3. PLC HARDWARE

Topics:
- PLC hardware configurations
- Input and outputs types
- Electrical wiring for inputs and outputs
- Relays
- Electrical Ladder Diagrams and JIC wiring symbols

Objectives:
- Be able to understand and design basic input and output wiring.
- Be able to produce industrial wiring diagrams.

3.1 INTRODUCTION

Many PLC configurations are available, even from a single vendor. But, in each of these there are common components and concepts. The most essential components are:

Power Supply - This can be built into the PLC or be an external unit. Common voltage levels required by the PLC (with and without the power supply) are 24Vdc, 120Vac, 220Vac.
CPU (Central Processing Unit) - This is a computer where ladder logic is stored and processed.
I/O (Input/Output) - A number of input/output terminals must be provided so that the PLC can monitor the process and initiate actions.
Indicator lights - These indicate the status of the PLC including power on, program running, and a fault. These are essential when diagnosing problems.

The configuration of the PLC refers to the packaging of the components. Typical configurations are listed below from largest to smallest as shown in Figure 14.

Rack - A rack is often large (up to 18” by 30” by 10”) and can hold multiple cards. When necessary, multiple racks can be connected together. These tend to be the highest cost, but also the most flexible and easy to maintain.
Mini - These are smaller than full sized PLC racks, but can have the same IO capacity.
Micro - These units can be as small as a deck of cards. They tend to have fixed quantities of I/O and limited abilities, but costs will be the lowest.
Software - A software based PLC requires a computer with an interface card, but allows the PLC to be connected to sensors and other PLCs across a network.

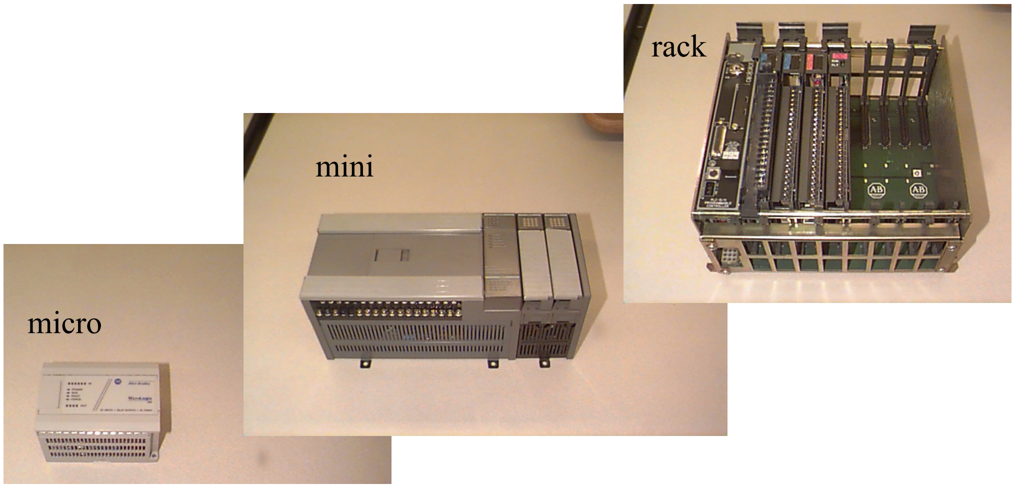


Figure 14 Typical Configurations for PLC

3.2 INPUTS AND OUTPUTS

Inputs to, and outputs from, a PLC are necessary to monitor and control a process. Both inputs and outputs can be categorized into two basic types: logical or continuous. Consider the example of a light bulb. If it can only be turned on or off, it is logical control. If the light can be dimmed to different levels, it is continuous. Continuous values seem more intuitive, but logical values are preferred because they allow more certainty, and simplify control. As a result most controls applications (and PLCs) use logical inputs and outputs for most applications. Hence, we will discuss logical I/O and leave continuous I/O for later.

Outputs to actuators allow a PLC to cause something to happen in a process. A short list of popular actuators is given below in order of relative popularity.

Solenoid Valves - logical outputs that can switch a hydraulic or pneumatic flow.
Lights - logical outputs that can often be powered directly from PLC output boards.
Motor Starters - motors often draw a large amount of current when started, so they require motor starters, which are basically large relays.
Servo Motors - a continuous output from the PLC can command a variable speed or position.

Outputs from PLCs are often relays, but they can also be solid state electronics such as transistors for DC outputs or Triacs for AC outputs. Continuous outputs require special output cards with digital to analog converters.

Inputs come from sensors that translate physical phenomena into electrical signals. Typical examples of sensors are listed below in relative order of popularity.

Proximity Switches - use inductance, capacitance or light to detect an object logically.
Switches - mechanical mechanisms will open or close electrical contacts for a logical signal.
Potentiometer - measures angular positions continuously, using resistance.

LVDT (linear variable differential transformer) - measures linear displacement continuously using magnetic coupling.

Inputs for a PLC come in a few basic varieties, the simplest are AC and DC inputs. Sourcing and sinking inputs are also popular. This output method dictates that a device does not supply any power. Instead, the device only switches current on or off, like a simple switch.

Sinking - When active the output allows current to flow to a common ground. This is best selected when different voltages are supplied.
Sourcing - When active, current flows from a supply, through the output device and to ground. This method is best used when all devices use a single supply voltage.

This is also referred to as NPN (sinking) and PNP (sourcing). PNP is more popular. This will be covered in detail in the chapter on sensors.

3.2.1 Inputs

In smaller PLCs the inputs are normally built in and are specified when purchasing the PLC. For larger PLCs the inputs are purchased as modules, or cards, with 8 or 16 inputs of the same type on each card. For discussion purposes we will discuss all inputs as if they have been purchased as cards. The list below shows typical ranges for input voltages, and is roughly in order of popularity.

12-24 Vdc
100-120 Vac
10-60 Vdc
12-24 Vac/dc
5 Vdc (TTL)
200-240 Vac
48 Vdc
24 Vac

PLC input cards rarely supply power, this means that an external power supply is needed to supply power for the inputs and sensors. The example in Figure 15 shows how to connect an AC input card.

