Three-Phase Circuits

EXERCISE OBJECTIVE

When you have completed this exercise, you will know what three-phase circuits are and how to solve balanced three-phase circuits connected in wye and delta configurations. You will also know the difference between line and phase voltages, and line and phase currents, as well as the relationship between line and phase parameter values in wye- and delta-connected three-phase circuits. You will know what the phase sequence of a three-phase circuit is. You will have learned how to calculate the active power dissipated in each phase of three-phase circuits, and how to calculate the total active power dissipated in a circuit. Finally, you will be able to use voltage and current measurements to verify the theory and calculations presented in this exercise.

DISCUSSION OUTLINE

The Discussion of this exercise covers the following points:

- Introduction to polyphase systems and three-phase circuits
- Wye and delta configurations
- Distinction between line and phase voltages, and line and phase currents
- Power in balanced three-phase circuits

DISCUSSION

Introduction to polyphase systems and three-phase circuits

A polyphase system is basically an ac system composed of a certain number of single-phase ac systems having the same frequency and operating in sequence. Each phase of a polyphase system (i.e., the phase of each single-phase ac system) is displaced from the next by a certain angular interval. In any polyphase system, the value of the angular interval between each phase depends on the number of phases in the system. This manual covers the most common type of polyphase system, the three-phase system.

Three-phase systems, also referred to as three-phase circuits, are polyphase systems that have three phases, as their name implies. They are no more complicated to solve than single-phase circuits. In the majority of cases, three-phase circuits are symmetrical and have identical impedances in each of the circuit's three branches (phases). Each branch can be treated exactly as a single-phase circuit, because a **balanced three-phase circuit** is simply a combination of three single-phase circuits. Therefore, voltage, current, and power relationships for three-phase circuits can be determined using the same basic equations and methods developed for single-phase circuits. Non-symmetrical, or unbalanced, three-phase circuits represent a special condition and their analysis is more complex. Unbalanced three-phase circuits are not covered in detail in this manual.

A three-phase ac circuit is powered by three voltage sine waves having the same frequency and magnitude and which are displaced from each other by 120°. The phase shift between each voltage waveform of a three-phase ac power source is therefore 120° (360° ÷ 3 phases). Figure 1 shows an example of a simplified three-phase generator (alternator) producing three-phase ac power. A rotating magnetic field produced by a rotating magnet turns inside three identical coils of wire (windings) physically placed at a 120° angle from each other, thus producing three separate ac voltages (one per winding). Since the generator's rotating magnet turns at a fixed speed, the frequency of the ac power that is produced is constant, and the three separate voltages attain the maximal voltage value one after the other at phase intervals of 120°.

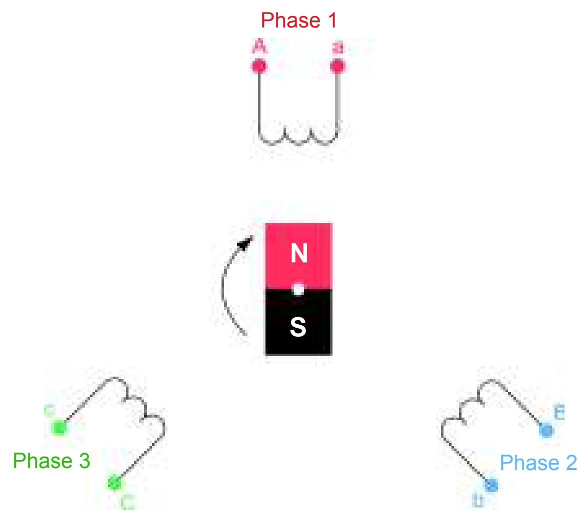
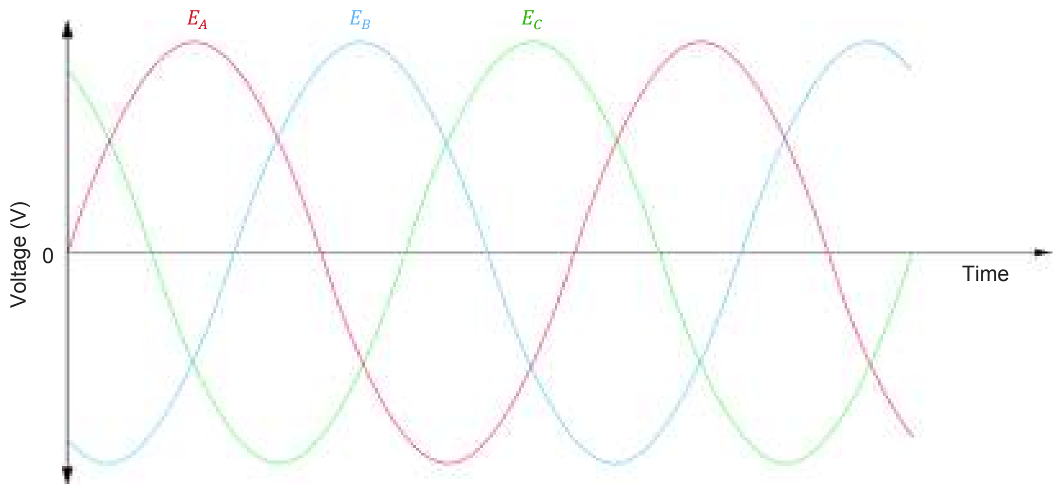


