Automation 101:
An Industry Guide To

Control System Engineering

A Condensed Guide to Automation Control System Specification, Design and Installation

A Publication of

AUTOMATIONDIRECT.com
the #1 value in automation

Version 1.0

TABLE OF CONTENTS

Introduction

The following is a general guide to the specification, design and installation of automated control systems. The information and references are presented in a logical order that will take you from the skills required to recognize an operation or process that may be suited for automating, to tips on setting up a program to maintain the control system. Whether an expert or a novice at electrical control devices and systems, the information presented should give you a check list to use in the steps to implementing an automated control system.

> "The engineer's first problem in any design situation is to discover what the problem really is."
>
> \- Unknown

CHAPTER

1

Consider Safety First

Safety

4 Things to Consider

The first most important item to consider before attempting an automated control system, or even a simple on/off control for a pump, is safety, both for personnel that may be working with or near the automated equipment, as well as to prevent damage to the equipment.

To **minimize the risk** of potential safety problems, you should follow all applicable local, state and national codes that regulate the installation and operation of your control system, along with the equipment or process it is designed to control. These codes vary by area and usually change over time, constantly being reviewed and updated. It will be your responsibility to determine which codes should be followed and to verify that the equipment, installation, and operation is in compliance with the latest revision of these codes. It would be wise to educate yourself as much as possible about electricity and electrical equipment in general. A good understanding of basic electricity, including DC and AC theory and practice, Ohm's Law, etc. will go a long way in helping you understand the various codes and standards.

Want to learn some basic principles of electricity?

We cover the basics of DC and AC theory, Ohm's Law, Kirchoff's Laws, and more in our blog post entitled "Basic Electrical Theory"

Visit N2ADC.com/us-ca to read more!

1. Avoid Endangering Your Personnel

Most likely your control system will be dealing with electrical energy, so your first goal will be to eliminate the **risk of fire and electrical shock** to personnel. At a minimum, you should follow all applicable sections of these two organizations.

- National Fire Protection Association (NFPA) fire code
- National Electrical Manufacturer's Association (NEMA)

  Some pertinent sections are:
  - ICS 1: General Standards for Industrial Control and Systems
  - ICS 3: Industrial Systems
  - ICS 6: Enclosures for Industrial Control Systems

Please keep in mind that if the automated control system you are developing needs to be accepted in the **international market**, the National Electrical Code (NEC), as a publication of NFPA, is being harmonized with the International Electrotechnical Commission (IEC) (Website: www.iec.ch/) and the European Hazardous Location Ratings. For more information, check the Instrument Society of America's (ISA) Website at www.isa.org. Additional resources on the subject can be found at www.ul.com/hazloc/.

2. Lockout/Tagout

Another area of safety that needs to be considered for automated control systems is lockout/tagout procedures as specified by **Occupational Safety and Health Administration (OSHA). "Lockout/tagout"** refers to specific practices and procedures to safeguard operators and maintenance personnel from the unexpected energization or startup of machinery and equipment, or the release of hazardous energy during service or maintenance activities. In order to have your control system make use of a lockout/tagout procedure, the design should include the ability to shut off, neutralize, or isolate any energy source, such as the main electrical feed, but also any pneumatic, hydraulic or mechanical energy storage device. The means to do this should be considered in the initial design of the automated control system. Additional information can be found on OSHA's Website.






3. Avoiding Device Failures

There are many reasons why the electrical devices that you will use in the design of your automated control system should be listed, approved or registered with a testing laboratory. One reason is to ensure that the device meets standards that will prevent failure that could cause catastrophic results. Another reason might be for insurance or compliance purposes. One of the most specified and premier safety testing laboratories is Underwriters Laboratories (UL). The most applicable area of interest for control systems is UL's Standard for Safety 508A. If your control system panel requires being built to UL508A, then you will need to contract directly with UL to become a UL508A panel builder or use an existing UL508A panel builder. Compliance to UL508A for AutomationDirect.com products can be found on our Website at N2ADC.com/fci7t.

4. Other Safety Considerations

- **Emergency Stop** – The control system must provide a quick manual method of disconnecting all system power to the machinery, equipment or process. The disconnect device or switch must be clearly labeled "Emergency Stop".

- **Accidental Powering of Outputs** - Do not rely on the automation control system alone to provide a safe operating environment. You should use external electromechanical devices, such as relays or limit switches that are independent of any electronic controlling device, such as a solid state relay or a PLC (Programmable Logic Controller) output module, to provide protection for any part of the system that may cause personal injury or damage. These devices should be installed in a manner that prevents any machine operations from occurring unexpectedly.
  - Ex. If the machine has a jammed part, the controlling system or PLC program can turn off the motor rotating a saw blade. However, since the operator must open a guard to remove the part, you should also include a bypass switch that disconnects all system power any time the guard is opened.

  External safety devices such as light curtains, magnetic safety switches and safety relays can be integrated into your system design.

- **Orderly Equipment Shutdown** – Whether using a control system designed around relays and timers or a PLC, an orderly system shutdown sequence should be included in your design. If a fault is detected, then any mechanical motion, valve position, etc., needs to be returned to its fail-safe position and the equipment/process stopped.

- **Grounding** – To prevent electrical shock, incorporate good grounding practices in the design, construction and installation of your system. Use protective devices for faulted conductors to prevent fire, and also realize that good grounding practices can reduce electromagnetic and radiated noise interference to sensitive electronic devices.

- **Control Power Distribution** – Develop a power distribution scheme in the control system circuitry, according to code, that ensures all circuits are protected with fusing, circuit breakers or other interrupting means coordinated such that only the faulted circuit will be opened (de-energized), allowing other powered equipment and devices to continue to operate.

- **Unauthorized Access** – Make sure all enclosures and cabinets that have energized circuits are secured to prevent unauthorized personnel from gaining access without the proper tool, key or other authorized means. Mechanical trapped key systems can be used to protect access to one or more physical locations of equipment in a control system.

- **Finger-Safe** – Another safety area to consider is the use of devices that have finger-safe terminal connections, which are surrounded by insulated guarding. The use of protective guards over live circuits should also be considered, even on control panels that have limited access, so it is safer for maintenance electricians and authorized personnel to troubleshoot or make adjustments to electrical control devices.

- **Dead Fronts** – Dead fronts should be used on control system enclosures where the operator needs to make adjustments to devices, such as selector switches, thumbwheels, potentiometers, etc., and the controls need to be inside the enclosure so as to protect them from outside weather conditions. The dead front is normally an interior door that is mounted in front of the main control panel. The outside enclosure door may still require key entry by the operator, but the dead front interior door with adjustable devices is interlocked so that it requires a switch to open it, disconnecting power to the electrical devices mounted on the main control panel.

- **Closed-loop Control** – It is your responsibility in any type of closed-loop control system to ensure that if the feedback signal is lost, the system shuts down so as not to cause injury to personnel or damage to the equipment.

CHAPTER

2

Identifying Processes for Automation

Identifying
Processes for Automation

After considering safety, the next step in configuring an automated control system is to identify what can be automated. It will help if you have an understanding of basic hydraulics, pneumatics, mechanical operating mechanisms, electronics, control sequences, etc. and a solid knowledge of the operation or process that you are going to automate.

You should understand how to control motion and movement, regulate the flow of fluids, dispense granular materials, orient parts, sense product in position, detect when an operation is complete, etc.

As an example

Let's say we have a conveyor that moves our product from point A to point B. The conveyor is powered by a 3-phase AC motor, which is turned off and on by a manually controlled motor starter and includes, for fire protection, both short circuit and overload protection. The system requires an operator to stand at the motor starter, watching as the product reaches the entrance to the conveyor, and turning the conveyor on to move the product. Then the operator must also turn the conveyor off once the product has reached the discharge end.

Check out this Brewed tea and coffee container filling machine at N2ADC.com/neyxb

How Can this Process be Automated?

To automate the conveyor, we will need to replace the manually controlled motor starter with an electrically controlled motor starter, including short circuit and overload protection. We will need to size the motor starter to work with the existing conveyor motor. (Visit N2ADC.com/xu5ln for information on specifying and sizing motor starters.)

Using sensors to start and stop the process…

We will need to identify where to locate sensors such as limit switches, photoelectric sensors, proximity sensors, etc. that will indicate when an operation is completed. This is required so our control system knows when to proceed to the next step in our operation. As an example, we usually see that we need a limit switch to detect when a pneumatic cylinder is fully extended, as in the case when the cylinder is used to push our product onto a conveyor. The cylinder "fully extended" signal is used to de-energize the solenoid valve that provided the air pressure to the pneumatic cylinder. We also need a limit switch to indicate when the cylinder has fully retracted, to provide a signal to the start/stop control of the conveyor that the product push cylinder is out of the way for the next product.

Using sensors to indicate if the product is present…

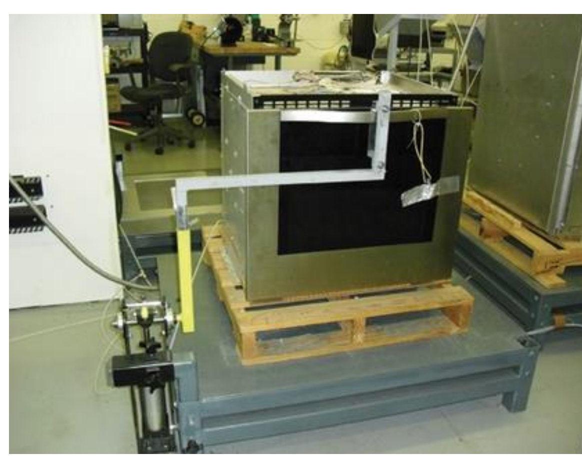
Another application for a sensor is to indicate when the product has reached the conveyor. The sensor can be a limit switch with a roller arm that comes in contact with the product, or a photoelectric sensor that can detect the product by using an infrared beam of light. The photoelectric approach may be the better choice because the position of the product on the conveyor belt may vary. (Refer to our website for information on selecting photoelectric sensors or visit N2ADC.com/yzrq6)

Continue looking for opportunities to control and sense

We would continue with this analysis, looking at each piece of equipment or component in our system, and select a device that could control or sense it. Some examples include an electrical solenoid valve to control water used to wash residue from a product, or a pneumatic valve to control air pressure to a cylinder operating a gate that diverts product on a conveyor, or energizing a control relay to signal that a product is in position on a scale.

In some instances we may need to vary the speed, rate or position of our controlling device, such as varying the speed of a conveyor, changing the amount a valve opens to control a flow rate, or remotely changing the setpoint level for a tank. This could be accomplished by using an analog output signal. An analog output signal is a varying signal that corresponds to the real value we have determined and calibrated into the device. For example, a 0 to 10 VDC signal could represent a conveyor speed of 0 to 500 feet per minute. An analog signal to the speed controlling device for the conveyor motor of 5VDC would result in a conveyor speed of 250 feet per minute.

VIKING®



Viking Range Automates Product Testing: Read how Viking Range automated its testing lab at N2ADC.com/21eeq.

Identifying I/O and Controllers

The task of identifying devices to control motion, flow, events, etc. and sensing completion is basically identifying the I/O (inputs and outputs) of our control system. Please keep in mind that by identifying devices that can be controlled by a PLC output module and identifying sensing devices that provide a signal to a PLC input module, these same devices can also be used in simple control circuits where the only requirements are relays and timers.

HMI Requirements

You will also want to determine if your automated control system will benefit from the use of an operator interface, also referred to as a Human Machine Interface (HMI). If your process requires making changes to setpoint values, process time, flow rates, etc., then the use of an HMI is the best way to proceed. In these situations, you most likely will need a PLC that can easily communicate with the HMI device.

SCADA?

If your application requires keeping data records for reference, traceability, history, trending, meeting regulations, etc., then you should be looking at using a control system that would fall into the category of a "Supervisory Control And Data Acquisition" (SCADA) system. Most of these control systems would be comprised of PLC-type I/O that interface to a PC with appropriate software, or a PLC paired with data collection software.

> "Normal people… believe that if it ain't broke, don't fix it. Engineers believe that if it ain't broke, it doesn't have enough features yet."
>
> \- Scott Adams

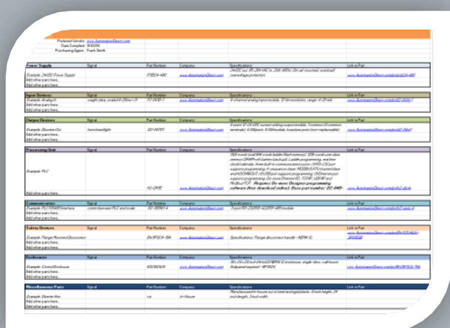
CHAPTER

3

Specifying Devices

Specifying Devices
What needs to be specified

Need help starting your project documentation?



Download a FREE template
[N2ADC.com/yknp2]

In this chapter we will cover how to specify the various devices required for controlling the equipment in an automated system. Your specifications need to include not only the "controlling" devices for your application, but also items such as the housing or enclosure for the devices, the type of wire required to meet the various codes, agency approvals required for safety and insurance purposes, environmental conditions, etc.

As stated in Chapter One, special expertise is generally required to design, wire, install, and operate industrial automation control systems. Persons without such expertise or guidance should not attempt to design control systems, but should consider seeking the services of a qualified system integrator. Control systems can fail and cause serious injury to personnel or damage to equipment. The information in this series of articles is provided "as is" without a guarantee of any kind.

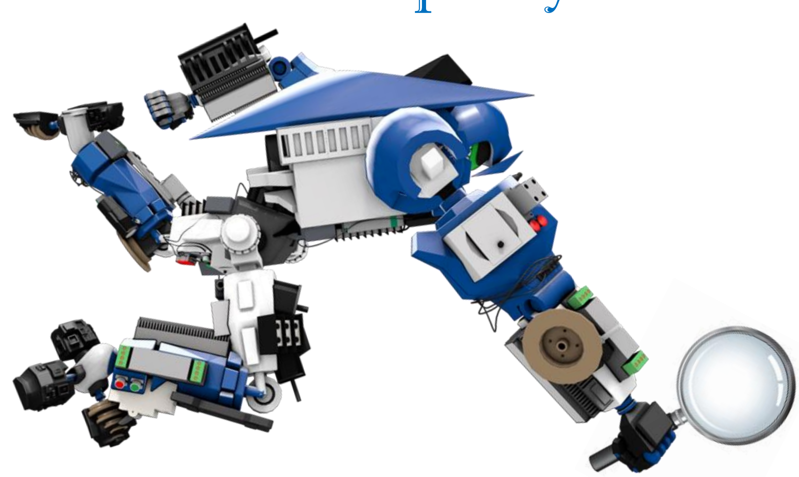
Gathering Parameters and Specifications

With that said, the first skill we need to develop in this effort will be the gathering of all the equipment parameters and specifications needed to specify the devices required to control the equipment. We need to be the proverbial detective who would ask questions such as;

- ✓ What is the operating voltage?
- ✓ What is the power rating?
- ✓ How much current does it draw?
- ✓ What is the operating temperature range?
- ✓ What is the relative humidity range?
- ✓ What are the mounting dimensions?
- ✓ What are the minimum mounting clearances?
- ✓ What is the duty cycle?
- ✓ How will the system be used?
- ✓ Who will be using the control system?

Control System Devices to Specify

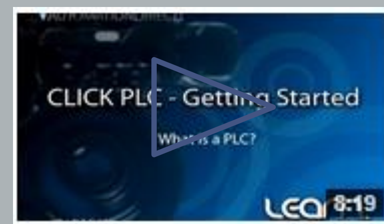
The devices you need to specify in your control system will generally fall into one of three categories; input devices, output devices and the processing unit.



1. The Processing Unit

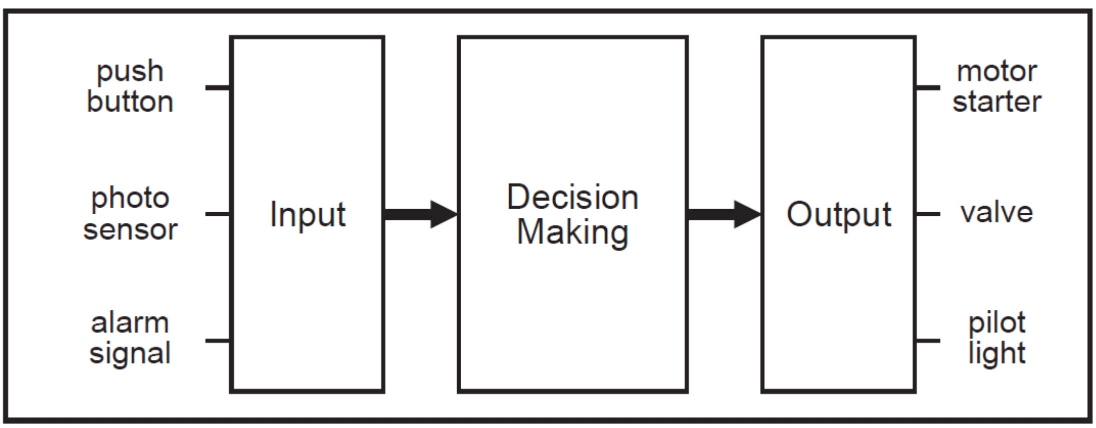
All control systems can typically be defined as having inputs, outputs and some form of decision making going on in between so that the outputs are controlled based on the status of the inputs. This device is the “decision-making” element. This element can be performed by a PLC, where we have inputs, outputs and a central processing unit (CPU) that uses ladder logic programming to make decisions based on input status and the logical conditions in the program.

“What is a PLC?”



Check out our video on YouTube!

http://youtu.be/iWgHqqunsyE



A similar device that can be looked at in the same manner is a personal computer (PC). PCs are used in some automated control systems as the decision making element, together with industrial I/O modules. These PC-based systems rely on the communication ports or Ethernet connections to monitor and control the I/O. The application software typically allows a programmer to develop a graphical interface that gives an operator interaction with the equipment or process. With some research and experience, you will learn how to determine how much “decision making” ability your control system requires. Cost restraints may require you to compare implementing the control system with either a PLC, PC-based control, or simple hardwired relay logic. But don’t forget that a PLC or PC-based control system allows easier changes and future expansion.