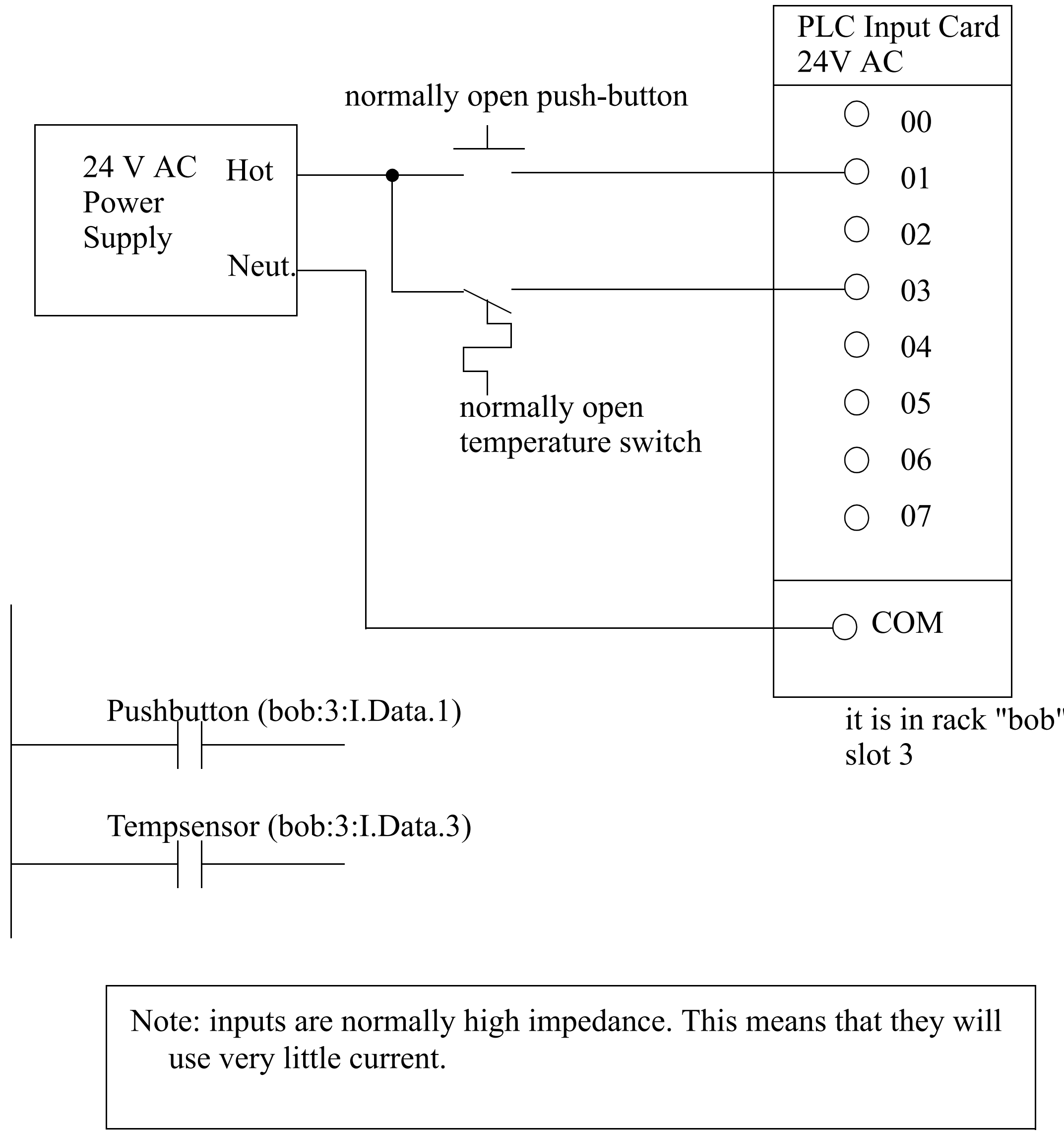


Figure 15 An AC Input Card and Ladder Logic

In the example there are two inputs, one is a normally open push button, and the second is a temperature switch, or thermal relay. (NOTE: These symbols are standard and will be discussed later in this chapter.) Both of the switches are powered by the positive/hot output of the 24Vac power supply - this is like the positive terminal on a DC supply. Power is supplied to the left side of both of the switches. When the switches are open there is no voltage passed to the input card. If either of the switches are closed power will be supplied to the input card. In this case inputs 1 and 3 are used - notice that the inputs start at 0. The input card compares these voltages to the common. If the input voltage is within a given tolerance range the inputs will switch on. Ladder logic is shown in the figure for the inputs. Here it uses Allen Bradley notation for ControlLogix. At the top is the tag (variable name) for the rack. The input card ('I') is in slot 3, so the address for the card is bob:3.I.Data.x, where 'x' is the input bit number. These addresses can also be given alias tags to make the ladder logic less confusing.

NOTE: The design process will be much easier if the inputs and outputs are planned first, and the tags are entered before the ladder logic. Then the program is entered using the much simpler tag names.

Many beginners become confused about where connections are needed in the circuit above. The key word to remember is *circuit*, which means that there is a full loop that the voltage must be able to follow. In Figure 15 we can start following the circuit (loop) at the power supply. The path goes *through* the switches, *through* the input card, and back to the power supply where it flows back *through* to the start. In a full PLC implementation there will be many circuits that must each be complete.

A second important concept is the common. Here the neutral on the power supply is the common, or reference voltage. In effect we have chosen this to be our 0V reference, and all other voltages are measured relative to it. If we had a second power supply, we would also need to connect the neutral so that both neutrals would be connected to the same common. Often common and ground will be confused. The common is a reference, or datum voltage that is used for 0V, but the ground is used to prevent shocks and damage to equipment. The ground is connected under a building to a metal pipe or grid in the ground. This is connected to the electrical system of a building, to the power outlets, where the metal cases of electrical equipment are connected. When power flows through the ground it is bad. Unfortunately many engineers, and manufacturers mix up ground and common. It is very common to find a power supply with the ground and common mislabeled.

Remember - Don't mix up the ground and common. Don't connect them together if the common of your device is connected to a common on another device.

One final concept that tends to trap beginners is that each input card is isolated. This means that if you have connected a common to only one card, then the other cards are not connected. When this happens the other cards will not work properly. You must connect a common for each of the output cards.

There are many trade-offs when deciding which type of input cards to use.

- DC voltages are usually lower, and therefore safer (i.e., 12-24V).
- DC inputs are very fast, AC inputs require a longer on-time. For example, a 60Hz wave may require up to 1/60sec for reasonable recognition.
- DC voltages can be connected to larger variety of electrical systems.
- AC signals are more immune to noise than DC, so they are suited to long distances, and noisy (magnetic) environments.
- AC power is easier and less expensive to supply to equipment.
- AC signals are very common in many existing automation devices.

ASIDE: PLC inputs must convert a variety of logic levels to the 5Vdc logic levels used on the data bus. This can be done with circuits similar to those shown below. Basically the circuits condition the input to drive an optocoupler. This electrically isolates the external electrical circuitry from the internal circuitry. Other circuit components are used to guard against excess or reversed voltage polarity.

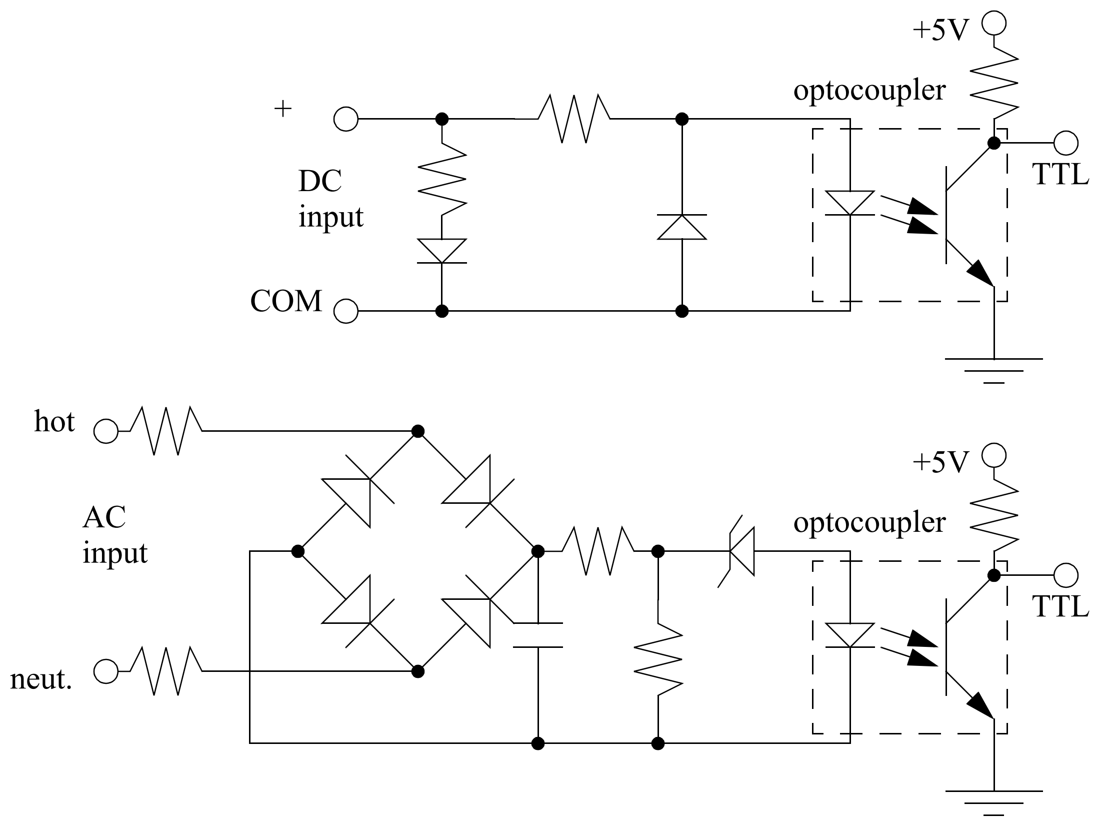


Figure 16 Aside: PLC Input Circuits

3.2.2 Output Modules

WARNING - ALWAYS CHECK RATED VOLTAGES AND CURRENTS FOR PLC's AND NEVER EXCEED!

As with input modules, output modules rarely supply any power, but instead act as switches. External power supplies are connected to the output card and the card will switch the power on or off for each output. Typical output voltages are listed below, and roughly ordered by popularity.