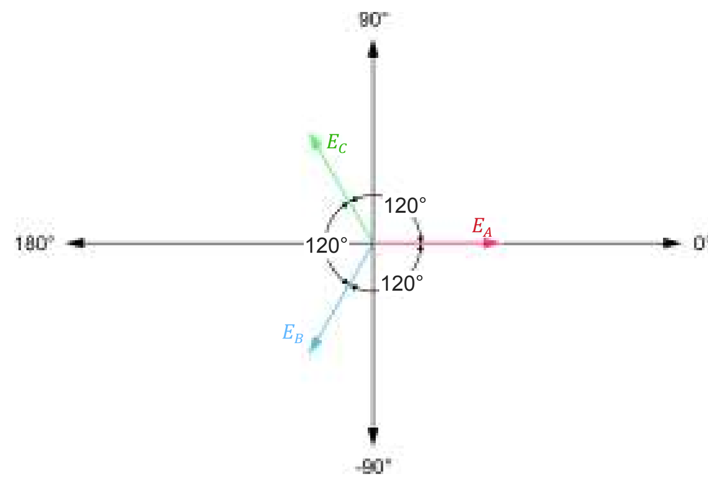
Figure 1. A simplified three-phase generator.

The **phase sequence** of the voltage waveforms of a three-phase ac power source indicates the order in which they follow each other and attain the maximal voltage value. Figure 2 shows an example of the voltage waveforms produced in a three-phase ac power source, as well as the phasor diagram related to the voltage waveforms. The voltage waveforms and voltage phasors in Figure 2 follow the phase sequence E_A, E_B, E_C, which, when written in shorthand form, is the sequence A-B-C. This phase sequence is obtained when the magnet in the three-phase generator of Figure 1 rotates clockwise.

The phase sequence of a three-phase ac power source is important because it determines the direction of rotation of any three-phase motor connected to the power source. If the phases are connected out of sequence, the motor will turn in the opposite direction, and the consequences could be serious. For example, if a three-phase motor rotating in the clockwise direction causes an elevator to go up, connecting the phase wires incorrectly to the motor would cause the elevator to go down when it is supposed to go up, and vice-versa, which could result in a serious accident.



(a) Voltage waveforms produced in a three-phase ac power source



(b) Phasor diagram related to the voltage waveforms shown in (a)

