Chapter 36

to operate on three phase power. A drive designed to operate on three phase power can generally be operated on single phase provided certain limitations are observed.

- The output horsepower of the drive must be derated.
- The three phase motor connected to the drive should be designed to operate on the voltage supplying power to the drive. If the drive is connected to 240 volts single phase, the motor should be designed to operate on 240 volts three phase.

Review Questions

1. What is the synchronous speed of a six-pole motor operated with an applied voltage of 20 Hz?
2. Why is it necessary to reduce the voltage to a motor when the frequency is reduced?
3. If an alternator is used to provide variable frequency, how is the output voltage of the alternator controlled?
4. What solid-state device is generally used to produce variable frequency in drives designed to control motors up to 500 HP?
5. Why are SCRs used to construct a bridge rectifier in many solid-state variable frequency drives?
6. What is the main disadvantage of using SCRs in a variable frequency drive?
7. How are junction transistors driven into saturation and what is the advantage of driving a transistor into saturation?
8. What is the disadvantage of driving a junction transistor into saturation?
9. What is the advantage of an IGBT over a junction transistor?
10. In variable frequency drives that employ IGBTs, how is the output voltage to the motor controlled?
11. What type of motor is generally used with IGBT drives?
12. What is the primary difference between a GTO and an SCR?
13. What is a thyristor?
14. After an SCR has been turned on, what must be done to permit it to turn off again?
15. What is meant by ramping and why is it used?

 Chapter 37- Not Assigned

The closest standard fuse size listed in *Section 240.6* without going over 304 amperes is 300 amperes, so 300 ampere fuses will be used to protect this circuit.

Review Questions

1. A 20 HP, DC motor is connected to a 500-volt DC line. What is the full load running current of this motor?
2. What rating is used to find the full load running current of a torque motor?
3. A ¾ HP, single phase squirrel cage motor is connected to 240-volt AC line. What is the full load current rating of this motor and what is the minimum size NEMA and IEC starters that should be used?
4. A 30 HP, two phase motor is connected to a 230-volt AC line. What is the rated current of the phase conductors and the rated current of the neutral?
5. A 125 HP, synchronous motor is connected to a 230-volt, three phase AC line. The motor is intended to operate at 80 percent power factor. What is the full load running current of this motor? What is the minimum size NEMA and IEC starters that should be used to connect this motor to the line?
6. What is the full load running current of a three phase, 50 HP motor connected to a 560-volt line? What minimum size NEMA and IEC starters should be used to connect this motor to the line?
7. A 125 HP, three phase squirrel cage induction motor is connected to 560 volts. The nameplate current is 115 amperes. It has a marked temperature rise of 40°C and a code letter J. The conductors are to be type THHN copper, and they are run in conduit. The short-circuit protective device is dual-element time delay fuses. Find the conductor size, overload heater size, fuse size, minimum NEMA and IEC starter sizes, and the upper and lower range of starting current for this motor. The motor starter employs the use of current transformers with a ratio of 200:5 to reduce the current to the overload heaters.
8. A 7.5 HP, single phase squirrel cage induction motor is connected to 120 VAC. The motor has a code letter of H. The nameplate current is 76 amperes. The conductors are copper with type TW insulation. The short-circuit protection device is a non–time delay fuse. Find the conductor size, overload heater size, fuse size, minimum NEMA and IEC starter sizes, and upper and lower starting currents.
9. A 75 HP, three phase, synchronous motor is connected to a 230-volt line. The motor is to be operated at 80 percent power factor. The motor nameplate lists a full load current of 185 amperes, a temperature rise of 40°C, and a code letter A. The conductors are to be made of copper and have type THHN insulation. The short-circuit protective device is to be an inverse time circuit breaker. Determine the conductor size, overload heater size, circuit breaker size, minimum size NEMA and IEC starters, and the upper and lower starting current. The starter contains current transformers with a ratio of 300:5 to reduce current to the overload heaters.
10. Three motors are connected to a single branch circuit. The motors are connected to a 480-volt, three phase line. Motor #1 is a 50 HP induction motor with a NEMA code B. Motor #2 is 40 HP with a code letter of H, and motor #3 is 50 HP with a NEMA code C. Determine the conductor size needed for the branch circuit supplying these three motors. The conductors are copper with type THWN-2 insulation.
11. The short-circuit protective device supplying the motors in question #10 is an inverse time circuit breaker. What size circuit breaker should be used?
12. Five 5 HP, three phase motors with NEMA code B are connected to a 240-volt line. The conductors are copper with type THWN insulation. What size conductor should be used to supply all of these motors?
13. If dual-element time delay fuses are to be used as the short circuit protective device, what size fuses should be used to protect the circuit in question #12?
14. A 75 HP, three phase squirrel cage induction motor is connected to 480 volts. The motor has a NEMA code D. What is the starting current for this motor?
15. A 20 HP, three phase squirrel cage induction motor has a NEMA code E. The motor is connected to 208 volts. What is the starting current for this motor?