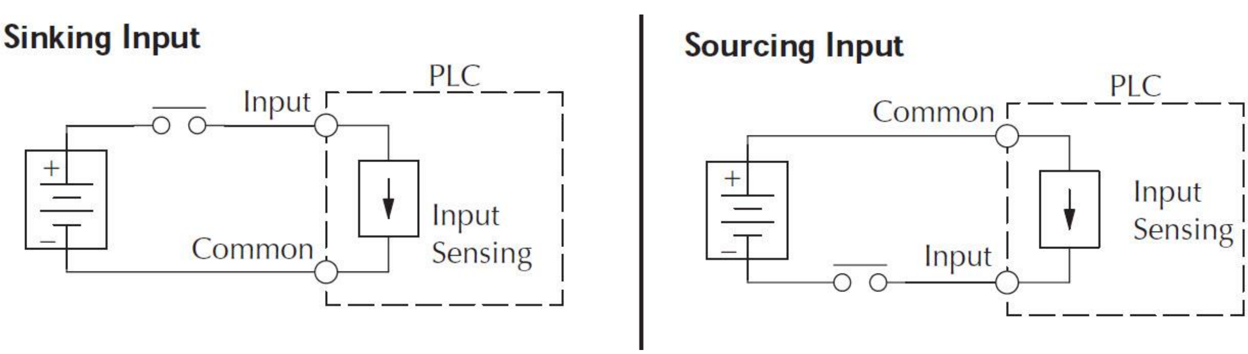
2. Discrete Input Devices

Discrete input devices are used to sense a condition, detect movement or position, indicate a limit or set point has been reached, sense intervention by an operator, detect an alarm, etc. Typical input devices may include limit switches, photo sensors, pushbuttons, proximity sensors, etc. These input signals are generally in an ON or OFF state. We can look at an input from a device, such as a photo sensor used to detect an obstruction, and state that when the photo sensor sees the obstruction the sensor is ON; in other words we have a true condition. When the photo sensor is not obstructed, then the input is OFF; or we can say the condition is false. These types of signals are called discrete signals, meaning they are always in one of two states; ON or OFF. They can be wired into a PLC input module and the PLC can be programmed to use the status of the signals to execute the logic to control the automated system. Or these same signals can be used in a “relay logic” system, where control relays are hardwired as the logic.

Of importance to our specifications are the ratings of these input devices.

- What is the operating voltage; 24, 120 or 240 Volt AC or DC?
- If they are rated for DC, are they sinking or sourcing?
- What distances can they sense?
- How much force can be applied to the actuator?
- How much current do they require?

As a note, most PLC DC input modules can be configured as sinking or sourcing.



Typical wiring for sinking and sourcing input devices

Also keep in mind that when selecting a sensor device, such as to detect the presence of product or sense the end of travel for a mechanism, it is very important to consider the environment in which the sensor will operate. This should not only include temperature and humidity ranges, but in some cases, indoor or outdoor use, altitude, ability for the sensor to be washed down, etc. For example, photoelectric sensors are sensitive to the atmosphere in which they can efficiently work. If there is a lot of dust, dirt and/or mist in the air, then the optics can easily become dirty or coated, reducing their sensitivity and operating distance.

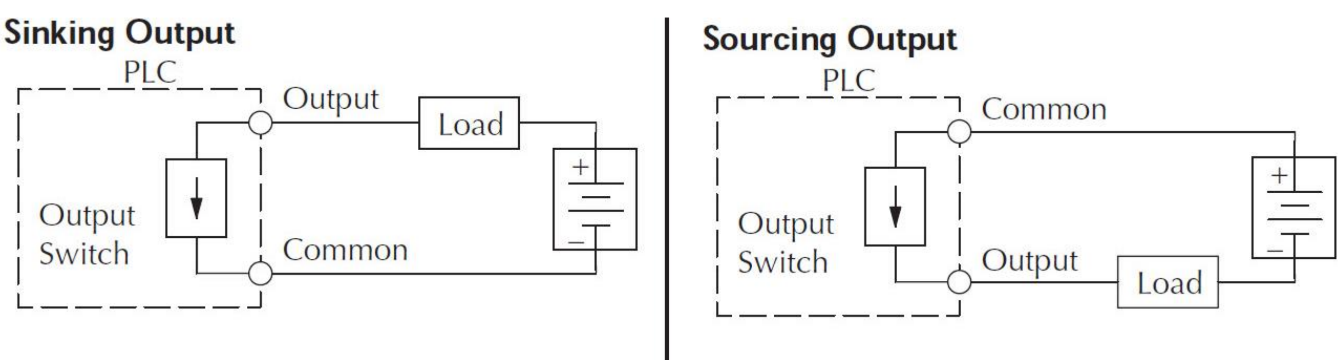
3. Discrete Output Devices

Discrete output devices are used to control actions such as motion, start/stop of equipment like conveyors and pumps, on/off control of valves, operator alerts/prompts, status indications, etc. Typical output devices include relays, motor starters, and pilot lights etc. These types of output signals are also discrete; either ON or OFF. The signals can be wired from a PLC output module to control the devices, such as starting and stopping motors, energizing a valve to control water flow, illuminating a pilot light to alert an operator to a condition such as “Bin Full”, etc. The output signals can also be wired directly to the controlling device based on hardwired relay logic.

Of importance to our specifications are the ratings of these output devices.

- What is the operating voltage; 24, 120 or 240 Volt AC or DC?
- If they are rated for DC, are they sinking or sourcing?
- What is the current draw?
- What is the duty cycle?
- What is the operating temperature range?
- What are the mounting dimensions?

For example, if our process uses a solenoid valve to control water flow to a wash station, we would need to know the operating voltage of the valve and how much current it draws. We also need to know not only the ON-state current draw of a valve, but also the inrush current, so that we can properly specify a PLC output module or a control relay. Although a valve may be rated to draw 250mA continuous current, it may have an inrush of 800mA when first energized. If a PLC output module has eight output points and each point is rated for 1 amp continuous duty, after thermal considerations, the entire output module has a total rating of 6 amps and therefore has a common fuse rated at 6 amps. If we had solenoid valves connected to all eight output points and our program called for them all to energize at the same time, the total inrush current would be 8 x 800mA or 6.4 amps total, and most likely would blow the fuse. The solution could be to select an output module with a higher current rating or to use the ladder program to sequence the valves, preventing them all from being energized at the same time. Another option is to split up the valves between several output modules, using the remaining points to power smaller loads such as pilot lights. Certain output types may have derating curves depending on the ambient temperature and the number of outputs energized. Keep in mind that DC output modules can be sinking or sourcing type.



Typical wiring for sinking and sourcing output devices

What to learn more about Sinking and Sourcing?

Sinking = provides a path to supply common (-)
Sourcing = provides a path to supply source (+)

Learn more by reading our blog post on the topic.
Visit [N2ADC.com/ciy3b](N2ADC.com/ciy3b)

4. Other Device Types That Will Need Specifying

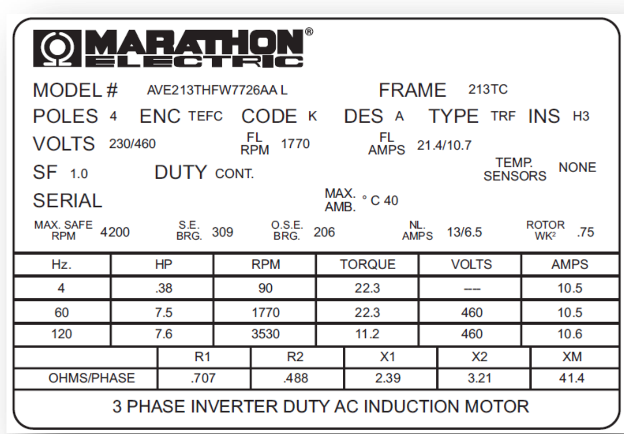
- **Analog Devices** - Another area of inputs and outputs involve the use of analog signals in a control system. Analog signals are variable and can represent a range of values. As a quick example, we may want to monitor the level of a liquid in a tank that is 100 feet tall. We can use a sensor that will produce a signal that is represented by a voltage range of 0 to 10 volts DC, with 0 feet being equal to 0VDC and 100 feet being equal to 10VDC. Analog signals are typically linear, so a 5VDC signal would tell us the tank level is at 50 feet. The analog signal could be wired into a PLC analog input module, and in the ladder program we could compare the actual level to a setpoint and produce a discrete signal that would cause an output point to start a pump to raise or lower the level.

- **Inductive Devices** - When selecting a device to control a prime mover, such as an industrial motor to power a conveyor, or a valve to control a hydraulic cylinder, you will need to determine the ratings of the controlled equipment:

  - What is the operating voltage?
  - What is the maximum current draw?
  - What type of environment is it being used in?

An industrial induction motor may have ratings such as 230/460 VAC, 3-phase, 1725 RPM, a FLA (full load ampere) of 10.5 amps at 460VAC, etc.

This information can be obtained from the manufacture's catalog or directly from the motor nameplate. In the case of a motor, you will need the various ratings to choose the motor starter or possibly a variable frequency drive for either start/stop control or speed control of the motor.



Other Considerations

There are other points to consider in the specification of devices being used in your automated control system; static electricity, duty cycle, surge suppression, power, environment, agency approvals, enclosure type as well as enclosure heating, cooling and lighting.

- **Static Electricity –** Most equipment and devices will operate down to 5% relative humidity. However, static electricity problems occur much more frequently at humidity levels below 30%. Make sure you take adequate precautions when you touch the equipment. Consider using ground straps, anti-static floor coverings, etc. if you use the equipment in low-humidity environments.

- **Duty Cycle -** When using a solenoid valve, you will want to know its operating voltage, nominal current draw and current inrush to help select the type of output device required to control its operation. It is also important to have an understanding of the solenoid valve's duty cycle. We would not want to operate a solenoid valve rated at 50% duty cycle in a continuous mode with an ON time of 10 seconds and an OFF time of only two seconds. The short OFF time would not allow for the solenoid to properly cool down.

- **Surge Suppression -** Solenoid valves, motor starters, etc. make use of an inductive coil for their operation and the coil can produce high voltage spikes that can damage output devices and nearby electronic equipment. It is always recommended to use some form of surge suppression to eliminate these voltage spikes.

- **DC Power -** If using DC voltage from a power supply in your control system, consider using a power supply rated for at least twice the calculated load. This should satisfy one of the requirements if you need to have your control system UL 508 approved and will allow the power supply to operate at a lower temperature, thus increasing its life.

- **Environmental Specifications -** The table below is an example of NEMA’s common environmental specifications that generally apply to automation equipment. IEC also has a list of common environmental specification designations for enclosures and equipment.

COMPARISON OF SPECIFIC NON-HAZARDOUS APPLICATIONS INDOOR LOCATIONS											
PROVIDES A DEGREE OF PROTECTION AGAINST THE FOLLOWING ENVIRONMENTAL CONDITIONS	TYPE OF ENCLOSURE										
	1	2	4	4X	5	6	6P	11	12	12K	13
Incidental contact w/ encl. equip.	●	●	●	●	●	●	●	●	●	●	●
Falling dirt	●	●	●	●	●	●	●	●	●	●	●
Falling liquids and light splashing		●	●	●		●	●	●	●	●	●
Dust, lint, fibers, and flyings			●	●	●	●	●		●	●	●
Hose down and splashing water			●	●		●	●				
Oil and coolant seepage									●	●	●
Oil or coolant spray and splashing											●
Corrosive agents				●			●	●			
Occasional temporary submersion						●	●				
Occasional prolonged submersion							●				

- **Agency Approvals -** Some applications require agency approvals for particular components. Some of these required approvals are:

  - UL (Underwriters' Laboratories, Inc.)
  - CUL (Canadian Underwriters' Laboratories, Inc.)
  - CE (European Economic Union)

  The requirements for any of these agency approvals need to be part of your specification and will determine the selection of most of your controlling devices.

- **Enclosures -** Selecting a proper enclosure is important to ensure safe and proper operation of your equipment. The minimum considerations for enclosures should include:

  - Conformance to electrical standards (Reference NEC)
  - Protection from the elements in an industrial environment (Reference NEMA, particularly section ICS_6)
  - Common ground reference (Reference NEC)
  - Access to the equipment (Reference OSHA)
  - Security or restricted access (Reference OSHA)
  - Sufficient space for proper installation and maintenance of equipment

  We need to consider the environment where the enclosure will be located. Outdoors? Indoors? Washdown required?

- **Enclosure Heating/Cooling -** Ensure that the devices used in your control system aren't subject to overheating, or if installed in a colder climate, the devices aren't being used below the listed low temperature operating range. Your control system, because of its physical location, may require you to have both a cooling system, such as an A/C unit, and a small heating unit as part of the same enclosure. This will ensure the devices are always operating within their temperature specifications. Basic thermal management is not difficult for most automated control systems. Investing a little thought during the specification stage can save you a great deal of redesign down the road.

- **Enclosure Lighting -** It is always a good idea to include interior lighting for your control system enclosure or cabinet to help during routine maintenance to the control system.

Additional Resources – You can find these additional resources in the Appendix of this book or by visiting the links below.

Worksheet for Choosing a Controller -------------- N2ADC.com/l8jv4

How to Select an Enclosure --------------------------- N2ADC.com/o8hyv

What do the NEMA Ratings Mean? ----------------- N2ADC.com/n2230

Understanding Enclosure Cooling ----------------- N2ADC.com/3btpr

Selecting an Enclosure Fan or Air Conditioner - N2ADC.com/q1bjh

Selecting a Heat Exchanger -------------------------- N2ADC.com/oo2ty

CHAPTER

4

Design

Design

Putting ideas on paper

The design for our control system will be in the form of a documenting task. The challenge will be to get our design specifics down on paper so that it can be easily understood. It is important that anyone can look at our documents in the future and be able to interpret the information. Useful to us at this step will be any notes and lists that were developed during the "Identifying" and "Specifying" phases of our automated control system.

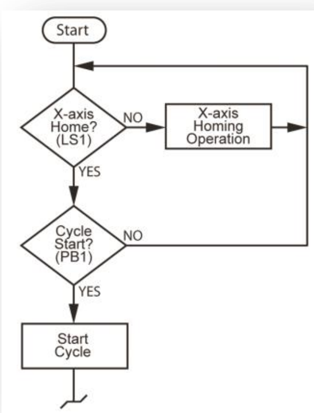
> "Optimist will tell you the glass is half-full; the pessimist, half-empty; and the engineer will tell you the glass is twice the size it needs to be."
>
> \- anonymous

Sequence of Operation

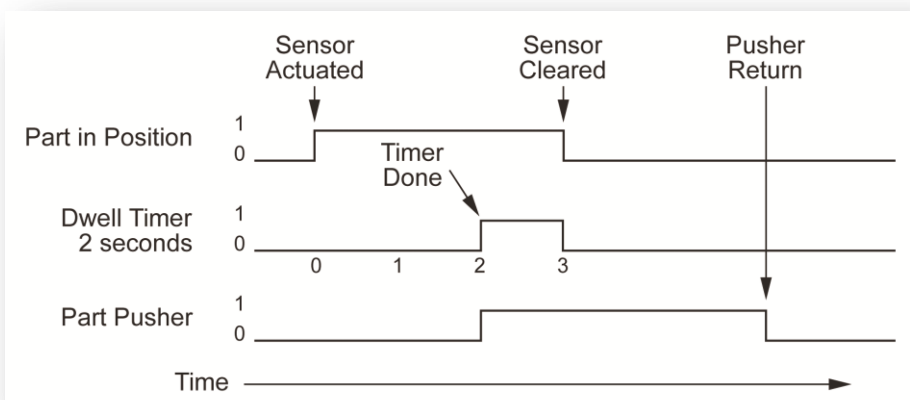
In most cases, the first step in designing our control system will be to define the process or actions to take place, by way of a "sequence of operations" description. The sequence should show or list each operational step in our process.

Our particular application may be better suited to using a flowchart that shows the sequence of operation by means of decision-making steps and actions that need to take place. A flowchart can be developed with graph paper and a pencil, or an application software program such as Microsoft Visio. Microsoft Word also has a built-in drawing tool that contains flowchart symbols.

In some cases, the application may be better suited to using a timing chart, in which each condition and event is graphed in a time relationship to each other, as shown below.



Flowchart



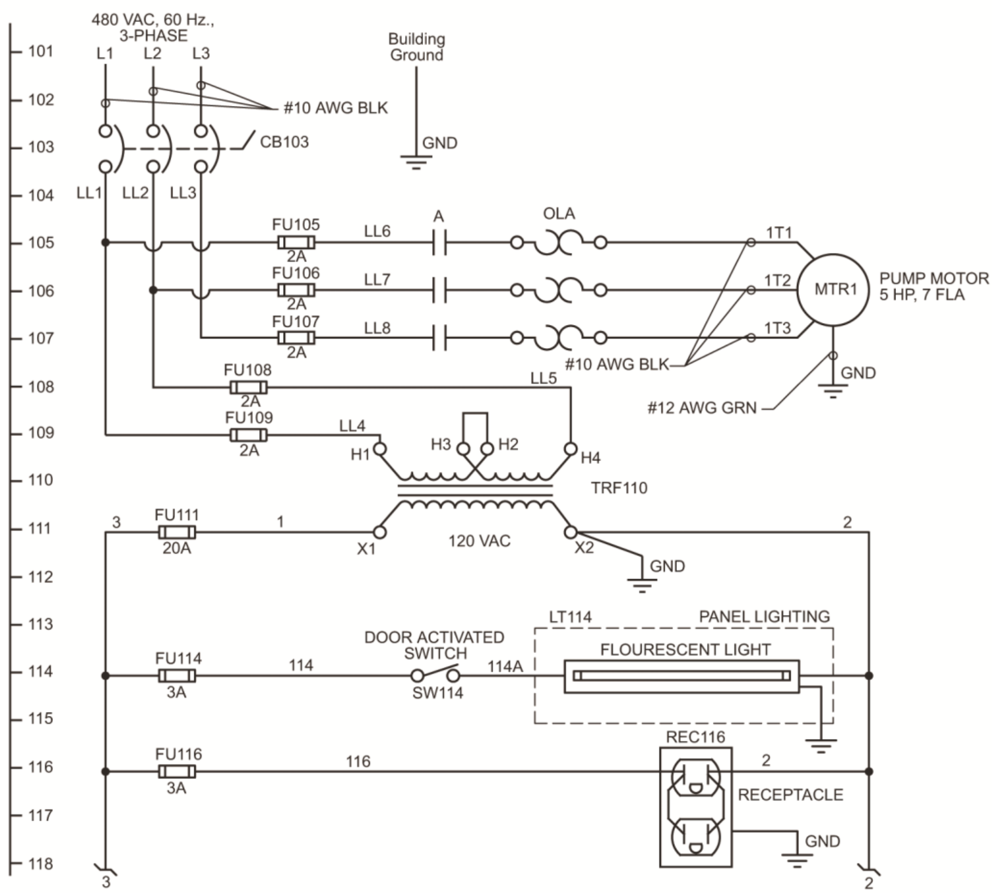
Timing Chart

Once we have a sequence of operation developed and a list of our input and output devices, we can determine if our automated control system is best suited for hard-wired relay logic or can benefit from a PLC. For example, a PLC can be cost-effective when used in place of a half dozen industrial relays and a couple electronic timers. It adds the flexibility of making future "logic" changes without the labor of making wiring changes.

Schematic

The next step in our design is to develop a schematic. Most electrical designers and engineers define a schematic as a drawing that shows the logical wiring of an automated control system. A control schematic is normally drawn in the form of a ladder, showing the various wiring conditions. This analogy of a ladder is what PLC ladder logic was based upon. It made the transition to PLC ladder logic easier for engineers and electricians because they were accustomed to troubleshooting hard-wired relay control systems documented in a ladder fashion.