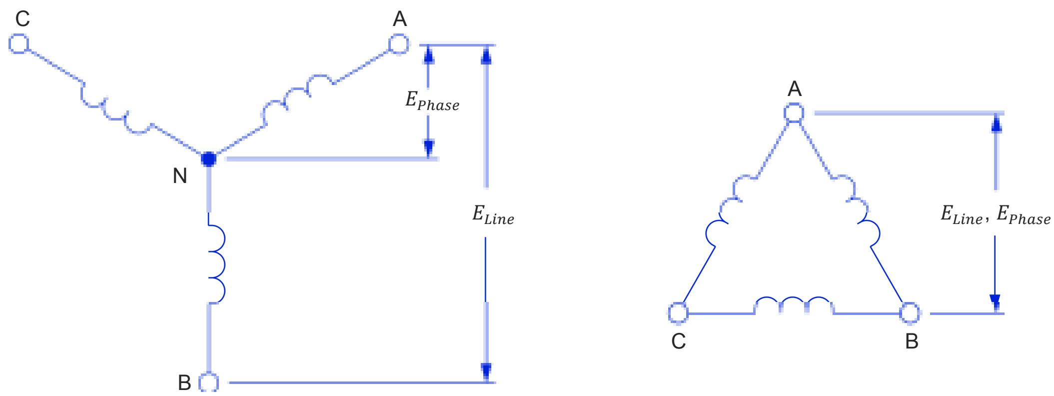
Figure 2. A-B-C phase sequence of a three-phase ac power source.

Wye and delta configurations

The windings of a three-phase ac power source (e.g., the generator in Figure 1) can be connected in either a **wye configuration**, or a **delta configuration**. The configuration names are derived from the appearance of the circuit drawings representing the configurations, i.e., the letter Y for the wye configuration and the Greek letter delta (Δ) for the delta configuration. The connections for each configuration are shown in Figure 3. Each type of configuration has definite electrical characteristics.

As Figure 3a shows, in a wye-connected circuit, one end of each of the three windings (or phases) of the three-phase ac power source is connected to a common point called the neutral. No current flows in the neutral because the currents flowing in the three windings (i.e., the phase currents) cancel each other out when the system is balanced. Wye connected systems typically consist of three or four wires (these wires connect to points A, B, C, and N in Figure 3a), depending on whether or not the neutral line is present.

Figure 3b shows that, in a delta-connected circuit, the three windings of the three-phase ac power source are connected one to another, forming a triangle. The three line wires are connected to the three junction points of the circuit (points A, B, and C in Figure 3b). There is no point to which a neutral wire can be connected in a three-phase delta-connected circuit. Thus, delta-connected systems are typically three-wire systems.



(a) Three-phase wye configuration

(b) Three-phase delta configuration

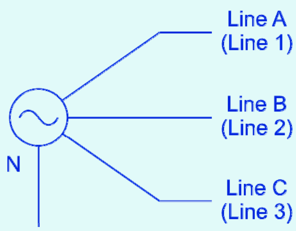
Figure 3. Types of three-phase system configurations.

Distinction between line and phase voltages, and line and phase currents

The voltage produced by a single winding of a three-phase circuit is called the line-to-neutral voltage, or simply the **phase voltage**, E_{Phase}. In a wye-connected three-phase ac power source, the phase voltage is measured between the neutral line and any one of points A, B, and C, as shown in Figure 3a. This results in the following three distinct phase voltages: E_{A-N}, E_{B-N}, and E_{C-N}.

The voltage between any two windings of a three-phase circuit is called the line-to-line voltage, or simply the **line voltage** E_{Line}. In a wye-connected three-phase ac power source, the line voltage is $\sqrt{3}$ (approximately 1.73) times greater than the phase voltage (i.e., $E_{Line} = \sqrt{3}\, E_{Phase}$). In a delta-connected three-phase ac power source, the voltage between any two windings is the same as the voltage across the third winding of the source (i.e., $E_{Line} = E_{Phase}$), as shows Figure 3b. In both cases, this results in the following three distinct line voltages: E_{A-B}, E_{B-C}, and E_{C-A}.

The following figure shows the electrical symbol representing a three-phase ac power source. Notice that lines A, B, and C are sometimes labeled lines 1, 2, and 3, respectively.