Chapter 38

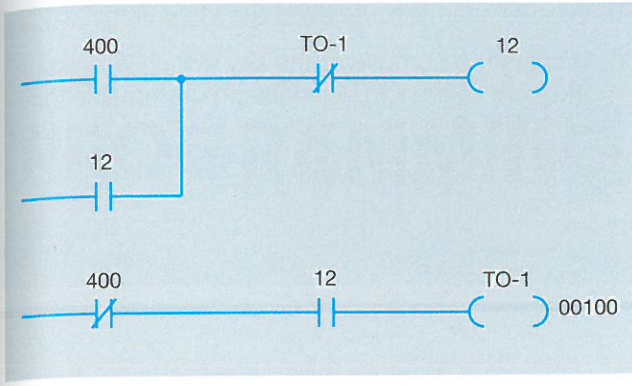

Figure 38–17 Off-delay timer circuit.

operation of an off-delay timer. When the timer coil is energized, the timed contacts change position immediately. When the coil is de-energized, the contacts remain in their energized state for some period of time before returning to their normal state. In the circuit shown in Figure 38–17, it is assumed that contact 400 controls the action of the timer. Coil 400 is an internal relay coil located somewhere in the circuit. Coil 12 is an output and controls some external device. Coil TO-1 is an on-delay timer set for 100 tenths of a second. When coil 400 is energized, both 400 contacts change position. The normally open 400 contact closes and provides a current path to coil 12. The normally closed 400 contact opens and prevents a circuit from being completed to coil TO-1 when coil 12 energizes. Note that coil 12 turned on immediately when contact 400 closed. When coil 400 is de-energized, both 400 contacts return to their normal position. A current path is maintained to coil 12 by the now-closed 12 contact in parallel with the normally open 400 contact. When the normally closed 400 contact returns to its normal position a current path is established to coil TO-1 through the now-closed 12 contact. This starts the time sequence of timer TO-1. After a delay of 10 seconds, the normally closed TO-1 contact opens and de-energizes coil 12, returning the two 12 contacts to their normal position. The circuit is now back in the state shown in Figure 38–17. Note the action of the circuit. When coil 400 was energized, output coil 12 turned on immediately. When coil 400 was de-energized, output 12 remained on for 10 seconds before turning off.

The number of internal relays and timers contained in a programmable logic controller is determined by the memory capacity of the computer. As a general rule, PLCs that have a large I/O capacity will have a large amount of memory. The use of programmable logic controllers has steadily increased since their invention in the late 1960s. A PLC can replace hundreds of relays and occupy only a fraction of the space. The circuit

Courtesy of Baldor Electric Company

Figure 38–18 A DC drive unit controlled by a programmable logic controller.

logic can be changed easily and quickly without requiring extensive hand rewiring. They have no moving parts or contacts to wear out, and their downtime is less than an equivalent relay circuit. When replacement is necessary they can be reprogrammed from a media storage device.

The programming methods presented in this textbook are general because it is impossible to include examples of each specific manufacturer. The concepts presented in this chapter, however, are common to all programmable controllers. A programmable logic controller used to control a DC drive is shown in Figure 38–18.

Chapter 38

Review Questions

1. What industry first started using programmable logic controllers?
2. Name two differences between PLCs and common home or business computers.
3. Name the four basic sections of a programmable logic controller.
4. In what section of the PLC is the actual logic performed?
5. What device is used to program a PLC?

See next Page

Chapter 38 Continued

6. What device separates the central processing unit from the outside world?
7. What is opto-isolation?
8. If an output I/O controls a DC voltage, what solid-state device is used to connect the load to the line?
9. If an output I/O controls an AC voltage, what solid-state device is used to connect the load to the line?
10. What is an internal relay?
11. What is the purpose of the key switch located on the front of the CPU in many programmable logic controllers?
12. What is a software switch?