120 Vac

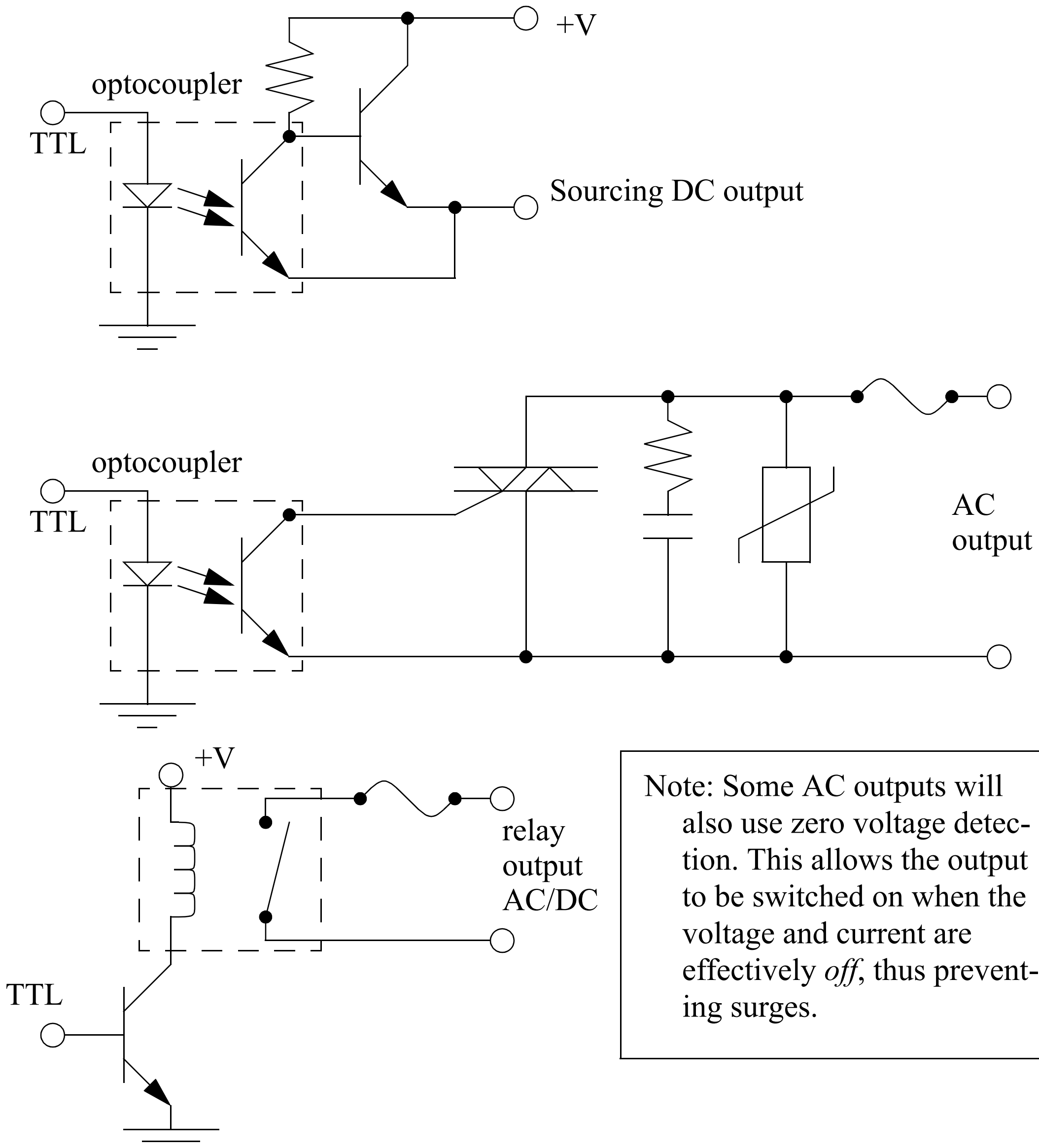
24 Vdc
12-48 Vac
12-48 Vdc
5Vdc (TTL)
230 Vac

These cards typically have 8 to 16 outputs of the same type and can be purchased with different current ratings. A common choice when purchasing output cards is relays, transistors or triacs. Relays are the most flexible output devices. They are capable of switching both AC and DC outputs. But, they are slower (about 10ms switching is typical), they are bulkier, they cost more, and they will wear out after millions of cycles. Relay outputs are often called dry contacts. Transistors are limited to DC outputs, and Triacs are limited to AC outputs. Transistor and triac outputs are called switched outputs.

Dry contacts - a separate relay is dedicated to each output. This allows mixed voltages (AC or DC and voltage levels up to the maximum), as well as isolated outputs to protect other outputs and the PLC. Response times are often greater than 10ms. This method is the least sensitive to voltage variations and spikes.

Switched outputs - a voltage is supplied to the PLC card, and the card switches it to different outputs using solid state circuitry (transistors, triacs, etc.) Triacs are well suited to AC devices requiring less than 1A. Transistor outputs use NPN or PNP transistors up to 1A typically. Their response time is well under 1ms.

ASIDE: PLC outputs must convert the 5Vdc logic levels on the PLC data bus to external voltage levels. This can be done with circuits similar to those shown below. Basically the circuits use an optocoupler to switch external circuitry. This electrically isolates the external electrical circuitry from the internal circuitry. Other circuit components are used to guard against excess or reversed voltage polarity.



Note: Some AC outputs will also use zero voltage detection. This allows the output to be switched on when the voltage and current are effectively *off*, thus preventing surges.

Figure 17 Aside: PLC Output Circuits

Caution is required when building a system with both AC and DC outputs. If AC is accidentally connected to a DC transistor output it will only be on for the positive half of the cycle, and appear to be working with a diminished voltage. If DC is connected to an AC triac output it will turn on and appear to work, but you will not be able to turn it off without turning off the entire PLC.

ASIDE: A transistor is a semiconductor based device that can act as an adjustable valve. When switched off it will block current flow in both directions. While switched on it will allow current flow in one direction only. There is normally a loss of a couple of volts across the transistor. A triac is like two SCRs (or imagine transistors) connected together so that current can flow in both directions, which is good for AC current. One major difference for a triac is that if it has been switched on so that current flows, and then switched off, it will not turn off until the current stops flowing. This is fine with AC current because the current stops and reverses every 1/2 cycle, but this does not happen with DC current, and so the triac will remain on.

A major issue with outputs is mixed power sources. It is good practice to isolate all power supplies and keep their commons separate, but this is not always feasible. Some output modules, such as relays, allow each output to have its own common. Other output cards require that multiple, or all, outputs on each card share the same common. Each output card will be isolated from the rest, so each common will have to be connected. It is common for beginners to only connect the common to one card, and forget the other cards - then only one card seems to work!

The output card shown in Figure 18 is an example of a 24Vdc output card that has a shared common. This type of output card would typically use transistors for the outputs.

