TEACHER'S GUIDE CHAPTER 7

CHAPTER 7
INDUSTRIAL POWER SUPPLIES, INVERTERS AND CONVERTERS

JOB ASSIGNMENT:

You are working on a process oven that is heated by an electric heating element. The process oven is used to heat various in the quality assurance testing laboratory. The process oven has a small conveyor that is powered by a three phase ac motor. The conveyor's speed is not adjustable at this time. Your supervisor informs you that due to changes in quality standards, the speed of the conveyor must now be adjustable. You are also informed that the lab technicians are adding a small computer to take quality control data such as temperature, cook time and conveyor speed. Your supervisor reminds you that the area of the country you are in is subject to numerous power outages at various times of the year and that it is important that you have the computers that gather the test data protected against the power losses. Your assignment is to select equipment that will provide a means to control the speed of a three phase ac motor, and equipment to protect against the loss of voltage to the computers and include a report that provides an explanation of the basic theory of operation for all of the equipment you have selected.

SOLUTION TO THE JOB ASSIGNMENT:

Your solution to the job assignment should include a variable frequency ac motor drive to control the speed of the three phase conveyor motor. An uninterruptible power supply should be part of your solution to provide backup power to the computer and PLC. The theory of operation for the variable frequency drive should include a three phase rectifier section that is used as the converter to produce full wave pulsing dc voltage. A capacitor is used to filter the voltage and an inductor is used to filter the current. The inverter for the motor drive will use pulse width modulation (PWM) or some other type of inverter circuit to change the dc voltage back to three phase ac voltage. The inverter will also determine the frequency of the output ac voltage which will change the speed of the conveyor motor. The theory of operation for the uninterruptible power supply (UPS) use a rectifier section and filter section that is similar to the variable frequency drive. The UPS uses a battery that is connected in parallel with the dc bus to store dc power that is used in case the incoming ac power is interrupted. The inverter is also connected in parallel to the dc bus, and it will take power directly from the rectifier section if the ac incoming power is being supplied. When the ac power is interrupted, the inverter will receive power from the battery. The inverter for the UPS may be the PWM type of any of the other types that were discussed.

QUESTIONS

1. Explain the operation of a single diode half wave rectifier and draw its input and output waveforms.
   Reference: Section 7.2.1 Fig. 7-1

   ANSWER: The single diode half wave rectifier provides a single half wave output when the input is a ac voltage sine wave. The diode produces the pulse by conducting when it is forward biased and blocking current when it is reversed biased. Use the diagram in Fig. 7-1 for the drawing.

2. Explain the operation of a two diode center tapped rectifier that produces a full wave output and draw its input and output waveforms.
   Reference: Section 7.2.2 and Fig. 7-2
   ANSWER: The two diode rectifier provides two half wave pulses at its output for a full wave ac sine wave input. One of the diodes conducts the positive half of the sine wave and the other diode conducts the negative half of the sine wave. Use the diagram in 7-2 for the drawing.

3. Explain the operation of a four diode full wave bridge rectifier and draw its input and output waveforms.
   Reference: Section 7.2.3 Figs. 7-3 and 7-4
   ANSWER: The four diode rectifier provides two half waves at its output when a ac sine wave is supplied as the input. Two of the diodes conducts the positive half of the sine wave and two diode conducts the negative half of the sine wave. Use the diagram in Fig 7-3 or 7-4 for the drawing.

4. Explain the function of the capacitor and inductor in a power supply.
   Reference: Section 7.2.8
   ANSWER: The capacitor filters the voltage and the inductor filters the current for the circuit.

5. Explain the function of a zener diode in a power supply.
   Reference: Section 7.2.9 Fig. 7-12
   ANSWER: The zener diode acts as a voltage regulator in the power supply circuit.

6. The fuse in a circuit can only protect against an over current. Explain what components can be added to the circuit to protect it against over voltage conditions.
   Reference: Section 7.2.10 Fig. 7-13 also pg 249 Section 7.2.11
   ANSWER: A metal oxide varistor (MOV) is connected in parallel across the incoming power lines. If the incoming voltage exceeds the level of the MOV, the MOVs will go into conduction which will cause extreme short circuit current to flow which will cause the fuse to blow. In most cases the MOV is placed in a circuit to protect the circuit against surges in voltages. Another way to protect a circuit against over voltage is to use a crowbar circuit shown in Fig. 7-14.

