage transformer used to stabilize input voltage.

## 4 I/O INSTALLATION, WIRING, AND PRECAUTIONS

Input/output installation is perhaps the biggest and most critical job when installing a programmable controller system. To minimize errors and simplify installation, the user should follow predefined guidelines. All of the people involved in installing the controller should receive these I/O system

installation guidelines, which should have been prepared during the design phase. A complete set of documents with precise information regarding I/O placement and connections will ensure that the system is organized properly. Furthermore, these documents should be constantly updated during every stage of the installation. The following considerations will facilitate an orderly installation.

## I/O MODULE INSTALLATION

Placement and installation of the I/O modules is simply a matter of inserting the correct modules in their proper locations. This procedure involves verifying the type of module (115 VAC output, 115 VDC input, etc.) and the slot address as defined by the I/O address assignment document. Each terminal in the module is then wired to the field devices that have been assigned to that termination address. The user should remove power to the modules (or rack) before installing and wiring any module.

## WIRING CONSIDERATIONS

**Wire Size.** Each I/O terminal can accept one or more conductors of a particular wire size. The user should check that the wire is the correct gauge and that it is the proper size to handle the maximum possible current.

**Wire and Terminal Labeling.** Each field wire and its termination point should be labeled using a reliable labeling method. Wires should be labeled with shrink-tubing or tape, while tape or stick-on labels should identify each terminal block. Color coding of similar signal characteristics (e.g., AC: red, DC: blue, common: white, etc.) can be used in addition to wire labeling. Typical labeling nomenclature includes wire numbers, device names or numbers, and the input or output address assignment. Good wire and terminal identification simplifies maintenance and troubleshooting.

**Wire Bundling.** **Wire bundling** is a technique commonly used to simplify the connections to each I/O module. In this method, the wires that will be connected to a single module are bundled, generally using a tie wrap, and then routed through the duct with other bundles of wire with the same signal characteristics. Input, power, and output bundles carrying the same type of signals should be kept in separate ducts, when possible, to avoid interference.

## WIRING PROCEDURES

Once the I/O modules are in place and their wires have been bundled, the wiring to the modules can begin. The following are recommended procedures for I/O wiring:

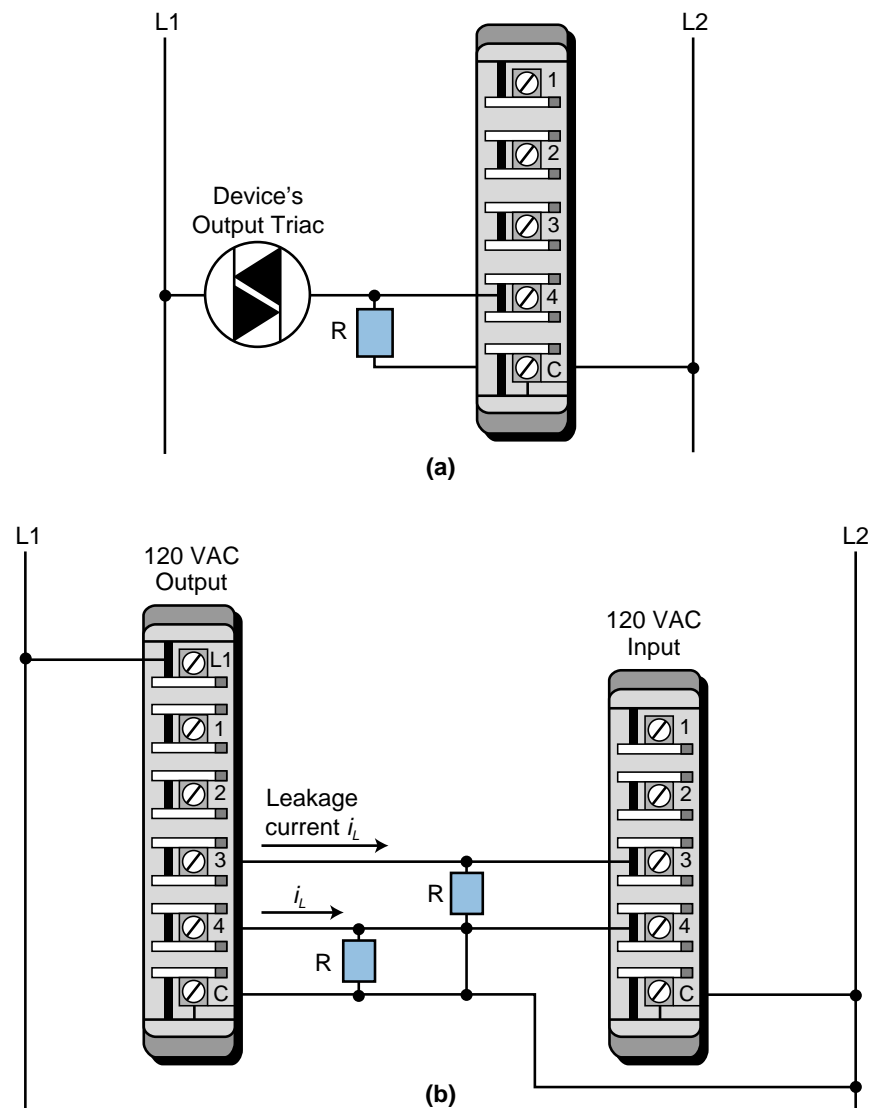
- Remove and lock out input power from the controller and I/O before any installation and wiring begins.
- Verify that all modules are in the correct slots. Check module type and model number by inspection and on the I/O wiring diagram. Check the slot location according to the I/O address assignment document.
- Loosen all terminal screws on each I/O module.
- Locate the wire bundle corresponding to each module and route it through the duct to the module location. Identify each of the wires in the bundle and check that they correspond to that particular module.
- Starting with the first module, locate the wire in the bundle that connects to the lowest terminal. At the point where the wire is at a vertical height equal to the termination point, bend the wire at a right angle towards the terminal.
- Cut the wire to a length that extends 1/4 inch past the edge of the terminal screw. Strip approximately 3/8 inch of insulation from the end of the wire. Insert the uninsulated end of the wire under the pressure plate of the terminal and tighten the screw.
- If two or more modules share the same power source, jumper the power wiring from one module to the next.
- If shielded cable is being used, connect only one end to ground, preferably at the rack chassis. This connection will avoid possible **ground loops**. A ground loop condition exists when two or more electrical paths are created in a ground line or when one or more paths are created in a shield (Section 7 explains how to identify a ground loop). Leave the other end cut back and unconnected, unless otherwise specified.
- Repeat the wiring procedure for each wire in the bundle until the module wiring is complete.
- After all of the wires are terminated, check for good terminations by gently pulling on each wire.

### SPECIAL I/O CONNECTION PRECAUTIONS

Certain field device wiring connections, however, may need special attention. These connections include leaky inputs, inductive loads, output fusing, and shielded cable.

**Connecting Leaky Inputs.** Some field devices have a small leakage current even when they are in the OFF state. Both triac and transistor outputs exhibit this leakage characteristic, although transistor leakage current is much lower. Most of the time, the leaky input will only cause the module's input indicator to flicker; but sometimes, the leakage can falsely trigger an input circuit, resulting in misoperation. A typical device that exhibits this leakage situation is a proximity switch. This type of leakage may also occur when an output module drives an input module when there is no other load.