Chapter 39

Review Questions

1. Why are NEMA symbols such as push buttons, float switches, or limit switches not used in programmable logic controller schematics?
2. How are such components as coils and contacts identified and distinguished from others in a PLC schematic?
3. Why are normally closed components such as STOP push buttons programmed normally open instead of normally closed when entering a program into the memory of a PLC?
4. What is an internal relay?
5. Why is the output of a PLC used to energize the coil of a motor starter instead of energizing the motor directly?
6. List four basic rules for developing a program for a PLC.
7. A programmable logic controller requires that times be programmed in 0.1-second intervals. What number should be entered to produce a time delay of 3 minutes?
8. When programming in Boolean, what statement should be used to connect components in series?
9. When programming in Boolean, what statement should be used to connect components in parallel?
10. In a control circuit, it is imperative that a coil energize before another one. How can this be done when entering a program into the memory of the PLC?
11. What is the function of a watchdog timer?

The Differential Amplifier

An electronic device that is often used to help overcome the problem of induced noise is the differential amplifier (Figure 40–7). This device detects the voltage difference between the pair of signal wires and amplifies this difference. Because the induced noise level should be the same in both conductors, the amplifier ignores the noise. For example, assume an analog sensor produces a 50-millivolt signal. This signal is applied to the input module, but induced noise is at a level of 5 volts. In this case the noise level is 100 times greater than the signal level. The induced noise level, however, is the same for both of the input conductors. Therefore, the differential amplifier ignores the 5-volt noise and amplifies only the voltage difference, which is 50 millivolts.

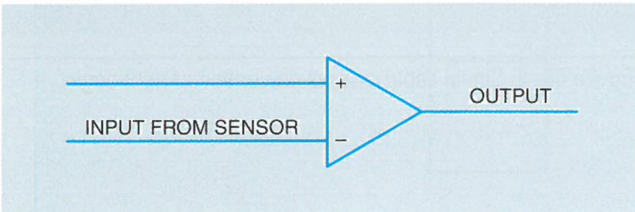

Figure 40–7 Differential amplifier detects difference in signal level.

Chapter 40

Review Questions

1. Explain the difference between digital inputs and analog inputs.
2. Why should signal wire runs be kept as short as possible?
3. When signal wiring must cross power wiring, how should the wires be crossed?
4. Why is shielded wire used for signal runs?
5. What is the brute-force method of grounding?
6. Explain the operation of the differential amplifier.