7. Explain the operation of an uninterruptible power supply.
   Reference: Section 7.3.3
   ANSWER: The uninterruptible power supply consists of a rectifier and battery. The rectifier changes ac to dc voltage and battery stores the dc voltage. The dc voltage is converted back to ac voltage through an inverter circuit. The battery stores enough voltage to supply the system enough ac voltage anytime the incoming ac voltage is interrupted. The UPS is generally used to backup for computer systems or PLCs.

8. Explain the operation of an inverter.
   Reference: Section 7.4
   ANSWER: An inverter changes dc voltage to ac voltage. Transistors are used in the inverter circuit and they are turned on to provide a waveform that looks somewhat like an ac sine wave. Different types of inverter circuits create different types of output waveforms.

9. List three types of inverter circuits and explain the output waveform of each.
Reference: Section 7.4.4, Section 7.4.5, and Section 7.4.6
ANSWER: The types of inverters include the Variable Voltage Input (VVI) whose waveform is shown in Fig. 7-22, the Pulse Width Modulation (PWM) whose waveform is shown in Fig. 7-23, and the Current Source Input (CSI) whose waveform is shown in Fig. 7-24.

10. Explain the difference between a linear power supply and a switch mode power supply.
Reference: Section 7.5.2 and Section 7.5.3
ANSWER: The linear power supply uses a diode rectifier and voltage regulator and load. The voltage regulator and load create a voltage divider to regulate the voltage. The switch mode power supply (SMPS) uses a rectifier and inverter to change ac to dc and back to ac. A transformer provides isolation and the ac voltage from the transformer secondary is rectified back to dc to provide the output voltage for the power supply. The inverter portion of the power supply regulates the output voltage.

TRUE AND FALSE

K1 1. F The two output of a single phase half wave rectifier is positive pulses for each sine wave input.
Reference: Section 7.2.1

K1 2. T The RMS value of voltage will always be smaller than the peak value for the same voltage.
Reference: Example 7-1, pg. 251

K1 3. T The three phase full wave rectifier uses 6 diodes and has 6 half wave outputs.
Reference: Section 7.2.4

K1 4. T An inverter changes DC voltage to AC voltage.
Reference: Section 7.4

K1 5. F A converter changes DC voltage to AC voltage.
Reference: Section 7.2

MULTIPLE CHOICE

K1 1. When power goes through an uninterruptible power supply a travels through the components to the load the following order; a
a. surge protection section, a rectifier section, the battery and then to the inverter section.
b. surge protection section, an inverter section, the battery and then to the rectifier section.
c. surge protection section, the battery, a rectifier section and then to the inverter section.
Reference: Section 7.3.3 Fig. 7-18

K1 2. The crow bar circuit uses ___c___

a. an overvoltage sensing circuit and triac to cause the circuit fuse to open when an overcurrent condition is sensed.

b. an overvoltage sensing circuit and a MOV to cause the circuit fuse to open when an overvoltage condition is sensed .

c. an overvoltage sensing circuit and a SCR to cause the circuit fuse to open when an overvoltage condition is sensed.

Reference: Section 7.2.11

K1 3. A pulse width modulation (PWM) type inverter provides ___c___

a. an output waveform that can have frequency varied.

b. an output waveform that can have its voltage varied.

c. an output waveform that can have frequency varied.

Reference: Section 7.4.5

K1 4. A chopper is ___c___

a. a converter circuit that changes ac to dc.

b. an inverter circuit that changes dc to dc.

c. a converter circuit that changes dc to dc.

Reference: Section 7.5

K1 5. A switch mode power supply (SMPS) consists of the following circuits ___b___

a. an input inverter circuit, a high frequency switch, a power transformer and an output inverter circuit.

b. an input rectification circuit, a high frequency switch, a power transformer, and an output rectification circuit

c. an input rectifier circuit, an input voltage regulator, a high frequency switch, an output voltage regulator and an output rectification circuit.