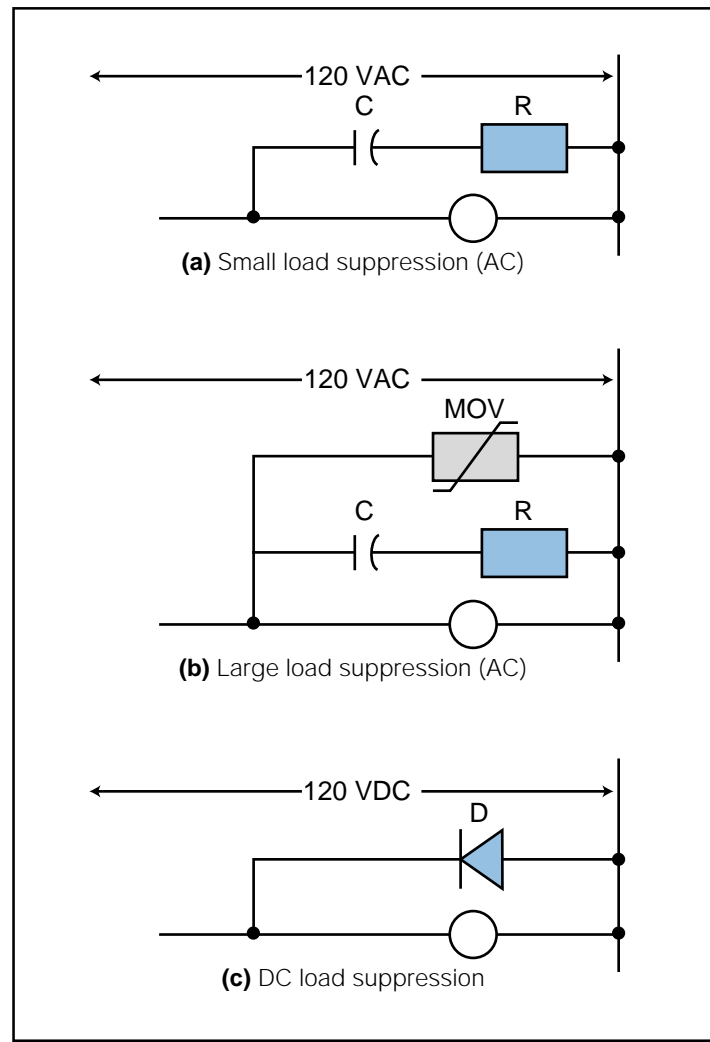
Figure 17 illustrates two leakage situations, along with their corrective actions. A leaky input can be corrected by placing a bleeding (or loading) resistor across the input. A bleeding resistor introduces resistance into the circuit, causing the voltage to drop on the line between the leaky field device



**Figure 17.** (a) A connection for a leaky input device and (b) the connection of an output module to an input module.

and the input circuit. This causes a shunt on the input's terminals. Consequently, the leakage current is routed through the bleeding resistor, minimizing the amount of current to the input module (or to the output device). This prevents the input or output from turning ON when it should be OFF.

**Suppression of Inductive Loads.** The interruption of current caused by turning an inductive load's output OFF generates a very high voltage spike. These spikes, which can reach several thousands of volts if not suppressed, can occur either across the leads that feed power to the device or between both power leads and the chassis ground, depending on the physical construction of the device. This high voltage causes erratic operation and, in some cases, may damage the output module. To avoid this situation, a snubber circuit, typically a resistor/capacitor network (RC) or metal oxide varistor (MOV), should be installed to limit the voltage spike, as well as control the rate of current change through the inductor (see Figure 18).

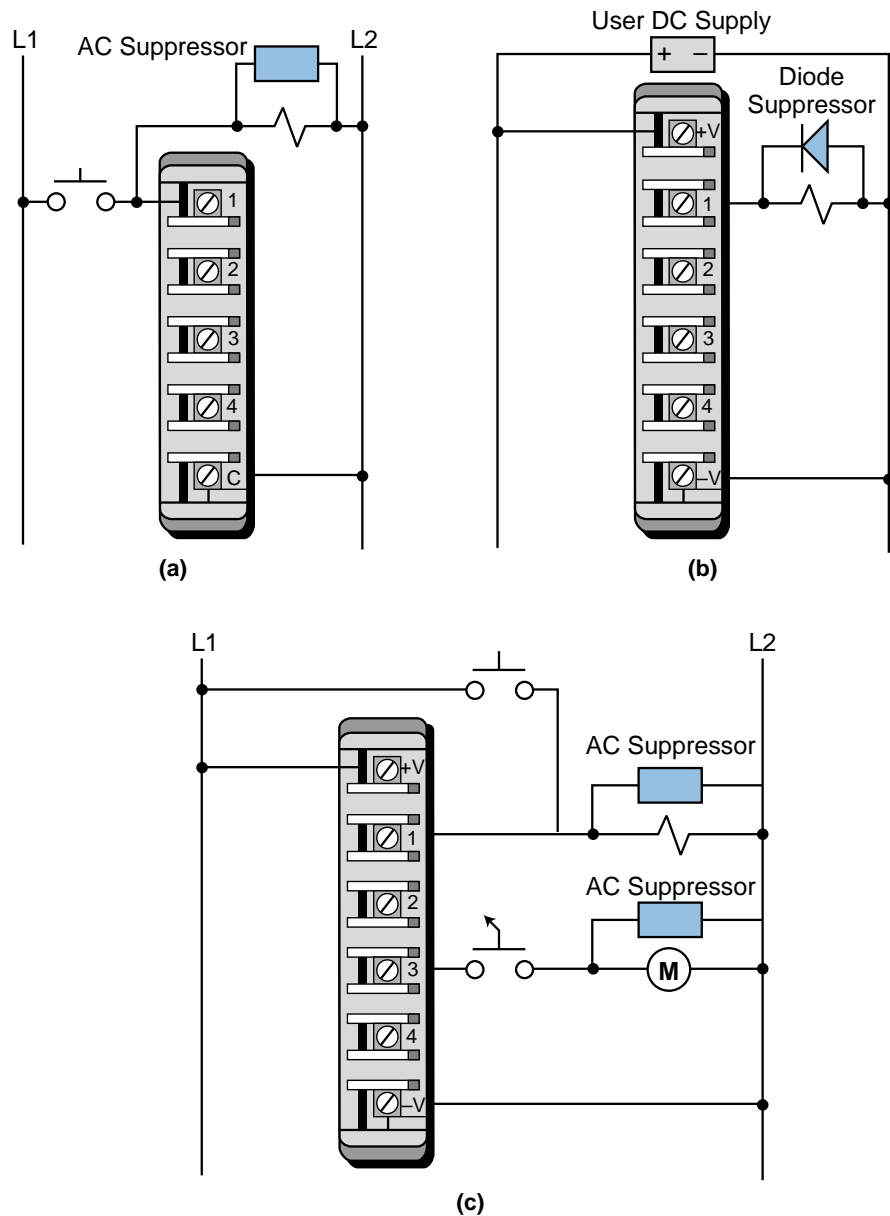


**Figure 18.** (a) Small, (b) large, and (c) DC load suppression techniques.



Most output modules are designed to drive inductive loads, so they typically include suppression networks. Nevertheless, under certain loading conditions, the triac may be unable to turn OFF as current passes through zero (commutation), thus requiring additional external suppression in the system.