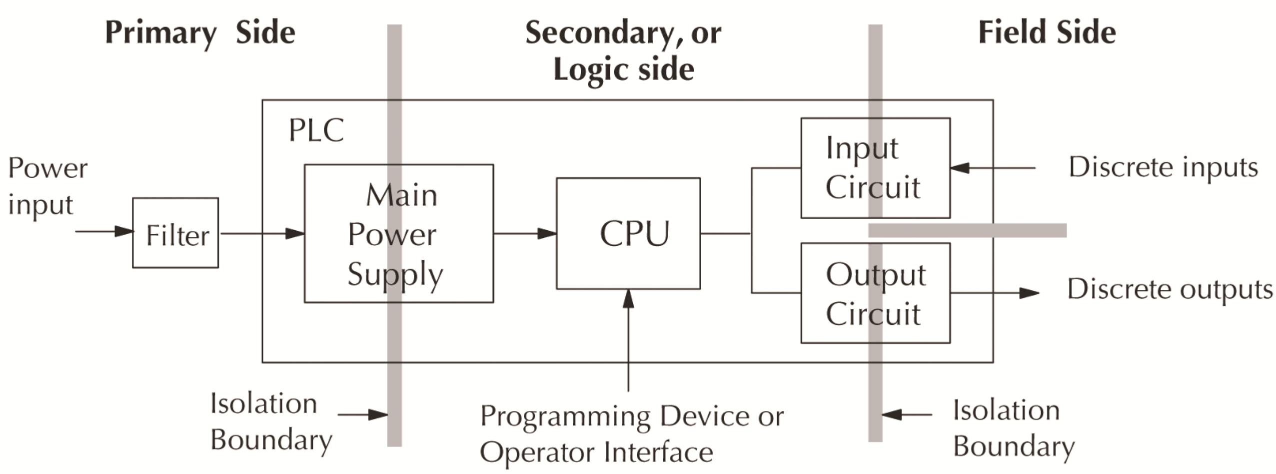
It is normal practice to show input type devices on the left-hand side of drawings and output devices on the right-hand side. For example, the symbols for protective devices (fuses), contacts and overload relay elements are shown to the left, while the symbol for the motor is shown to the right.



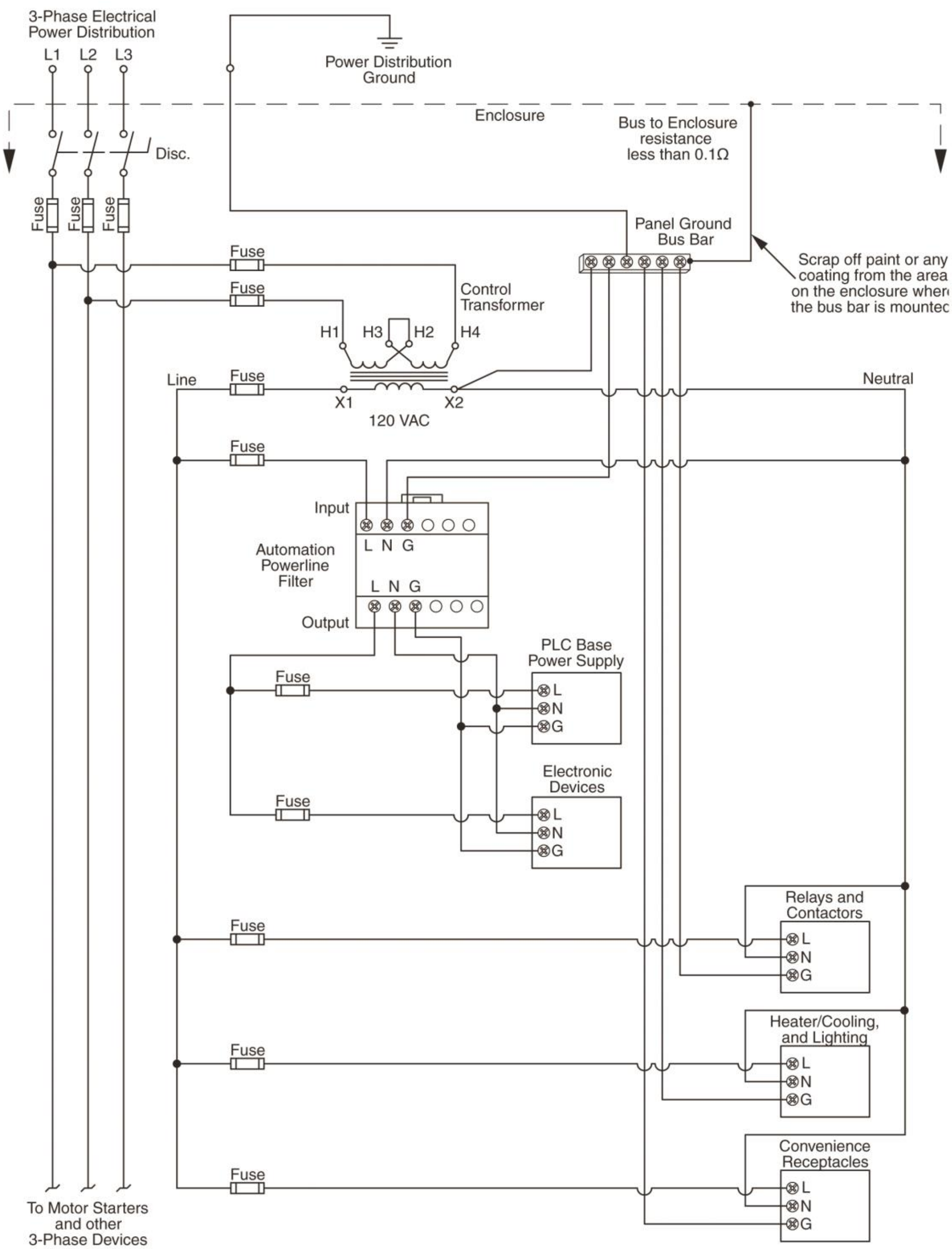
The schematic should start with the incoming power, including protective devices such as circuit breakers and/or fuses. Our design should show the distribution of the AC power and include all circuitry and required devices for conformance to the National Electrical Code (NEC) and any local codes that might apply in our area.

It is normal practice to show any high-voltage devices, such as 3-phase motors, 480 or 240VAC auxiliary equipment, etc. in this first section of the schematic. Next, we will show a control power transformer used to step the higher incoming voltage down to our system control voltage (115VAC). Our control voltage can be something other than 115VAC; for example, we could have a control voltage of 24VDC, which is common for many electrical control devices. The control transformer needs to be sized (VA rating) based on our known or calculated “load” of devices that will be powered from the transformer in our automated control system.

At this point in our schematic, we need to look at device wiring isolation strategies. PLCs provide ideal isolation because its circuitry is divided into three main regions separated by isolation boundaries as shown below. The PLC’s main power supply includes a transformer that provides isolation, and the input and output circuits that use opto-couplers to provide additional isolation. When wiring a PLC, it is extremely important to avoid making external connections that connect logic side circuits to any other.



Electrical isolation provides safety, so that a fault in one area does not damage another. Using the figure below as a reference, we see a transformer which provides magnetic isolation between its primary (high voltage) and secondary (control voltage) sides. A powerline filter provides isolation between the control power source and the electronic devices.



The previous image also shows some general suggestions for device grounding and distributing the control power to various devices, along with individually fusing these devices.

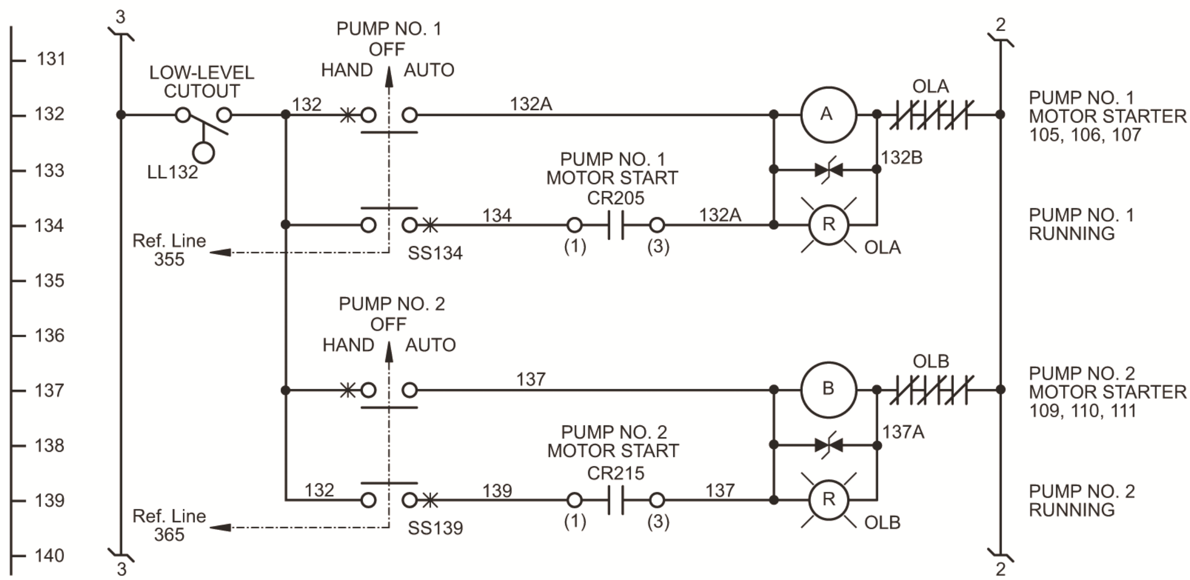
Proper grounding is one of the most important things in good automated control system design. The more details we can show on the schematic to reflect all points that need to be grounded, the better chance we have of a properly grounded control system that provides both safety and functionality.

Why is grounding important? Electronic instrumentation such as PLCs and field I/O are typically surrounded by various types of electronic devices and wires. These electronic devices may include power supplies, input/output signals from other instrumentation, and even devices that are near the instrumentation enclosure. All these may present a risk of **Electromagnetic Interference (EMI)** or transient interference. This type of interference may cause failure or erratic operation of the device.

We should consider using a second transformer to source AC power to DC power supplies. Input circuits should be utilized to isolate the output circuits and prevent voltage from the output transients (spikes) from being induced into the input circuits. In some cases, we may need to use a constant voltage transformer to stabilize the incoming AC power source supplying the PLC to minimize shutdowns due to power surges, voltage dips and brownouts. When using a constant voltage transformer to power a PLC, the sensors connected to the PLC inputs should use the same power source. Otherwise, the AC source voltage could drop low enough to cause inaccurate input data. Also, the use of an isolation transformer, for example 115VAC primary to 115VAC secondary, can provide additional suppression of EMI from other equipment. Isolation transformers should be used near equipment that produces excessive electrical noise.

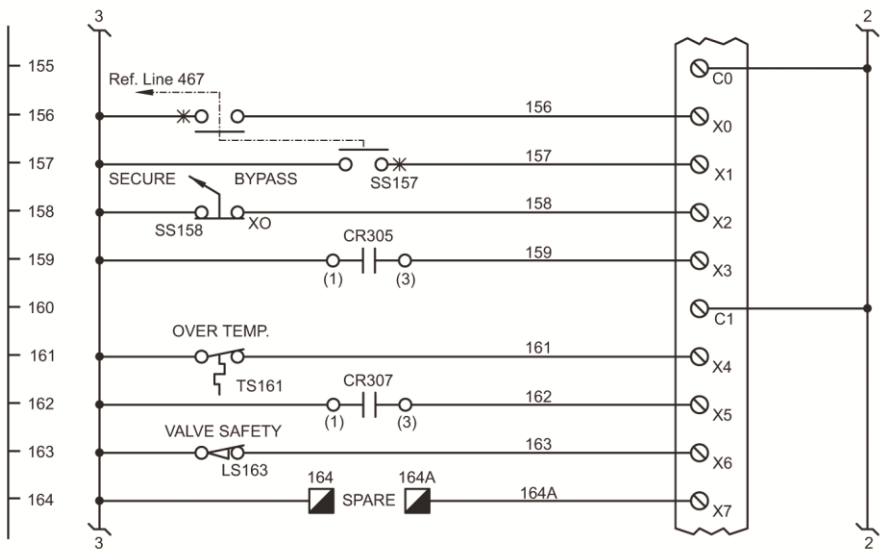
If DC power is required in our control system, we need to calculate the worst case amperage draw (load) of all the devices that will be powered from the DC supply. We also need to look at the amount of “ripple” the devices being powered can tolerate and select a DC power supply that can meet the most stringent requirement. Ripple is the amplitude of the AC component that rides on the DC voltage signal. A typical rating for most applications involving DC powered sensors would be 100mV peak-to-peak. It is also a good idea to double the calculated amperage capacity of the DC power supply. This is especially important if our control system needs to meet UL (Underwriters’ Laboratories, Inc.) 508A standard.

The next section of our schematic will show the hard-wired devices that are powered from our control voltage (115VAC). If our control “logic” is based on hard-wired relays, this is where we would show the hard-wired connections, along with the normal 115VAC powered devices, such as DC power supplies, 115VAC power to PLC power supplies, auxiliary devices, etc. The figure below is a partial example of the hard-wired section of our schematic.



This is a good time to mention surge suppression. Surge suppression devices are an important component in achieving a reliable power distribution system. These devices protect the electronic components from sudden power surges that can cause considerable damage. Inductive load devices (devices with a coil) generate transient voltages when de-energized with a relay contact. When a relay contact is closed it "bounces," which energizes and de-energizes the coil until the "bouncing" stops. The transient voltages generated are much larger in amplitude than the supply voltage, especially with a DC supply.

If using a PLC, the final section of our schematic will show the input and output modules with their device wiring. Below is an example of the wiring for an input module.

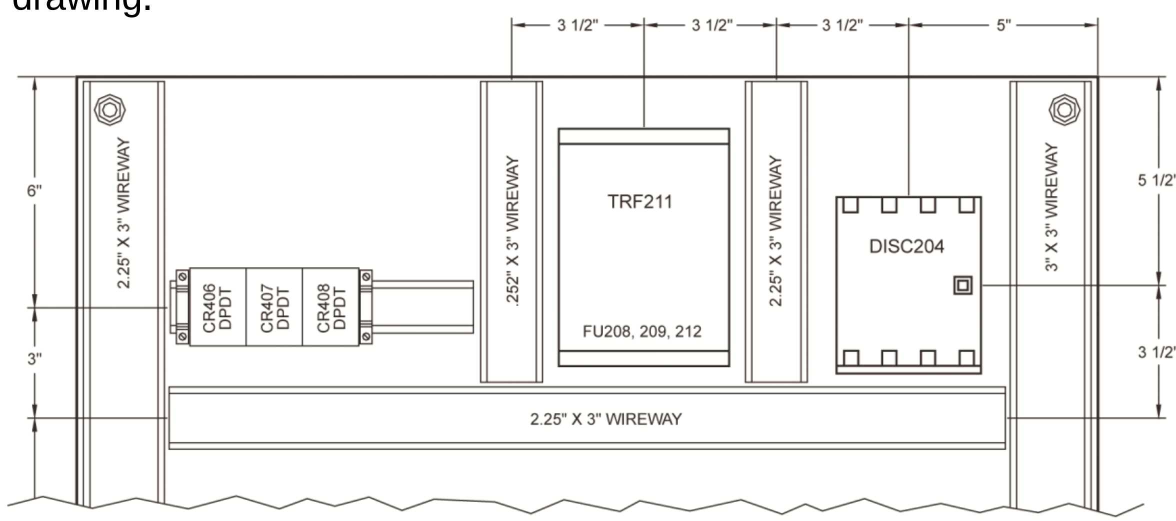


We would make use of reference line numbering and, in most cases, we would show all of the input modules first, then the output modules. If we have analog I/O, we would want to show the analog input modules, then the analog output modules, and finally any specialty modules such as high speed counters or communications. Generally we would use one sheet of our schematic to show each module.

> "As technology advances, it reverses the characteristics of every situation again and again. The age of automation is going to be the age of do it yourself".
>
> \- Marshall McLuhan

Panel Layout

Once we have our schematic finalized, the next step is a panel layout drawing. In most cases, the actual panel is referred to as a subpanel. We can mount all the components to a structure (the subpanel), wire all the components, and do this before mounting the subpanel in the control system enclosure. The panel layout drawing should be done to scale and include dimensions for the panel builder to follow when laying out the components. Special attention should be given to component location and spacing. We need to follow the manufacturer-recommended mounting distances and clearances. Below is a partial example of a panel layout drawing.



The higher voltage devices (those that operate at 240/480 VAC) should be mounted toward the top of the panel, keeping as much distance as possible between the high-voltage devices and any electronic devices, such as PLCs, DC power supplies, electronic timers, etc. Keeping the high-voltage devices toward the top allows us to cover all of the high-voltage devices with a non-conductive safety shield for personnel safety. It keeps the lower voltage devices grouped together, allowing access to wiring terminals that will aid in troubleshooting our control system. In some cases, a metal partition between the high-voltage section of our control panel and any sensitive electronic devices can act as a shield from any EMI generated by the high-voltage devices.

In our panel layout design, we need to include wire duct between the various components. The wire duct simplifies the wire routing between components, keeps the wires in place, makes working with the wires easier, and gives the panel a well-organized look. We should also make use of terminal blocks in our design. Terminal blocks can be sized, organized and even color-coded to handle the different types of signals that enter and leave our control panel. We may choose to use black for high voltage, red for inputs, violet for outputs, etc. We should try to locate the terminal blocks so they provide the best wire routing from the components to the terminal blocks. The terminal blocks also make it convenient for the electrician to terminate his field wiring when the control enclosure is installed.

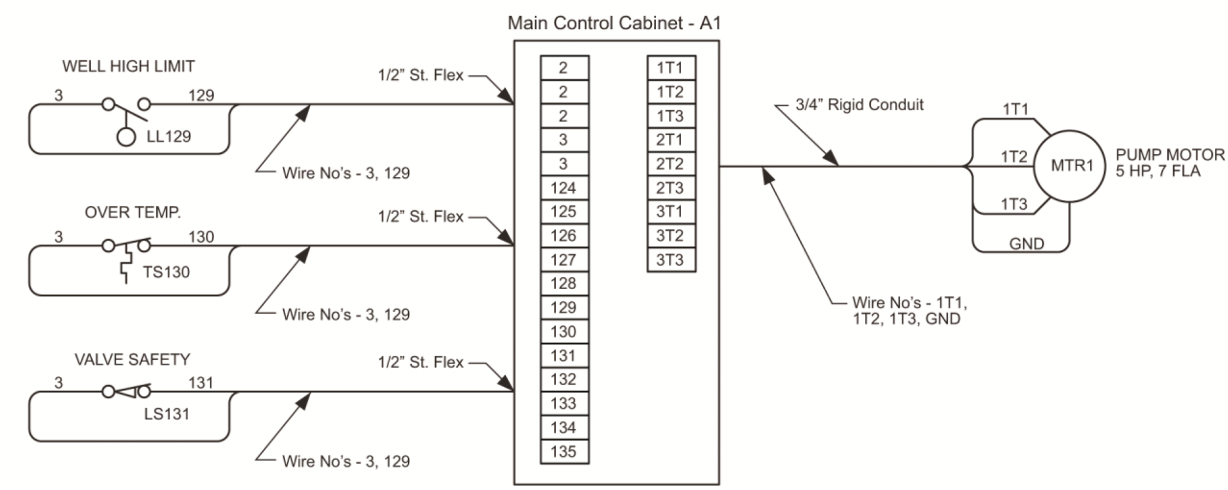
Bill of Materials

The Bill of Materials (BOM) should list each component in our automated control system, the quantity of each component, any designations or "marks" that allow us to easily identify the component on our schematic, a description of the component, and its part number. We can also have comments or remarks about the component that will help the panel builder know what needs to be done when the control panel is being built. Below is a short example of a bill of materials. The BOM can be in the form of a table drawn on one of the sheets along with the schematic and panel layout. It can also be done as a spreadsheet, which would allow easy indexing and future referencing.