The three line wires (wires connected to points A, B, and C) and the neutral wire of a three-phase power system are usually available for connection to the load, which can be connected in either a wye configuration or a delta configuration. The two types of circuit connections are illustrated in Figure 4. Circuit analysis demonstrates that the voltage (line voltage) between any two line wires, or lines, in a wye-connected load is $\sqrt{3}$ times greater than the voltage (phase voltage) across each load resistor. Furthermore, the **line current** I_{Line} flowing in each line of the power source is equal to the **phase current** I_{Phase} flowing in each load resistor. On the other hand, in a delta-connected load, the voltage (phase voltage) across each load resistor is equal to the line voltage of the source. Also, the line current is $\sqrt{3}$ times greater than the current (phase current) in each load resistor. The phase current in a delta-connected load is therefore $\sqrt{3}$ times smaller than the line current.

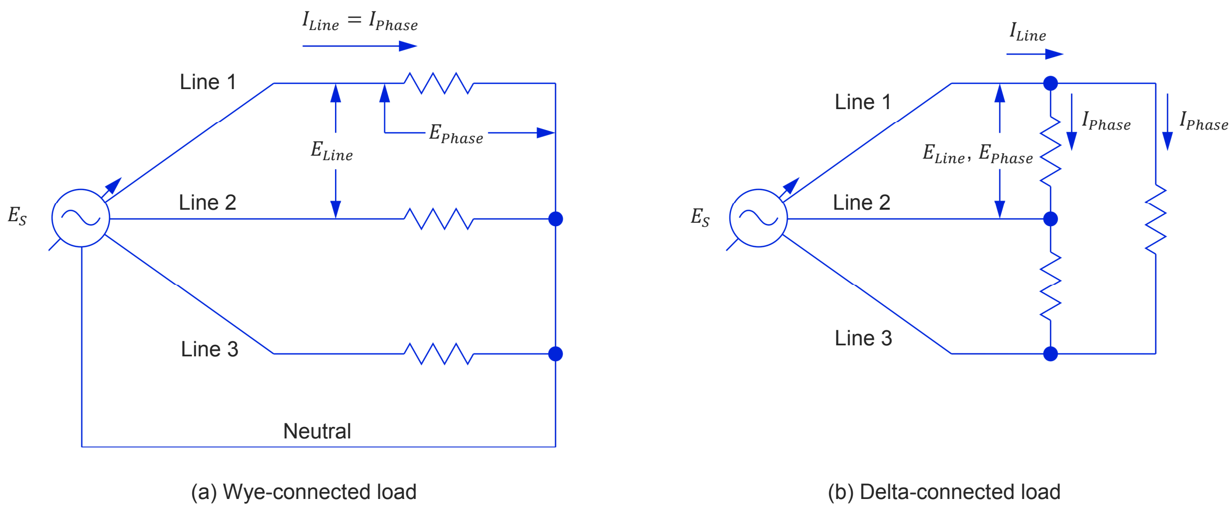


Figure 4. Types of load connections.

The relationships between the line and phase voltages and the line and phase currents simplify the analysis of balanced three-phase circuits. A shorthand way of writing these relationships is given below.

- In wye-connected circuits:

$$E_{Line} = \sqrt{3}\, E_{Phase} \text{ and } I_{Line} = I_{Phase}$$

- In delta-connected circuits:

$$E_{Line} = E_{Phase} \text{ and } I_{Line} = \sqrt{3}\, I_{Phase}$$

Power in balanced three-phase circuits

The formulas for calculating active, reactive, and apparent power in balanced three-phase circuits are the same as those used for single-phase circuits. Based on the formula for power in a single-phase circuit, the active power dissipated in each phase of either a wye- or delta-connected load is equal to:

$$P_{Phase} = E_{Phase} \times I_{Phase} \times \cos\varphi \qquad (1)$$

where P_{Phase} is the active power dissipated in each phase of a three-phase circuit, expressed in watts (W)

E_{Phase} is the phase voltage across each phase of a three-phase circuit, expressed in volts (V)

I_{Phase} is the phase current flowing in each phase of a three-phase circuit, expressed in amperes (A)

φ is the angle between the phase voltage and current in each phase of a three-phase circuit, expressed in degrees (°)

Therefore, the total active power P_T dissipated in a three-phase circuit is equal to:

$$P_T = 3 \times P_{Phase} = 3 \times E_{Phase} \times I_{Phase} \times \cos\varphi \qquad (2)$$

where P_T is the total active power dissipated in a three-phase circuit, expressed in watts (W)