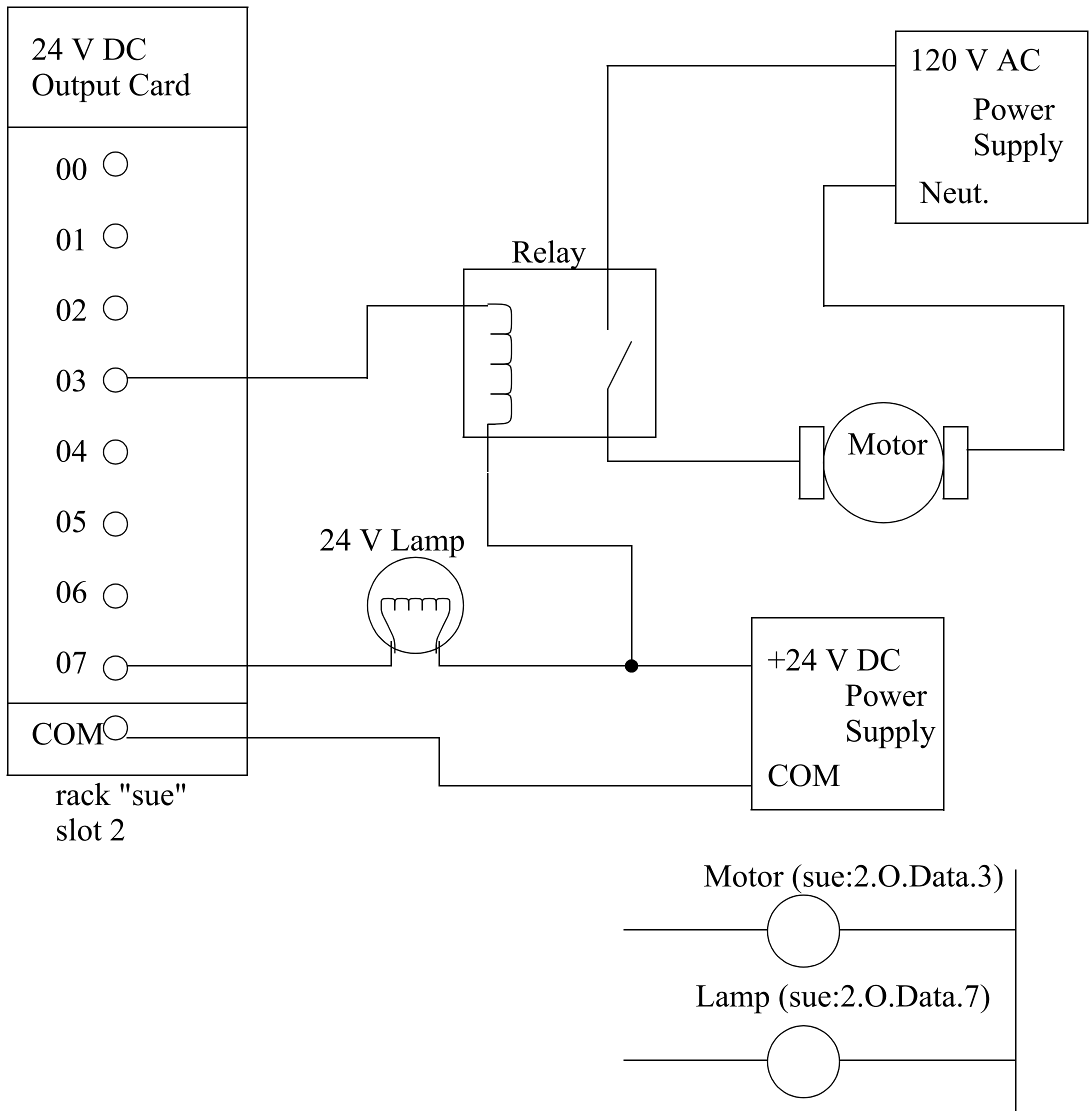


Figure 18 An Example of a 24Vdc Output Card (Sinking)

In this example the outputs are connected to a low current light bulb (lamp) and a relay coil. Consider the circuit through the lamp, starting at the 24Vdc supply. When the output *07* is on, current can flow in *07* to the *COM*, thus completing the circuit, and allowing the light to turn on. If the output is off the current cannot flow, and the light will not turn on. The output *03* for the relay is connected in a similar way. When the output *03* is on, current will flow through the relay coil to close the contacts and supply 120Vac to the motor. Ladder logic for the outputs is shown in the bottom right of the figure. The notation is for an Allen Bradley ControlLogix. The output card ('O') is in a rack labelled 'sue' in slot 2. As indicated for the input card, it is good practice to define and use an alias tag for an output (e.g. Motor) instead of using the full description (e.g. sue:2.O.Data.3). This card could have many different voltages applied from different sources, but all the power supplies would need a single shared common.

The circuits in Figure 19 had the sequence of power supply, then device, then PLC card, then power supply. This requires that the output card have a common. Some output schemes reverse the device and PLC card, thereby replacing the common with a voltage input. The example in Figure 18 is repeated in Figure 19 for a voltage supply card.

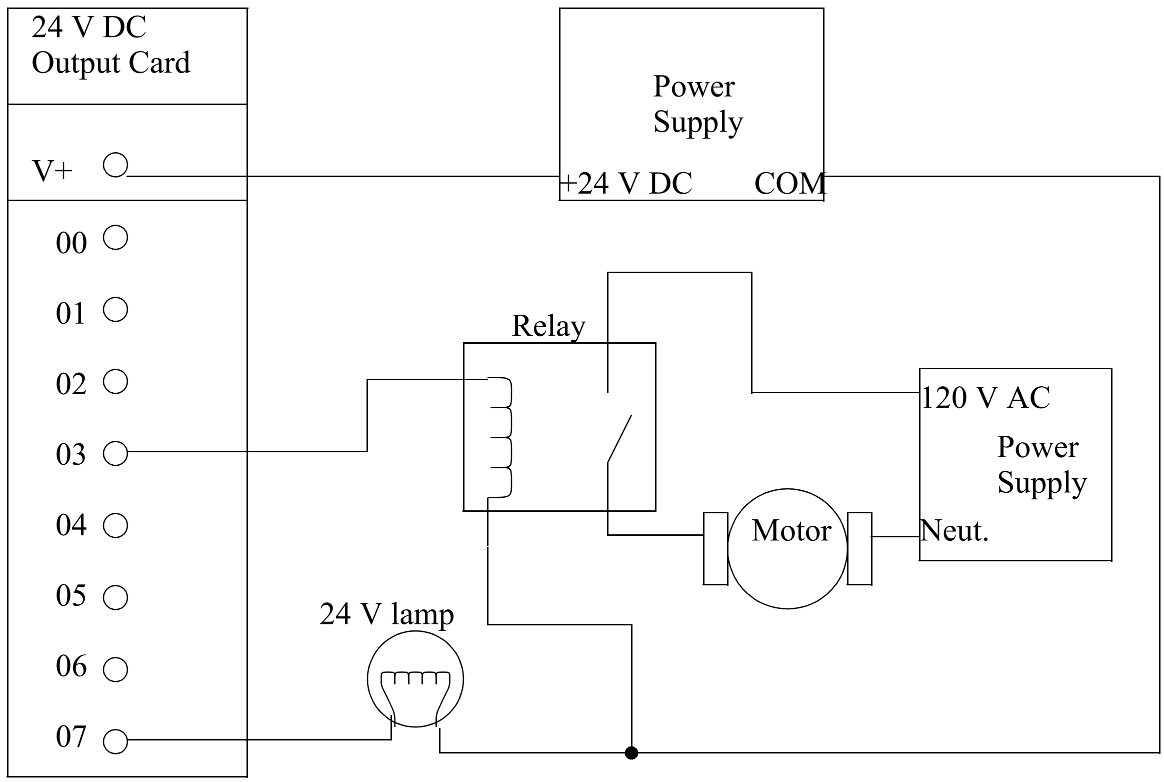


Figure 19 An Example of a 24Vdc Output Card With a Voltage Input (Sourcing)

In this example the positive terminal of the 24Vdc supply is connected to the output card directly. When an output is on power will be supplied to that output. For example, if output *07* is on then the supply voltage will be output to the lamp. Current will flow through the lamp and back to the common on the power supply. The operation is very similar for the relay switching the motor. Notice that the ladder logic (shown in the bottom right of the figure) is identical to that in Figure 18. With this type of output card only one power supply can be used.

We can also use relay outputs to switch the outputs. The example shown in Figure 18 and Figure 19 is repeated yet again in Figure 20 for relay output.

