Chapter 2

Creating Electrical Designs

In this chapter, we will learn the following to World Class standards:

- **Understanding Control and Power Circuits**
- **Drawing the Control Circuit**
- **Selecting the Pushbutton Switch**
- **Drawing the Power Relay**
- **Selecting the Terminal Blocks**
- **Drawing a Wiring Diagram**

Understanding Control and Power Circuits

In most of our electrical designs, we have two types of electrical circuits to develop, the power and the control circuit. The power circuit does the work that we need to have done such as running the motor or energizing and lighting the lamps. The logical network that determines whether our device is running or is off is the control circuit. Both areas of electrical design requires diligence and understanding, since we wish to create an efficient product that does not interfere with other electrical devices and our customers are always demanding flexibility in managing their assemblies. Again, in designing electrical products, safety is paramount in every aspect of the design, from spacing of components, to grounding of the enclosure. Electrical designers become even better mechanical designers since their designs are much more than static or dynamic parts, but we now include the electromagnetic force controlled by actuators and we view display indicators to see the status of our mechanism. As we learn to design with electrical circuits, we will continually grow in our knowledge and eventually learn to control our circuits with more complex circuits, even with computer programs.

When we start working with the types of power to run a machine or light a large number of lamps, the amount of current in the conducting wire increases. Not only does the wire diameter increase, but also in the electrical products, the contacts need to have a thicker cross section to handle the flow of electricity. In the table shown in figure 2.1, we can see that the size of the wire to carry 20 amps of current is the American Wire Gauge (AWG), size 14 conductor, when we are using PVC insulation at 80°C. This wire is much larger than the conductors we see on devices such as headphones.

CURRENT CARRYING CAPACITY OF COPPER CONDUCTORS (Measured in Amperes)					
	Insulation Materials at Given Temperatures				
Conductor Size	Polyethylene Neoprene Polyurethane Polyvinyl-Chloride (semi-rigid) at 80° **c**	Poly-Propylene Polyethylene (high density) at 90° **c**	Polyvinyl-Chloride PVC (irradiated) nylon at 105° **c**	Kynar Polyethylene (Crosslinked) Thermoplastic Elastomer S at 125° **c**	Kapton Teflon Silicone at 200° **c**
26 AWG	4	5	5	6	7
24 AWG	6	7	7	8	10
22 AWG	8	9	10	11	13
20 AWG	10	12	13	14	17
18 AWG	15	17	18	20	24
16 AWG	19	22	24	26	32
14 AWG	27	30	33	40	45
12 AWG	36	40	45	50	55
10 AWG	47	55	58	70	75
8 AWG	65	70	75	90	100
6 AWG	95	100	105	125	135
4 AWG	125	135	145	170	180
2 AWG	170	180	200	225	240

Figure 2.1 – American Wire Gauge Conductor Sizes[1]

[1] Current Carrying Capacity Chart, 2009, World Wide Wire, <http://www.worldwidewire.com/technical-specs/amperage-chart.htm>

We can see in our industry, two types of interfaces to control equipment such as fans, motors and lights. In buildings and homes, we use larger conductors and switches that fill a wall with a row of interfaces to the point that we need a half square foot of space for control of just a few devices. In a dwelling, where surface area does not seem to be a problem, we have historically chosen to use these bigger interfaces.

In modern washers, dryers and automobiles we never see massive switches that can control the electromagnetic force that powers our conveniences, such as air conditioning, heaters or lights. Why is that? The designer places relays or power contactors safely away from the person, and utilize smaller voltage and currents in the control circuit, enabling the interface panel to hold ten to hundreds of buttons. Can we imagine using typical house light switches on the controls of our stereos and computers? We know that we do not have room to use these power-switching devices, so we need another technique to manage our appliances.

Therefore, we develop the control circuit where we can use smaller wires and contacts carrying one ampere of electrical current or less. The American Wire Gauge or AWG conductor that can carry that type of current is 28 AWG and that is very much smaller in diameter. The control wires take the electrical signal to the contactor or relay coil and can energize the power circuit, which will run the motor or energize the lamps.

Drawing a Control Circuit

When making a wiring diagram, we need to know what components we need and we should have the ability to draw the proper symbols representing the electrical devices. In our problem, we need to have a symbol for the pushbutton switch, the control terminal block, the Earth ground, a screw connecting the Earth ground to the enclosure, and the power relay.

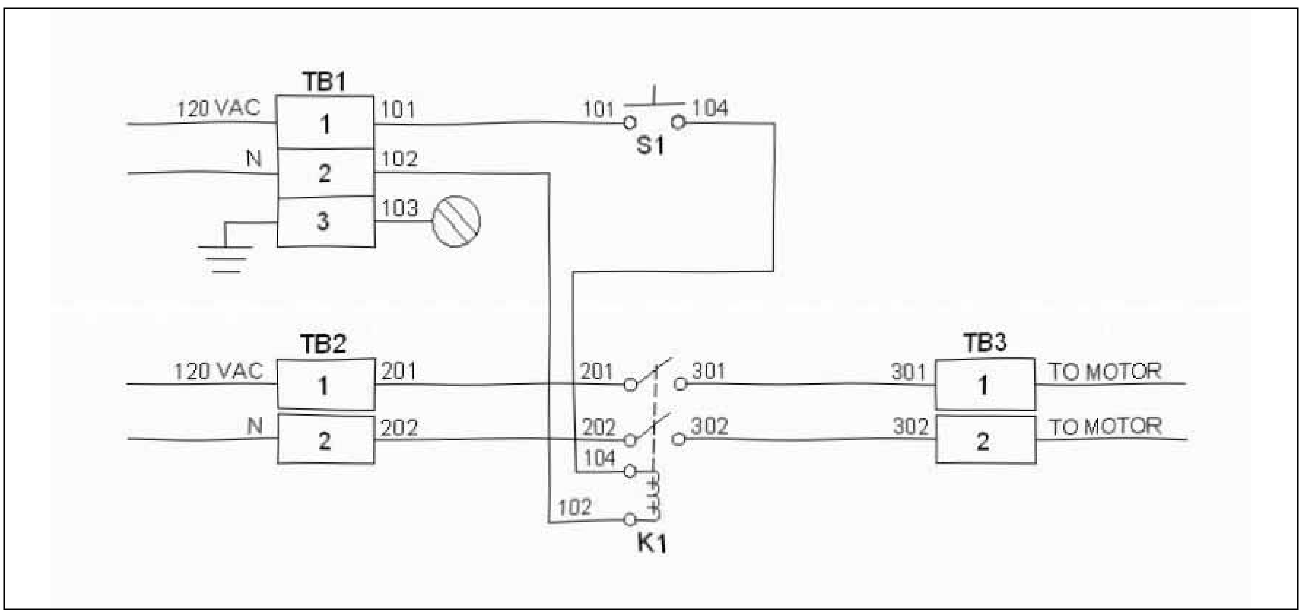
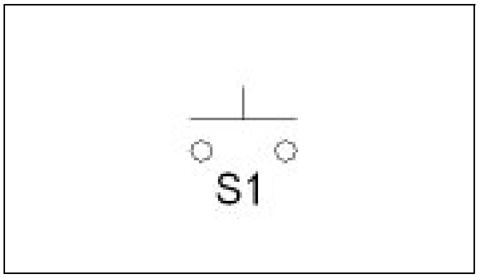