ITEM	QTY	MARK	DESCRIPTION	PART NUMBER	REMARKS
1	1	CB104	Circuit Breaker, 3-pole, 30 Amp, 480 VAC	G3P-030	
2	1	TRF107	Control Power Transformer, 230/460 VAC Pri., 115 VAC Sec., 250 VA	CPT115-250-F	
3	2	FU107, 109	Fuse, Class CC, Current Limiting, Fast-acting, 600 VAC, 1 AMP	HCLR1	
4	1	FU114	Fuse, Time Delay, 500 VAC, 2 AMP	MEQ2	
5	1	PB207	Pushbutton, 30mm, Momentary, Flush Head, Green, 1-NO Contact	HT8AAGA	
6	1	PB209	Pushbutton. 30mm, Momentary, Extended Head, Red, 1-NC Contact	HT8ABRB	
7	1	A	Contactor, 9 AMP, 110-120 VAC Coil	SC-E02-110VAC	Motor Starter A
8	1	OLA	Overload Relay, 6-9 AMPS Adjustable	TK-E02-900	Motor Starter A
9	1	LS308	Limit Switch, Side Rotary Lever, 1-NO and 1-NC Contact	ABP1H41Z11	
10	as req'd	n/a	Wire Duct with Cover, Grey, 2.25" X 3"	T1-2230G-1	

Wiring Diagram

A wiring diagram, sometimes referred to as an interconnecting diagram, is used mainly for installation by the electrician for routing and terminating the wiring between the various devices and enclosures in the control system. It should include all control enclosures or cabinets, any external devices that are wired into control enclosures, junction boxes, conduits, wireways, etc. The wiring diagram usually includes conduit sizes, distances, number of conductors between devices, wire sizes, colors, wire numbers, terminal blocks, etc. The wiring diagram is also useful for system startup and later for locating wire routing and devices during troubleshooting. Bellow is an example of a wiring diagram.



> "Strive for perfection in everything you do. Take the best that exists and make it better. When it does not exist, design it."
>
> \- Sir Henry Royce

Design Tools

Although all of the tasks related to documenting the design can be performed with nothing more than a pencil, paper and a ruler, it is normally more efficient to use a software drafting utility, such as AutoDesk's AutoCAD® or AutoCAD LT® software. The biggest advantage in using a software drafting program to create schematics, panel layouts, bill of materials and wiring diagrams is the ability to re-use the work for future electrical control system designs. The drafting software can also be used to create our sequence of operation, flowchart or timing diagram. Add-ins for various drafting software packages can be geared toward electrical control system design. These add-ins contain pre-constructed elements of different manufacturers' electrical devices. This may include schematics of PLC I/O modules, power supplies, communication devices, etc. These pre-constructed elements also include scaled outlines of relays, motor starters, terminal blocks, etc. that can be dropped into your panel layout design.

This type of software has the ability to act as a database for components that would be used in our control system design and can aid in coordinating the components between our schematic, panel layout and bill of materials.

CHAPTER

5

Build

Build
Let the Fun Begin!

Let's review some practical suggestion and guidelines on building your control panels for easier installation and maintenance.

During the design of our control panel, we pointed out the benefits of using a removable subpanel. In building the subpanel, it is best to secure the components from the front side. This will make it easier to replace any failed device or component in the future.

We can also make installation and maintenance easier by using terminal blocks mounted to the subpanel that will connect to all external devices. This will allow the installing electrician to quickly dress and terminate the field wires. Another terminating method that has added benefits is to design our control panel with mating connectors so that the field wiring could be plugged into connectors mounted on the panel.

Wiring Recommendations

The following guidelines provide general information on how to wire most automation equipment. For specific information on wiring a particular PLC or device, refer to the installation manual included with your equipment.

- Review terminal connection specifications for capacity - for example, a PLC input module terminal may accept one 16AWG or two 18AWG size wires. Do not exceed the recommended capacity.
- Always use a continuous length of wire. Do not splice wires to attain a needed length.
- Use the shortest possible wire length.
- Use wire trays for routing where possible.
- Avoid running wires near high energy wiring.
- Avoid running input wiring close to output wiring where possible.
- To minimize voltage drops when wires must run a long distance, consider using multiple wires for the return line.
- Avoid running DC wiring in close proximity to AC wiring where possible.
- Avoid creating sharp bends in the wires.
- Install a powerline filter to reduce power surges and EMI/RFI noise.

⚠ **Warning:**

Providing a safe operating environment for personnel and equipment is your responsibility and should be a primary goal during system planning and installation. Automation systems can fail and may result in situations that can cause serious injury to personnel or damage to equipment. Do not rely on the automation system alone to provide a safe operating environment. Use external electro-mechanical devices, such as relays or limit switches that are independent of the automation equipment, to provide protection for any part of the system that may cause personal injury or damage.

⚠ **Warning:**

Every automation application is different. Therefore, there may be special requirements for your particular application. Be sure to follow all National, State, and local government requirements for the proper installation and use of your equipment.

Grounding

Electronic instrumentation such as PLCs and field I/O are typically surrounded by various types of electronic devices and wires. All these may present a risk of Electromagnetic Interference (EMI) or transient interference. This type of interference may cause erratic operation of components and cause failures.

In addition to device interference, automation equipment and devices could be damaged by powerful line surges. These line surges may come from common voltage fluctuations from a power supply, lightning, or unintentional contact with a high voltage line. A power surge will cause a temporary failure, fuse burn-up, or even very serious damage to the equipment.

Grounding provides a low impedance path that limits these voltages and stabilizes interference. Grounding is a must to protect your automation equipment and devices from serious damage, failures, and even potential risk to users.

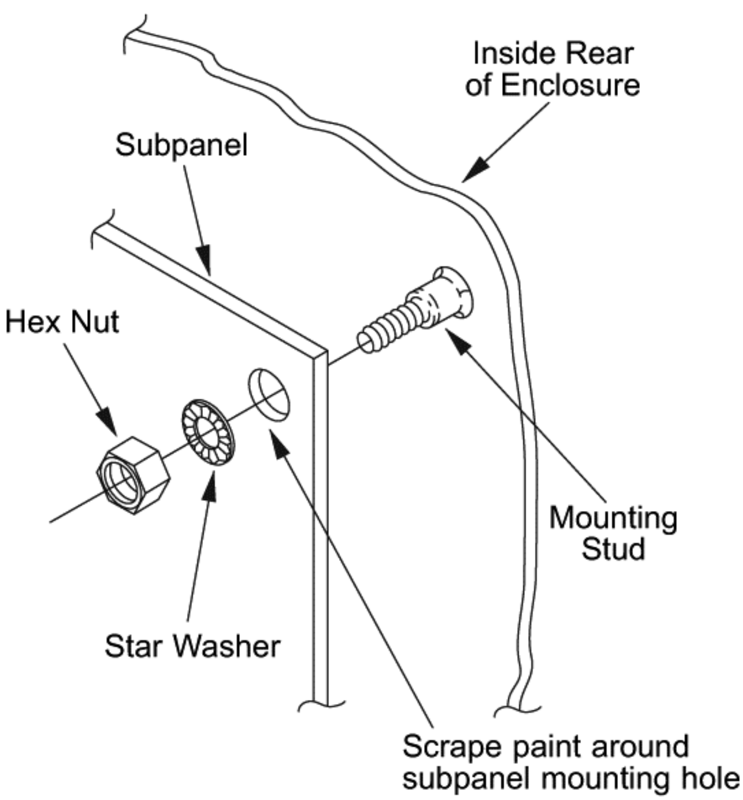
Grounding is the foundation of achieving a reliable power distribution system. During the panel and control system build, it is important that a reliable grounding system be implemented. Poor grounding or improper or defective wiring may be the cause of most problems affecting power quality. The following is a list of existing grounding standards that may be used for reference:

- IEEE Green Book (Standard 142)
- IEEE Emerald Book (Standard 1100)
- UL96A, Installation Requirements for Lighting Protection Systems
- IAEA 1996 (International Association of Electrical Inspectors) Soars Book on Grounding
- EC&M - Practical Guide to Quality Power for Electronic Equipment
- Military Handbook - Grounding Bonding and Shielding of Electronic Equipment

Once all the important considerations mentioned above have been determined, the mounting, bonding, and grounding of the chassis may be started. The following list provides a brief explanation of each of these terms:

- **Mounting:** refers to the actual physical installation of each device, instrument or component to either the subpanel or other connected equipment.
- **Bonding:** refers to the joining of metallic parts of a chassis such as; frames, shields, assemblies and enclosures. Joining or bonding these components properly reduces the interference from EMI and ground noise.
- **Grounding:** refers to a connection to a grounding conductor to provide overload and interference protection.

As mentioned before, grounding protects the instrumentation, devices, or components from power surges and reduces the effect of EMI and ground noise. The below figure shows a typical method for grounding the subpanel to the enclosure cabinet to assure proper grounding.



Note: Please remember that bonding and grounding are important safety requirements that are mandatory by local codes and regulations. The installer must verify the local codes to determine what grounding and bonding methods are permitted. Always make sure that power supplies are properly grounded to ensure elimination of electronic noise interference.

Note: When using ground lugs and installing more than one on the same stud, make sure to install the first lug between two star washers and tie it with a nut. Install the second lug over the nut of the first lug followed by a star washer and another tightened nut.

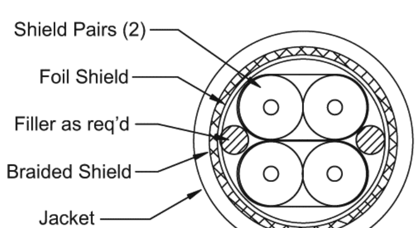
Shielded Cables

A shielded cable is an insulated cable consisting of strands of copper or other material enclosed with a metallic shield underneath a jacketed sheath. Shielded cables are used to reduce the interference from electrical noise.

Some instrumentation requires the use of shielded cables for specific connections. When installing instrumentation, verify whether any connection requires a shielded cable. Failure to use the shielded cable will result in erratic readings or signals from the instrumentation. If the product being installed requires shielded cables, the grounding specifications provided by the manufacturer manual must be followed. Improper installation of shielded cables may cause a ground loop that will cause failure on a processor or would allow noise into the logic circuit.

There are various types of shielded cable available for different uses. The shielded cables listed below are the most commonly used for automation control systems and instrumentation:

- **Foil Shield**: These cables consist of aluminum foil laminated to a polyester or polypropylene film. The film provides mechanical strength and additional insulation. The foil shield provides 100% cable coverage for electrostatic shielded protection. Foil shields are normally used for protection against capacitive (electric field) coupling where shielded coverage is more important than low DC resistance.
- **Braided Shield**: These cables consist of groups of tinned, bare copper, or aluminum strands. One set is woven in a clockwise direction, then interwoven with another set in a counter-clockwise direction. Braided shields provide superior performance against diffusion coupling, where low DC resistance is important, and to a lesser extent, capacitive and inductive coupling.
- **Spiral Shield**: The spiral shield consists of wire (usually copper) wrapped in a spiral around the inner cable core. The spiral shield is used for functional shielding against diffusion and capacitive coupling at audio frequencies only.
- **Combination Shield**: These cables consist of more than one layer of shielding. The combination shield is used to shield against high frequency radiated emissions coupling and electrostatic discharge (ESD.) It combines the low resistance of braid with 100% coverage of foil shields and is one of the more commonly used types of shielded cable in today's industry.



This figure shows a typical cross sectional area of a shielded cable that makes use of combination shields.

Mounting of Electronic Instrumentation

Electronic instrumentation is typically installed inside an enclosure with other devices. Therefore, the installation of the instrumentation must take into consideration that the panel layout accommodates all the necessary components. In addition to the panel layout, the following specifications should be considered:

Electronic instrumentation can be affected by interference from other electronic devices or EMI. This interference causes static that may interrupt communications or signals from other devices. Address these considerations to prevent any possibility of interference with your equipment:

- Environmental specifications that cover the operating temperature, humidity, vibration, noise immunity, etc.
- Power requirements are specific to each piece of equipment. When installing instrumentation always make sure to follow the manufacturer's power requirement guidelines for your specific piece of equipment.
- Use components with Agency Approvals such as UL, CE, etc.
- Make enclosure selections based on component dimensions, recommended mounting clearances, heat dissipation and EMI.

If installing a PLC base or chassis, which consists mainly of mounting, bonding, and grounding, it is very critical to the proper operation of the PLC and its related devices to closely follow the manufacturer's recommendations. There are many cases of a PLC experiencing "noise" problems, when the problem is found to be that the base wasn't grounded to the subpanel.

Wiring and I/O Testing

The last item to consider at the completion of building your control panels is to do a complete I/O checkout. This will assure that the point-to-point wiring between the I/O module terminals and the field wiring terminal blocks has been done correctly.

To start, create a list with each I/O point shown and include any details of what criteria is being tested. It is also helpful to include a check box that can be used to check off each point after it is tested. Normally this list can be created from an I/O list or tag name list that was created when designing your PLC ladder logic or HMI operator interface.

Include the test criteria for each point on the list. As an example, discrete input and output points would be listed as normally “OFF” and then checked for their “ON” state. Analog points, both input and output, could be checked at different values. For example, if using a current input module, you may want to simulate 4mA (low value), 12mA (middle value) and 20mA (high value).

The actual testing normally requires a two-person team. One person uses a PC connected to the PLC to view the status of each point tested and to simulate outputs, and the other person physically applies a signal to inputs and monitors outputs with the use of an indicator on discrete outputs and a meter on analog outputs.

At this point, you can also perform simple testing of your control program by simulating the inputs and ensuring the logic performs as expected.

Learn more about I/O for PLCs

Understand the difference between Discrete I/O and Analog I/O in this blog post!

Visit: [N2ADC.com/ve5cw](N2ADC.com/ve5cw)

CHAPTER

6

Install and Start-up

Install

It all comes together!

Our control system may be installed by a combination of contractors and in-house personnel. Personnel will need access to our schematics/wiring diagrams, as well as installation drawings showing the physical locations and mechanical requirements for all field devices. These drawings should include notations for mounting, type of conduit and wire, etc. Field devices such as sensor and motors would typically be installed by mechanical specialists and wired by electrical specialists. Power and field wiring would then be run through conduit or wireways and terminated at the control locations (our enclosures containing the PLC, I/O, or hardwired control devices).

> “I love it when a plan comes together.”
>
> - John “Hannibal” Smith

Plan for Safety

As we have stressed, the best way to provide a safe operating environment is to make personnel and equipment safety part of the planning process. Examine every aspect of the system to determine which areas are critical to operator or machine safety.

If you are not familiar with system installation practices, or your company does not have established installation guidelines, you should obtain additional information from the following sources:

NEMA: The National Electrical Manufacturers Association, located in Washington, D.C., publishes many different documents that discuss standards for industrial control systems. You can order these publications directly from NEMA. Some of these include:

- ICS 1: General Standards for Industrial Control and Systems
- ICS 3: Industrial Systems
- ICS 6: Enclosures for Industrial Control Systems

NEC: The National Electrical Code provides regulations for the installation and use of various types of electrical equipment. Copies of the NEC Handbook can often be obtained from your local electrical equipment distributor or your local library.

Local and State Agencies: Many local governments and state governments have additional requirements above and beyond those described in the NEC Handbook. Check with your local Electrical Inspector or Fire Marshal office for information.

Start-up

The Moment of Truth!

The startup of our automated control system begins once we have installed our control system enclosure and auxiliary equipment, terminated all field wiring, and completed required testing. This process is also called “commissioning” the automated control system and related equipment/process.

As a starting point, it is best to isolate the various sections of our control system power wiring by removing the fuses and/or opening circuit breakers. The best tool to use during commissioning is the schematic diagrams. We will want to start at the incoming power, and basically work our way through the entire schematic.

As a first step, we may want to apply power to the main circuit breaker or fused disconnect of our control system. Then, measure the voltage for proper values, phase-to-phase and each phase-to-ground, if the incoming power is three phase. Next, we can turn on the main circuit protector and check the voltage at each device that is fed from the main source. Then start turning the circuit breakers on or replace the fuses one circuit at a time and make additional voltage checks as well as test equipment operation that may be powered from the circuit.

Keep in mind that every control system will not be the same. Therefore, each system will require a different strategy to bring the equipment online safely. Consider having motors uncoupled from their respective loads, air pressure off, disabling hydraulics, and using Lockout/Tagout (LOTO) procedures. Measure voltages as you go. If using a PLC, connect a PC to it and monitor the I/O to make sure their states are responding correctly. During this time it is best to have a null (empty) program in the PLC so you do not energize actual equipment while continuity testing is in progress.

Once you have tested electrical continuity and corrected any wiring errors or problems, you can connect all uncoupled devices and load the control program into the PLC.

Testing the logic of your program should be done with safety in mind. If you will be energizing live loads as you test, ensure all personnel are aware and a technician is physically observing operations in the event of a malfunction or incorrect programming. You may want to disable all outputs and enable one section of the program at a time to test.

CHAPTER

7

Maintain

Maintain

Keeping your Baby Running!

It is important to develop a routine maintenance schedule for your automated control system. Having a routine schedule for checking critical components and devices in the system will increase the longevity of the system and more importantly, it will help reduce future problems. Set up the schedule based on a monthly or quarterly time period, depending on the item to be done. The following are some of the items you may want to consider in your maintenance schedule:

- ❑ Check and record voltages at various circuits
- ❑ Tighten all connections (with power removed)
- ❑ Check backup batteries, and/or replace on a routine schedule
- ❑ Check indicators and perform lamp tests
- ❑ Visually inspect for loose or frayed wiring, moisture in enclosure, etc.
- ❑ Check to make sure plug-in connectors are tight and secured
- ❑ Test all alarm systems, horns, sirens, etc.
- ❑ Check and record any configuration settings
- ❑ Perform and record calibrations
- ❑ Check all I/O points on a yearly basis
- ❑ Check and record power usage
- ❑ Check equipment run times for determining maintenance or replacement
- ❑ Measure device current to set a benchmark and compare for changes
- ❑ Review any diagnostic history, including events and alarms
- ❑ Check diagnostics that may be programmed into the HMI operator interface

This wraps up this eBook on automated control system specification, design and installation. We hope you have found this information useful. I know that you're sad that our time together has come to an end, but take heart because there is plenty more where this came from. Just visit us at AutomationDirect.com/Newsletter to sign up for our newsletter and you will be the first to get all the goodies from AutomationDirect.com.