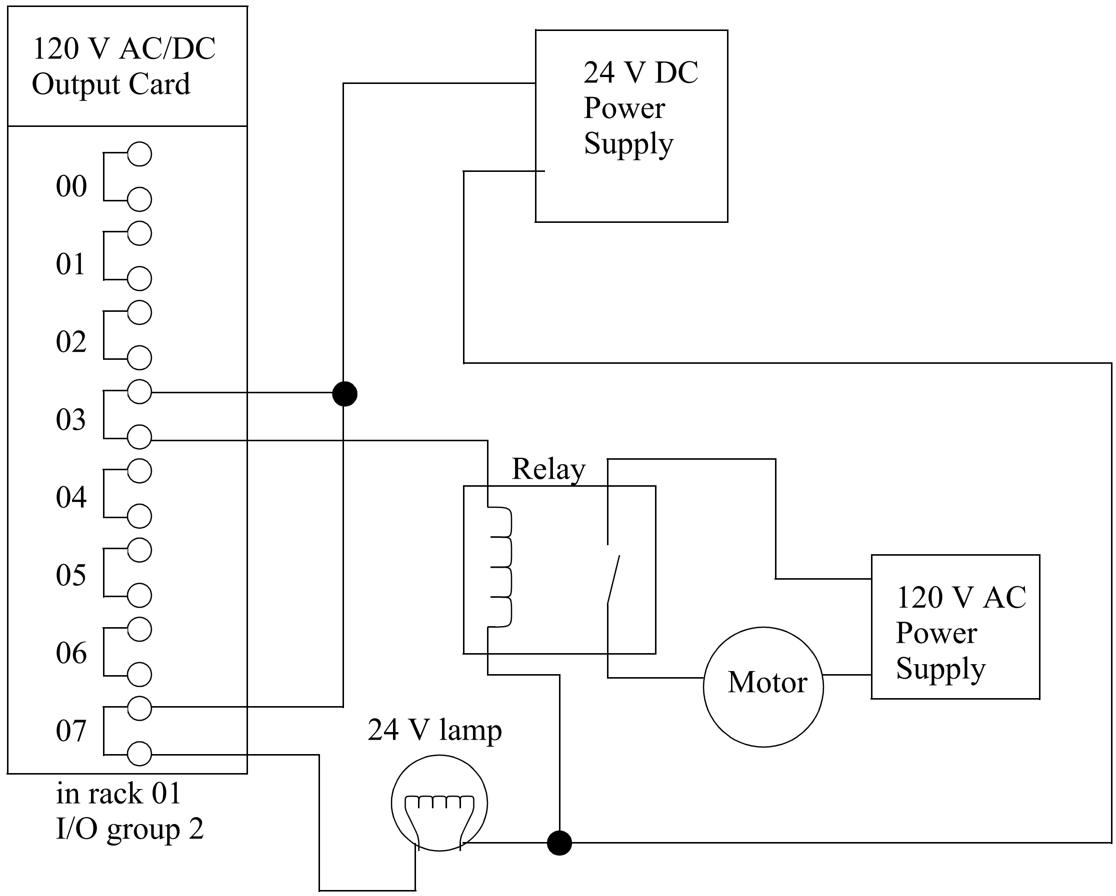


Figure 20 An Example of a Relay Output Card

In this example the 24Vdc supply is connected directly to both relays (note that this requires 2 connections now, whereas the previous example only required one.) When an output is activated the output switches on and power is delivered to the output devices. This layout is more similar to Figure 19 with the outputs supplying voltage, but the relays could also be used to connect outputs to grounds, as in Figure 18. When using relay outputs it is possible to have each output isolated from the next. A relay output card could have AC and DC outputs beside each other.

3.3 RELAYS

Although relays are rarely used for control logic, they are still essential for switching large power loads. Some important terminology for relays is given below.

Contactor - Special relays for switching large current loads.
Motor Starter - Basically a contactor in series with an overload relay to cut off when too much current is drawn.
Arc Suppression - when any relay is opened or closed an arc will jump. This becomes a major problem with large relays. On relays switching AC this problem can be overcome by opening the relay when the voltage goes to zero (while crossing between negative and positive).

When switching DC loads this problem can be minimized by blowing pressurized gas across during opening to suppress the arc formation.

AC coils - If a normal coil is driven by AC power the contacts will vibrate open and closed at the frequency of the AC power. This problem is overcome by relay manufacturers by adding a shading pole to the internal construction of the relay.

The most important consideration when selecting relays, or relay outputs on a PLC, is the rated current and voltage. If the rated voltage is exceeded, the contacts will wear out prematurely, or if the voltage is too high fire is possible. The rated current is the maximum current that should be used. When this is exceeded the device will become too hot, and it will fail sooner. The rated values are typically given for both AC and DC, although DC ratings are lower than AC. If the actual loads used are below the rated values the relays should work well indefinitely. If the values are exceeded a small amount the life of the relay will be shortened accordingly. Exceeding the values significantly may lead to immediate failure and permanent damage. Please note that relays may also include minimum ratings that should also be observed to ensure proper operation and long life.

- Rated Voltage - The suggested operation voltage for the coil. Lower levels can result in failure to operate, voltages above shorten life.
- Rated Current - The maximum current before contact damage occurs (welding or melting).

3.4 A CASE STUDY

(Try the following case without looking at the solution in Figure 21.) An electrical layout is needed for a hydraulic press. The press uses a 24Vdc double actuated solenoid valve to advance and retract the press. This device has a single common and two input wires. Putting 24Vdc on one wire will cause the press to advance, putting 24Vdc on the second wire will cause it to retract. The press is driven by a large hydraulic pump that requires 220Vac rated at 20A, this should be running as long as the press is on. The press is outfitted with three push buttons, one is a NC stop button, the other is a NO manual retract button, and the third is a NO start automatic cycle button. There are limit switches at the top and bottom of the press travels that must also be connected.

SOLUTION

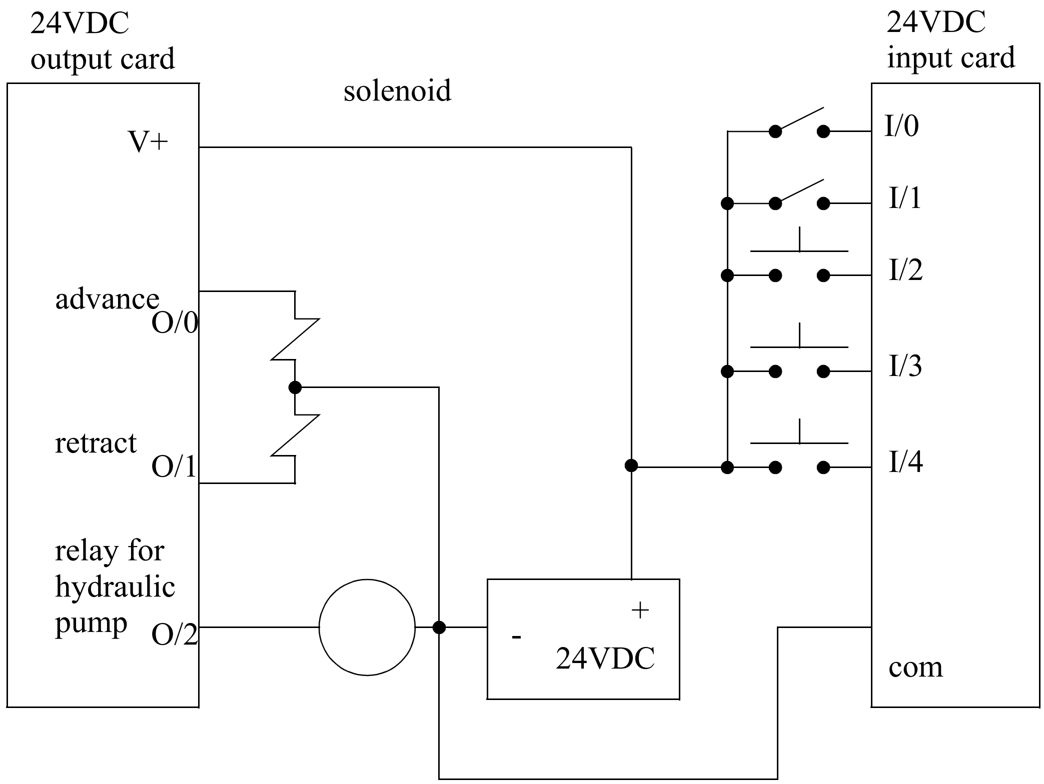


Figure 21 Case Study for Press Wiring

The input and output cards were both selected to be 24Vdc so that they may share a single 24Vdc power supply. In this case the solenoid valve was wired directly to the output card, while the hydraulic pump was connected indirectly using a relay (only the coil is shown for simplicity). This decision was primarily made because the hydraulic pump requires more current than any PLC can handle, but a relay would be relatively easy to purchase and install for that load. All of the input switches are connected to the same supply and to the inputs.

3.5 ELECTRICAL WIRING DIAGRAMS

When a controls cabinet is designed and constructed ladder diagrams are used to document the wiring. A basic wiring diagram is shown in Figure 22. In this example the system would be supplied with AC power (120Vac or 220Vac) on the left and right rails. The lines of these diagrams are numbered, and these numbers are typically used to number wires when building the electrical system. The switch before line 010 is a master disconnect for the power to the entire system. A fuse is used after the disconnect to limit the maximum current drawn by the system. Line 020 of the diagram is used to control power to the outputs of the system. The stop button is normally closed, while the start button is normally open. The branch, and output of the rung are CR1, which is a master control relay. The PLC receives power on line 30 of the diagram.

The inputs to the PLC are all AC, and are shown on lines 040 to 070. Notice that Input I:0/0 is a set of contacts on the MCR *CR1*. The three other inputs are a normally open push button (line 050), a limit switch (060) and a normally closed push button (070). After line 080 the MCR *CR1* can apply power to the outputs. These power the relay outputs of the PLC to control a red indicator light (040), a green indicator light (050), a solenoid (060), and another relay (080). The relay on line 080 switches a relay that turn on another device *drill station*.