Figure 2.2 – The Sketch of the Control Circuit

The electrical engineer for the project will draw the diagram that we need to build. We need to keep the sketches and other markups the project engineer gives us, so we can reference this material anytime questions arise when working on the project. After developing experience with electrical drawings, the designer can draw the circuit and the electrical engineer with check the drawing for accuracy.

In the drawing in figure 2.2, the project manager wants to use a pushbutton switch to energize the power relay.



The symbol for the pushbutton switch has two contacts with a wiper horizontally across the top of the switch. When we draw a switch, we can show the contacts as Normally Open (NO) or Normally Closed (NC). The switch shown in figure 2.3 is normally open, which means that the operator needs to press the button in order to activate the relay coil that will close the relay contacts and power the appliance.

Figure 2.3 – Pushbutton Switch

Another consideration when choosing a switch is whether we want the actuator to be maintain or momentary. When we press a maintained button, the switch changes to normally closed where the wiper lies across the contacts permanently until the worker depresses the switch button again, turning the control circuit off. On most maintain switches, we will hear an audible click when operating the toggle of button of a maintain switch. For a momentary switch, the wiper touches the contacts when we press down the button, however when we remove the force of our finger, the wiper returns to the normally open position,

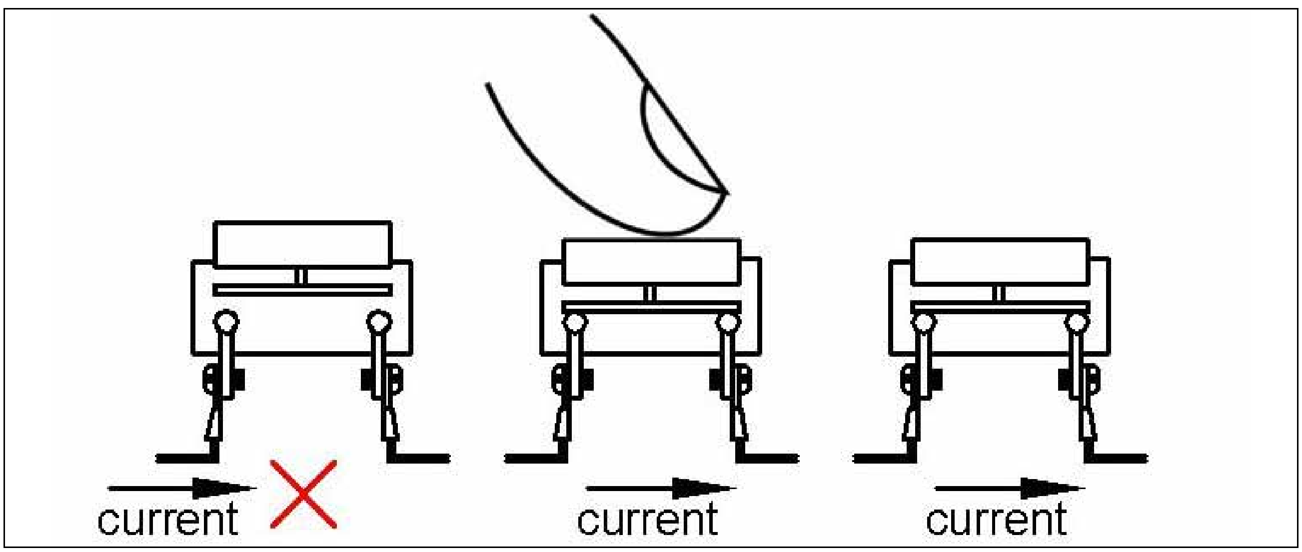


Figure 2.4 – Switch Actions for a Maintain Switch

When we draw a control diagram as shown in the sketch in figure 2.2, we show the switches and relay contacts in their inactivated states. In our example, we show the pushbutton switch as normally open. In figure 2.4, we can see the inside of the normally open switch on the left side and that the electromagnetic force cannot continue since the conducting bar does not connect the two contacts. When we depress the switch as shown in the center of the picture, the conducting bar makes contact with the both sides of the control circuit and the electrical current will flow through the switch. On our maintain actuator, the switch will remain locked in position as shown in the right image until the operator presses the button again.

Another consideration we make in selecting the switch is the amount of voltage and current the contacts need to withstand. When we allow electrical current to flow through the switch, the conducing material will heat up. Every manufacturer of electrical components tests and rates their devices for specific maximum potentials measured in volts and currents measured in amps. If necessary, we can protect our control circuit with a fuse, which is a device that will fail when the current exceeds the current specification for a period of time. Another more expensive circuit protection device that acts similar to the fuse is the circuit breaker. This component will break the control circuit when the current exceeds the rated value for a certain time. In following chapters, we will learn how to draw the electrical symbols and place fuses or circuit breaker into a design.

Selecting the Pushbutton Switch

Now that we know how to draw the switch in the electrical control diagram, we need to develop the skill of selecting the correct component in the assembly. Again, we will choose the switch that has contact ratings of 120 VAC and can carry 1 ampere of current. When we press the actuator, the pushbutton will maintain position until pressed again. The switch has one pole.