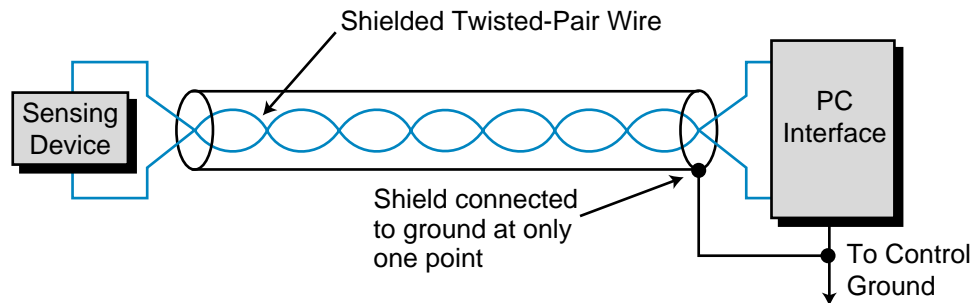
An RC snubber circuit placed across the device can provide additional suppression for small AC devices, such as solenoids, relays, and motor starters up to size 1. Larger contactors (size 2 and above) require an MOV in addition to the RC network. A free-wheeling diode placed across the load can provide DC suppression. Figure 19 presents several examples of inductive load suppression.



**Figure 19.** Suppression of (a) a load in parallel with a PLC input module, (b) a DC load, and (c) loads with switches in parallel and series with a PLC output module.

**Fusing Outputs.** Solid-state outputs normally have fusing on the module, to protect the triac or transistor from moderate overloads. If the output does not have internal fuses, then fuses should be installed externally (normally at the terminal block) during the initial installation. When adding fuses to an output circuit, the user should adhere to the manufacturer's specifications for the particular module. Only a properly rated fuse will ensure that the fuse will open quickly in an overload condition to avoid overheating of the output switching device.

**Shielding.** Control lines, such as TTL, analog, thermocouple, and other low-level signals, are normally routed in a separate wireway, to reduce the effects of signal coupling. For further protection, shielded cable should be used for the control lines, to protect the low-level signals from electrostatic and magnetic coupling with both lines carrying 60 Hz power and other lines carrying rapidly changing currents. The twisted, shielded cable should have at least a one-inch lay, or approximately twelve twists per foot, and should be protected on both ends by shrink-tubing or a similar material. The shield should be connected to control ground at only one point (see Figure 20), and shield continuity must be maintained for the entire length of the cable. The shielded cable should also be routed away from high noise areas, as well as insulated over its entire length.



**Figure 20.** Shielded cable ground connection.

## 5 PLC START-UP AND CHECKING PROCEDURES

Prior to applying power to the system, the user should make several final inspections of the hardware components and interconnections. These inspections will undoubtedly require extra time. However, this invested time will almost always reduce total start-up time, especially for large systems with many input/output devices. The following checklist pertains to prestart-up procedures:

- Visually inspect the system to ensure that all PLC hardware components are present. Verify correct model numbers for each component.

- Inspect all CPU components and I/O modules to ensure that they are installed in the correct slot locations and placed securely in position.
- Check that the incoming power is correctly wired to the power supply (and transformer) and that the system power is properly routed and connected to each I/O rack.
- Verify that the I/O communication cables linking the processor to the individual I/O racks correspond to the I/O rack address assignment.
- Verify that all I/O wiring connections at the controller end are in place and securely terminated. Use the I/O address assignment document to verify that each wire is terminated at the correct point.
- Check that the output wiring connections are in place and properly terminated at the field device end.
- Ensure that the system memory has been cleared of previously stored control programs. If the control program is stored in EPROM, remove the chips temporarily.

## STATIC INPUT WIRING CHECK

A **static input wiring check** should be performed with power applied to the controller and input devices. This check will verify that each input device is connected to the correct input terminal and that the input modules or points are functioning properly. Since this test is performed before other system tests, it will also verify that the processor and the programming device are in good working condition. Proper input wiring can be verified using the following procedures:

- Place the controller in a mode that will inhibit the PLC from any automatic operation. This mode will vary depending on the PLC model, but it is typically *stop*, *disable*, *program*, etc.
- Apply power to the system power supply and input devices. Verify that all system diagnostic indicators show proper operation. Typical indicators are *AC OK*, *DC OK*, *processor OK*, *memory OK*, and *I/O communication OK*.
- Verify that the emergency stop circuit will de-energize power to the I/O devices.
- Manually activate each input device. Monitor the corresponding LED status indicator on the input module and/or monitor the same address on the programming device, if used. If properly wired, the indicator will turn ON. If an indicator other than the expected one turns ON when the input device is activated, the input device may be wired to

the wrong input terminal. If no indicator turns ON, then a fault may exist in either the input device, field wiring, or input module (see Section 4).

- Take precautions to avoid injury or damage when activating input devices that are connected in series with loads that are external to the PLC.

## STATIC OUTPUT WIRING CHECK

A **static output wiring check** should be performed with power applied to the controller and the output devices. A safe practice is to first locally disconnect all output devices that involve mechanical motion (e.g., motors, solenoids, etc.). When performed, the static output wiring check will verify that each output device is connected to the correct terminal address and that the device and output module are functioning properly. The following procedures should be used to verify output wiring:

- Locally disconnect all output devices that will cause mechanical motion.
- Apply power to the controller and to the input/output devices. If an emergency stop can remove power to the outputs, verify that the circuit does remove power when activated.
- Perform the static check of the outputs one at a time. If the output is a motor or another device that has been locally disconnected, reapply power to that device only prior to checking. The output operation check can be performed using *one* of the following methods:
  - Assuming that the controller has a forcing function, test each output, with the use of the programming device, by forcing the output ON and setting the corresponding terminal address (point) to 1. If properly wired, the corresponding LED indicator will turn ON and the device will energize. If an indicator other than the expected one turns ON when the terminal address is forced, then the output device may be wired to the wrong output terminal (Inadvertent machine operation does not occur because rotating and other motion-producing outputs are disconnected). If no indicator turns ON, then a fault may exist in either the output device, field wiring, or output module (see Section 4).
  - Program a dummy rung, which can be used repeatedly for testing each output, by programming a single rung with a single normally open contact (e.g., a conveniently located push button) controlling the output. Place the CPU in either the RUN, single-scan, or a similar mode, depending on the controller. With the controller

in the RUN mode, depress the push button to perform the test. With the controller in single-scan mode, depress and maintain the push button while the controller executes the single-scan. Observe the output device and LED indicator, as described in the first procedure.

## CONTROL PROGRAM REVIEW

The **control program checkout** is simply a final review of the control program. This check can be performed at any time, but it should be done prior to loading the program into memory for the dynamic system checkout.