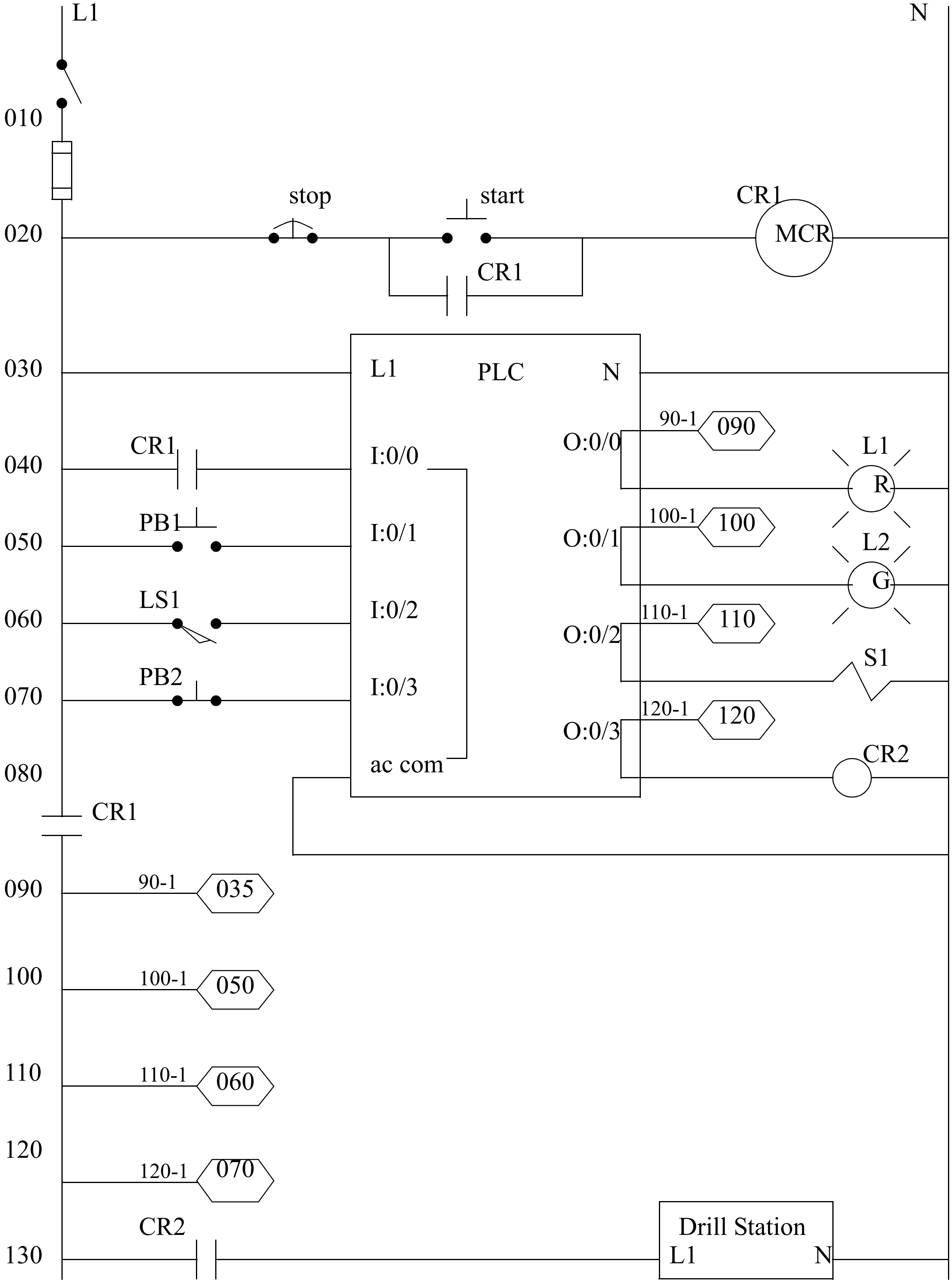


Figure 22 A Ladder Wiring Diagram

In the wiring diagram the choice of a normally close stop button and a normally open start button are intentional. Consider line 020 in the wiring diagram. If the stop button is pushed it will open the switch, and power will not be able to flow to the control relay and output power will shut off. If the stop button is damaged, say by a wire falling off, the power will also be lost and the system will shut down - safely. If the stop button used was normally open and this happened the system would continue to operate while the stop button was unable to shut down the power. Now consider the start button. If the button was damaged, say a wire was disconnected, it would be unable to start the system, thus leaving the system unstarted and safe. In summary, all buttons that stop a system should be normally closed, while all buttons that start a system should be normally open.

3.5.1 JIC Wiring Symbols

To standardize electrical schematics, the Joint International Committee (JIC) symbols were developed, these are shown in Figure 23, Figure 24 and Figure 25.