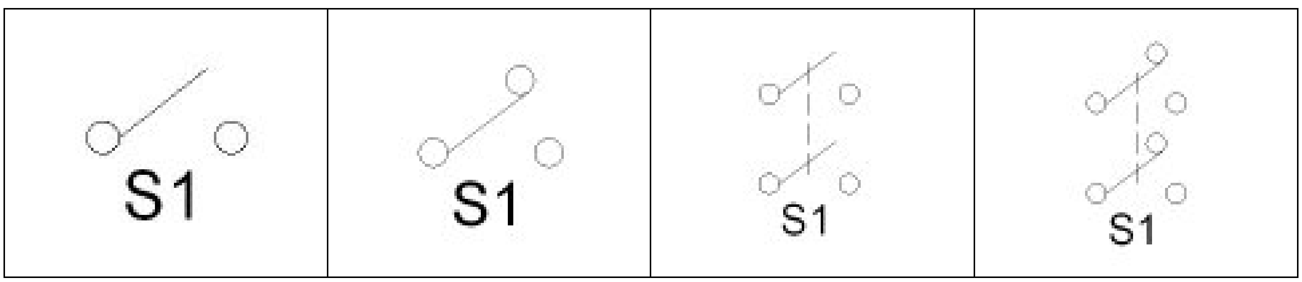
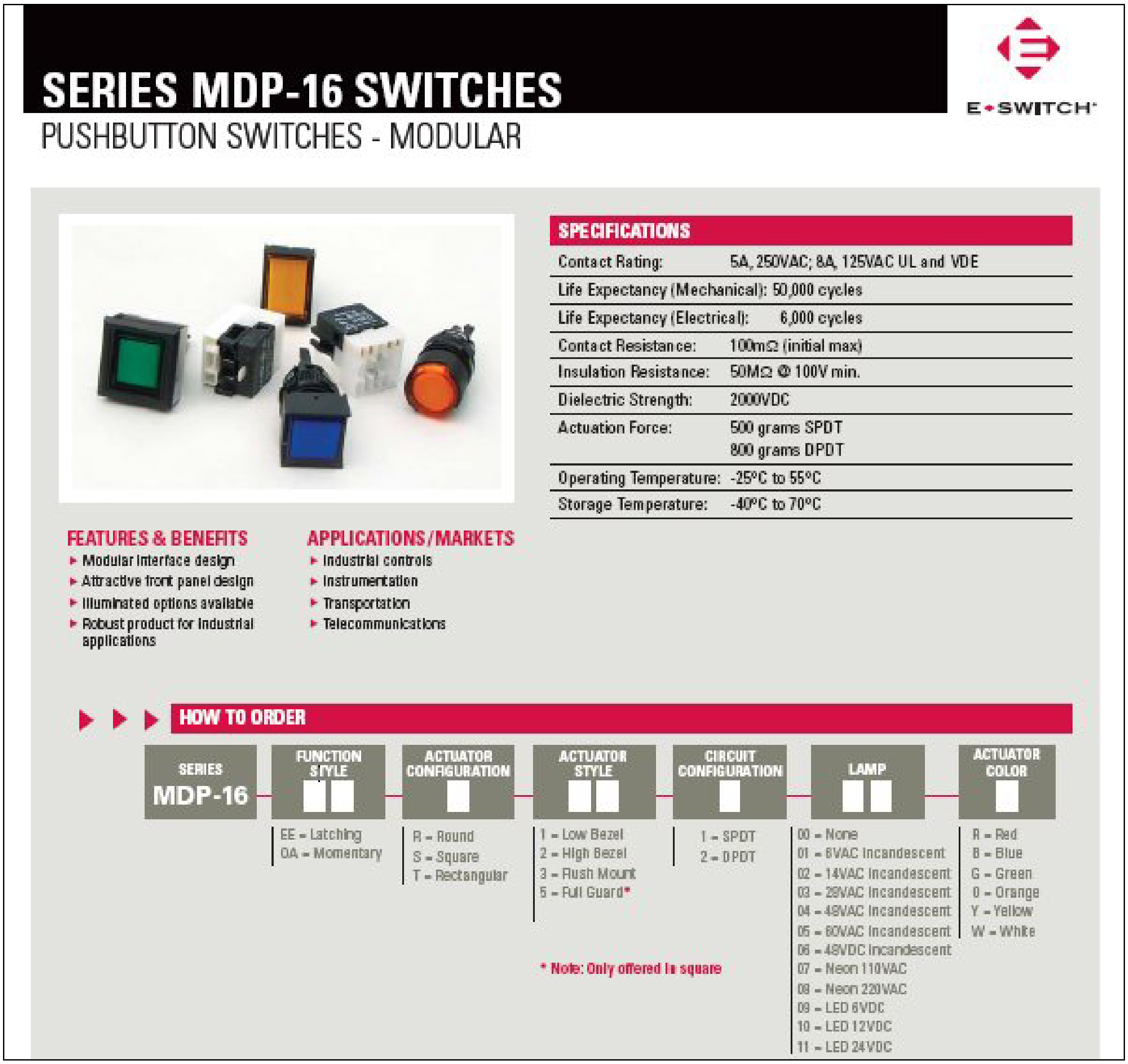


Figure 2.5 – Different Types of Poles

The switch we are using has a single pole, so that when turn the actuator on the current will flow. This type of switch is common and shown in the left pane in figure 2.5. The next type is the single pole double throw style shown in the next pane to the right. When the switch actuator is in the off position, the electrical current can flow to that normally closed contact. Imagine that we want to choose between a high and low setting, we can wire the normally closed side to the low output and the normally open to the high output. We typically use a toggle or rotary switch actuator on a panel, so the operator can toggle the switch in either direction for the low or high setting.

Another option for a switch is shown in the third panel form the left, the double pole – single throw option. We use this preference so we can obtain two affects in the control circuit and only use one switch. If we want two things to happen when we toggle a switch, we can wire the switch so that one normally open pole goes to one output and the other normally open pole goes to the other output. We accomplish the act with one switch. We can purchase a switch that is double pole, double throw, and pick up even more possibilities. There are switches available in the industry that allow us to stack even more poles on the same actuator to the point that we can have an eight pole double throw combination.