This eBook is based on an article series featured in our AutomationNotebook entitled A Condensed Guide to Automation Control System Specification. Written by Tom Elavsky.

Appendix

AKA Awesome Stuff to help you out!

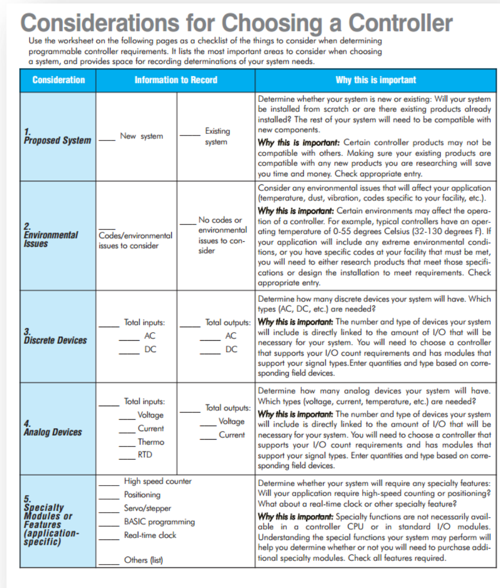
Steps for Choosing a Controller

Choosing the most effective controller for your application depends on a number of factors. Use the steps below to help you know what to consider when determining programmable controller requirements. You can download a PDF worksheet with space for recording determinations for your system by visiting N2ADC.com/l8jv4

Step 1:

Determine whether your system is new or existing: Will your system be installed from scratch or are there existing products already installed? The rest of your system will need to be compatible with new components.

Why this is important: Certain controller products may not be compatible with others. Making sure your existing products are compatible with any new products you are researching will save you time and money. Check appropriate entry.



Considerations for Choosing a Controller

Use the worksheet on the following pages as a checklist of the things to consider when determining programmable controller requirements. It lists the most important areas to consider when choosing a system, and provides space for recording determinations of your system needs.

Consideration	Information to Record		Why this is important
1. Proposed System	___ New system	___ Existing system	Determine whether your system is new or existing: Will your system be installed from scratch or are there existing products already installed? The rest of your system will need to be compatible with new components. ***Why this is important:*** Certain controller products may not be compatible with others. Making sure your existing products are compatible with any new products you are researching will save you time and money. Check appropriate entry.
2. Environmental Issues	___ Codes/environmental issues to consider	___ No codes or environmental issues to consider	Consider any environmental issues that will affect your application (temperature, dust, vibration, codes specific to your facility, etc.). ***Why this is important:*** Certain environments may affect the operation of a controller. For example, typical controllers have an operating temperature of 0-55 degrees Celsius (32-130 degrees F). If your application will include any extreme environmental conditions, or you have specific codes at your facility that must be met, you will need to either research products that meet those specifications or design the installation to meet requirements. Check appropriate entry.
3. Discrete Devices	___ Total inputs: ___ AC ___ DC	___ Total outputs: ___ AC ___ DC	Determine how many discrete devices your system will have. Which types (AC, DC, etc.) are needed? ***Why this is important:*** The number and type of devices your system will include is directly linked to the amount of I/O that will be necessary for your system. You will need to choose a controller that supports your I/O count requirements and has modules that support your signal types.Enter quantities and type based on corresponding field devices.
4. Analog Devices	___ Total inputs: ___ Voltage ___ Current ___ Thermo ___ RTD	___ Total outputs: ___ Voltage ___ Current	Determine how many analog devices your system will have. Which types (voltage, current, temperature, etc.) are needed? ***Why this is important:*** The number and type of devices your system will include is directly linked to the amount of I/O that will be necessary for your system. You will need to choose a controller that supports your I/O count requirements and has modules that support your signal types. Enter quantities and type based on corresponding field devices.
5. Specialty Modules or Features (application-specific)	___ High speed counter ___ Positioning ___ Servo/stepper ___ BASIC programming ___ Real-time clock ___ Others (list)		Determine whether your system will require any specialty features: Will your application require high-speed counting or positioning? What about a real-time clock or other specialty feature? ***Why this is important:*** Specialty functions are not necessarily available in a controller CPU or in standard I/O modules. Understanding the special functions your system may perform will help you determine whether or not you will need to purchase additional specialty modules. Check all features required.

Step 2:

Consider any environmental issues that will affect your application (temperature, dust, vibration, codes specific to your facility, etc.).

Why this is important: Certain environments may affect the operation of a controller. For example, typical controllers have an operating temperature of 0-55 degrees Celsius (32-130 degrees F). If your application will include any extreme environmental conditions, or you have specific codes at your facility that must be met, you will need to either research products that meet those specifications or design the installation to meet requirements. Check appropriate entry.

Step 3:

Determine how many discrete devices your system will have. Which types (AC, DC, etc.) are needed?

Why this is important: The number and type of devices your system will include is directly linked to the amount of I/O that will be necessary for your system. You will need to choose a controller that supports your I/O count requirements and has modules that support your signal types. Enter quantities and type based on corresponding field devices

Step 4:

Determine how many analog devices your system will have. Which types (voltage, current, temperature, etc.) are needed?

Why this is important: The number and type of devices your system will include is directly linked to the amount of I/O that will be necessary for your system. You will need to choose a controller that supports your I/O count requirements and has modules that support your signal types. Enter quantities and type based on corresponding field devices

Step 5:

Determine whether your system will require any specialty features: Will your application require high-speed counting or positioning? What about a real-time clock or other specialty feature?

Why this is important: Specialty functions are not necessarily available in a controller CPU or in standard I/O modules. Understanding the special functions your system may perform will help you determine whether or not you will need to purchase additional specialty modules. Check all features required..

Step 6:

Determine the type of CPU you will need: How much memory will your system require? How many devices will your system have (determines data memory)? How large is your program, and what types of instructions will your program include (determines program memory)? How fast a scan time do you need?

Why this is important: Data memory refers to the amount of memory needed for dynamic data manipulation and storage in the system. For example, counter and timer instructions typically use data memory to store setpoints, current values, and other internal flags. If the application requires historical data retention, such as measured device values over a long period of time, the size of the data tables required may determine the CPU model you choose. Program memory is the amount of memory needed to store the sequence of program instructions that have been selected to perform the application. Each type of instruction requires a specific amount of program memory, typically defined in a programming manual. Applications that are basically sequential in nature can rely on the I/O device rule of thumb to estimate program memory (five words of memory for each I/O device); complex applications will be more difficult to judge.

If scan time is important in your application, consider the CPU processor speed as well as instruction execution speed. Some CPUs are faster at boolean logic but slower with data handling instructions.

If special functions such as PID are required, the CPU you select may make those functions easier to perform. For program memory required, follow this rule of thumb: 5 words of program memory for each discrete device and 25 words for each analog device. Check or calculate all requirements that apply.

Step 7:

Determine where your I/O will be located: Will your system require only local I/O, or both local and remote I/O locations?

Why this is important: If subsystems will be needed at long distances from the CPU, you will need a controller that supports remote I/O. You will also have to determine if the remote distances and speeds supported will be adequate for your application. Serial and Ethernet-based I/O hardware are two typical choices available for most systems. This I/O may also be referred to as distributed I/O, and may require a particular protocol, such as Modbus.

Step 8:

Determine your communication requirements: Will your system be communicating to other networks, systems or field devices?

Why this is important: Communication ports (other than the programming port) are not always included with a controller. Knowing your system communication requirements will help you choose a CPU that supports your communication requirements, or additional communication modules if necessary. Check any/all communications.

Step 9:

Determine your programming requirements: Does your application require only traditional programming instructions, or are special instructions necessary?

Why this is important: Certain controllers may not support every type of instruction. You will need to choose a model that supports all instructions that you may need for a specific application. For example, built-in PID functions are much easier to use than writing your own code to perform closed-loop process control. Typical instructions such as timers, counters, etc. are available in most controllers; note any other special instructions required here. Check any/all programming functions required.

Download a PDF worksheet with space for recording the determinations for your system by visiting [N2ADC.com/l8jv4](N2ADC.com/l8jv4)

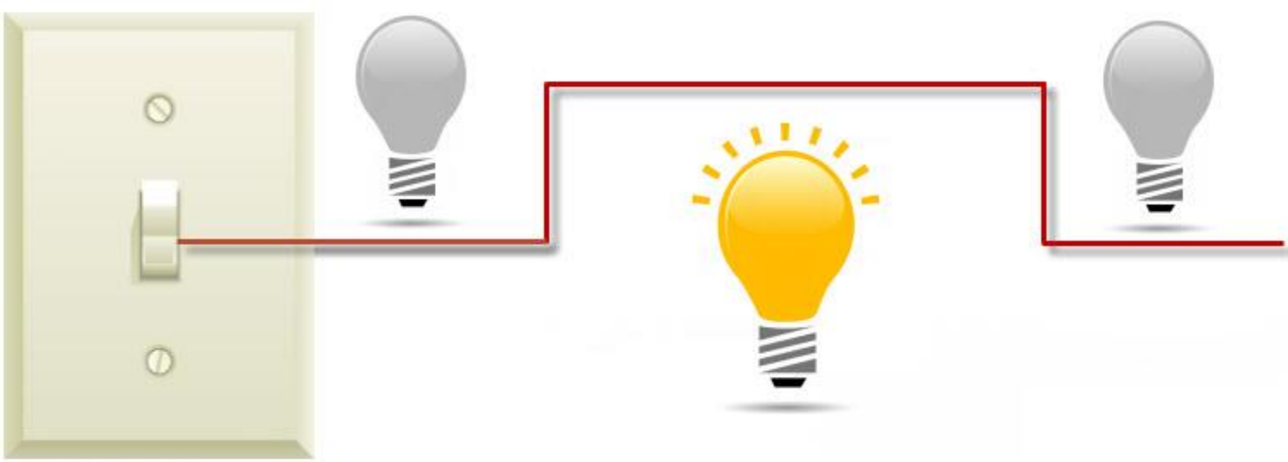
Understanding Discrete and Analog I/O

So what do you think, is this glass half full or half empty? For me, that could be a little difficult to answer and could vary based on the day I'm having, but if we are asking about the level, why not let the PLC answer? In fact, why not have the PLC tell us the level, the temperature of the water, the flow rate at which it was filled, the available capacity of the glass and the pressure exerted on the bottom?

Ok, normally you wouldn't use a PLC for such a small application, but on a larger scale, say a reservoir, it is possible for the PLC to answer all of those questions. But how can we make the PLC even "see" this reservoir, let alone tell us how full it is? Well I'm glad you asked, or I asked, or whatever. We need a device that can allow the PLC to take information in from its surroundings and process it. We also need a device that will allow the PLC to affect its surroundings as needed. What we need is I/O, and what I mean by I/O is Inputs and Outputs. For this discussion, we'll focus on the two main types of I/O: analog and discrete.

Discrete I/O

Let's take the simplest first, discrete. Discrete signals are signals that are either on or off, true or false. Think of a light switch in your house. The switch either turns the light on or it turns it off, unless it is a florescent tube – then it's probably still blinking. Because discrete signals exist in one of these two states, they are represented with a square wave as seen below.



In the PLC world, there are many uses for discrete I/O. Some of the devices that supply on/off signals are pushbuttons, photoeyes, limit switches, float switches and proximity switches. In my startup days, I did a lot of work with a certain parcel service. They use a lot of on/off sensing and control in order to track packages and get them to the right destination or truck. Photoeyes, which are devices that emit an infrared light beam and can sense when that beam has been broken, are used extensively to detect and track packages through their sorting process. The application of your control system will determine the types of discrete devices you choose. There are a variety of discrete end devices and modules that can be used in a PLC system to send and receive on/off signals. These devices can be AC or DC and are available in different voltage ranges. 0-24VDC and 0-230VAC are two voltage ranges available, with 0 being the OFF signal and 24VDC or 230VAC being the ON signal. Usually there is a threshold for detection, where the 0-24VDC module will detect anything over 22VDC as the ON signal and anything below 2VDC as the OFF. Now let's look at analog.

Analog I/O

Analog signals are signals that can vary or change. We live in an analog world and our senses are analog receivers. "Feel how hot it is!", "Can you speak up?" and "Look at all the colors!" are statements that show how the variation in analog signals like temperature, sound, and light can affect our senses. Back to the light switch example; let's now install a little mood lighting in our home. Instead of the regular on/off switch we are going to use a dimmer switch. The dimmer switch will vary the resistance in the line, causing the light to dim or brighten as we choose. Newer dimmer switches have advanced to be more efficient but for this example we are going old school. The voltage supplied to the light will not be a constant level but a changing one set between the upper and lower limits. This is usually represented by a sine wave.

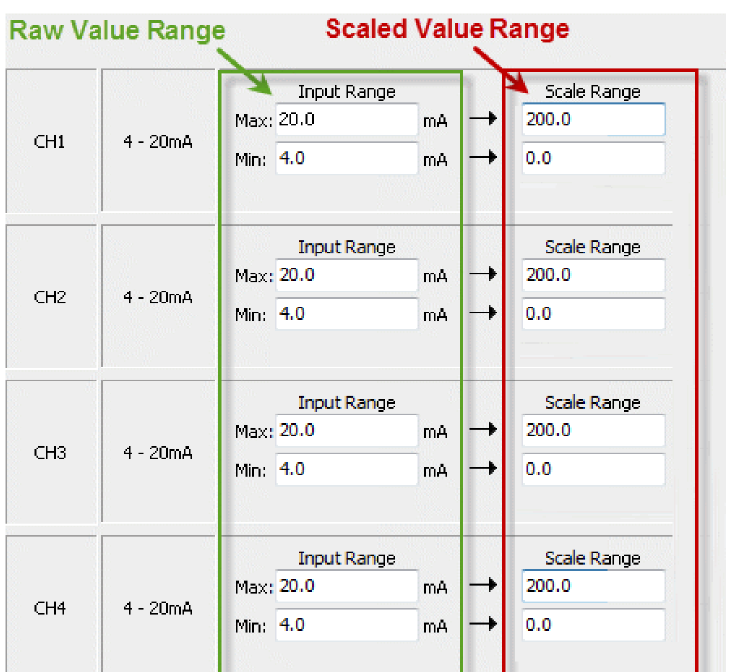
Using Transducers

Position, level, temperature, pressure, flow and speed are just some of the measurements that analog devices can provide to a control system. You are probably asking yourself: "How does pressure, which is a physical quantity, become an electrical signal?" That is a great question! The conversion is done using transducers. A transducer will take a physical quantity like pressure and convert it to an electrical signal. A lot of transducers use the physical quantity to control the resistance in the electrical circuit. For example, an RTD (Resistance Temperature Detector) will change its resistance value based on heat. As heat increases so does the resistance in the circuit, altering the supplied voltage or current. Same holds true for pressure transducers that use strain gauges. As pressure is applied to the strain gauge, the resistance in the circuit goes up and the voltage or current level changes. Some flow detectors will use the flow of a fluid to push a fin that is connected to a rotary potentiometer. Faster flow equals more resistance change. One of the coolest transducers that I ran across in my days working in the offshore oil industry was the sand detector. This transducer was acoustic and was attached to pipes that were drawing oil out from the sea floor. It would actually listen for sand rubbing against the inside of the pipe. The amount of sound was converted into an analog signal used to alert personnel if the drilling was drawing out too much sand, which could collapse the well.

The electrical signals that transducers provide can be voltage or current based. 4 to 20mA, 0 to 20mA, 0 to 10VDC and -10 to +10 VDC are a few of the available ranges produced by transducers. The PLC supplies the voltage or current and the transducer will return a value in its configured range. That value will be proportional to the amount of pressure, flow, etc. that is present. We now arrive at two important parts of this discussion: scaling and resolution.

Scaling

Scaling is when we take the raw voltage or current value returned and translate it into a meaningful measurement. Let's say I have a 4-20mA flow meter that is returning an 8mA signal to the PLC. That would mean that 8mA of fluid is flowing at this time, right? Of course not. We need to take the raw value and scale it to something meaningful, let's say gallons per minute. We know from the manufacturer that the flow meter is calibrated to read a flow of 0 to 200 gpm. Therefore, we can scale the raw value 4-20mA to equal 0-200 gpm in our system. Normally, this can be done using the programming software, as seen below, and after our value of 8mA is scaled we see that there is currently a flow of 50 gallons per minute.

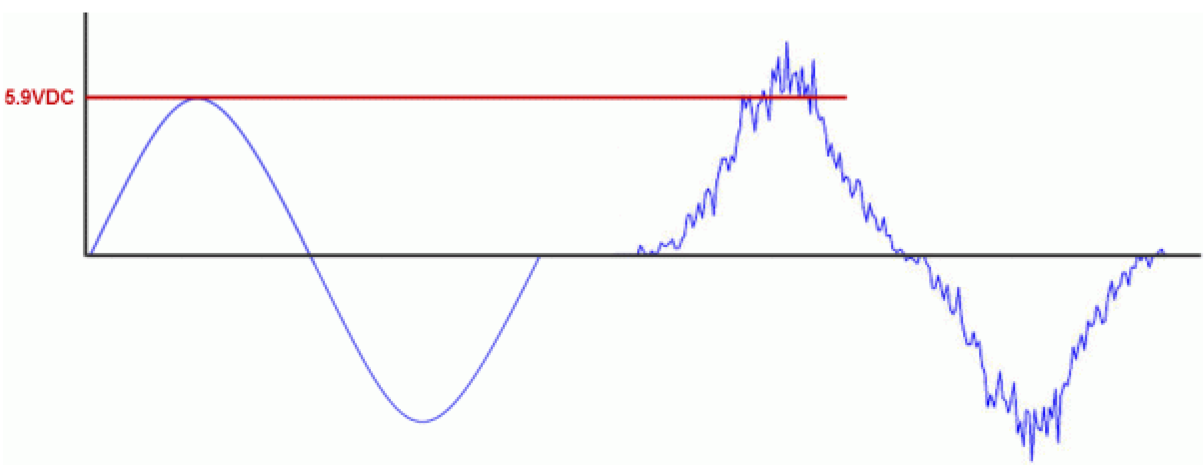


Resolution

Now let's look at resolution. Resolution and accuracy go hand in hand; the more resolution you have, the more accurate your measurement will be. Analog modules are rated with the resolution they provide. 12-bit, 13-bit and 16-bit resolutions are a few that are available. So what does it mean to have a 4-20mA module with a 12-bit resolution? A 12-bit binary word can have 4096 different combinations. Therefore, our module with a 12-bit resolution can have 4096 (4095 with a sign) different measurements within the 4-20mA range. In other words, the 4-20 range can be broken into 4096 different pieces. The more pieces, the more accurate. How accurate? Well, our total range is 16mA (20 minus 4) and if we divide our total range by 4096 pieces, we see that our module can detect each 0.00390625mA of change.