In purely resistive three-phase circuits, the voltage and current are in phase, which means that $\cos\varphi$ equals 1. Therefore, the total active power P_T dissipated in purely resistive three-phase circuits is equal to:

$$P_T = 3 \times E_{Phase} \times I_{Phase}$$

PROCEDURE OUTLINE

The Procedure is divided into the following sections:

- Setup and connections
- Phase and line voltage measurements in the Power Supply
- Voltage, current, and power measurements in a wye-connected circuit
- Voltage, current, and power measurements in a delta-connected circuit

PROCEDURE

WARNING

High voltages are present in this laboratory exercise. Do not make or modify any banana jack connections with the power on unless otherwise specified.

Setup and connections

In this section, you will set up the equipment to measure the line-to-neutral (phase) and line-to-line (line) voltages of the three-phase ac power source in the Power Supply.

1. Refer to the Equipment Utilization Chart in Appendix A to obtain the list of equipment required to perform this exercise.

Install the required equipment in the Workstation.

Make sure that the ac and dc power switches on the Power Supply are set to the O (off) position, then connect the Power Supply to a three-phase ac power outlet.

Connect the *Power Input* of the Data Acquisition and Control Interface to a 24 V ac power supply. Turn the 24 V ac power supply on.

2. Connect the USB port of the Data Acquisition and Control Interface to a USB port of the host computer.

3. Turn the host computer on, then start the LVDAC-EMS software.

In the LVDAC-EMS Start-Up window, make sure that the Data Acquisition and Control Interface is detected. Make sure that the *Computer-Based Instrumentation* function for the Data Acquisition and Control Interface is available. Select the network voltage and frequency that correspond to the voltage and frequency of your local ac power network, then click the *OK* button to close the LVDAC EMS Start-Up window.

4. In LVDAC-EMS, start the Metering application. Set the meters to measure the rms values (ac) of the voltages at inputs *E1*, *E2*, and *E3* of the Data Acquisition and Control Interface. Click the *Continuous Refresh* button to enable continuous refresh of the values indicated by the various meters in the Metering application.

5. Set up the circuit shown in Figure 5.

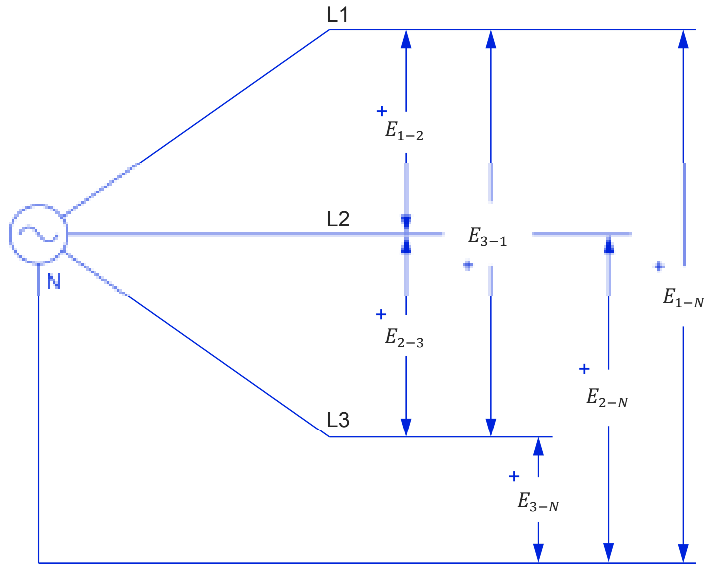


Figure 5. Line and phase voltage measurements.

Connect inputs *E1*, *E2*, and *E3* of the Data Acquisition and Control Interface to first measure the Power Supply phase voltages E_{1-N}, E_{2-N}, and E_{3-N}, respectively. Later, you will modify the connections to inputs *E1*, *E2*, and *E3* to measure the Power Supply line voltages E_{1-2}, E_{2-3}, and E_{3-1}, respectively.