A complete documentation package that relates the control program to the actual field devices is required to perform the control program checkout. Documents, such as address assignments and wiring diagrams, should reflect any modifications that may have occurred during the static wiring checks. When performed, this final program review will verify that the final hardcopy of the program, which will be loaded into memory, is either free of error or at least agrees with the original design documents. The following is a checklist for the final control program checkout:

- Using the I/O wiring document printout, verify that every controlled output device has a programmed output rung of the same address.
- Inspect the hardcopy printout for errors that may have occurred while entering the program. Verify that all program contacts and internal outputs have valid address assignments.
- Verify that all timer, counter, and other preset values are correct.

## DYNAMIC SYSTEM CHECKOUT

The **dynamic system checkout** is a procedure that verifies the logic of the control program to ensure correct operation of the outputs. This checkout assumes that all static checks have been performed, the wiring is correct, the hardware components are operational and functioning correctly, and the software has been thoroughly reviewed.

During the dynamic checkout, it is safe to gradually bring the system under full automatic control. Although small systems may be started all at once, a large system should be started in sections. Large systems generally use remote subsystems that control different sections of the machine or process. Bringing one subsystem at a time on-line allows the total system to start up with maximum safety and efficiency. Remote subsystems can be temporarily disabled either by locally removing their power or by disconnecting their communications link with the CPU. The following practices outline procedures for the dynamic system checkout:

- Load the control program into the PLC memory.
- Test the control logic using *one* of the following methods:
  - Switch the controller to the TEST mode, if available, which will allow the execution and debugging of the control program while the outputs are disabled. Check each rung by observing the status of the output LED indicators or by monitoring the corresponding output rung on the programming device.
  - If the controller must be in the RUN mode to update outputs during the tests, locally disconnect the outputs that are not being tested, to avoid damage or harm. If an MCR or similar instruction is available, use it to bypass execution of the outputs that are not being tested, so that disconnection of the output devices is not necessary.
- Check each rung for correct logic operation, and modify the logic if necessary. A useful tool for debugging the control logic is the single scan. This procedure allows the user to observe each rung as every scan is executed.
- When the tests indicate that all of the logic properly controls the outputs, remove all of the temporary rungs that may have been used (MCRs, etc.). Place the controller in the RUN mode, and test the total system operation. If all procedures are correct, the full automatic control should operate smoothly.
- Immediately document all modifications to the control logic, and revise the original documentation. Obtain a reproducible copy (e.g., 3.5" disk, etc.) of the program as soon as possible.

The start-up recommendations and practices presented in this section are good procedures that will aid in the safe, orderly start-up of any programmable control system. However, some controllers may have specific start-up requirements, which are outlined in the manufacturer's product manual. The user should be aware of these specific requirements before starting up the controller.

## 6 PLC SYSTEM MAINTENANCE

Programmable controllers are designed to be easy to maintain, to ensure trouble-free operation. Still, several maintenance aspects should be considered once the system is in place and operational. Certain maintenance measures, if performed periodically, will minimize the chance of system malfunction. This section outlines some of the practices that should be followed to keep the system in good operating condition.

## PREVENTIVE MAINTENANCE

Preventive maintenance of programmable controller systems includes only a few basic procedures, which will greatly reduce the failure rate of system components. Preventive maintenance for the PLC system should be scheduled with the regular machine or equipment maintenance, so that the equipment and controller are down for a minimum amount of time. However, the schedule for PLC preventive maintenance depends on the controller's environment—the harsher the environment, the more frequent the maintenance. The following are guidelines for preventive measures:

- Periodically clean or replace any filters that have been installed in enclosures at a frequency dependent on the amount of dust in the area. Do not wait until the scheduled machine maintenance to check the filter. This practice will ensure that clean air circulation is present inside the enclosure.
- Do not allow dirt and dust to accumulate on the PLC's components; the central processing unit and I/O system are not designed to be dust proof. If dust builds up on heat sinks and electronic circuitry, it can obstruct heat dissipation, causing circuit malfunction. Furthermore, if conductive dust reaches the electronic boards, it can cause a short circuit, resulting in possible permanent damage to the circuit board.
- Periodically check the connections to the I/O modules to ensure that all plugs, sockets, terminal strips, and modules have good connections. Also, check that the module is securely installed. Perform this type of check more often when the PLC system is located in an area that experiences constant vibrations, which could loosen terminal connections.
- Ensure that heavy, noise-generating equipment is not located too close to the PLC.
- Make sure that unnecessary items are kept away from the equipment inside the enclosure. Leaving items, such as drawings, installation manuals, or other materials, on top of the CPU rack or other rack enclosures can obstruct the airflow and create hot spots, which can cause system malfunction.
- If the PLC system enclosure is in an environment that exhibits vibration, install a vibration detector that can interface with the PLC as a preventive measure. This way, the programmable controller can monitor high levels of vibration, which can lead to the loosening of connections.

## SPARE PARTS

It is a good idea to keep a stock of replacement parts on hand. This practice will minimize downtime resulting from component failure. In a failure situation, having the right spare in stock can mean a shutdown of only minutes, instead of hours or days. As a rule of thumb, the amount of a spare part stocked should be 10% of the number of that part used. If a part is used infrequently, then less than 10% of that particular part can be stocked.

Main CPU board components should have one spare each, regardless of how many CPUs are being used. Each power supply, whether main or auxiliary, should also have a backup. Certain applications may require a complete CPU rack as a standby spare. This extreme case exists when a downed system must be brought into operation immediately, leaving no time to determine which CPU board has failed.

## REPLACEMENT OF I/O MODULES

If a module must be replaced, the user should make sure that the replacement module being installed is the correct type. Some I/O systems allow modules to be replaced while power is still applied, but others may require that power be removed. If replacing a module solves the problem, but the failure reoccurs in a relatively short period, the user should check the inductive loads. The inductive loads may be generating voltage and current spikes, in which case, external suppression may be necessary. If the module's fuse blows again after it is replaced, the problem may be that the module's output current limit is being exceeded or that the output device is shorted.

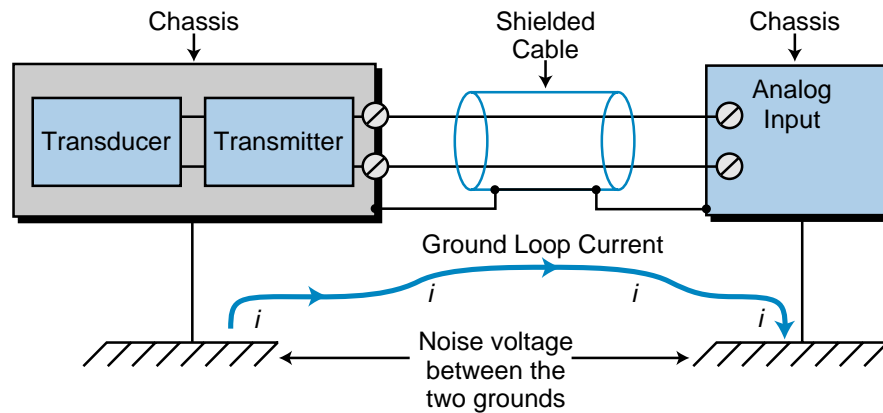
# 7 TROUBLESHOOTING THE PLC SYSTEM

## TROUBLESHOOTING GROUND LOOPS

As mentioned earlier, a ground loop condition occurs when two or more electrical paths exist in a ground line. For example, in Figure 21, the transducers and transmitter are connected to ground at the chassis (or device enclosure) and connected to an analog input card through a shielded cable. The shield connects to both chassis grounds, thereby creating a path for current to flow from one ground to another since both grounds have different potentials. The current flowing through the shield could be as high as several amperes, which would induce significant magnetic fields in the signal transmission. This could create interference that would result in a possible misreading of the analog signal. To avoid this problem, the shield should be