Noise

One last thing, when using analog signals it is important to remember that they are highly susceptible to noise. Noise can cause wrong readings and erratic behavior in a control system. Take a look at the diagram below. My system will open a pressure relief valve on a tank when the raw pressure signal from inside the tank reaches 5.9VDC. With the returning signal on the left that's no problem. With the noise induced on the right, good luck!

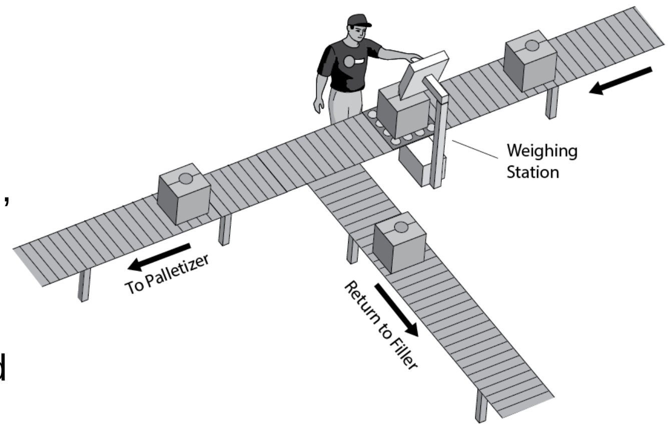


Equipment Specification Template

So you found a task that you'd like to automate but you need a way to sort out what pieces are needed and how they fit together. At this phase of development, organization is key. When specifying a project, staying organized can keep you on track and help you see the big picture. Flow charts, graphs and spreadsheets are a few tools that can not only help you visualize the process but also track your progress.

So, how about an example:

To the right, you see the bulk shipping conveyor line for a factory. What is this factory producing? Well, this is our example so it can be anything you choose. Since I like to eat, especially the sweet stuff, my factory is producing candy bars, and boy, are they delicious!

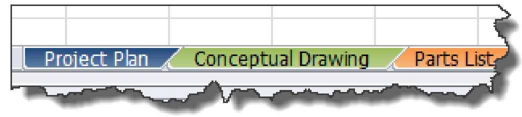


Chad here has the important task of verifying that each of the boxes leaving the factory is filled with the appropriate amount of candy bars. Each box will hold 150 bars. We don't expect Chad to count each candy bar, so he uses a scale to weigh each box. As the filled boxes come down the line, he stops the conveyor, weighs the box and if correct, sends the box on to our palletizing system. The boxes are then put on pallets and shipped to our major customers. If the box is not the right weight, then Chad will send the box back to the filling station. This process works, but it is slowing down our delivery time. In order to stay competitive we need to get these candy bars out as quickly as possible, so we decide to automate.

Below is an example of how the automation will work and the planning involved. First, the static scale will be replaced with a conveyor scale so we can alleviate the belt stoppages. The conveyor scale will communicate with a PLC (programmable logic controller) inside of our control enclosure. The scale will inform the PLC when a box is present, the weight of the box and when the box has cleared the scale. The PLC will then determine if the box needs to go back to be refilled or not. If it does need to be refilled, a diverter arm will extend and guide the box to the recirculating conveyor belt.

Using the Equipment Specification Template

In order to stay organized as we specify equipment for our example project outlined above, we have put together a spread sheet with three different tabs.

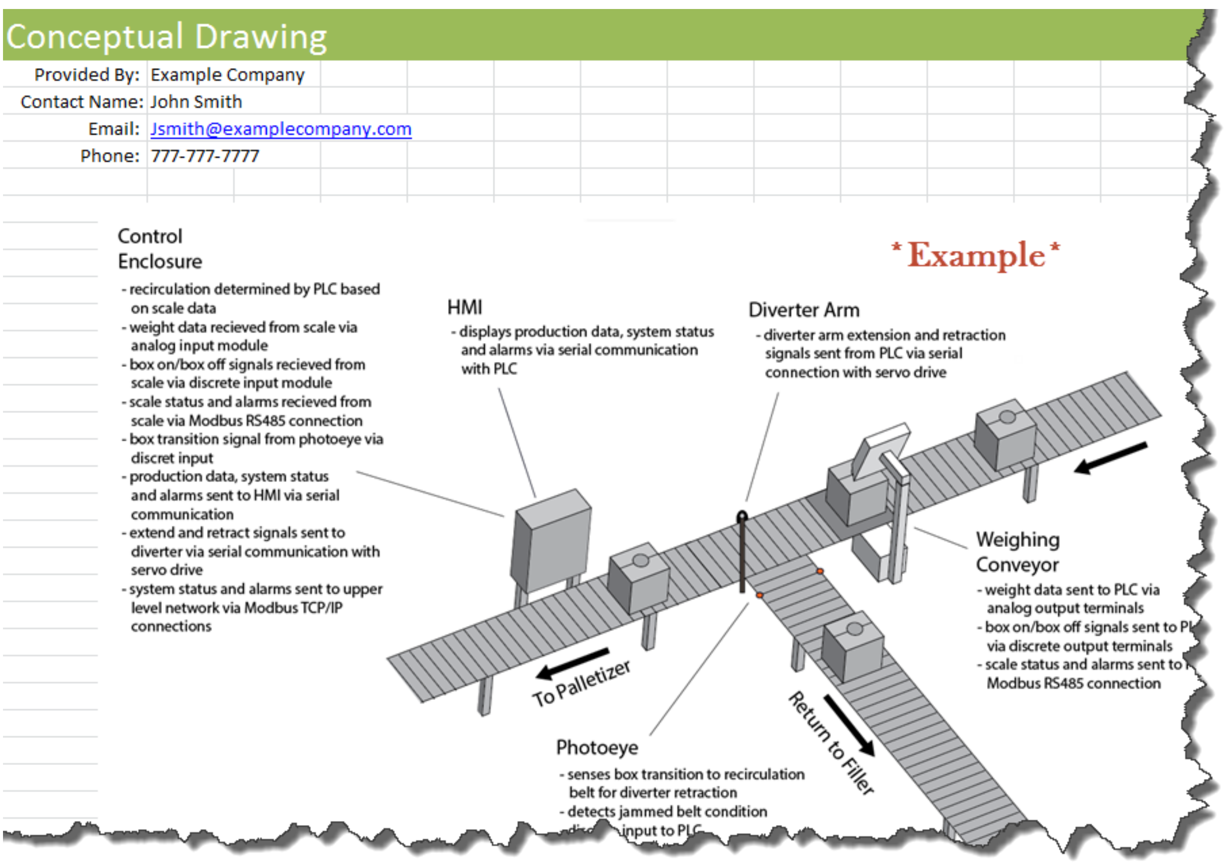


We have labeled our tabs: Project Plan, Conceptual Drawing, Parts List. Let's take a look at each of these tabs; if you would like to follow along you can download our example template by [clicking here.]

<u>Project Plan</u>: On this tab we included the high-level information that we needed to ensure that everyone was aware of what was included in this project. We gave the project a name, we described it, and outlined the plan. Next we pointed out some important requirements that our system will have to conform to. We point out Environmental Concerns, System Power Constraints, Scan Time/High-Speed Requirements, and the Network Protocol. (Note that depending on your project and environment you might need to highlights some additional requirements, but for our example we will keep it simple.)

Project Name:	Example Candy Bar Shipping Prep Improvement	
Project Sponsor or lead Engineer:	John Doe	
Estimated Completion date:	TBD	
oject Description	Project Plan	Environmental
ere: *the verification process of a bulk rification is accomplished by t is shipped. Process is too time to be automated.*	Your project plan will go here: *Example: Alleviate the time needed to weigh each package by installing a conveyor scale system and adding a PLC controlled diverter for refilling needs. System will also detect jams on recirculation belt, track the number of recircs and track the total number shipped.*	Your enviromental concerns will *Example: System will be located in warehouse. No exposure to eleme hazardous location (explosion p waterproofing or wash-down req and debris from packaging.*

<u>Conceptual Drawing</u>: Our next tab is dedicated to our conceptual drawings. Drawings are a very important part of our planning process because it takes what is in your mind and lays it out so others can see it. This help to ensure that everyone is on the same page but it also helps us to identify any needs or problems that we might not have otherwise seen.



Parts List: On the parts list tab we have taken the time to list out all the parts we think are needed for this project. We also took the time to list the specifications, part number and a link to for each part. This tab serves multiple functions. First, while filling it out, it will help trigger things in your mind you forgot you would need. Also it will help ensure that come installation day you don't have to halt all work to order another part. Additionally, by providing specifications and links for all part numbers you can refer to this list in the future if you need to find replacement parts or technical documentation.

Parts List

Preferred Vendor:	www.AutomationDirect.com			
Date Compiled:	9/1/2014			
Purchasing Agent:	Frank Smith			
Power Supply	Signal	Part Number	Company	Specifications
Example: 24VDC Power Supply		*PSB24-480*	*www.AutomationDirect.com*	*24VDC out, 85-264 VAC in, protection.*
Add other parts here...				
Add other parts here...				
Input Devices	Signal	Part Number	Company	Specifications
Example: Analog In	*weight data, scaled 4-20ma = 0-50lbs*	*F2-041D-1*	*www.AutomationDirect.com*	*4-channel analog input mo*
Add other parts here...				
Add other parts here...				
Output Devices	Signal	Part Number	Company	Specifications
Example: Discrete Out	*horn/stacklight*	*D2-04TD1*	*www.AutomationDirect.com*	*4-point 12-24 VDC current si terminals), 4.0A/point, 8.0*
Add other parts here...				
Add other parts here...				
Processing Unit	Signal	Part Number	Company	Specifications

Conclusion

Device specification is a major part of the automating process but it is only a part. Because of that, the devices chosen at this point are not concrete. In later phases of development, issues may arise that can cause the choices made here to change. One final thought on system specification; when specifying a system always plan for safety, use redundancy where needed and consider future expansion possibilities.

Download Template at: N2ADC.com/yknp2

Specifying and Sizing Motor Starters

There are four basic motor control options available: Basic contactors, traditional starters, manual motor starters, or combination starters. A basic contactor is a special purpose relay that is used to control large electrical currents. Similarly, a traditional starter utilizes overload relays, auxiliary and alarm contacts, and mechanical interlocks to create a reversing unit. On the other hand a manual motor starter is a protective device for motor use that provides optimal protection by integrating the functions of a molded case circuit breaker and thermal overload relay into a compact unit. In comparison, a combination starter is comprised of combining a manual motor starter and a magnetic contactor to achieve a compact motor control that minimizes enclosure space requirements.

Simply follow these 3 steps to choose the best fit.

1. What Does the Application Require

Basic Contactors Only

Contactor

Typical Applications:

- Electronic switching
- Lighting
- Resistive loads
- Non-motor-related inductive loads
- Disconnect switches
- VFD bypass/isolation

Traditional Starters

Contactor & Overload Relay

Typical Applications:

- Inductive motor starting and control
- NEC 430 and 409 fulfillment
- Nm starter replacement/ retrofit

Manual Motor Starters

Manual Motor Starters(MMS)

Typical Applications:

- Inductive motor starting and manual control
- NEC 430 fulfillment
- Lockout/tagout
- UL 508, Type E
- Not AC-4 rated

Combination Starters

Manual Motor Starter, Contactor, Link Module, and Base Plate

Typical Applications:

- Inductive motor starting and control
- NEC 430 and 409 fulfillment
- Lockout/tagout
- UL 508, Type F

2. Consider These Factors When Selecting Components:

- Load type: Resistive (AC-1) or inductive (AC-3)
- Duty cycle: One direction, reversing, plugging (AC-4)
- Horsepower (hp) and full load amperage (FLA)

3. Select Your Components.

Parts listed here are Fuji Electric motor controls components available at www.AutmationDirect.com/Motor-Controls.

Basic Contactors Only	Traditional Starters	Manual Motor Starters	Combination Starters
Duo Series *SC-E Contactor* • 1/2 to 100 hp @ 480 V • 9-150 A (AC-3) ***Odyssey Series*** *3N Contactor* • 60 to 300 hp • 180-361 A (AC-3)	***Duo Series*** *SC-E Contactor* *TK-E Overload Relay* • 1/2 to 100 hp @ 480 V ***Odyssey Series*** *3N Contactor* *3N Overload Relay* • 60 to 300 hp	***Duo Series*** *BM3 Manual Motor Starter* • 1/2 to 100 hp @ 480 V	***Duo Series*** *BM3 Manual Motor Starter* *SC-EContactor BZ0L Link Module* *BZ0BP Base Plate* • 1/2 to 100 hp @ 480 V

If you would like to learn more visit www.AutomationDirect.com/motor-controls.

What photoelectric sensor is best for me?

There are many different styles of photoelectric sensors, but really only four basic technologies: through-beam, reflective, diffuse, and background suppression. The chart describes some advantages and disadvantages of each technology.

Type	Advantages	Disadvantages
Through-beam	• Most accurate • Longest sensing range • Very reliable	• Must install at two points on system: emitter and receiver • Costly – must purchase both emitter and receiver
Reflective	• Cost less than through-beam • Only slightly less accurate than through-beam • Sensing range better than diffuse • Very reliable	• Must install at two points on system: sensor and reflector • Slightly more costly than diffuse • Sensing range less than through-beam
Diffuse	• Only install at one point • Cost less than through-beam or reflective	• Less accurate than through-beam or reflective • More setup time involved
Background Suppression	• Effective with reflective backgrounds	• Cost more than diffuse, reflective or through-beam • Most setup time required

If you would like to learn more visit www.AutomationDirect.com/Photoelectric.

Choosing the Right Proximity Sensor

Proximity sensors allow non-contact detection of objects. Therefore, they are used in many industries, including manufacturing, robotics, semiconductor, and many more. Inductive sensors detect metallic objects while capacitive sensors detect all other materials. Ultrasonic sensors detect all materials by using sound wave reflections to determine presence.

All applications have certain specific needs, but, in general, the following steps will help you choose the correct sensor for your application:

Step 1:

What is the sensing distance required?

The sensing distance is the distance between the tip of the sensor and the object to be sensed. In our catalog, the selection guide and the specifications table for each sensor family lists the sensing distances.

Some things to keep in mind are:

A. In many applications, it is beneficial to place the sensor as far as possible from the sensing object due to temperature concerns. If a sensor is placed too close to a hot temperature source, the sensor will fail quicker and require more maintenance.

Greater distance may be achieved with extended and triple range sensors. In many applications, a sensor may not be mountable close to the sensed object. In this case, longer sensing distances are needed. For example, AutomationDirect extended sensing distance sensors are offered in 8mm to 30mm diameters, and triple sensing distance sensors in 8mm and 12mm formats.

In many cases, using an extended distance sensor to get the sensor farther away from the detected object can be beneficial to the life of the sensor. For example, without an extended distance sensor you may not be able to place the sensor far enough away from the detectable object, or you may need to buy more expensive high temperature sensors. Another example would be a mechanical overshoot situation, where mounting the sensor farther from the detection object may eliminate unneeded contact with the sensor, thereby extending the life of the sensor.

These are just a few examples, but the benefits of using extended distance sensors are obvious in many applications. Think of how extended distance sensors could save you time and money in your application.

B. The material being sensed (i.e. brass, copper, aluminum, steel, etc.) makes a difference in the type of sensor needed.

Note: If you are sensing a non-metallic object, you must use a capacitive sensor.

The sensing distances we specified in our catalog were calculated using FE360 material. Many materials are more difficult to sense and require a shorter distance from the sensor tip to the object sensed.

If sensing a material that is difficult to sense, you may consider using our unique stainless steel sensing technology. This will measure virtually all materials at the specified distances.

Step 2:

How much space is available for mounting the sensor?

Have you ever tried using a round sensor or short body version, and not been able to make it fit? Rectangular sensors can meet your needs. The same technology used in a standard round proximity sensor is enclosed in a rectangular housing. This technology includes sensing distances, electrical protection and switching frequencies similar to round sensors.

Step 3:

Is a shielded or unshielded sensor needed?

Shielded and unshielded sensors are also referred to as embeddable and non-embeddable. Unshielded sensors allow longer sensing distances but shielded sensors allow flush mounting.

Step 4:

Consider environmental placement concerns.

Will the sensor be placed underwater, in a high-temperature environment, continually splashed with oil, etc.? This will determine the type of sensor you may use. In the selection table and in the specification tables for each sensor family in our catalog, we list the environmental protection degree ratings. Most of our sensors are rated IEC-IP67 and others are rated IP65 or IP68; we also carry a range of IP69K rated sensors for harsh conditions.

- **IP65**: Protection from live or moving parts, dust, and protection from water jets from any direction.
- **IP67**: Protection from live or moving parts, dust, and protection from immersion in water.
- **IP68**: Protection from live or moving parts, dust, and protection from submersion in water under pressure.
- **IP69K**: Protection against high-pressure/steam-jet cleaning.

Step 5:

What is the sensor output connected to?

Note: If using AC sensors, please skip this step.
The type of output required must be determined (i.e., NPN, PNP or analog). Most PLC products will accept any output. If connecting to a solid state relay, a PNP output is needed.

Step 6a:

Do I need 2, 3, or 4-wire discrete outputs?

This is somewhat determined by what the sensor will be connected to. Some simple guidelines to use are:

Type	Guidelines
2-wire	• Will work with sinking or sourcing . . . devices. • Only 2 wires to terminate. • Higher leakage current.
3-wire	• Most popular output. Familiar to most users. (Must select between NPN and PNP outputs.)
4-wire	• Allows configurability in one device. . . May have both NPN/PNP selection or NO/NC selection. Allows user to stock one part for numerous applications.

Step 6b:

Do I need analog outputs?

This is determined by the sensor application and what the sensor will be connected to. Sensors with analog outputs produce an output signal approximately proportional to the target's distance from sensor.

If you only need to sense presence of an object, you do not need an analog output. Note that many discrete-output proximity sensors come with "adjustable" ranges, i.e. "adjustable from 20-80 mm". This means only that you can set the target distance for presence detection within that range; it does not mean you are getting a variable output.

Step 7:

Determine output connection type.

Do you want an axial cable factory attached to the sensor (pigtail) or a quick-disconnect cable?

There are many advantages to using a quick-disconnect cable, such as easier maintenance and replacement. All proximity sensors will fail in time and using a Q/D (quick-disconnect) cable allows for simple replacement. Factory attached axial cables come in a 2 meter length. In our catalog, CD08/CD12 Q/D cables come in 2 meter, 5 meter, and 7 meter lengths. Extension cables are available in 1 meter and 3 meter lengths to extend the length of the standard Q/D cables.

Q/D cables are offered in PVC and PUR jackets for meeting the requirements of all applications. Axial cables typically come with a PVC jacket. PVC is a general purpose insulation while PUR provides excellent oxidation, oil and ozone resistance. PUR is beneficial if the cable is exposed to oils or placed in direct sunlight.

There are also advantages to a factory attached axial cable:

- **Cost**: The cable is integrated into the sensor and included in the price. Q/D cables must be purchased separately.

- **Environmental Impact:** Since the cable is sealed into the sensor, there is less chance of oil, water or dust penetration into the sensor, which could cause failure.