We went out on the Internet and found a switch made by E-Switch. The contact rating is 8 A at 125 VAC. We need to consider other specifications such as life expectancy, dielectric strength and operating temperature. In order to make these decisions, we need to know how long the product needs to last and the number of times the switch will change position. Engineers and customers are constantly examining these parameters to meet the product expectation and to control costs. We could make all switches to last for millions of actions, however higher process for each item would raise the cost of the final assembly.


SERIES MDP-16 SWITCHES

PUSHBUTTON SWITCHES - MODULAR

E-SWITCH

SPECIFICATIONS

Contact Rating:	5A, 250VAC; 8A, 125VAC UL and VDE
Life Expectancy (Mechanical):	50,000 cycles
Life Expectancy (Electrical):	6,000 cycles
Contact Resistance:	100mΩ (initial max)
Insulation Resistance:	50MΩ @ 100V min.
Dielectric Strength:	2000VDC
Actuation Force:	500 grams SPDT 800 grams DPDT
Operating Temperature:	-25°C to 55°C
Storage Temperature:	-40°C to 70°C

FEATURES & BENEFITS
- Modular interface design
- Attractive front panel design
- Illuminated options available
- Robust product for industrial applications

APPLICATIONS/MARKETS
- Industrial controls
- Instrumentation
- Transportation
- Telecommunications

HOW TO ORDER

SERIES	FUNCTION STYLE	ACTUATOR CONFIGURATION	ACTUATOR STYLE	CIRCUIT CONFIGURATION	LAMP	ACTUATOR COLOR
MDP-16	EE = Latching OA = Momentary	R = Round S = Square T = Rectangular	1 = Low Bezel 2 = High Bezel 3 = Flush Mount 5 = Full Guard*	1 = SPDT 2 = DPDT	00 = None 01 = 6VAC Incandescent 02 = 14VAC Incandescent 03 = 28VAC Incandescent 04 = 48VAC Incandescent 05 = 60VAC Incandescent 06 = 48VDC Incandescent 07 = Neon 110VAC 08 = Neon 220VAC 09 = LED 6VDC 10 = LED 12VDC 11 = LED 24VDC	R = Red B = Blue G = Green O = Orange Y = Yellow W = White

* Note: Only offered in square

Figure 2.6 – Catalog Sheet of Pushbutton Switch made by E-Switch[2]

[2] E-Switch Online Catalog, 2009, E Switch Inc, http://e-switch.com/pdf/MDP-16.pdf

After picking a switch, we want to obtain the mechanical data, so we will be able to draw the switch in our CAD program. Then we want the mounting hole size, so we can create a drawing detail showing the machining of the front panel that will hold the pushbutton switch. We show the image of the switch and the mounting dimensions in figure 2.7. Some companies will machine the key in the panel, so that a single switch will not rotate when assembled to the enclosure. When we place multiple switches up against each other in a row, we can eliminate the key, since the rectangular body of the switch housing will prevent rotation.

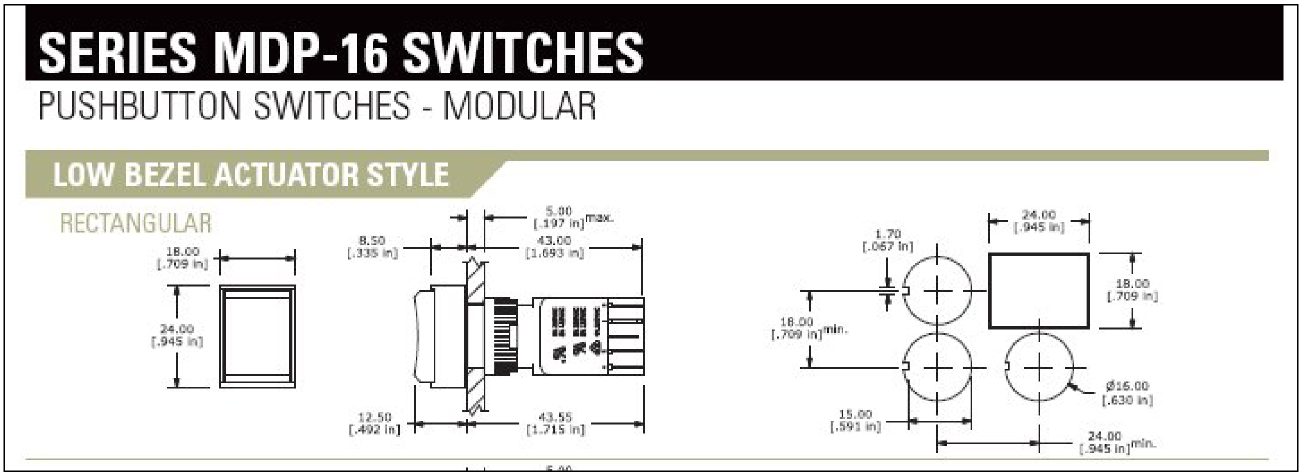
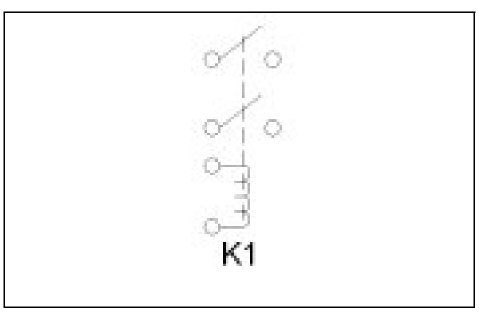


Figure 2.7 – Catalog Sheet of Pushbutton Switch made by E-Switch[3]

Drawing the Power Relay

We use power relays and contactors to close power circuits and turn on major appliances such as fans, motors and large banks of lights. We also use these devices as a strategy to locate the larger electrical components that switch larger currents and voltages farther away from the operator. Where there is little risk of fire in a small control circuit, there is always a higher probability with fire, product failure and lightning with high power devices. Separating the control and power circuits enables the designer to place more switches and indicators on the control panel and generally increases the safety of the operator.