Reference: Fig. 7-26 Section 7.5.3

PROBLEMS

K1 1. Calculate the average dc output voltage from the input rms voltage for the single diode half wave rectifier, if the voltage at the transformer secondary is 208 volts rms.

Reference: Section 7.2.1

ANSWER: 93.4v dc.

K1 2. Calculate the average dc output voltage for a two diode center tapped rectifier if the input voltage at the secondary of the transformer is 230 volts rms.

Reference: Section 7.2.2

ANSWER: 206.7v dc.

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K/1 3. Calculate the average dc output voltage for a four diode full wave bridge rectifier if the input voltage at the secondary of the transformer is 230 volts rms.

Reference: Section 7.2.3

Vp = Vrms X 1.414 = 1.414 X 230 = 352.2v

ANSWER: 206.7v dc.

K/1 4. Show two ways that MOVs can be connected in a power supply to protect it from over voltage.

Reference: Fig. 7-13

ANSWER: Use the diagrams in Fig. 7-13.

K/1 5. Draw the circuit for a linear power supply and explain the points you would test and what the waveform of the voltage would look like at each point.

Reference: Fig. 7-25

ANSWER: Use the diagram in Fig. 7-25 and the waveform will be a sine wave as the input voltage, half waves as the voltage comes through the rectifier, flat line pure dc if a filter is used, and pure dc at the load.

K/1 6. Draw two ways SCRs can be used in crowbar circuits and explain operation of each of the circuits.

Reference: Fig. 7-14

ANSWER: Use the diagrams in Fig. 7-14.

K/1 7. Draw the block diagram circuit for an uninterruptible power supply and identify its components.

Reference: Fig. 7-18.

ANSWER: Use the diagram in Fig. 7-18.

REFERENCES

1. Bulletin 1336 Adjustable Frequency AC Drive Maintenance Manual, Allen-Bradley, 1201 South Second Street, Milwaukee, Wi., 53204
2. Bulletin 1336 Adjustable Frequency AC Drive User Manual, Allen-Bradley, 1201 South Second Street, Milwaukee, Wi., 53204
3. Kissell, Thomas E., Modern Industrial 1 Electrical Motor Controls, Prentice-Hall Inc., Englewood Cliffs, N.J., 1990.
4. Maloney, Timothy J., Industrial Solid-State Electronics, 2nd ed. Prentice-Hall Inc., Englewood Cliffs, N.J., 1986.
5. Power Supply Reference Guide, Power One Inc., 740 Calle Piano, Camarillo, Ca. 93012.
6. UP Station D Series UPS, Liebert Corporation, 1050 Dearborn Drive, P.O. Box 29186, Columbus, Oh. 43229

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QUESTIONS

1. Illustrate the difference between an on-off type signal and an analog type signal. Provide an example of where you would use each type of signal.

   Reference: Section 10.1.2

   ANSWER: Analog signals represent a value from minimum to maximum that is proportional to the condition causing the change in the sensor. The on-off type signal has only two possible conditions, on or off. An example of an analog signal is a level sensor that produces a value of voltage from 0-10 volts or a milli amp signal from 4-20 ma that indicates the level of liquid in a tank. An on-off type level sensor would be placed at a specific level in the tank and if the level of the liquid is below the sensor, the sensor will produce an off type signal, and if the liquid level is above the sensor, the sensor will produce an on type signal.

2. Explain why it is so important to understand the theory of operation for each of the types of sensors so that you can troubleshoot them.

   Reference: Section 10.1

   ANSWER: If you understand the theory of operation of a sensor, you have an idea of how it should respond to changing conditions. You should also have a good idea of the type of signal it produces when it is at it minimum setting and when it is at its maximum setting.

3. Provide an application where you would use a bourdon tube type pressure sensor, a strain gage type pressure sensor, and a piezoelectric type pressure sensor.

   Reference: Section 10.3.3

   ANSWER: The bourdon tube type pressure sensor is used for higher pressure type applications such as hydraulic pressure gages or sensors or steam gages.

   Reference: Section 10.3.7

   ANSWER: The strain gage type pressure sensor is used in load cells that are in weighing applications.