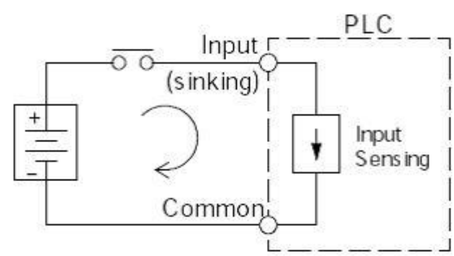
If you would like to learn more visit N2ADC.com/4iiuk

Sinking and Sourcing Concepts

When choosing the type of input or output module for your PLC system, it is very important to have a solid understanding of sinking and sourcing concepts. Use of these terms occurs frequently in discussion of input or output circuits. It is the goal of this section to make these concepts easy to understand, so you can make the right choice the first time when selecting the type of I/O points for your application. This section provides short definitions, followed by general example circuits.

First you will notice that the diagrams on this page are associated with only DC circuits and not AC, because of the reference to (+) and (-) polarities. Therefore, sinking and sourcing terminology applies only to DC input and output circuits. Input and output points that are sinking or sourcing can conduct current in one direction only. This means it is possible to connect the external supply and field device to the I/O point, with current trying to flow in the wrong direction, and the circuit will not operate. However, the supply and field device can be connected correctly every time based on an understanding of sourcing and sinking.

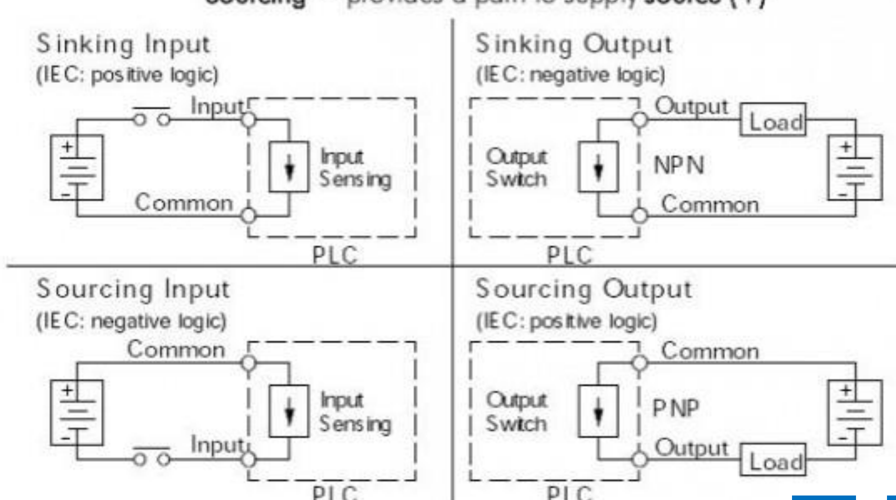
The figure to the right depicts a sinking input. To properly connect the external supply, it must be connected so the input provides a path to supply common(-). So, start at the PLC input terminal, follow through the input sensing circuit, exit at the common terminal, & connect the supply (-) to the common terminal. By adding the switch between the supply (+) and the input, the circuit is completed. Current flows in the direction of the arrow when the switch is closed.



By applying the circuit principles to the four possible combinations of input/output sinking/sourcing types, there are four circuits, as shown below. The common terminal is the terminal that serves as the common return path for all I/O points in the bank.

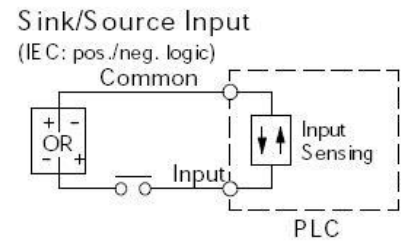
Sinking = provides a path to supply **common** (-)

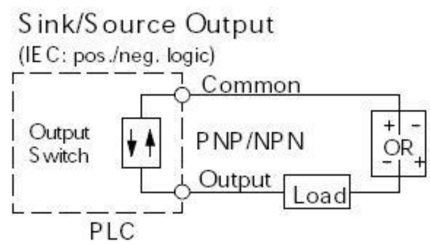
Sourcing = provides a path to supply **source** (+)



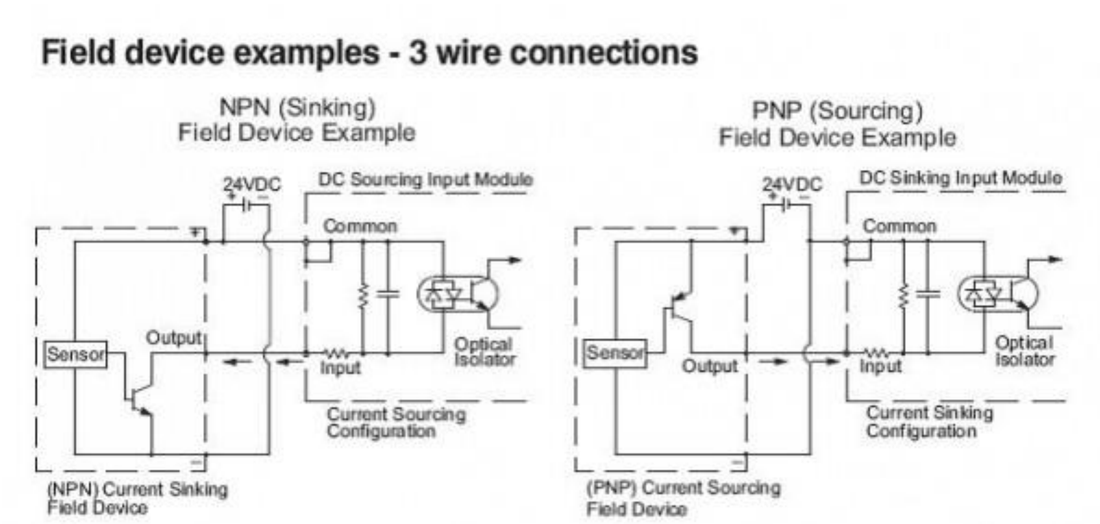
Sink/source I/O circuits combine sinking and sourcing capabilities. This means that the I/O circuitry in the PLC will allow current to flow in either direction, as shown at the right. The common terminal connects to one polarity, and the I/O point connects to the other polarity (through the field device). This provides flexibility in making connections to your field power supply. Please note:

- Wire all I/O points with a shared common as either sinking or sourcing.
- Do not use an AC power supply on a DC sink/source I/O point.





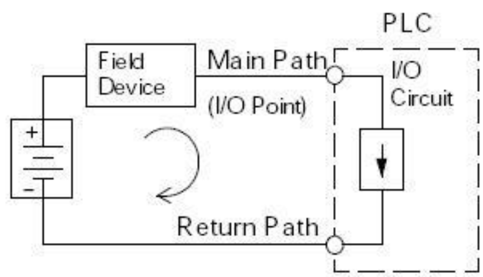
Below are detailed electrical diagrams for sinking and sourcing configurations, showing typical PLC input module and field device circuitry.

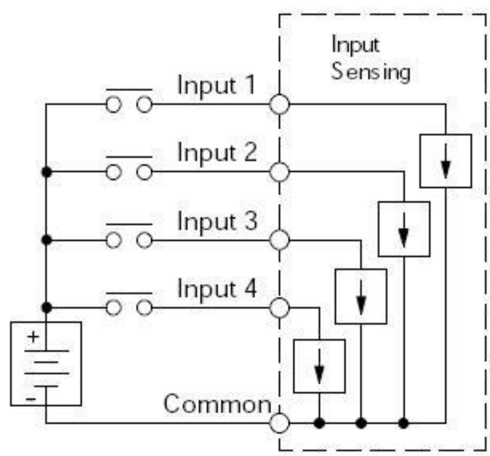


Common terminals and how to use them.

In order for a PLC I/O circuit to operate, current must enter at one terminal and exit at another. This means at least two terminals are associated with every I/O point. In the figure below, the input or output terminal is the main path for the current. One additional terminal must provide the return path to the power supply. Together, the main path and the return path create a loop, or a complete circuit for current to flow.

If there was unlimited space and budget for I/O terminals, then every I/O point could have two dedicated terminals. However, providing this level of flexibility is not practical or even necessary for most applications. So, most input or output points on PLCs are in groups that share the return path (called commons). The figure below shows a group (or bank) of four input points that share a common return path. In this way, the four inputs require only five terminals instead of eight.





NOTE: Assuming all input circuits have a similar resistance, the current at the common terminal is four times greater than the current at any one of the inputs. This effect is especially important to note for output circuits, where the current through a common terminal can reach several amperes. You will need to decide whether to fuse each output point individually, or to put a fuse in the common terminal path.

What do The NEMA Ratings Mean?

Designed to house all kinds of electrical components from simple terminal blocks, to industrial automation systems, to high voltage switchgear, NEMA enclosures are also used in industrial applications to house motor controls, drives, PLC/PC control systems, pushbuttons, and termination systems. NEMA enclosures meet the National Electrical Manufacturers Association standards for performance and protection of the electrical equipment installed within them. They are typically made from carbon steel or stainless steel. But, how do you know which one is best for your application? This article defines some NEMA ratings for enclosures that are used in industrial settings. Along with a description clarifying what each NEMA rating actually means, you'll also find an explanation on what the enclosures are typically used for. Hubbell-Wiegmann enclosures mentioned are sold by AutomationDirect.

NEMA 1 Enclosure

NEMA 3R Enclosure

NEMA 4 Enclosure

NEMA 1

NEMA 1 enclosures are typically used for protecting controls and terminations from objects and personnel. This style of enclosure, while offering a latching door, does not have a gasketed sealing surface. NEMA 1 enclosures are used in applications where sealing out dust, oil, and water is not required. Motor start/stop stations are often housed in NEMA 1 enclosures.

NEMA 3R

NEMA 3R enclosures are typically used in outdoor applications for wiring and junction boxes. This style of enclosure provides protection against falling rain, sleet, snow, and external ice formation. Indoors they protect against dripping water. This style of enclosure does not have a gasketed sealing surface. Some models have hasps for padlocking.

NEMA 3S

NEMA 3S enclosures are intended for outdoor use primarily to provide a degree of protection against windblown dust, rain, sleet, and to provide for operation of external mechanisms when ice laden.

NEMA 4

NEMA 4 enclosures are used in many applications where an occasional washdown occurs or where machine tool cutter coolant is used. They also serve in applications where a pressurized stream of water will be used. NEMA 4 enclosures are gasketed and the door is clamped for maximum sealing. They have continuous hinges, mounting feet, and padlock hasps. NEMA 4 enclosures are available in sizes from small wall mounts to two-door floor mount models.

NEMA 4X Enclosure

NEMA 4X

NEMA 4X enclosures are made of stainless steel or plastic. NEMA 4X enclosures are used in harsher environments than standard NEMA 4 units. Applications where corrosive materials and caustic cleaners are used necessitate the use of a NEMA 4X enclosure. Applications include food, such as meat/poultry processing facilities, where total washdown with disinfectants occur repeatedly and petro-chemical facilities, including offshore petroleum sites. NEMA 4X is used when protection from the worst environments is required. NEMA 4X enclosures are available in sizes from small wall mounts to two-door floor mount models. Wiegmann NEMA 4X enclosures are made of 304 stainless steel.

NEMA 12 Enclosure

NEMA 6P

NEMA 6P enclosures are intended for indoor or outdoor use primarily to provide a degree of protection against the entry of water during prolonged submersion at a limited depth.

NEMA 12

NEMA 12 enclosures are designed to prevent the ingress of dust, water, and oil. NEMA 12 enclosures are most often used for indoor applications of automation control and electronic drives systems. Some examples are packaging, material handling, non-corrosive process control, and manufacturing applications. Gasketed doors seal the enclosure's contents from airborne contaminants and non-pressurized water and oil. NEMA 12 enclosures are available in sizes from small wall mounts to two-door floor mount models.

NEMA 4 & 12 Enclosure

NEMA 4 & 12

Wiegmann's “412” enclosures combine the attributes of NEMA 4 and NEMA 12 in an attractive, clean line enclosure. This enclosure features reversible doors for left or right opening, concealed hinges, and rear mounting holes for a more attractive installation. Optional mounting feet are available for conventional wall mounting. Wiegmann's 412 enclosures are available in wall mount models up to 60" x 36".

NEMA 13

NEMA 13 enclosures are intended for indoor use primarily to provide a degree of protection against dust, spraying of water, oil, and non-corrosive coolant.

Understanding Enclosure Cooling

You need to cool down - Heat inside an enclosure can decrease the life expectancy of controlling units such as your PLC, HMI, AC drives and other items. Excessive heat can cause nuisance faults from your electrical and electronic components: for example, overloads tripping unexpectedly. Heat will also change the expected performance of circuit breakers and fuses, which can cause whole systems to shut down. So, if you have any electronic equipment or other heat sensitive devices, you may want to consider these enclosure cooling tips.

What causes all that heat?
There are basically two sources that can cause the enclosure's internal temperature to rise above the ratings of the control equipment.

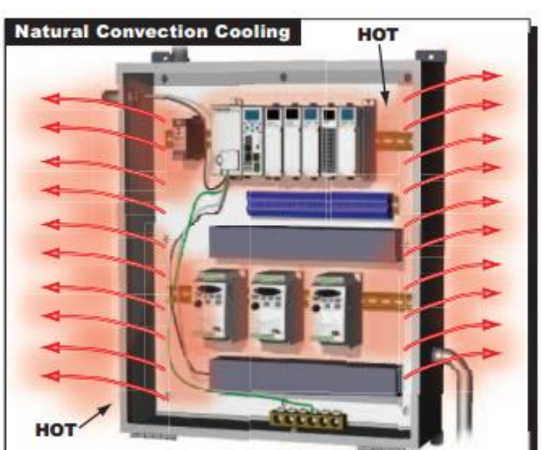
Internal Sources The same items that can be damaged by heat may also be the source of the heat. These include items such as:

- Power supplies
- Servos
- AC Drives/inverters
- Soft starters
- Transformers
- PLC systems
- Communication products
- HMI systems
- Battery back-up systems

External Sources Other sources of heat that can cause the internal temperature of your enclosure to rise above a desired level involve the external environment. These include items such as:

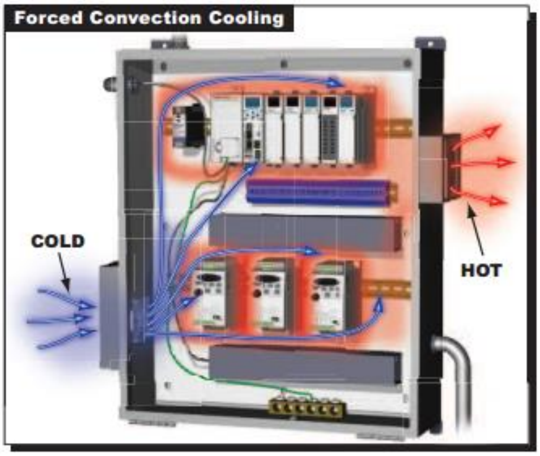
- Industrial ovens
- Solar heat gain
- Foundry equipment
- Blast furnaces

How to Get the Heat Out
How do you get the heat out of your enclosure and away from those critical components? Here are three basic enclosure cooling tips and methods.



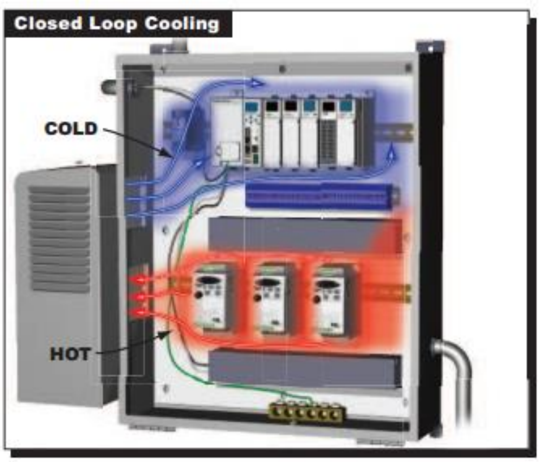
1. Natural Convection Cooling

If the ambient temperature outside the enclosure is cooler than the inside of the enclosure, then the heat can be dissipated into the atmosphere by radiating it through the surface of the enclosure and through the use of louvers or grilles with filters.



2. Forced Convection Cooling

If you have clean and cool ambient air outside of the enclosure, then a simple forced-air system may be adequate. A system such as a filter fan and the associated grille with the appropriate filter may be an acceptable option.



3. Closed Loop Cooling

A system that will keep the ambient air separate from the internal enclosure air is needed if the environment is harsh, there are washdown requirements, heavy dust and debris or the presence of airborne chemicals, and the ambient temperature is as high as or higher than the desired internal temperature. Air conditioners are an example of a closed loop system.

Learn more about enclosure cooling by reading this blog post and more online at [***N2ADC.com/3btpr***](N2ADC.com/3btpr)

Selecting an Enclosure Fan or Air Conditioner

Internal and external sources often cause enclosure internal temperatures to rise above the ratings of the control equipment. Internally, the same items that can be damaged by heat (power supplies, PLC systems, AC drives/inverters, HMI systems, battery back-up systems, servos, etc.) may also be the source of the heat. Externally, sources of heat that can cause the internal temperature of your enclosure to rise above a desired level include items such as industrial ovens, blast furnaces, foundry equipment, solar heat gain, and more. But, how do you get the heat out of your enclosure and away from those critical components? Here are factors to consider when selecting an enclosure fan or air conditioner.

Fan Selection

To select the proper size (CFM) fan for your forced air cooling solution, you need to determine the amount of heat to be removed (in watts) and determine the Delta T (Max. allowable internal enclosure temperature °F – Max. outside ambient temperature °F).

CFM = Cubic Feet per Minute
P = Power to be dissipated in watts
CFM = (3.17 x P_{watts}) / Delta T °F
Delta T = max. allowable internal enclosure temperature °F – max. outside ambient temperature °F

Fan Selection Example

A NEMA 12 Hubbell Wiegmann N12302412 enclosure (30" high x 24" wide x 12" deep) contains a GS3-2020 AC drive (20hp 230 volt) that has a maximum allowable operating temperature of 104°F and is located in a warehouse that has a maximum outside ambient air temperature of 95°F.
Power to be dissipated is stated in the specifications of the GS3-2020 and is found to be 750 watts, so P=750 watts

Delta T = Max. operating temperature for the GS3-2020 is 104°F – Max. ambient air temperature of 95°F

Delta T = 9°F
CFM = (3.17 x 750 watts) / 9°F
CFM = 264

Choose a Hubbell Wiegmann WPF60-115BK filter fan kit that provides 295 CFM with exhaust kit WPFA50-60BK

Parts in example are available at:
[N2ADC.com/w0jl8](N2ADC.com/w0jl8)

Air Conditioner Selection

To select the proper size air conditioner, the worst-case conditions should be considered, but take care not to choose an oversized unit.