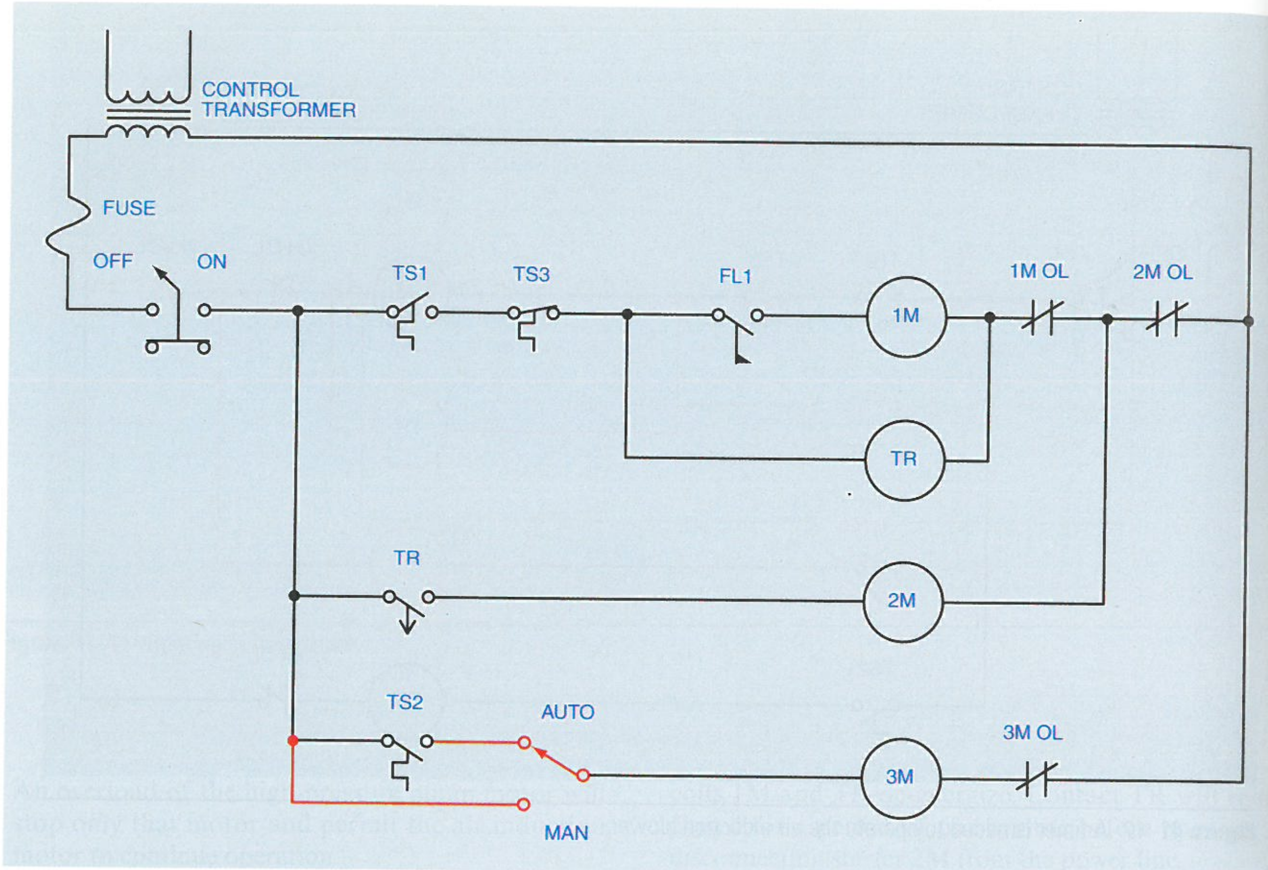

Figure 41–14 An AUTO-MANUAL switch is added to the blower motor.

Review Questions

To answer the following questions refer to the circuit in Figure 41–6.

1. The pressure switch is shown as:
   a. Normally open
   b. Normally closed
   c. Normally open held closed
   d. Normally closed held open
2. When the pressure switch closes, which starter will energize first, 1M or 2M? Explain your answer.
3. Is timer TR an on-delay timer or an off-delay timer? Explain how you can determine which it is by looking at the schematic diagram.
4. What is the purpose of timer TR in this circuit?
5. What is the purpose of the rotary switch connected after the pressure switch?

To answer the following questions refer to the circuit shown in Figure 41–10.

6. Is timer 1TR an on-delay or off-delay timer?
7. Assume that the THIRD SPEED push button is pressed. Explain the sequence of operation for the circuit.
8. Assume that the THIRD SPEED push button is pressed and the motor starts in its first or lowest speed. After a delay of 3 seconds the motor accelerates to its second speed, but never accelerates to its highest or third speed. Which of the following could cause this problem?
   a. CR coil is open.
   b. Coil 2TR is open.
   c. Coil 1TR is open.
   d. Coil 1S is open.
9. Assume that both timers are set for a delay of 3 seconds. Now assume that coil 1S is open. If the THIRD SPEED push button is pressed, will the motor accelerate to third speed after a delay of 6 seconds? Explain your answer.

10. Assume that timer 2TR is replaced with an off-delay timer, and that both timers are set for a delay of 3 seconds. Explain the operation of the circuit when the THIRD SPEED push button is pressed. Also explain the operation of the circuit when the STOP button is pressed.

To answer the following questions refer to the circuit shown in Figure 41–14.

11. Temperature switch TS1 is shown as:
    a. Normally open
    b. Normally closed
    c. Normally open held closed
    d. Normally closed held open
12. Temperature switch TS2 is shown as:
    a. Normally open
    b. Normally closed
    c. Normally open held closed
    d. Normally closed held open
13. Is timer TR an on-delay or off-delay timer?
14. Temperature switch TS3 is shown as:
    a. Normally open
    b. Normally closed
    c. Normally open held closed
    d. Normally closed held open
15. Assume that contact TS1 closes and the air injection blower motor starts operating, but the high-pressure pump motor does not start. What could cause this problem?
    a. Temperature switch TS3 is open.
    b. Coil 2M is open.
    c. Flow switch FL1 is defective and did not close.
    d. Coil TR is open.

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Motor C

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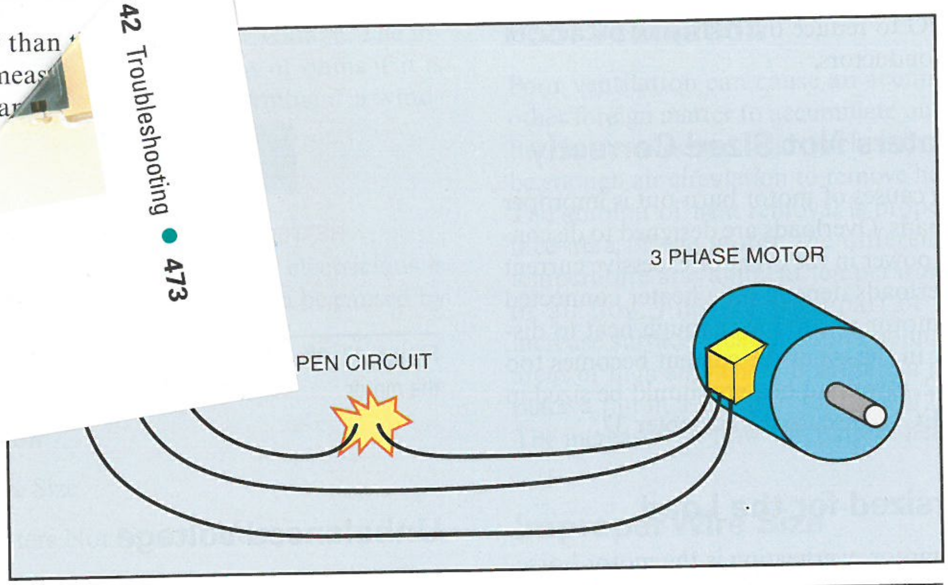