Phase and line voltage measurements in the Power Supply

In this section, you will measure the phase voltages of the three-phase ac power source in the Power Supply, and observe the phase voltage waveforms of the three-phase ac power source using the Oscilloscope, as well as the phase voltage phasors of the three-phase ac power source using the Phasor Analyzer. You will measure the line voltages of the three-phase ac power source in the Power Supply. You will then calculate the ratio of the average line voltage to the average phase voltage and confirm that the ratio is equal to $\sqrt{3}$.

6. Turn the three-phase ac power source in the Power Supply on.

7. Measure and record below the phase voltages of the three-phase ac power source.

$E_{1-N} =$ ________ V

$E_{2-N} =$ ________ V

$E_{3-N} =$ ________ V

Determine the average value of the phase voltages.

$$\text{Average } E_{Phase} = \frac{E_{1-N} + E_{2-N} + E_{3-N}}{3} = \_\_\_\_\_\_\_ \text{ V}$$

8. In LVDAC-EMS, open the Oscilloscope, then make the appropriate settings in order to observe the phase voltage waveforms related to inputs *E1*, *E2*, and *E3*.

Is the phase shift between each voltage sine wave of the three-phase ac power source equal to 120°?

❑ Yes ❑ No

9. In LVDAC-EMS, open the Phasor Analyzer, then make the appropriate settings in order to observe the phase voltage phasors related to inputs *E1*, *E2*, and *E3*.

Is the phase shift between each voltage phasor of the three-phase ac power source equal to 120°?

❑ Yes ❑ No

Turn the three-phase ac power source in the Power Supply off.

10. Modify the connections to the voltage inputs to measure the line voltages of the three-phase ac power source, then turn the three-phase ac power source in the Power Supply on. Measure and record below the line voltages of the three-phase ac power source. Turn the three-phase ac power source in the Power Supply off.

$E_{1-2} = \_\_\_\_\_\_\_ \text{ V}$

$E_{2-3} = \_\_\_\_\_\_\_ \text{ V}$

$E_{3-1} = \_\_\_\_\_\_\_ \text{ V}$

Determine the average value of the line voltages.

$$\text{Average } E_{Line} = \frac{E_{1-2} + E_{2-3} + E_{3-1}}{3} = \_\_\_\_\_\_\_ \text{ V}$$

11. Calculate the ratio of the average line voltage E_{Line} to the average phase voltage E_{Phase}.

$$\frac{\text{Average } E_{Line}}{\text{Average } E_{Phase}} = \_\_\_\_\_\_\_$$

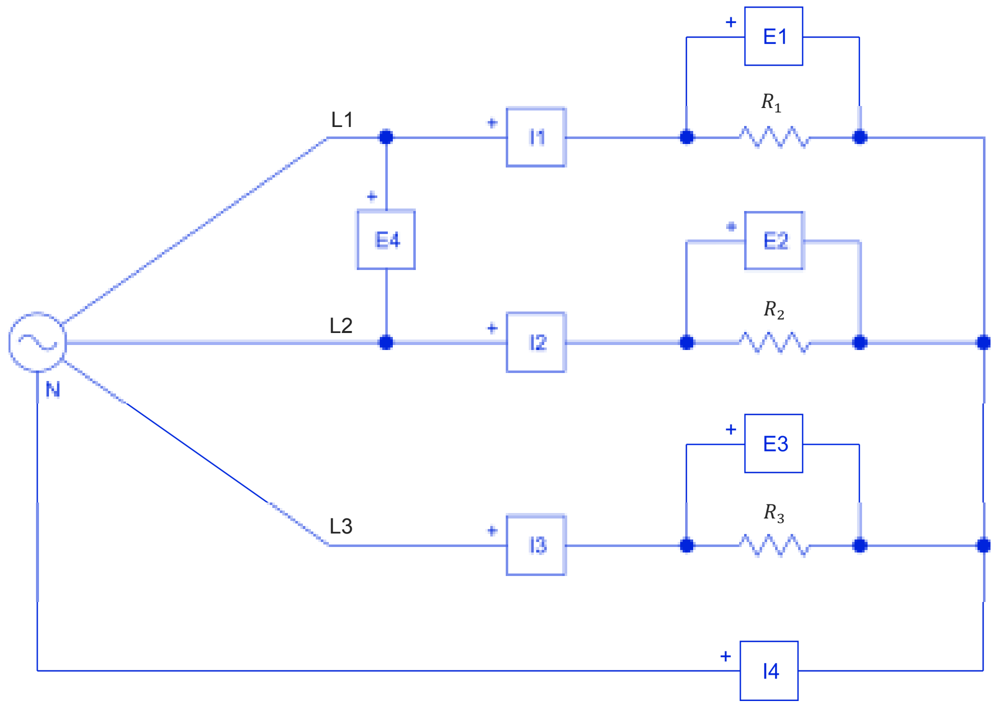
12. Is the ratio of the average line voltage E_{Line} to the average phase voltage E_{Phase} calculated in the previous step approximately equal to 1.73 $(\sqrt{3})$?