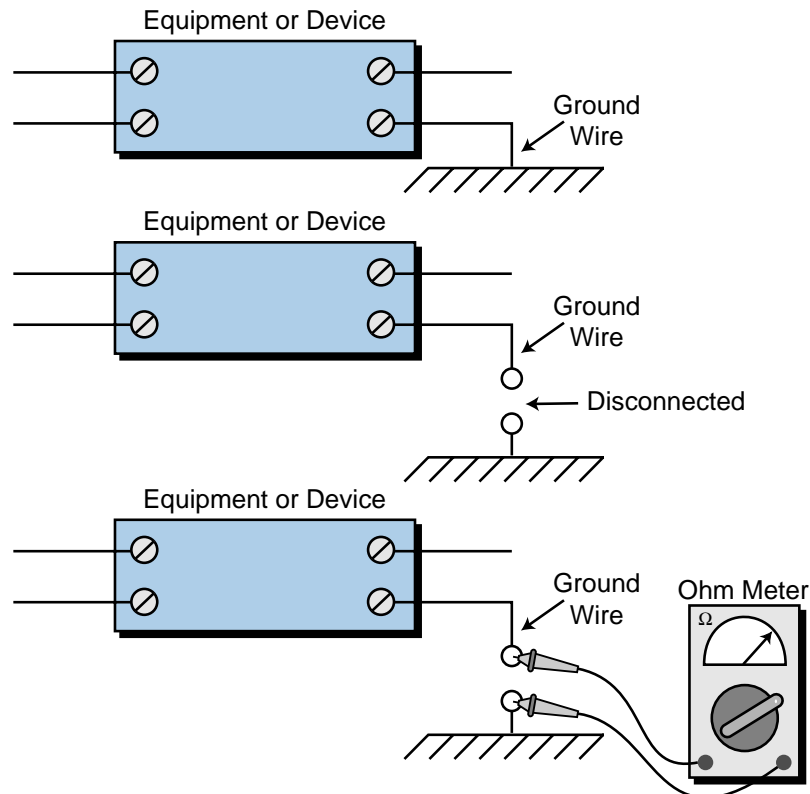


connected to ground on only one side of the chassis, preferably the PLC side. In the example shown in Figure 21, the shield should only be connected to ground at the analog input interface.



**Figure 21.** Ground loop created by shielded cable grounded at both ends.

To check for a ground loop, disconnect the ground wire at the ground termination and measure the resistance from the wire to the termination point where it is connected (see Figure 22). The meter should read a large ohm value. If a low ohm value occurs across this gap, circuit continuity exists, meaning that the system has at least one ground loop.



**Figure 22.** Procedure for identifying ground loops.

## DIAGNOSTIC INDICATORS

LED status indicators can provide much information about field devices, wiring, and I/O modules. Most input/output modules have at least a single indicator—input modules normally have a power indicator, while output modules normally have a logic indicator.

For an input module, a lit power LED indicates that the input device is activated and that its signal is present at the module. This indicator alone cannot isolate malfunctions to the module, so some manufacturers provide an additional diagnostic indicator, a logic indicator. An ON logic LED indicates that the input signal has been recognized by the logic section of the input circuit. If the logic and power indicators do not match, then the module is unable to transfer the incoming signal to the processor correctly. This indicates a module malfunction.

An output module's logic indicator functions similarly to an input module's logic indicator. When it is ON, the logic LED indicates that the module's logic circuitry has recognized a command from the processor to turn ON. In addition to the logic indicator, some output modules incorporate either a blown fuse indicator or a power indicator or both. A blown fuse indicator indicates the status of the protective fuse in the output circuit, while a power indicator shows that power is being applied to the load. Like the power and logic indicators in an input module, if both LEDs are not ON simultaneously, the output module is malfunctioning.

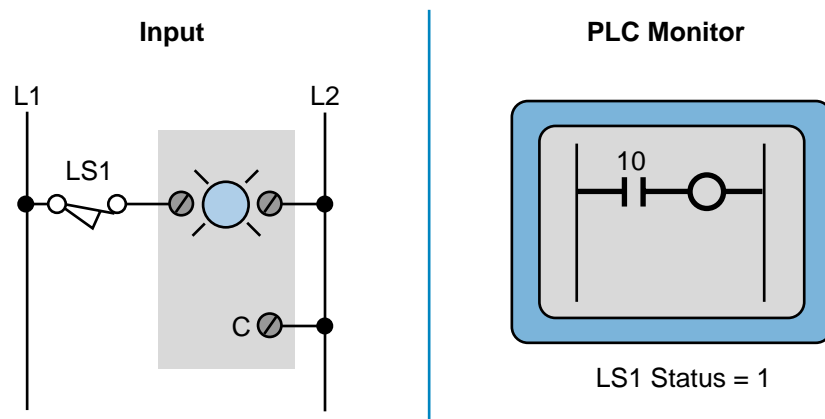
LED indicators greatly assist the troubleshooting process. With both power and logic indicators, the user can immediately pinpoint a malfunctioning module or circuit. LED indicators, however, cannot diagnose all possible problems; instead, they serve as preliminary signs of system malfunctions.

## TROUBLESHOOTING PLC INPUTS

If the field device connected to an input module does not seem to turn ON, a problem may exist somewhere between the L1 connection and the terminal connection to the module. An input module's status indicators can provide information about the field device, the module, and the field device's wiring to the module that will help pinpoint the problem.

The first step in diagnosing the problem is to place the PLC in standby mode, so that it is not activating the output. This allows the field device to be manually activated (e.g., a limit switch can be manually closed). When the field device is activated, the module's power status indicator should turn ON, indicating that power continuity exists. If the indicator is ON, then wiring is not the cause of the problem.

The next step is to evaluate the PLC's reading of the input module. This can be accomplished using the PLC's test mode, which reads the inputs and executes the program but does not activate the outputs. In this mode, the PLC's display should either show a 1 in the image table bit corresponding to the activated field device or the contact's reference instruction should become highlighted when the device provides continuity (see Figure 23). If the PLC is reading the device correctly, then the problem is not located in the input module. If it does not read the device correctly, then the module could be faulty. The logic side of the module may not be operating correctly, or its optical isolator may be blown. Moreover, one of the module's interfacing channels could be faulty. In this case, the module must be replaced.



**Figure 23.** Highlighted contact indicating power continuity.

If the module does not read the field device's signal, then further tests are required. Bad wiring, a faulty field device, a faulty module, or an improper voltage between the field device and the module could be causing the problem. First, close the field device and measure the voltage to the input module. The meter should display the voltage of the signal (e.g., 120 volts AC). If the proper voltage is present, the input module is faulty because it is not recognizing the signal. If the measured voltage is 10–15% below the proper signal voltage, then the problem lies in the source voltage to the field device. If no voltage is present, then either the wiring or the field device is the cause of the problem. Check the wiring connection to the module to ensure that the wire is secured at the terminal or terminal blocks.