There are two main factors in choosing an uninsulated metal NEMA rated enclosure located indoors: 1.) Internal heat load 2.) Heat load transfer

Internal Heat Load

Internal heat load is the heat generated by the components inside the enclosure. This can be determined by a few different methods. The preferred method is to add the maximum heat output specifications that the manufacturers list for all the equipment installed in the cabinet. This is typically given in Watts, so use the following conversion:

BTU per Hour = Watts x 3.413

Example: The Watt-loss chart for the AutomationDirect.com GS3 drives shows that a GS3-2020 AC drive has a Watt-loss of 750 watts.

BTU per Hour = 750 watts x 3.413
BTU per Hour = 2559

Heat Load Transfer

Heat load transfer is the heat lost (negative heat load transfer) or gained (positive heat load transfer) through the enclosure walls with the surrounding ambient air. This can be calculated by the following formula:

Heat load transfer (BTU/H) = 1.25 x surface area (sq. ft.) x (max. outside ambient air (°F) – max. allowable internal enclosure temperature air (°F)) Surface Area (sq. ft.) = 2 [(H x W) + (H x D) + (W x D)] / 144 sq. inches

Note: 1.25 is an industry standard constant for metal enclosures; 0.62 should be used for plastic enclosures.

Once you have determined your Internal Heat Load and the Heat Load Transfer, you can choose the proper size unit by calculating the needed cooling capacity.

Cooling capacity (BTU/H) = Internal Heat Load ± Heat Load Transfer

Air Conditioner Selection Example

A NEMA 12 Hubbell Wiegmann N12302412 enclosure (30" high x 24" wide x 12" deep) contains a GS3-4030 AC drive 30 HP 460 volt) that has a maximum allowable operating temperature of 104°F and is located in a warehouse that has a maximum outside ambient air temperature of 115°F. Power to be dissipated is stated in the specifications of the GS3-4030 and is found to be 1290 watts.

Internal heat load:
BTU per Hour = 1290 watts x 3.413
BTU per Hour = 4403 BTU/H

Heat Load transfer:
Heat Load transfer (BTU/H) = 1.25 x 19 sq. ft. x (115°F - 104 °F)
Heat Load transfer (BTU/H) = 261.25 BTU/H

Cooling capacity:
(BTU/H) = 4403 BTU/H + 261.25 BTU/H
Cooling capacity (BTU/H) = 4664.25 BTU/H

In this example, you are able to determine that a 5000 BTU/H unit is needed. Select a TA10-050-16-12 Stratus air conditioner.

Selecting a Heat Exchanger

Heat inside an enclosure can decrease the life expectancy of controlling units such as your PLC, HMI, AC drives and other items. Excessive heat can cause nuisance faults from your electrical and electronic components. Heat will also change the expected performance of circuit breakers and fuses, which can cause whole systems to shut down unexpectedly. So, if you have any electronic equipment or other heat sensitive devices, you may need cooling. If you have determined that a heat exchanger is the best cooling option for your enclosure, consider these factors in selecting the right capacity.

Heat Exchanger Selection

To select the proper size heat exchanger, the worst-case conditions should be considered. For a heat exchanger to work, the ambient air temperature must be lower than the desired internal enclosure air temperature.

There are three main factors in choosing a heat exchanger for an uninsulated metal NEMA rated enclosure located indoors: (1.) Internal heat load (2.) Delta T (3.)Heat load transfer

Internal Heat Load

Internal heat load is the heat generated by the components inside the enclosure. This can be determined by a few different methods. The preferred method is to add the maximum heat output specifications that the manufacturers list for all the equipment installed in the cabinet. This is typically given in Watts.

Delta T (ΔT)

Delta T = maximum allowable internal enclosure temperature °F – maximum outside ambient temperature °F

Heat Load Transfer

Heat load transfer is the heat lost (negative heat load transfer) or gained (positive heat load transfer) through the enclosure walls with the surrounding ambient air. This can be calculated by the following formulas:

Surface Area (sq. ft.) = 2 [(H x W) + (H x D) + (W x D)] / (144 sq. inches/sq. ft.)
Note: Only include exposed surfaces of enclosure in calculations. Exclude surfaces such as a surface mounted to a wall.

Heat Load Transfer (W/ °F) = 0.22 W/ °F sq. ft. x surface area
Note: Use 0.22 Watts/° F sq. ft. for painted steel and nonmetallic enclosures. Use 0.10 Watts/ °F sq. ft. for stainless steel and bare aluminum enclosures.

Cooling Capacity

Once you have determined your Internal Heat Load, the Heat Load Transfer and the Delta T, you can choose the proper size unit by calculating the needed cooling capacity.
Cooling Capacity (W/ °F) = Internal Heat Load / ΔT - Heat Load Transfer

Heat Exchanger Selection Example

A NEMA 12 Hubbell Wiegmann N12302412 enclosure (30" high x 24" wide x 12" deep) contains a GS3-4010 AC drive 10 HP 460 volt) that has a maximum allowable operating temperature of 104°F and is located in a warehouse that has a maximum outside ambient air temperature of 90°F.
Power to be dissipated is stated in the specifications of the GS3-4010 and is found to be 345 watts.

Internal heat load:
Internal Heat Load = 345 Watts

Delta T:
ΔT (°F) 104°F – 90°F = 14 °F

Heat load transfer:
Surface Area (ft.²) = 2 [(30 x 24) + (30 x 12) + (24 x 12)] / 144 sq. inches = 19 ft.²
Heat Load Transfer = 0.22 x 19 ft.² = 4.2 Watts/°F

Cooling capacity:
Cooling Capacity = 345 Watts/14°F - 4.2 Watts/°F = 20.4 Watts/°F

In this example, you are able to determine that a Stratus heat exchanger, with a capacity of at least 20.4 Watts/°F is needed, such as a TE30-030-17-04.

**This selection procedure applies to metal and non-metal, uninsulated, sealed enclosures in indoor locations. This selection procedure gives the minimum required size; be careful not to undersize when purchasing.*

Parts in example are available at:
[N2ADC.com/w0jl8](N2ADC.com/w0jl8)

Maintenance Check List

Because each machine is unique, you will want to develop your own maintenance check list, but we hope that our list below will help give you a good jumpstart. You can download a Excel template for a maintenance check by visiting N2ADC.com/g50mf.

- ❑ Check and record voltages at various circuits
- ❑ Tighten all connections (with power removed)
- ❑ Check backup batteries, and/or replace on a routine schedule
- ❑ Check indicators and perform lamp tests
- ❑ Visually inspect for loose or frayed wiring, moisture in enclosure, etc.
- ❑ Check to make sure plug-in connectors are tight and secured
- ❑ Test all alarm systems, horns, sirens, etc.
- ❑ Check and record any configuration settings
- ❑ Perform and record calibrations
- ❑ Check all I/O points on a yearly basis
- ❑ Check and record power usage
- ❑ Check equipment run times for determining maintenance or replacement
- ❑ Measure device current to set a benchmark and compare for changes
- ❑ Review any diagnostic history, including events and alarms
- ❑ Check diagnostics that may be programmed into the HMI operator interface

Memory Aids

We all have used an acronym, mnemonic, rhyme, word association, or other technique to help us remember information, lists, events, etc. I know they work because most of them are still stuck in my head. See how many of the following you may remember.

Resistor Color Code – '*Better Be Right Or Your Great Big Venture Goes West'*

Color bands are used to represent numeric values in ohms on certain types of resistors. The numbers 0 through 9 are represented by the colors black, brown, red, orange, yellow, green, blue, violet, gray, and white respectively. The first and second band are typically the resistor's first two significant digits, the third band is the number of zeros following the first two digits, and the forth band is the resistor's tolerance. There are many variations to this type of resistor coding, but to recall the basic color order, you can memorize the saying 'Better Be Right Or Your Great Big Venture Goes West'. A little investigation will most likely discover many other sayings for memorizing the resistor color code, some not as elegant as the one we have shared.

Visible Color Spectrum – '*Roy G. Biv'*

To remember the main colors that we may see in a rainbow, or viewing the result of light that has traveled through a prism, think of Roy G. Biv. The colors with the longest to shortest wave length are Red, Orange, Yellow, Green, Blue, Indigo and Violet. You may have noticed that other than Indigo, the color spectrum order matches part of the Resistor Color Code.

ELI the ICE Man

In an AC circuit involving inductance or capacitance, the voltage and current in the circuit will be out of phase with each other. An inductive circuit will cause a phase shift in one direction and a capacitive circuit will cause the opposite. To remember which is which, think of ELI the ICE man, where E = Voltage, I = Current, L = Inductor, and C = Capacitor, therefore: ELI (Inductive Circuit) – Voltage leads Current ICE (Capacitive Circuit) – Current leads Voltage

Memory Aids

Algebraic Expressions

Solving algebraic expressions can be somewhat confusing unless we understand the order of operations that have been defined. Take the following equation: 7 + 6 / 2 – 2 * 3 = In which order do we solve the various elements? Can we take 7, add it to 6, then divide the result by 2, or maybe divide 6 by 2 and take the result away from 7? Luckily the order has been defined for us. We solve algebraic expressions by doing the computations in Parentheses first, if they are present, followed by Exponents, then either Multiplication or Division (order does not matter), and finally either Addition or Subtraction (again order does not matter). An easy way to remember this order is to memorize the saying ‘Please Excuse My Dear Aunt Sally’.

Value of Pi

If you forget Pi = 3.14159, you can get a quick approximation on a simple calculator by solving 22/7, or for more accuracy while just a bit harder to remember, solve 355/113.

A Guide to Common Automation Terms

The glossary below is an excerpt from Jon Stenerson's "Fundamentals of Programmable Logic Controllers, Sensors, and Communications". For the complete list, go to the Technical Support section of the AutomationDirect Web site.

- **Accumulated value**: Applies to the use of timers and counters. The accumulated value is the present count or time.
- **Accuracy:** The deviation between the actual position and the theoretical position.
- **Address:** Number used to specify a storage location in memory.
- **Analog:** Signal with a smooth range of possible values. For example, a temperature that could vary between 60 and 300 degrees would be analog in nature.
- **Backplane:** Bus in the back of a PLC chassis. It is a printed circuit board with sockets that accept various modules.
- **Baud rate:** Speed of serial communications. The number of bits per second transmitted. For example, RS-232 is normally used with a baud rate of 9600. This would be about 9600 bits per second. It takes about 10 bits in serial to send an ASCII character so that a baud rate of 9600 would transmit about 960 characters per second.
- **Binary:** Base-two number system. Binary is a system in which ones and zeros are used to represent numbers.
- **Binary-coded decimal (BCD):** A number system. Each decimal number is represented by four binary bits. For example, the decimal number 967 would be represented by 1001 0110 0111 in BCD.
- **Bit:** Binary digit. The smallest element of binary data. A bit will be either a zero or a one.
- **Byte:** Eight bits or two nibbles. (A nibble is 4 bits.)
- **Central processing unit (CPU):** Microprocessor portion of the PLC. It is the portion of the PLC that handles the logic.
- **Compare instruction:** PLC instruction that is used to test numerical values for equal, greater than, or less than relationships.
- **Contact:** Symbol used in programming PLCs to represent inputs. There are normally open and normally closed contacts. Contacts are also the conductors in electrical devices such as starters.
- **Contactor:** Special-purpose relay that is used to control large electrical current.
- **Current sinking:** Refers to an output device (typically an NPN transistor) that allows current flow from the load through the output to ground.
- **Current sourcing:** Output device (typically a PNP transistor) that allows current flow from the output through the load and then to ground.

- **Data table:** A consecutive group of user references (data) of the same size that can be accessed with table read/write functions.
- **Debugging:** Process of finding problems (bugs) in any system.
- **Digital output:** An output that can have two states: on or off. These are also called discrete outputs.
- **Downtime:** The time a system is not available for production or operation is called downtime. Downtime can be caused by breakdowns in systems.
- **EEPROM:** Electrically erasable programmable read only memory.
- **Energize:** Instruction that causes a bit to be a one. This turns an output on.
- **Examine-off:** Contact used in ladder logic. It is a normally closed contact. The contact is true (or closed) if the real-world input associated with itis off.
- **Examine-on:** Contact used in ladder logic programming. Called a normally open contact. This type of contact is true (or closed) if the real- world input associated with it is on.
- **Firmware:** A series of instructions contained in read-only memory (ROM) that are used for the operating system functions. Some manufacturers offer upgrades for PLCs. This is often done by replacing a ROM chip. Thus the combination of software and hardware lead to it being called firmware.
- **Force:** Refers to changing the state of actual I/O by changing the bit status in the PLC. In other words, a person can force an output on by changing the bit associated with the real-world output to a 1. Forcing is normally used to troubleshoot a system.
- **Ground:** Direct connection between equipment (chassis) and earth ground.
- **Hexadecimal:** Numbering system that utilizes base 16.
- **Hysteresis:** A dead band that is purposely introduced to eliminate false reads in the case of a sensor. In an encoder hysteresis would be introduced in the electronics to prevent ambiguities if the system happens to dither on a transition.
- **Image table:** Area used to store the status of input and output bits.
- **Instruction set:** Instructions that are available to program the PLC.
- **I/O (input/output):** Used to speak about the number of inputs and outputs that are needed for a system, or the number of inputs and outputs thata particular programmable logic controller can handle.
- **IP rating:** Rating system established by the IEC that defines the protection offered by electrical enclosures. It is similar to the NEMA rating system.
- **K:** Abbreviation for the number 1000. In computer language it is equal to two to the tenth, or 1024.
- **Ladder diagram:** Programmable controller language that uses contacts and coils to define a control sequence.
- **LAN:** See Local area network.

- **LAN:** See Local area network.
- **Leakage current:** Small amount of current that flows through load-powered sensors. The small current is necessary for the operation of the sensor. The small amount of current flow is normally not sensed by the PLC input. If the leakage is too great a bleeder resistor must be used to avoid false inputs at the PLC.
- **LED (light-emitting diode):** A solid-state semiconductor that emits red, green, or yellow light or invisible infrared radiation.
- **Line driver:** A line driver is a differential output driver intended for use with a differential receiver. These are usually used where long lines and high frequency are required and noise may be a problem.
- **Line-powered sensor:** Normally, three-wire sensors, although four-wire sensors also exist. The line-powered sensor is powered from the power supply. A separate wire (the third) is used for the output line.
- **Load:** Any device that current flows through and produces a voltage drop.
- **Load-powered sensor:** A load-powered sensor has two wires. A small leakage current flows through the sensor even when the output is off. The current is required to operate the sensor electronics.
- **LSB:** Least significant bit.
- **Master:** The master on a network is the device that controls communication traffic. The master of a network usually polls every slave to check if it has something to transmit. In a master-slave configuration, only the active master can place a message on the bus. The slave can reply only if it receives a frame from the master that contains a logical token that explicitly enables the slave to reply.
- **Master control relay (MCR):** Hardwired relay that can be deenergized by any hardwired series-connected switch. Used to deenergize all devices. If one emergency switch is hit it must cause the master control relay to drop power to all devices. There is also a master control relay available in most PLCs. The master control relay in the PLC is not sufficient to meet safety requirements.
- **Microsecond:** A microsecond is one millionth (0.000001) of a second.
- **Millisecond:** A millisecond is one thousandth (.001) of a second.
- **MSB:** Most significant bit.
- **Network:** System that is connected to devices or computers for communication purposes.
- **Nonretentive coil:** A coil that will turn off upon removal of applied power to the CPU.
- **Nonretentive timer:** Timer that loses the time if the input enable signal is lost.
- **Nonvolatile memory:** Memory in a controller that does not require power to retain its contents.
- **Octal:** Number system based on the number 8, utilizing numbers 0 through 7.

- **Off-delay timer:** This is a type of timer that is on immediately when it receives its input enable. It turns off after it reaches its preset time.
- **Off-line programming:** Programming that is done while not attached to the actual device. For example, a PLC program can be written for a PLC without being attached. The program can then be downloaded to the PLC.
- **On-delay timer:** Timer that does not turn on until its time has reached the preset time value.
- **One-shot contact:** Contact that is only on for one scan when activated.
- **Parity:** Bit used to help check for data integrity during a data communication.
- **Peer-to-peer:** This is communication that occurs between similar devices. For example, two PLCs communicating would be peer-to-peer. A PLC communicating to a computer would be device-to-host.
- **PID (Proportional, integral, derivative) control:** Control algorithm that is used to closely control processes such as temperature, mixture, position, and velocity. The proportional portion takes care of the magnitude of the error. The integral takes care of small errors over time. The derivative compensates for the rate of error change.
- **PLC:** Programmable logic controller.
- **Programmable controller:** A special-purpose computer. Programmed in ladder logic. It was also designed so that devices could be easily interfaced with it.
- **PPR (Pulses per revolution):** This refers to the number of pulses an encoder produces in one revolution.
- **Quadrature:** Two output channels out of phase with each other by 90 degrees.
- **Retentive coil:** A coil that will remain in its last state, even though power was removed.
- **Retentive timer:** Timer that retains the present count even if the input enable signal is lost. When the input enable is active again, the timer begins to count again from where it left off.
- **ROM (read-only memory):** This is operating system memory. ROM is nonvolatile. It is not lost when the power is turned off.
- **RS-232:** Common serial communications standard. This standard specifies the purpose of each of 25 pins. It does not specify connectors or which pins must be used.
- **RS-422:** Standards for two types of serial communication. RS-422 is a balanced serial mode. This means that the transmit and receive lines have their own common instead of sharing one like RS-232. Balanced mode is more noise immune. This allows for higher data transmission rates and longer transmission distances.
- **RS-485:** Similar to the RS-422 standard. Receivers have additional sensitivity which allows for longer distances and more communication drops. Includes some extra protection for receiver circuits.

- **Scan time:** Amount of time it takes a programmable controller to evaluate a ladder diagram. The PLC continuously scans the ladder diagram. The time it takes to evaluate it once is the scan time. It is typically in the low-millisecond range.
- **Sequencer:** Instruction type that is used to program a sequential operation.
- **Serial communication:** Sending of data one bit at a time. The data is represented by a coding system such as ASCII.
- **Slave:** On a master-slave configured network, there is usually one master and several slaves. The slaves are nodes of the network that can transmit informations to the master only when they are polled (called) from it. The rest of the time a slave never transmits anything.
- **Thermocouple:** A thermocouple is a sensing transducer. It changes a temperature to a current. The current can then be measured and converted to a binary equivalent that the PLC can understand.
- **Thumbwheel:** Device used by an operator to enter a number between 0 and 9. Thumbwheels are combined to enter larger numbers. Thumbwheels typically output BCD numbers to a device.
- **Timer:** Instruction used to accumulate time until a certain value is achieved. The timer then changes its output state.
- **UL (Underwriters Laboratory):** Organization that operates laboratories to investigate systems with respect to safety.
- **User memory:** Memory used to store user information. The user’s program, timer/counter values, input/output status, and so on, are all stored in user memory.
- **Volatile memory:** Memory that is lost when power is lost.
- **Watchdog timer:** Timer that can be used for safety. For example, if there is an event or sequence that must occur within a certain amount of time, a watchdog timer can be set to shut the system down in case the time is exceeded.
- **Word:** Length of data in bits that a microprocessor can handle. For example, a word for a 16-bit computer would be 16 bits long, or two bytes. A 32-bit computer would have a 32-bit word.