❑ Yes ❑ No

Voltage, current, and power measurements in a wye-connected circuit

In this section, you will set up a wye-connected, three-phase circuit using three load resistors. You will measure the phase voltages and currents in the circuit, as well as the circuit line voltage and neutral line current. You will confirm that the load is balanced and that the ratio between the line voltage and the average phase voltage in the circuit is equal to $\sqrt{3}$*. You will verify that the current flowing in the neutral line is equal to zero and that removing the neutral line does not affect the measured voltages and currents. You will then calculate the active power dissipated in each phase of the circuit and the total active power dissipated in the circuit using the measured phase voltages and currents. Finally, you will calculate the total active power dissipated in the circuit using the measured average phase voltage and current, and compare the two calculated total active power values.*

13. Set up the wye-connected, resistive, three-phase circuit shown in Figure 6.



Local ac power network		R_1 (Ω)	R_2 (Ω)	R_3 (Ω)
Voltage (V)	Frequency (Hz)			
120	60	300	300	300
220	50	1100	1100	1100
240	50	1200	1200	1200
220	60	1100	1100	1100

Figure 6. Wye-connected, three-phase circuit supplying power to a three-phase resistive load.

The values of certain components (e.g., resistors, capacitors) used in the circuits of this manual depend on your local ac power network voltage and frequency. Whenever necessary, a table below the circuit diagram indicates the value of each component for ac power network voltages of 120 V, 220 V, and 240 V, and for ac power network frequencies of 50 Hz and 60 Hz. Make sure to use the component values corresponding to your local ac power network voltage and frequency.

14. Make the necessary switch settings on the Resistive Load module in order to obtain the resistance values required.

Appendix C lists the switch settings required on the Resistive Load in order to obtain various resistance values.

15. In the Metering window, make the required settings in order to measure the rms values of voltages E_{R1}, E_{R2}, E_{R3}, and E_{Line} (inputs *E1*, *E2*, *E3*, and *E4*, respectively), and currents I_{R1}, I_{R2}, I_{R3}, and I_N (inputs *I1*, *I2*, *I3*, and *I4*, respectively).

16. Turn the three-phase ac power source in the Power Supply on.

Measure and record below the voltages and currents in the circuit of Figure 6, then turn the three-phase ac power source in the Power Supply off.

E_{R1} = _______ V E_{R2} = _______ V

E_{R3} = _______ V E_{Line} = _______ V

I_{R1} = _______ A I_{R2} = _______ A

I_{R3} = _______ A I_N = _______ A

17. Compare the individual load voltages E_{R1}, E_{R2}, and E_{R3} measured in the previous step. Are they approximately equal?

❑ Yes ❑ No

Compare the individual load currents I_{R1}, I_{R2}, and I_{R3} measured in the previous step. Are they approximately equal?

❑ Yes ❑ No

Does this mean that the three-phase load is balanced?

❑ Yes ❑ No

18. Calculate the average phase voltage E_{Phase} using the phase voltages recorded in step 16.

$$\text{Average } E_{Phase} = \frac{E_{R1} + E_{R2} + E_{R3}}{3} = \_\_\_\_\_\_\_ \text{ V}$$

19. Is the ratio of the line voltage E_{Line} to the average phase voltage E_{Phase} approximately equal to $\sqrt{3}$?

❑ Yes ❑ No

20. Is the current I_N flowing in the neutral line approximately equal to zero?

❑ Yes ❑ No

21. Disconnect the neutral line, then turn the three-phase ac power source in the Power Supply on.

Does disconnecting the neutral line affect the measured voltages and currents indicated in the Metering window?