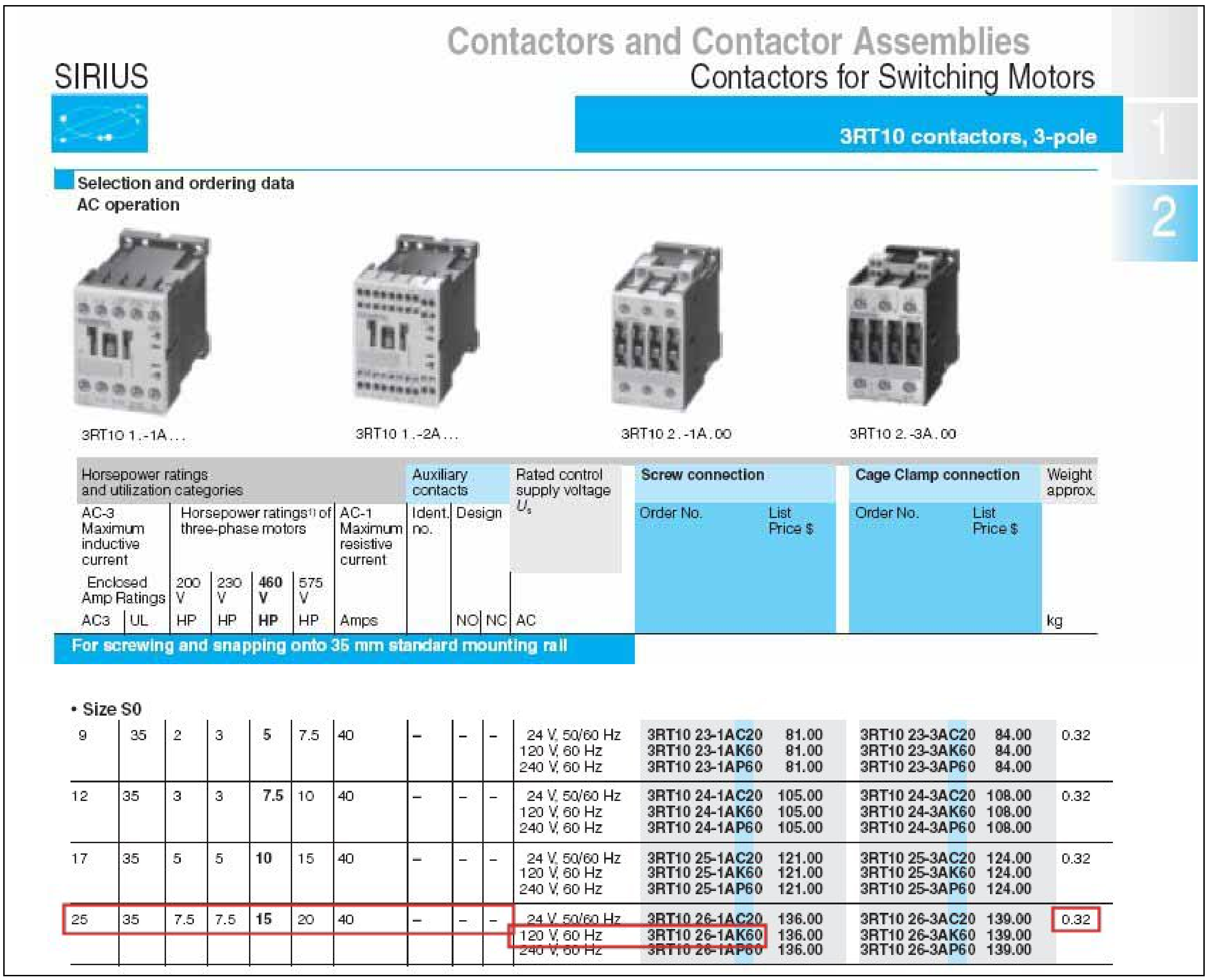
In a typical relay or contactor, the design uses a magnetic coil to pull the normally open contacts closed when energized and we show the symbol in figure 2.8. The dotted line runs through the relay coil and up through the two wipers in the two poles. Some relays operate with smaller Direct Current (DC) voltages of 5, 12 or 24 volts. In our project, we will be using 120 VAC at 1 ampere current in the control circuit, so we will select a coil rating to match.

Figure 2.8 – SPST Relay

[3] E-Switch Online Catalog, 2009, E Switch Inc, http://e-switch.com/pdf/MDP-16.pdf

When we select the voltage and current rating for the contacts on the power relay or contactor, we will make sure the device can safely switch the appliance on and off, so we have to verify these electrical numbers. Many designers have the capability to select relays and contactors from a catalog when working on similar designs and then present the entire drawing package and catalog sheets to the electrical engineer for verification.

We went to the Siemens Contactor web catalog and we want to select a contactor for an inductive load. We can see that the contactors have an AC3, inductive load amperage and AC1 resistive load amperage. We can use the resistive current rating or AC1 column when turning on light bulbs and heaters. We use the AC3 inductive rating for motors and transformers. The contactor we select has a 25 amp AC3 rating. The coil works with 120 Volts AC and 60-Hertz frequency. The contactor has three poles, which we will only use two.



Horsepower ratings and utilization categories: AC-3 Maximum inductive current, Enclosed Amp Ratings AC3	UL	Horsepower ratings[1] of three-phase motors 200 V HP	230 V HP	460 V HP	575 V HP	AC-1 Maximum resistive current Amps	Auxiliary contacts Ident. no.	Design NO	NC	Rated control supply voltage U_s AC	Screw connection Order No.	List Price $	Cage Clamp connection Order No.	List Price $	Weight approx. kg
For screwing and snapping onto 35 mm standard mounting rail															
• **Size S0**															
9	35	2	3	5	7.5	40	–	–	–	24 V, 50/60 Hz 120 V, 60 Hz 240 V, 60 Hz	3RT10 23-1AC20 3RT10 23-1AK60 3RT10 23-1AP60	81.00 81.00 81.00	3RT10 23-3AC20 3RT10 23-3AK60 3RT10 23-3AP60	84.00 84.00 84.00	0.32
12	35	3	3	7.5	10	40	–	–	–	24 V, 50/60 Hz 120 V, 60 Hz 240 V, 60 Hz	3RT10 24-1AC20 3RT10 24-1AK60 3RT10 24-1AP60	105.00 105.00 105.00	3RT10 24-3AC20 3RT10 24-3AK60 3RT10 24-3AP60	108.00 108.00 108.00	0.32
17	35	5	5	10	15	40	–	–	–	24 V, 50/60 Hz 120 V, 60 Hz 240 V, 60 Hz	3RT10 25-1AC20 3RT10 25-1AK60 3RT10 25-1AP60	121.00 121.00 121.00	3RT10 25-3AC20 3RT10 25-3AK60 3RT10 25-3AP60	124.00 124.00 124.00	0.32
25	35	7.5	7.5	15	20	40	–	–	–	24 V, 50/60 Hz 120 V, 60 Hz 240 V, 60 Hz	3RT10 26-1AC20 3RT10 26-1AK60 3RT10 26-1AP60	136.00 136.00 136.00	3RT10 26-3AC20 3RT10 26-3AK60 3RT10 26-3AP60	139.00 139.00 139.00	0.32