To further pinpoint the problem, check that voltage is present at the field device. With the device activated, measure the voltage across the device using a voltmeter. If no voltage is present on the load side of the device (the side that connects to the module), then the input device is faulty. If there is power, then the problem lies in the wiring from the input device to the module. In this case, the wiring must be traced to find the problem.

## TROUBLESHOOTING PLC OUTPUTS

PLC output interfaces also contain status indicators that provide useful troubleshooting information. Like the troubleshooting of PLC inputs, the first step in troubleshooting outputs is to isolate the problem to either the module, the field device, or the wiring.

At the output module, ensure that the source power for switching the output is at the correct level. In a 120 VAC system, this value should be within 10% of the rated value (i.e., between 108 and 132 volts AC). Also, examine the output module to see if it has a blown fuse. If it does have a blown fuse, check the fuse's rated value. Furthermore, check the output device's current requirements to determine if the device is pulling too much current.

If the output module receives the command to turn ON from the processor yet the module's output status does not turn ON accordingly, then the output module is faulty. If the indicator turns ON but the field device does not energize, check for voltage at the output terminal to ensure that the switching device is operational. If no voltage is present, then the module should be replaced. If voltage is present, then the problem lies in the wiring or the field device. At this point, make sure that the field wiring to the module's terminal or to the terminal block has a good connection and that no wires are broken.

After checking the module, check that the field device is working properly. Measure the voltage coming to the field device while the output module is ON, making sure that the return line is well connected to the device. If there is power yet the device does not respond, then the field device is faulty.

Another method for checking the field device is to test it without using the output module. Remove the output wiring and connect the field device directly to the power source. If the field device does not respond, then it is faulty. If the field device responds, then the problem lies in the wiring between the device and the output module. Check the wiring, looking for broken wires along the wire path.

## TROUBLESHOOTING THE CPU

PLCs also provide diagnostic indicators that show the status of the PLC and the CPU. Such indicators include *power OK*, *memory OK*, and *communications OK* conditions. First, check that the PLC is receiving enough power from the transformer to supply all the loads. If the PLC is still not working, check for voltage supply drop in the control circuit or for blown fuses. If the PLC does not come up even with proper power, then the problem lies in the CPU. The diagnostic indicators on the front of the CPU will show a fault in either memory or communications. If one of these indicators is lit, the CPU may need to be replaced.

## SUMMARY OF TROUBLESHOOTING METHODS

In conclusion, the best method for diagnosing input/output malfunctions is to isolate the problem to the module, the field device, or the wiring. If both power and logic indicators are available, then module failures become readily apparent. The first step in solving the problem is to take a voltage measurement to determine if the proper voltage level is present at the input or output terminal. If the voltage is adequate at the terminal and the module is not responding, then the module should be replaced. If the replacement module has no effect, then field wiring may be the problem. A proper voltage level at the output terminal while the output device is OFF also indicates an error in the field wiring. If an output rung is activated but the LED indicator is OFF, then the module is faulty. If a malfunction cannot be traced to the I/O module, then the module connectors should be inspected for poor contact or misalignment. Finally, check for broken wires under connector terminals and cold solder joints on module terminals.

# **PLC Start-Up and Maintenance**

*Study Guide and Review  
Questions*

## **PLC Skills**

- **Review**
- **Reinforce**
- **Test**
- **Sharpen**

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## STUDY GUIDE

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- The system layout is the conscientious approach to placing and interconnecting the system components not only to satisfy the application, but also to ensure that the controller will operate trouble free in its environment.
- The system layout takes into consideration not only the PLC components as well as other equipment, such as isolation transformers, auxiliary power supplies, safety control relays, and incoming line noise suppressors.
- PLC system layout includes the consideration of many factors. Some guidelines for system layout, wiring, and component placement are as follows:
  - The best location for the PLC enclosure is near the machine or process that it will be controlling. The enclosure should conform to NEMA standards for the operating environment.
  - The temperature inside the enclosure should not exceed the controller's maximum operating temperature, which is typically 60°C.
  - A fan or blower should be installed if "hot spots" develop inside the enclosure. If condensation occurs, a thermostat-controlled heater should be installed.
  - The system enclosure (with the PLC) should not be placed close to equipment generating high noise, such as welding machines.
  - To allow for maximum convection cooling, all controller components should be mounted in a vertical (upright) position.
  - Grouping of common I/O modules is a good practice. All AC wiring should be kept away from low-level DC wiring to avoid crosstalk interference. If I/O wiring must cross AC power lines, it should do so at right angles.
  - The duct and wiring layout defines the physical location of wireways and the routing of field I/O signals, power, and controller connections within the enclosure.
  - Proper grounding techniques specify that the grounding path must be permanent, continuous, and able to safely conduct the ground-fault current in the system with minimal impedance.
- PLC system power requirements include the following:
  - The system power supply and I/O devices should have a common AC source to minimize line interference and prevent faulty input signals.
  - The use of an isolation transformer is recommended if noise is likely to be introduced into the power lines by noise-generating equipment. A constant voltage transformer should be used in the event of soft AC lines.
- The PLC system should contain enough emergency circuits to either partially or totally stop controller and machine operation in the event of an emergency. Emergency devices include emergency stops, master and safety control relays, and emergency power disconnects.

- Excessive noise, heat, and line voltage variations can all have a detrimental effect on the PLC system. Thus, the components should be placed away from high noise-generating devices, temperature levels should be kept within specifications, and the incoming voltage should be kept to within acceptable parameters. Typical PLC conditions include:
  - 60% of the inputs are ON at any one time
  - 30% of the outputs are ON at any one time
  - the currents supplied by all modules average a certain value
  - the ambient temperature is around 40°C
- When installing the I/O devices, the user should make sure that the modules are installed in the correct locations, the correct size wire is used, the wires and terminals are labeled, and the wires to each module are bundled together.
- Certain field device wiring connections require special attention. These connections include leaky inputs, inductive loads, output fusing, and shielded cables.
  - A bleeding resistor may be used in cases where a field device exhibits an output current leakage that could cause the input circuitry to turn ON.
  - Inductive loads should be suppressed using RC snubbers and/or MOVs.
  - If fuses are not incorporated into an output module, they should be installed externally at the terminal block.
  - Shielded cables should be grounded at one end only, preferably at the chassis rack.
- The system start-up includes prestart-up procedures, the static input wiring check, the static output wiring check, the control program review, and the dynamic system checkout.
  - The prestart-up procedure involves several inspections of the hardware components before power is applied to the system.
  - The static input wiring check should be performed with power applied to the controller and input devices. This check verifies that each input device is connected to the correct terminal and that the input modules are functioning properly.
  - The static output wiring check should be performed with power applied to the controller and output devices. All the devices that will cause mechanical motion should be locally disconnected.
  - The control program review consists of a final review of the complete documentation package of the control program.
  - The dynamic system checkout involves bringing the entire system under PLC control to verify correct operation of the outputs according to the logic program.
- Even though a PLC system requires minimal maintenance, certain maintenance measures should be performed periodically to reduce the chance of system malfunction. These preventative maintenance procedures should be scheduled during regular machine maintenance to minimize downtime.
- As a rule of thumb, 10% of each part used in the PLC system, as well as one of each main board, should be kept as spare parts.