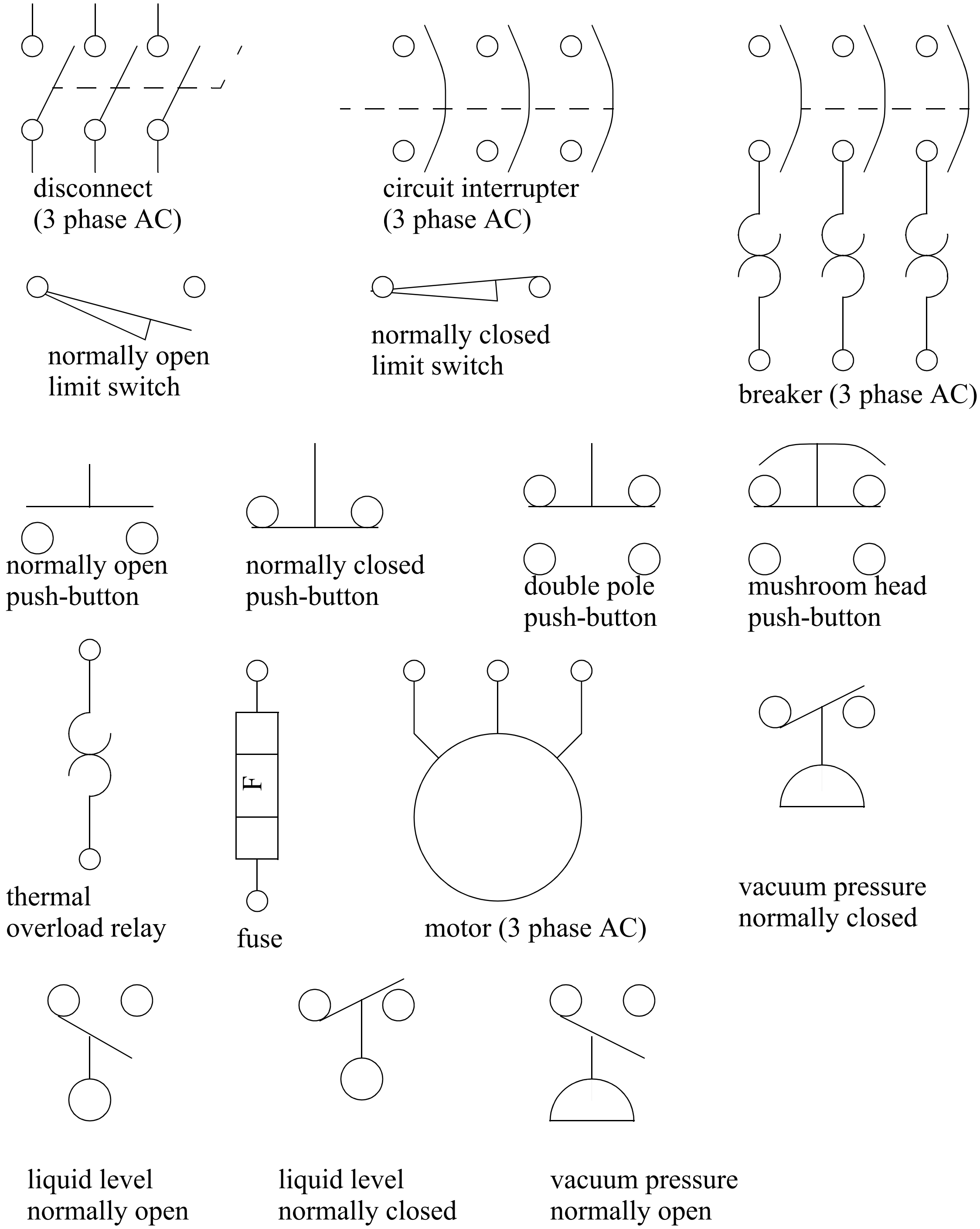


Figure 23 JIC Schematic Symbols

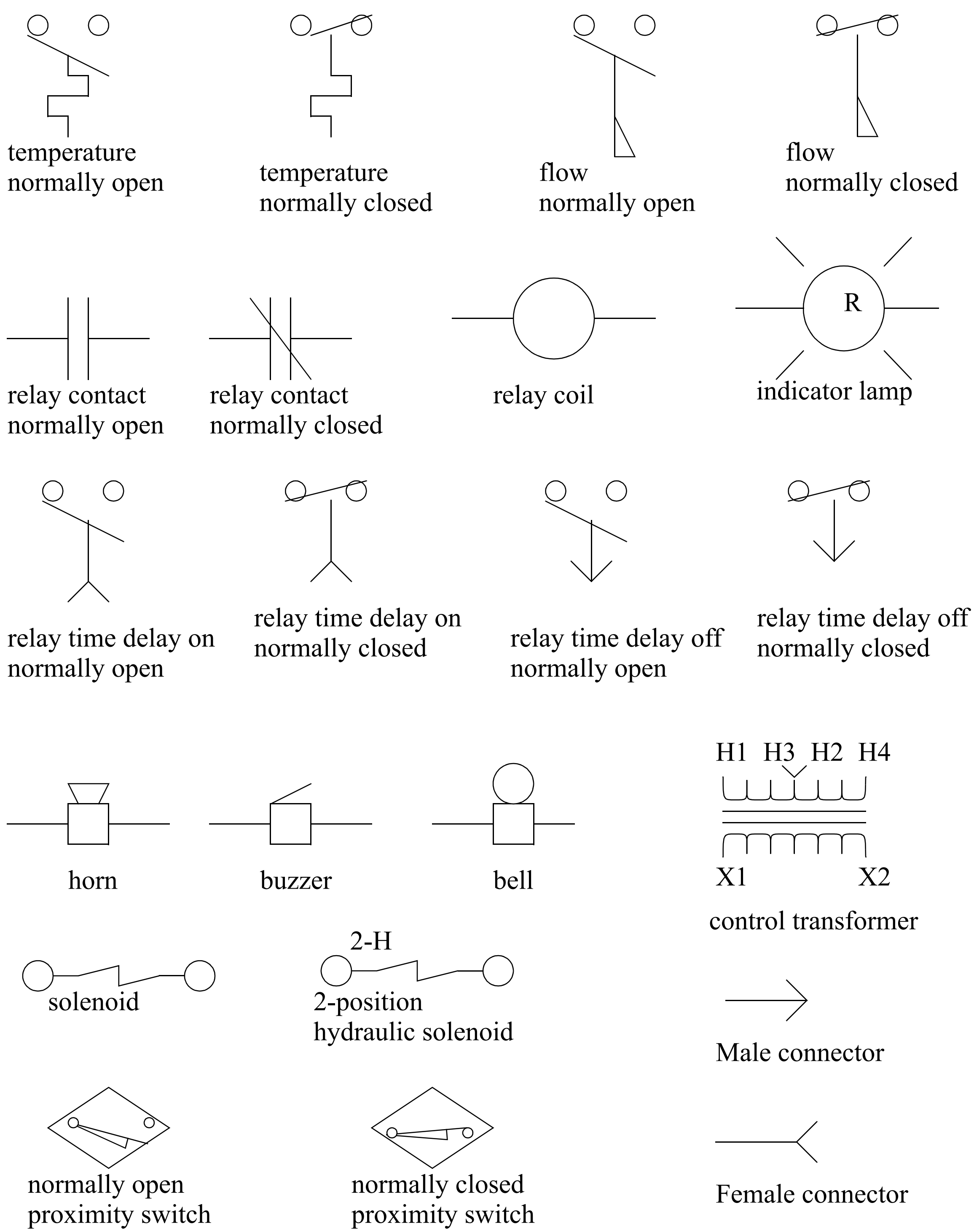


Figure 24 JIC Schematic Symbols

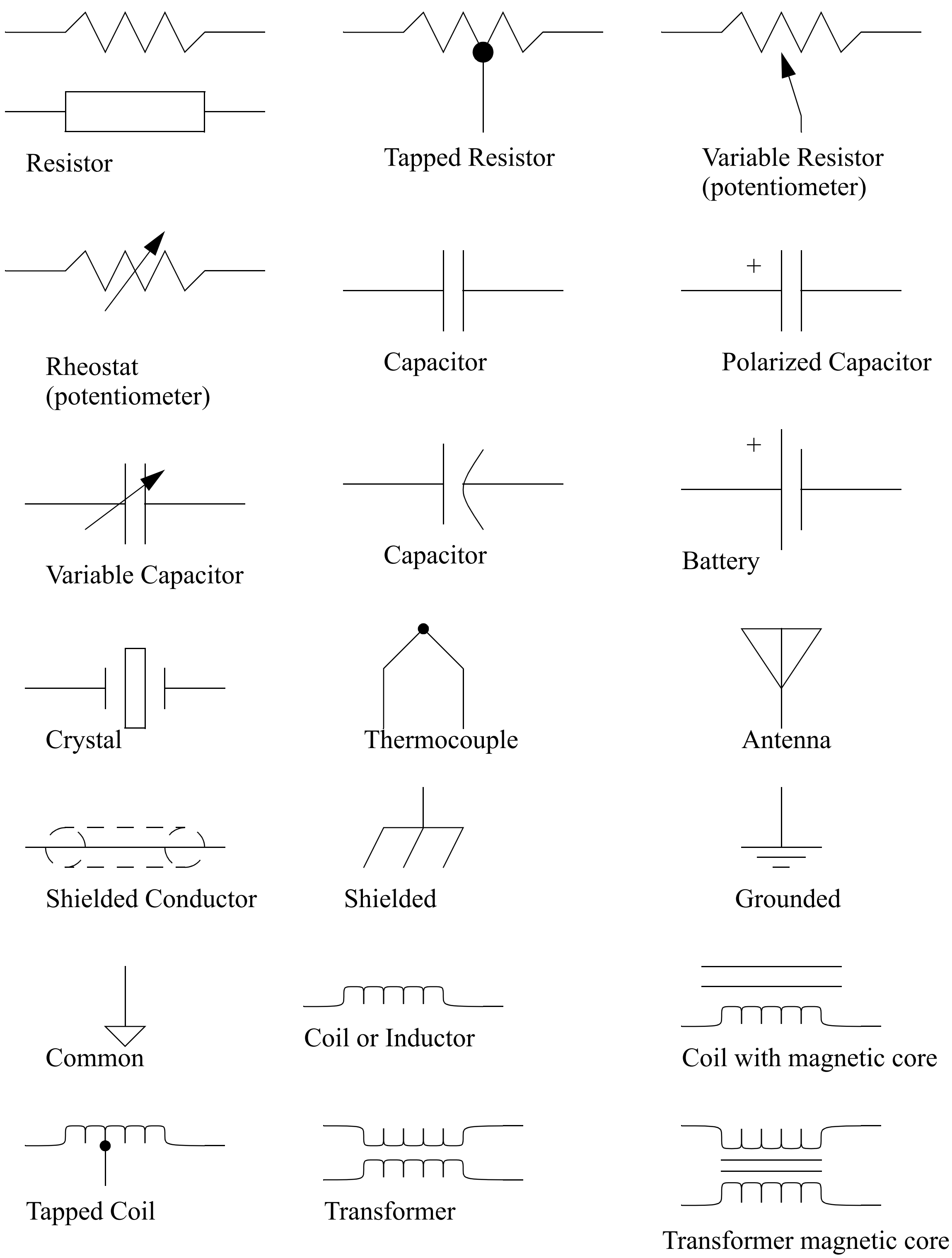


Figure 25 JIC Schematic Symbols

3.6 SUMMARY

• PLC inputs condition AC or DC inputs to be detected by the logic of the PLC.

• Outputs are transistors (DC), triacs (AC) or relays (AC and DC).
• Input and output addresses are a function of the card location/tag name and input bit number.
• Electrical system schematics are documented with diagrams that look like ladder logic.