   Reference: Section 10.3.8.1

   ANSWER: The piezoelectric sensor requires a larger amount of pressure to cause the sensor to produce a signal, this means that the applications for the piezoelectric sensor are higher pressure applications.

4. Explain the operation of strain gage and indicate the type of signal you would expect from it.

   Reference: Section 10.3.7

   ANSWER: The strain gage consists of a grid of very fine wire that is bonded to a surface. When the surface moves due to changes in pressure, the resistance in the wire changes. The strain gage must be connected to a resistive circuit such as a Wheatstone bridge.

5. Explain the operation of a piezoelectric pressure sensor and indicate the type of signal you would get from it.

   Reference: Section 10.3.11 Fig. 10-53

   ANSWER: The piezoelectric pressure sensor consists of a piezoelectic crystal and a pressure sensing diaphragm. When pressure is applied to the diaphragm, the pressure is transferred to the crystal which produces a small amount of voltage. The voltage is proportional to the deformation caused by the pressure. A traditional voltage from the sensor is 0-10 VDC.

6. Identify the two broad categories that load cells fall into.
   Reference: Section 10.3.8
   ANSWER: The two types of load cells are the bending beam load cell and the shear beam load cell.
7. Explain how you would troubleshoot a load cell.
   Reference: Section 10.3.8.2
   ANSWER: Load cells are easy to troubleshoot because they act like other resistive type sensors. Since they use an exciter voltage like a Wheatstone bridge, you can start the troubleshooting procedure by measuring the supply voltage. The next step is to apply pressure to the load cell and measure any change in voltage. The output rating of the load cell is rated in millivolts per volt (mV/V).

8. Compare the terms laminar flow and turbulent flow.
   Reference: Section 10.4.1 Fig. 10-54
   ANSWER: Laminar flow means that the fluid flows parallel to the pipe and the flow is rather smooth. Turbulent flow is characterized by swirling action of the fluid inside the flow.

9. Explain the operation of sonic type flowmeter and explain why you would use this type of flowmeter instead of the other types of flowmeters.
   Reference: Section 10.4.4.5 Fig. 10-66
   ANSWER: The ultrasonic "sonic" type flowmeter uses Doppler meters to measure the shift of a frequency signal that is sent into the liquid flowing through a pipe. This type of meter is used as a portable flow meter as well as a meter in systems where the flow can not be disturbed. Since this type of meter is mounted outside the pipe wall, it will not disturb the flow in any way.

10. Explain the operation of a Coriolis type mass flow meter.
    Reference: Section 10.4.6 Fig. 10-68
    ANSWER: The Coriolis mass flow meter uses a U-shaped tube that is designed to measure the flow of gases as well as other fluids. This type of meter uses the U-shape tube that is vibrated up and down at it natural frequency by a strong magnet while fluid is flowing though it. When the fluid flows through the tube it opposes the up and down movement, which will cause the tube to twist. The amount of twist is directly proportional to the amount of flow and a sensor is placed to measure the amount of twist and convert it into a signal.

11. What is a Reynolds number and what is it used for?
    Reference: Section 10.4. .1
    ANSWER: A Reynolds number is the ratio of a fluid's inertial forces to its drag forces. The flow rate and the specific gravity of a liquid are part of its inertial forces and the pipe diameter and viscosity of the fluid make up its drag forces. The Reynolds number is dimensionless.

12. Explain the operation of a thermal type mass flowmeter.
    Reference: Section 10.4.6
    ANSWER: The thermal mass flow meter uses a thermal element whose temperature changes as fluid flows through it. The thermal element is mounted close to the fluid flow but it does not come directly into contact with the fluid. This allows this type of mass flow meter to be used in all types of applications where the density, pressure, and viscosity may change. The flow meter uses an electronic package that contains a flow analyzer, temperature compensator and a signal conditioner to provide a linear output.

13. Explain why density measurements would be used in industrial applications.
Reference: Section 10.5
ANSWER: Products such as paint, or food products such as tomato paste need to be tested for their density.

14. Describe the operation of a R.F. admittance (capacitance) type level sensor operates.
Reference: Section 10.6.2.1
ANSWER: The admittance Capacitance level sensor uses pulsed radio frequency waves to determine when material or liquid is touching the end of its probe. Since this type of sensor uses a change in dielectric to determine the level of a liquid or granular solid material, it is also called a capacitance level sensor.