- Ground loops can occur in a PLC system when two or more electrical paths exist in a ground line. To avoid this problem, shielded cable should only be connected to ground at only one end.
- When diagnosing I/O malfunctions, the first check should be the LED power and/or logic indicators in the module. After that, the key to finding the problem, whether it is an input or output problem, is to isolate the problem to either the module, the field device, or the wiring.

## REVIEW QUESTIONS

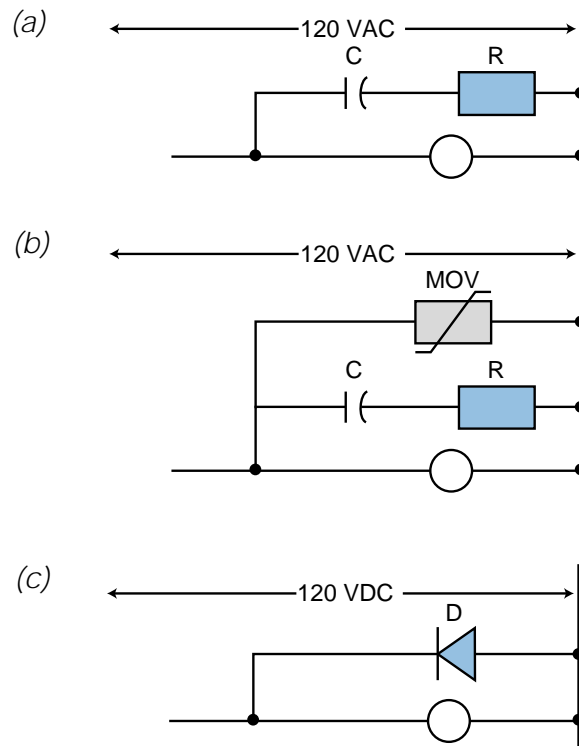
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- 1 Briefly define the term *system layout*.
- 2 *True/False*. In a proper system layout, the components can be easily maintained, but components may not be easily accessible.
- 3 Name three types of equipment other than the PLC that can form part of the system layout.
- 4 The best location for the PLC enclosure is:  
a–close to the incoming power  
b–in the control room  
c–close to the machine or process  
d–far away from the machine or process
- 5 Placing a remote I/O panel close to the controlled machine will generally:  
a–simplify start-up  
b–minimize wire runs  
c–simplify maintenance and troubleshooting  
d–all of the above
- 6 A NEMA panel enclosure can provide protection from all of the following conditions except:  
a–atmospheric contaminants  
b–vibration  
c–conductive dust  
d–moisture
- 7 Name four guidelines concerning the placement of components inside the enclosure, the wiring of I/O, and the location of the enclosure.
- 8 *True/False*. Placing AC power outlets inside the enclosure should be avoided when possible.
- 9 Typically, programmable controller systems installed inside an enclosure can withstand a maximum temperature of:  
a–60°C outside the enclosure  
b–50°C outside the enclosure  
c–60°C inside the enclosure  
d–50°C inside the enclosure

- 10 If "hot spots" are generated inside the enclosure, a(n) \_\_\_\_\_ should be installed to help dissipate the heat.
- 11 A thermostat-controlled heater should be used in a panel enclosure if \_\_\_\_\_ is anticipated.
- 12 *True/False.* A PLC can operate trouble free near an arc welding machine if it is installed in an enclosure.
- 13 Most controllers should be mounted in a(n) \_\_\_\_\_ position to allow maximum convection cooling.
- a–horizontal
  - b–vertical
  - c–sideways
  - d–inverted
- 14 The \_\_\_\_\_ dissipates more heat than any other system component.
- 15 Input/output racks are not typically placed:
- a–adjacent to the CPU
  - b–beside the power supply
  - c–directly above the CPU
  - d–in a remote enclosure
- 16 Other equipment inside the enclosure should be placed away from the controller components so that:
- a–power is independent
  - b–space is maximized
  - c–the effects of noise are minimized
  - d–none of the above
- 17 *True/False.* Fans or blowers should be placed at the top of the panel enclosure.
- 18 One good reason for grouping common I/O modules is to minimize \_\_\_\_\_ interference.
- a–crisscross
  - b–crosswave
  - c–crosscorner
  - d–crosstalk
- 19 What does the duct and wiring layout define?
- 20 *True/False.* The enclosure's duct and wiring layout depends on the placement of I/O modules within each I/O rack.
- 21 Incoming AC power lines should be kept \_\_\_\_\_ low-level DC lines.
- a–separate from
  - b–together with
  - c–adjacent to
  - d–level with

- 
- 22 If the I/O wiring must cross the AC power lines, it should do so at \_\_\_\_\_.
- 23 The National Electric Code (NEC) article 250 provides data such as size, type of conductors, colors, and connections necessary for safe \_\_\_\_\_ of electrical components.
- 24 Proper grounding procedures specify that the ground termination must be a(n) \_\_\_\_\_ connection.
- 25 *True/False.* All electrical racks should be grounded to a central ground bus.
- 26 What precaution should be taken when grounding a chassis or rack to the enclosure?
- 27 *True/False.* It is a good practice to use a common AC source for the system power supply and I/O devices.
- 28 When is the use of an isolation transformer required?
- 29 *True/False.* To avoid uncontrollable conditions, emergency stop switches should be wired to the programmable controller.
- 30 *True/False.* To minimize wiring, a system should have as few emergency stops as possible.
- 31 \_\_\_\_\_ can be used as a convenient way to remove power to the I/O system in an emergency situation.  
a–Electromechanical MCRs  
b–Software MCRs  
c–Software routines  
d–Bleeding resistors
- 32 Briefly describe outrush, what causes it to occur, and how it can be avoided.
- 33 Temperature specifications for PLCs consider typical conditions to exist when:  
a–60% of the inputs are ON at one time  
b–60% of the outputs are ON at one time  
c–60% of the inputs and 30% of the outputs are ON at one time  
d–40% of the inputs and 60% of the outputs are ON at one time
- 34 A(n) \_\_\_\_\_ transformer can be used in an installation that is subject to soft AC lines.
- 35 The I/O placement and wiring documents should be updated:  
a–during maintenance  
b–every time there is a change  
c–at the end of the project  
d–during the documentation
- 36 *True/False.* All wires can be bundled together as long as the bundles are kept neat.