Figure 42–34 Single phasing occurs when a three-phase motor looses one phase.

- Step 3 - Subtract the average voltage from the reading that results in the greatest difference.

$$496 - 476 = 20 \text{ volts}$$

- Step 4 - Determine the percent difference.

The amount of heat rise in the winding with the highest current due to unbalanced voltages is equal to twice the percent squared.

$$\text{Heat rise} = 2 \times (\text{percent voltage unbalance})^2$$
$$2 \times 4.2 \times 4.2 = 35.28\%$$

In this example the winding with the highest current will experience a 35.28 percent increase in temperature.

Review Questions

1. What are the three main electrical test instruments used in troubleshooting?
2. What is the advantage of a plunger type voltage tester?
3. A motor is tripping out on overload. The motor nameplate reveals a full load current of 68 amperes. When the motor is operating under load, an ammeter indicates the following: Phase #1 = 106 amperes, Phase #2 = 104 amperes, and Phase #3 = 105 amperes. What is the most likely problem with this motor?
4. A motor is tripping out on overload. The motor nameplate reveals a full load current of 168 amperes. When the motor is operating under load, an ammeter indicates the following: Phase #1 = 166 amperes, Phase #2 = 164 amperes, and Phase #3 = 225 amperes. What is the most likely problem with this motor?
5. Refer to the circuit shown in Figure 42–17. The motor will not start in either the forward or reverse direction when the START push buttons are pressed. Which of the following could *not* cause this problem?
   a. F coil is open.
   b. The overload contact is open.
   c. The control transformer fuse is blown.
   d. The stop push button is not making a complete circuit.

6. Refer to the circuit shown in Figure 42–17. Assume that the motor is running in the forward direction. When the REVERSE push button is pressed, the motor continues to run in the forward direction. Which of the following could cause this problem?
   a. The normally open side of the reverse push button is not making a complete circuit when pressed.
   b. R contactor coil is open.
   c. The normally closed side of the reverse push button is not breaking the circuit when the reverse push button is pressed.
   d. There is nothing wrong with the circuit. The stop push button must be pressed before the motor will stop running in the forward direction and permit the motor to be reversed.

7. Refer to the circuit shown in Figure 42–21. When the THIRD SPEED push button is pressed, the motor starts in first speed but never accelerates to second or third speed. Which of the following could *not* cause this problem?
   a. Control relay CR1 is defective.
   b. Control relay CR2 is defective.
   c. Timer TR1 is defective.
   d. Contactor coil S1 is open.

8. Refer to the circuit shown in Figure 42–21. Assume that the THIRD SPEED push button is pressed. The motor starts in second speed, skipping first speed. After 5 seconds, the motor accelerates to third speed. Which of the following could cause this problem?
   a. S1 contactor coil is open.
   b. CR1 contactor coil is open.
   c. TR1 timer coil is open.
   d. S1 load contacts are shorted.

9. Refer to the circuit shown in Figure 42–17. If a voltmeter is connected across the normally open FORWARD push button, the meter should indicate a voltage value of:
   a. 0 volts
   b. 30 volts
   c. 60 volts
   d. 120 volts

10. Refer to the circuit shown in Figure 42–21. Assume that a fused jumper is connected across terminals 1 and 3 of TR2 timer. What would happen if the jumper were left in place and the FIRST SPEED push button pressed?
    a. The motor would start in its lowest speed and progress to second speed, but never increase to third speed.
    b. The motor would start operating immediately in third speed.
    c. The motor would not start.
    d. The motor would start in second speed and then increase to third speed.

11. The voltages supply a three-phase squirrel cage induction motor are as follows: A−B = 202 volts; A−C = 216 volts; B−C = 207 volts. What is the percent voltage unbalance?

12. Using the values in question 11, determine the percent of heat rise in the winding with the highest current.