Figure 2.9 – Siemens Contactor Online Catalog[4]

In figure 2.9, we circled the 3RT10 26-1AK60 contactor for our project and then we went back to

[4] Siemens Online Catalog, 2009, http://cmsapps.sea.siemens.com/controls/icc/06IndControl_%20pdfs/06IC_02/02_017-018.pdf. (Note: we removed the middle of the catalog sheet, so the Size SO contactor is directly beneath the headings)

the online catalog and found the dimensions page showing the size of the contactor. The drawing does not show the standard American orthographic rotation, but shows the left side of the device on the right side of the top view. Since there are two types of orthographic rotation used in the world, this can cause some interpretation errors. The dimensions shown are in millimeters. We will not use auxiliary contacts, so we can ignore the dotted lines in the sketch. The mounting dimensions are shown on the far right side of the diagram.

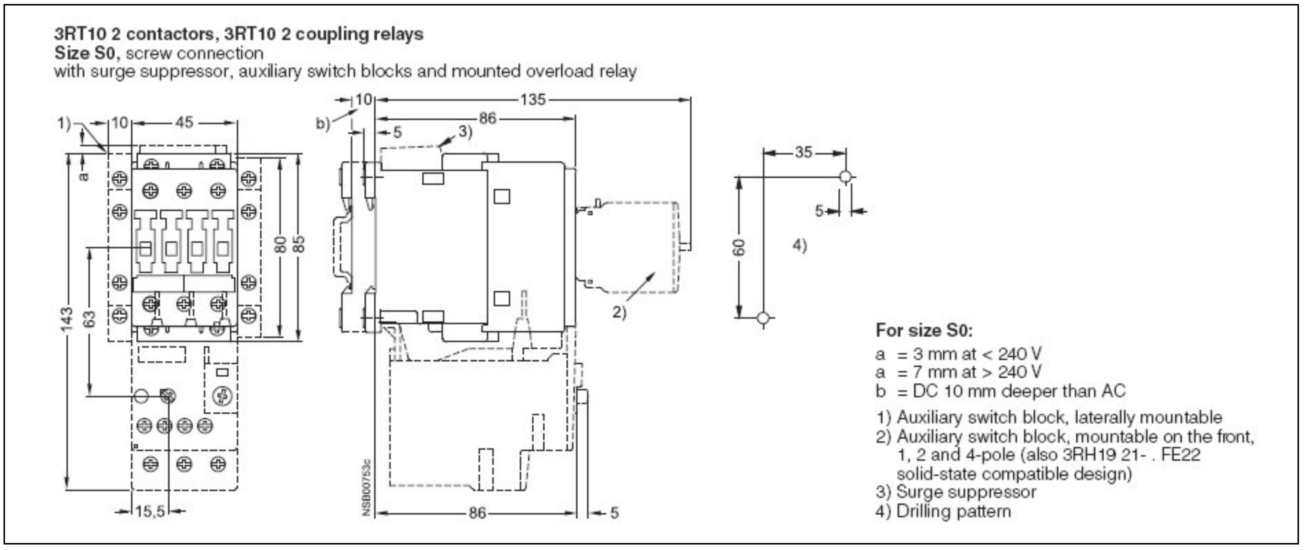


Figure 2.10 –Dimensions of 3RT102 Contactor from the Siemens Online Catalog[5]

Selecting the Terminal Blocks

A terminal block is a specific style of electrical product that allows an electrician to attach an external wire to our assembly. As we can see in figure 2.11, the electrician's wire can be inserted into a screw clamp on the left side and the electrical current flows from there, through the bus bar to the screw clamp on the other side. We insert our wire into the screw clamp on the right side and the wire takes the current to electrical components in our switch and contactor enclosure. So a terminal block is a simple transfer device.

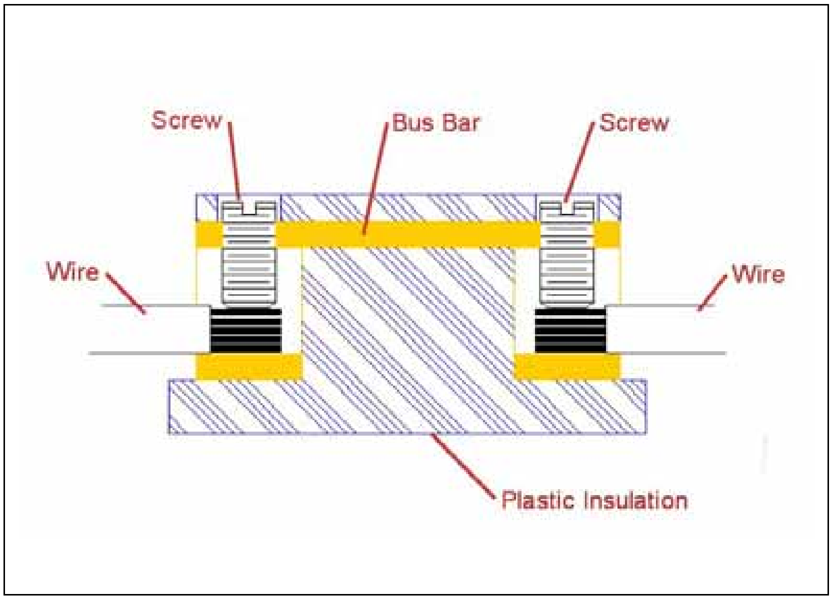


Figure 2.11 –Cross Section of a Terminal Block

[5] Siemens Online Catalog, 2009, https://www.sea.siemens.com/controls/icc/06%20IndControls%20pdfs/06IC_02/02_177-179.pdf

Now that we have the contactor and the control switch selected, we can pick the terminal blocks, which will allow the electrician to connect external wires to our assembly. We will use the same style of terminal block for the control circuit as we utilized in the last chapter. The control terminal block shown in figure 2.12 exhibits an assembly that can hold a 26 to 16 American Wire Gauge (AWG) wire. The terminal block rating is a maximum of 250 volts and 25 amps. The manufacturer makes the plastic terminal block for ten circuits. Companies that purchase the Europa style terminal block will cut the plastic between circuits and just use the number of circuits we need. In our assembly, we will use three circuits.