- 37 Which of the following is not a common method for terminal and wire labeling?  
 a-color coding  
 b-the use of wire numbers  
 c-the use of address numbers  
 d-size matching
- 38 When placing I/O modules in the I/O racks, the following should be checked:  
 a-type of module  
 b-slot address  
 c-I/O address assignment  
 d-all of the above
- 39 *True/False.* If two or more modules share the same power source, the power wiring can be jumpered from one module to the next.
- 40 Identify three types of devices that may require special wiring considerations.
- 41 Some input devices may have a small leakage current when they are in the \_\_\_\_\_ state.
- 42 *True/False.* Transistors exhibit more current leakage than triacs.
- 43 A leakage problem can occur when connecting an output module to an input module of another PLC; this problem can be corrected by using a(n) \_\_\_\_\_ across the input.
- 44 *True/False.* Snubber circuits are used for the suppression of inductive loads.
- 45 Label the following drawings according to the type of suppression they provide:



- 46 *True/False.* If fuses are not provided as part of the PLC's output modules, they should be installed at the terminal blocks, especially when the output is driving an inductive load.
- 47 *True/False.* The static input wiring check should be performed with power applied to the controller and input devices.
- 48 *True/False.* The static output wiring check is performed with power applied to the controller but not to the output modules.
- 49 When testing output wiring, all outputs that create mechanical motion should be \_\_\_\_\_.
- a—at half-stepping speed
  - b—connected
  - c—disconnected
  - d—at normal speed
- 50 Output devices can be tested by using a forcing function or by programming a(n) \_\_\_\_\_.
- 51 Dynamic system checkout assumes that:
- a—the static checks have been completed
  - b—the wiring is correct
  - c—the software has been reviewed
  - d—all of the above
- 52 When should changes to the control logic be documented and stored on a permanent storage device?
- 53 When is it appropriate to perform preventive maintenance for a PLC system?
- 54 Why is it a good practice to clean dust build-up off of heat sinks and electric circuitry?
- 55 *True/False.* Plugs, sockets, and terminal connections should be checked periodically in environments where vibration exists.
- 56 Leaving materials, such as drawings, manuals, and other items, on top of a CPU rack or I/O rack can cause:
- a—the system to malfunction due to heat
  - b—obstruction of air flow
  - c—hot spots
  - d—all of the above
- 57 As a rule of thumb, the following items should be kept as spare parts for a PLC system:
- a—10% of input modules
  - b—10% of output modules
  - c—a power supply and one of each main board
  - d—all of the above

- 58 If a module's fuse blows repeatedly, the probable cause may be that:
- a—the module's output current is being exceeded
  - b—the output device is shorted
  - c—the fuse rating is incorrect
  - d—all of the above
- 59 Explain a ground loop condition.
- 60 Input modules generally have a power indicator to show that power is present at the module; however, some input modules also have a logic indicator whose function is to:
- a—show that the isolation circuit works
  - b—show that the logic side is ON
  - c—indicate that the PLC should read a logic 1
  - d—all of the above
- 61 What is the first step to perform when troubleshooting a PLC malfunction?
- 62 Indicate the order in which the following steps should occur when troubleshooting a PLC input:
- \_\_\_\_\_ check the wiring connection to the module
  - \_\_\_\_\_ close the field device and measure the voltage to the input module
  - \_\_\_\_\_ place the PLC in standby mode
  - \_\_\_\_\_ evaluate the PLC's reading of the module
  - \_\_\_\_\_ check for voltage at the field device
- 63 The key in diagnosing I/O malfunctions is to:
- a—observe the LEDs
  - b—check the I/O wiring
  - c—isolate the problem to the module, the field device, or the field wiring
  - d—measure the input or output voltage

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## ANSWERS

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- 1 The system layout is the conscientious approach to placing and interconnecting the PLC's components not only to satisfy the application, but also to ensure that the controller will operate trouble free in its environment.
- 2 false; in a proper system layout, the components are easily accessible
- 3 Components other than the PLC that may be part of the system layout include:
  - isolation transformers
  - auxiliary power supplies
  - safety control relays
  - circuit breakers
  - fuse blocks
  - line noise suppressors
- 4 c—close to the machine or process
- 5 d—all of the above
- 6 b—vibration
- 7 General enclosure and I/O wiring guidelines include the following:
  - The enclosure should be placed in a position that allows the doors to be opened fully for easy access to wiring and components for testing or troubleshooting.
  - The enclosure should be deep enough to allow clearance between the closed enclosure door and either the print-pocket mounted on the door or the enclosed components and related cables.
  - The enclosure's back panel should be removable to facilitate mounting of the components and other assemblies.
  - An emergency disconnect device should be mounted in the cabinet in an easily accessible location.
  - Accessories, such as AC power outlets, interior lighting, and a gasketed plexiglass window to allow viewing of the processor and I/O indicators, should be considered for installation and maintenance convenience.
- 8 false; a power outlet is very convenient inside the enclosure to allow for a programming terminal to be plugged in during start-up
- 9 c—60°C inside the enclosure
- 10 fan or blower
- 11 condensation
- 12 false; it is a good practice to place a PLC system far away from high noise generating equipment, such as arc welders
- 13 b—vertical
- 14 power supply
- 15 c—directly above the CPU
- 16 c—the effects of noise are minimized
- 17 false; fans should be placed near hot spots
- 18 d—crosstalk

- 
- 19 The duct and wiring layout defines the physical location of wireways and the routing of field I/O signals, power, and PLC interconnections within the enclosure.
- 20 true
- 21 a-separate from
- 22 a right angle
- 23 grounding
- 24 permanent
- 25 true
- 26 Paint and nonconductive materials should be scraped away to provide a good ground connection.
- 27 true
- 28 Isolation transformers are required in cases in where heavy equipment is likely to introduce noise onto the AC line.
- 29 false; emergency stop switches should not be wired to the PLC
- 30 false; emergency stops should be used when necessary to maintain the safety of the control system
- 31 a-Electromechanical MCRs
- 32 Outrush is a condition that occurs when output triacs are turned off by throwing the power disconnect, thus causing the energy stored in an inductive load to seek the nearest path to ground, which is often through the triacs. To correct this problem, a capacitor may be placed across the disconnect (0.47  $\mu$ F for 120 VAC, 0.22  $\mu$ F for 240 VAC).
- 33 c-60% of the inputs and 30% of the outputs are ON at one time
- 34 constant voltage transformer
- 35 b-every time there is a change
- 36 false; the input power and the AC and DC wire bundles should be kept separate
- 37 d-size matching
- 38 d-all of the above
- 39 true
- 40 Special wiring considerations may be necessary for:
- leaky inputs
  - inductive loads
  - output fusing
  - shielding of low-level and analog signals
- 41 OFF
- 42 false; triacs leak more than transistors
- 43 bleeding resistor
- 44 true



- 45 (a) small AC load suppression  
(b) large AC load suppression  
(c) DC load suppression
- 46 true
- 47 true
- 48 false; in the static output wiring check, power is applied to both the controller and the output devices
- 49 c–disconnected
- 50 dummy rung
- 51 d–all of the above
- 52 Changes to the control logic should be documented immediately.
- 53 Preventive PLC maintenance should be performed during the scheduled maintenance of the machine.
- 54 Any build-up of dust or dirt can obstruct the heat dissipation of components in the system.
- 55 true
- 56 d–all of the above
- 57 d–all of the above
- 58 d–all of the above
- 59 A ground loop condition occurs when two or more electrical paths to ground exist in a ground line.
- 60 d–all of the above
- 61 The first step should be to check the input power and/or logic indicators.
- 62   4   check the wiring connection to the module  
  3   close the field device and measure the voltage to the input module  
  1   place the PLC in standby mode  
  2   evaluate the PLC's reading of the module  
  5   check the voltage at the field device
- 63 c–isolate the problem to the module, the field device, or the field wiring