3.7 PRACTICE PROBLEMS

1. Can a PLC input switch a relay coil to control a motor?

2. How do input and output cards act as an interface between the PLC and external devices?

3. What is the difference between wiring a sourcing and sinking output?

4. What is the difference between a motor starter and a contactor?

5. Is AC or DC easier to interrupt?

6. What can happen if the rated voltage on a device is exceeded?

7. What are the benefits of input/output modules?

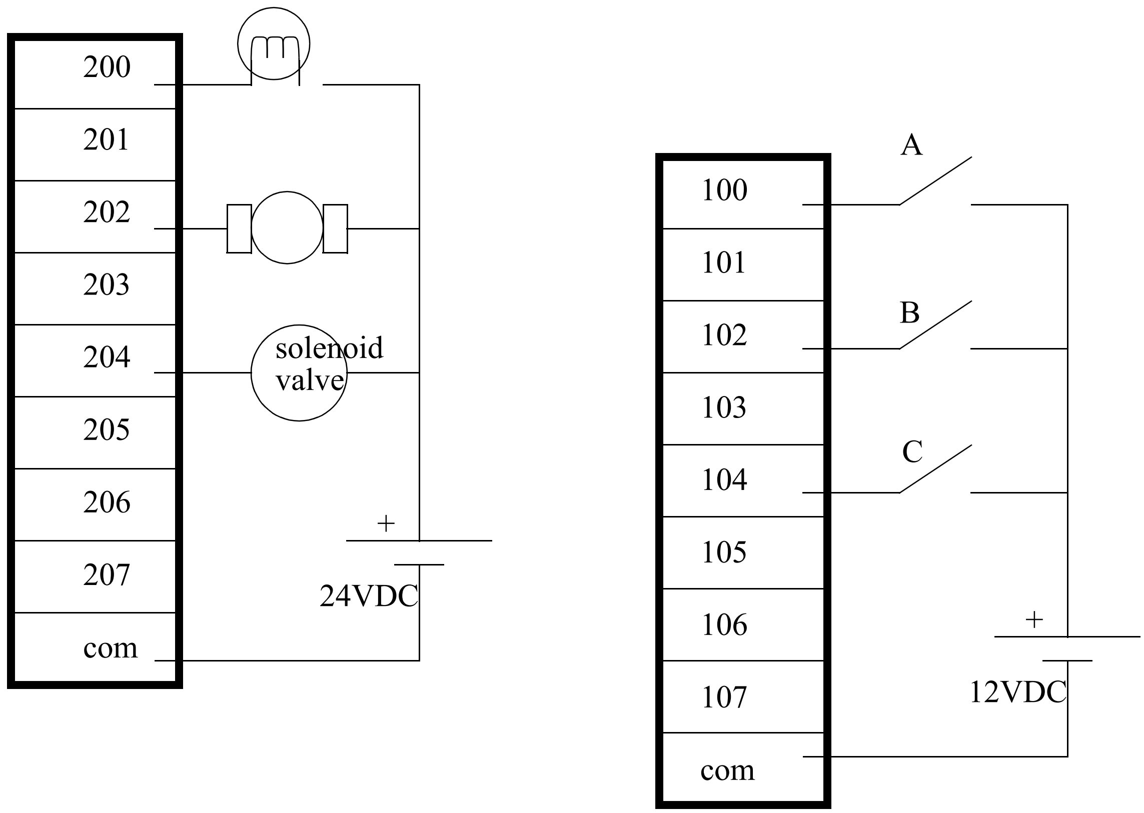
8. (for electrical engineers) Explain the operation of AC input and output conditioning circuits.

9. What will happen if a DC output is switched by an AC output.

10. Explain why a stop button must be normally closed and a start button must be normally open.

11. For the circuit shown in the figure below, list the input and output addresses for the PLC. If switch A con-

trols the light, switch B the motor, and C the solenoid, write a simple ladder logic program.



12. We have a PLC rack with a 24 VDC input card in slot 3, and a 120VAC output card in slot 2. The inputs are to be connected to 4 push buttons. The outputs are to drive a 120VAC light bulb, a 240VAC motor, and a 24VDC operated hydraulic valve. Draw the electrical connections for the inputs and outputs. Show all other power supplies and other equipment/components required.

13. You are planning a project that will be controlled by a PLC. Before ordering parts you decide to plan the basic wiring and select appropriate input and output cards. The devices that we will use for inputs are 2 limit switches, a push button and a thermal switch. The output will be for a 24Vdc solenoid valve, a 110Vac light bulb, and a 220Vac 50HP motor. Sketch the basic wiring below including PLC cards.

14. Add three push buttons as inputs to the figure below. You must also select a power supply, and show all

necessary wiring.

1
com
2
com
3
com
4
com
5
com

15. Three 120Vac outputs are to be connected to the output card below. Show the 120Vac source, and all wiring.

V
00
01
02
03
04
05
06
07

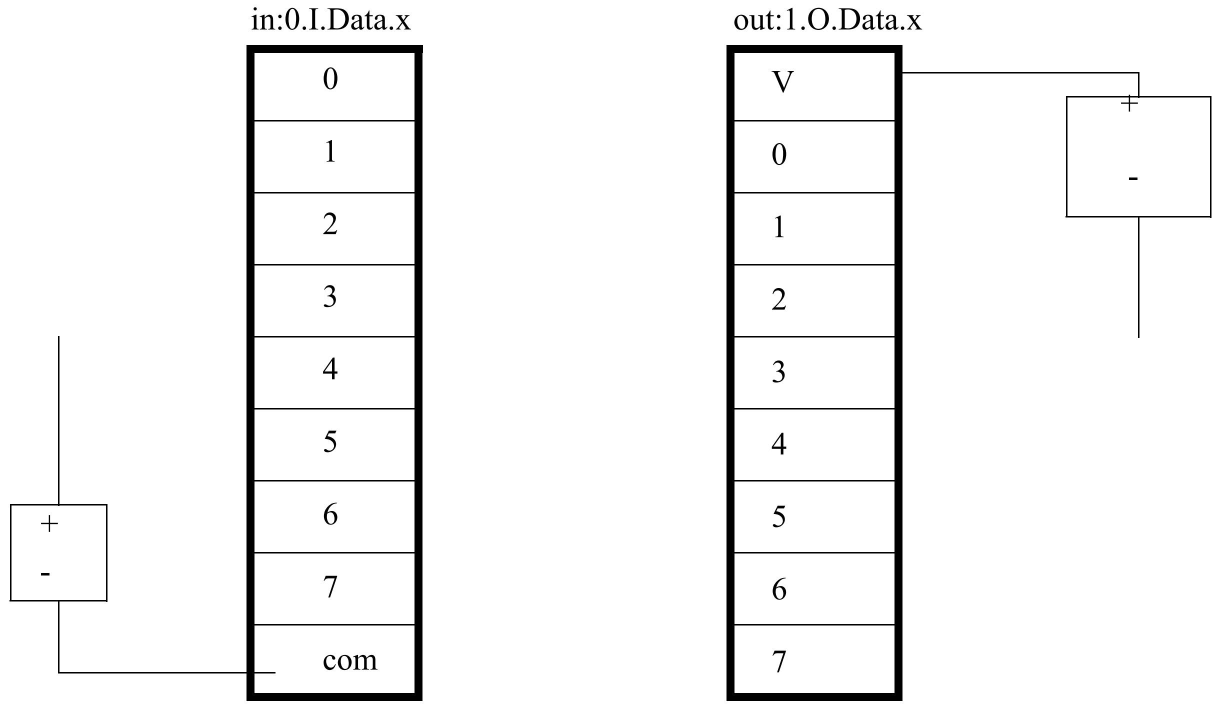
16. Sketch the wiring for PLC outputs that are listed below.
   - a double acting hydraulic solenoid valve (with two coils)
   - a 24Vdc lamp
   - a 120 Vac high current lamp
   - a low current 12Vdc motor

3.8 ASSIGNMENT PROBLEMS

1. Describe what could happen if a normally closed start button was used on a system, and the wires to the button were cut.

2. Describe what could happen if a normally open stop button was used on a system and the wires to the button were cut.

3. a) For the input ('in') and output ('out') cards below, add three output lights and three normally open push button inputs. b) Redraw the outputs so that it uses a relay output card.



4. Draw an electrical wiring (ladder) diagram for PLC outputs that are listed below.
   - a solenoid controlled hydraulic valve
   - a 24Vdc lamp
   - a 120 Vac high current lamp
   - a low current 12Vdc motor

5. Draw an electrical ladder diagram for a PLC that has a PNP and an NPN sensor for inputs. The outputs are two small indicator lights. You should use proper symbols for all components. You must also include all safety devices including fuses, disconnects, MCRs, etc...

6. Draw an electrical wiring diagram for a PLC controlling a system with both NPN and PNP input sensors. The outputs include an indicator light and a relay to control a 20A motor load. Include ALL safety circuitry.

7. Develop a wiring diagram for a system that has the following elements. Include all safety circuitry.
   2 NPN proximity sensors
   2 N.O. pushbuttons
   3 solenoid outputs
   A 440Vac 3ph. 20HP (i.e., large) motor

8. Draw a ladder wiring diagram for a system that has 2 PNP inputs, and 2 solenoid outputs. All inputs and outputs are 24Vdc. Include ALL safety circuitry.

9. Develop a ladder wiring diagram, including all safety circuitry that uses an PNP and an NPN input sensors. The outputs is a relay controlled AC light.

10. Draw a complete ladder wiring diagram for a PLC based control system with the following components. Include all necessary safety circuitry.
    1 large 3 phase (AC) motor
    2 PNP sensors
    1 NO pushbutton
    1 NC pushbutton
    1 solenoid output