Figure 2.13 – Terminal Block made by Buchanan[6]

There is a clearance hole between each circuit in this variety of terminal block. When we cut the terminal block between the third and fourth circuit, we will have two holes to mount the Europa terminal block.

For the power contactor, we choose to use the Allen Bradley panel mount blocks. The Allen Bradley block can receive wire from 30 to 12 AWG. The specification shows that the block can handle 600 volts and 25 amperes of current. This block comes with 6 poles or circuits molded into the assembly.

When we make our assembly, we will label the terminal block as number 2 (TB2) and then positions 1 and 2 will have the incoming power wires and positions 5 and 6 can hold the outgoing cables to the motor. Positions 3 and 4 can be left open.

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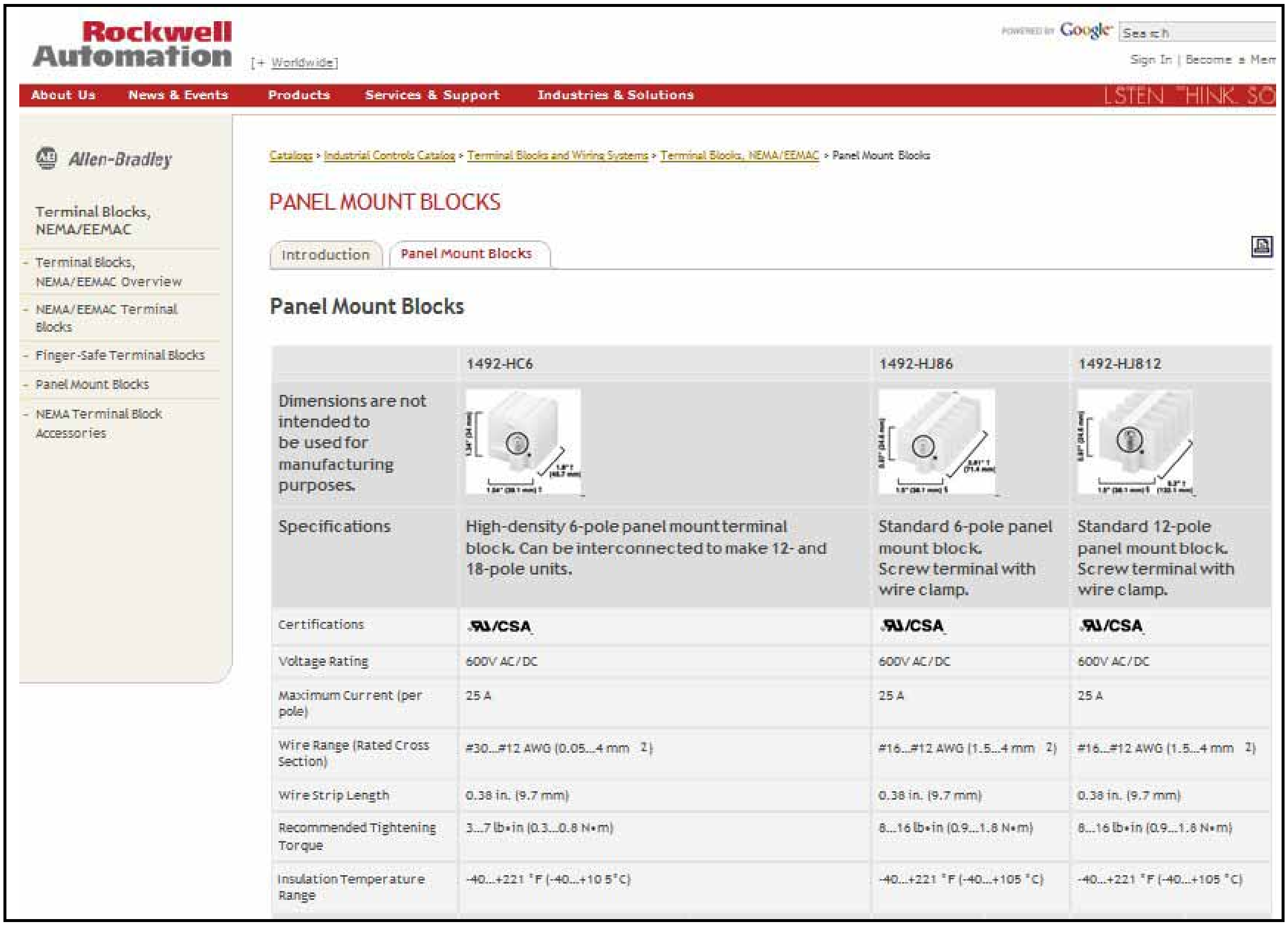
[6] Europa Terminal Block, 2008, Tyco Electronics Corporation, http://catalog.tycoelectronics.com/catalog/bin/TE.Connect?C=16696&M=PPROP&P=&BML=&LG=1&PG=1&IDS=370022,370023,370024,370009,370010,370012,370014,370015,370016,370018,370019,370021,370025,370026,370028,370029,370030,370031,370032,370034&N=1#features



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LISTEN THINK SO

Allen-Bradley

Terminal Blocks, NEMA/EEMAC

- Terminal Blocks, NEMA/EEMAC Overview
- NEMA/EEMAC Terminal Blocks
- Finger-Safe Terminal Blocks
- Panel Mount Blocks
- NEMA Terminal Block Accessories

Catalogs > Industrial Controls Catalog > Terminal Blocks and Wiring Systems > Terminal Blocks, NEMA/EEMAC > Panel Mount Blocks