15. Explain how a sounding type level sensor operates.
Reference: Section 10.6.2.3 Fig. 10-87
ANSWER: The sounding type level sensor is sometimes called a fishing reel type sensor. A weight is attached to a line and the line is lowered from the top of a tank. The weight will cause the line to have tension as long as it is suspended in air. When the weight comes into contact with the level of the material, the tension in the line changes and a sensor detects this amount of change. When the tension changes, a mechanism stops the line from lowering any further and begins to retrieve the line. The amount of line that is retrieved is measured and the level of material is determined by the amount of line that is retrieved.

16. Explain how a sonic type level sensor operates.
Reference: Section 10.6.2.2 Fig. 10-86
ANSWER: The sonic-level sensor takes advantage of the principal that the speed of sound waves traveling through air or gas can be measured and timed. The longer the distance the sound waves travel, the longer the time it will take for them to be sent and reflected. The sonic transmitter is mounted in the top of a tank. The sensor has a transmitter and receiver mounted in the same head. The sound waves are generated in the head and directed at the level of the material being measured. When the sound waves reflect off the material they are detected by the sensor in the head and the amount of time is measured. The level of the material is calculated from this function.

17. Provide an application where a linear potentiometer and a rotary potentiometer can be used.
Reference: Section 10.7
ANSWER: The linear potentiometer can be used with a rack and pinion or ball screw mechanism to produce a linear positioning measurement. A linear potentiometer can also be used to make linear positioning measurements.

18. Explain the operation of a magnetostrictive type position sensor.
Reference: pg. 428 Section 10.7.4
ANSWER: The magnetostrictive type positioning sensor uses a magnetic field that is distorted as a waveguide is moved through the field to determine position. The fixed part of the sensor is attached to the stationary part of a machine and the movable part of the sensor is attached to the movable part of the machine

19. Describe the basic operation of an accelerometer. Be sure to include the function of the piezoelectric element.
Reference: Section 10.8.1
ANSWER: Acceleration is the rate of change of velocity and velocity is defined as the rate of change of position. Acceleration sensors convert motions that represent the aspects of acceleration into an electrical signal. This is accomplished by measuring dv/dt (delta velocity over delta time). Most accelerometers use quarts or ceramic crystals to generate the piezoelectric effect that is converted to an electrical output.

20. Explain the pH scale and give an example of a substance that is an acid, a base, and neutral. Be sure to give the pH strength of the examples that you provide.
Reference: Section 10.9 Fig. 10-118
ANSWER: The pH scale indicates how strong an acid or alkaline solution is based on the concentration of hydrogen ions. The pH scale runs from 0-14. A neutral substance is rated as a 7 on the scale. Acids are rated by numbers below 7 with 0 being the strongest acid. The base materials are rated by numbers above 7, with 14 being the strongest base.

TRUE AND FALSE

K1 1. T One advantage of a 4-20 ma signal over a 0-10v dc signal is that the 4-20 ma signal which uses a live zero makes it easier to detect a broken wire in a sensor or transducer.
Reference: Section 10.1

K1 2. F A strain gage is a larger version of a load cell.
Reference: Section 10.3.7

K1 3. T The positive displacement type flow meter provides a more accurate measure of flow than a delta P-type flow meter .
Reference: Section 10.4.5

K1 4. T A turbine flowmeter uses a turbine wheel that is turned when fluid flow past it. The number of revolutions of the turbine shaft is then converted to amount of flow.
Reference: Section 10.4.4.2

K1 5. F A vortex-type flowmeter use LEDs to measure fluid flow.
Reference: Section 10.4.4.3

K1 6. T The pressure differential (delta P) type flow sensor uses an orifice plate to create a pressure drop that is used to calculate flow
Reference: Section 10.4.3

K1 7. T Pressure can be used to measure temperature, flow and level because there is a relationship between each that can be used in calculations.
Reference: Section 10.3

K1 8. T A positioning system that uses an absolute encoder does not need a home switch.
Reference: Section 10.7.7.2