PANEL MOUNT BLOCKS

Introduction | Panel Mount Blocks

Panel Mount Blocks

	1492-HC6	1492-HJ86	1492-HJ812
Dimensions are not intended to be used for manufacturing purposes.			
Specifications	High-density 6-pole panel mount terminal block. Can be interconnected to make 12- and 18-pole units.	Standard 6-pole panel mount block. Screw terminal with wire clamp.	Standard 12-pole panel mount block. Screw terminal with wire clamp.
Certifications	UL/CSA	UL/CSA	UL/CSA
Voltage Rating	600V AC/DC	600V AC/DC	600V AC/DC
Maximum Current (per pole)	25 A	25 A	25 A
Wire Range (Rated Cross Section)	#30...#12 AWG (0.05...4 mm2)	#16...#12 AWG (1.5...4 mm2)	#16...#12 AWG (1.5...4 mm2)
Wire Strip Length	0.38 in. (9.7 mm)	0.38 in. (9.7 mm)	0.38 in. (9.7 mm)
Recommended Tightening Torque	3...7 lb•in (0.3...0.8 N•m)	8...16 lb•in (0.9...1.8 N•m)	8...16 lb•in (0.9...1.8 N•m)
Insulation Temperature Range	-40...+221 °F (-40...+105 °C)	-40...+221 °F (-40...+105 °C)	-40...+221 °F (-40...+105 °C)

Figure 2.12 – Panel Mount Terminal Blocks from the Allen Bradley Online Catalog[7]

Drawing a Wiring Diagram

Now that we know more about the actual design and the components, we can draw the wiring diagram in our CAD program. We will use the 2-pole relay contact and relay coil blocks in the schematic. We also add notes to the wiring diagram discussing the location of the components.

Most electrical enclosures have a document pocket on the inside of the door that can hold the wiring diagram, manual and guarantee papers. We recommend that a laminated electrical diagram be mounted on the inside of the enclosure door, so the electrician, maintenance staff or engineer can quickly refer to the document when troubleshooting the assembly.

On some diagrams, we can see the pin numbers where the wires land. This can be helpful,

[7] Allen Bradley's Panel Mount Terminal Block webpage, 2009, Rockwell International, http://www.ab.com/en/epub/catalogs/12768/229240/229268/471152/471154/tab2.html

however manufacturers frequently change components in assemblies either from better pricing, delivery or safety concerns. If we replace the Siemens contactor with another brand, the connection numbers would change and the diagram would only apply to a certain revision of the panel. If you wish to add the pin numbers to the diagram, use the text command in the CAD program to add the information.

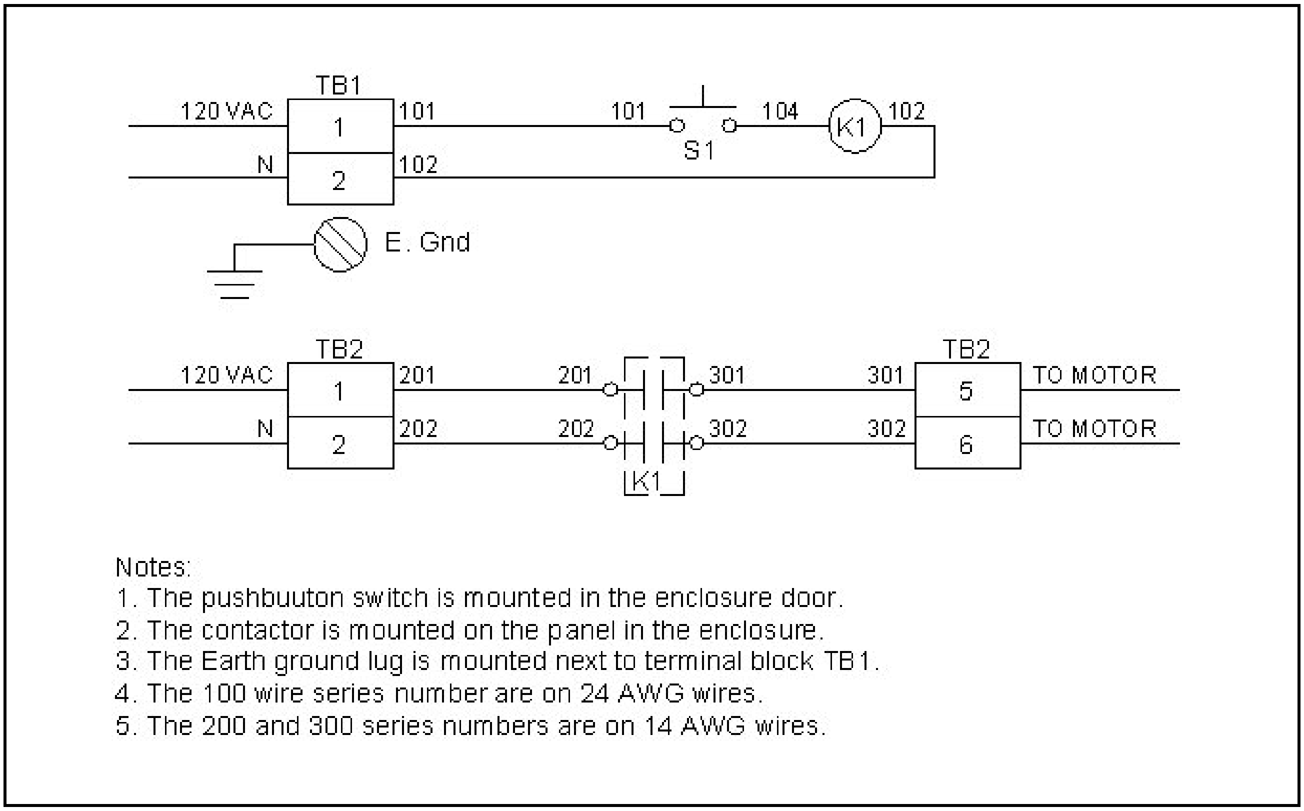

Figure 2.13 – Wiring Diagram of the Relay Panel

*** World Class CAD Challenge 9-2 * - Draw an electrical symbol of a switch, terminal block, relay coil, relay contacts and chassis ground. Create a wiring diagram of a relay assembly using the CAD block symbols along with border and completed title block in 30 minutes.**

Continue this drill four times using some other ideas, such as single pole, double throw switch or with multiple switches, each time completing the drawing under 30 minutes to maintain your World Class ranking.