❑ Yes ❑ No

Is the neutral line required in a balanced, wye-connected, three-phase circuit?

❑ Yes ❑ No

22. Turn the three-phase ac power source in the Power Supply off.

23. Calculate the active power dissipated in each phase of the circuit and the total active power P_T dissipated in the circuit using the voltages and currents recorded in step 16.

$P_{R1} = E_{R1} \times I_{R1} =$ _______ W

$P_{R2} = E_{R2} \times I_{R2} =$ _______ W

$P_{R3} = E_{R3} \times I_{R3} =$ _______ W

$P_T = P_{R1} + P_{R2} + P_{R3} =$ _______ W

24. Calculate the average phase current I_{Phase} using the phase currents recorded in step 16.

$$\text{Average } I_{Phase} = \frac{I_{R1} + I_{R2} + I_{R3}}{3} = \_\_\_\_\_\_\_ \text{ A}$$

25. Calculate the total active power P_T dissipated in the circuit using the average phase voltage E_{Phase} and current I_{Phase}, and compare the result with the total active power P_T calculated in step 23. Are both values approximately equal?

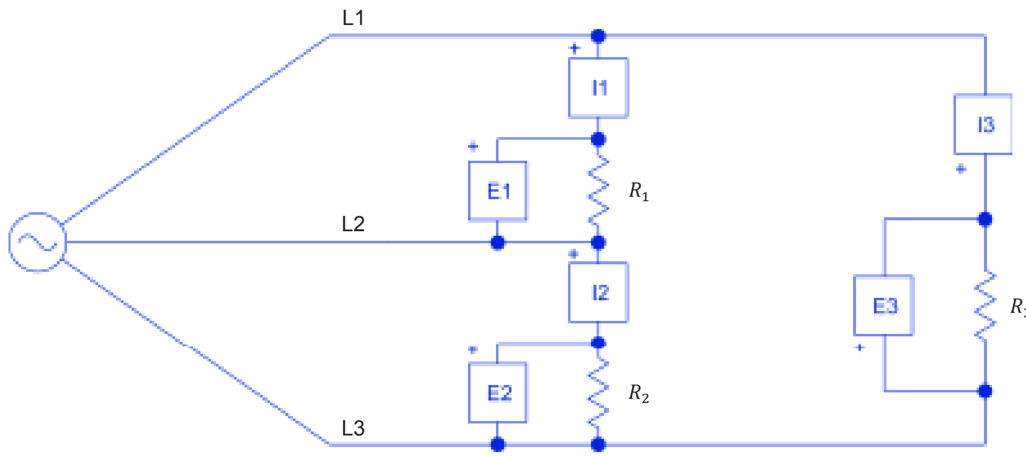
$P_T = 3\,(E_{Phase} \times I_{Phase}) =$ _______ W

❑ Yes ❑ No

Voltage, current, and power measurements in a delta-connected circuit

In this section, you will set up a delta-connected, three-phase circuit using three load resistors. You will measure the phase voltages and currents in the circuit. You will then modify the circuit in order to measure the line currents in the circuit. You will confirm that the load is balanced and that the ratio between the average line current and the average phase current in the circuit is equal to $\sqrt{3}$. You will then calculate the active power dissipated in each phase of the circuit and the total active power dissipated in the circuit using the measured phase voltages and currents. Finally, you will calculate the total active power dissipated in the circuit using the measured average phase voltage and current, and compare the two calculated total active power values.

26. Set up the delta-connected, resistive, three-phase circuit shown in Figure 7.



Local ac power network		R_1 (Ω)	R_2 (Ω)	R_3 (Ω)
Voltage (V)	Frequency (Hz)			
120	60	300	300	300
220	50	1100	1100	1100
240	50	1200	1200	1200
220	60	1100	1100	1100

Figure 7. Delta-connected, three-phase circuit supplying power to a three-phase resistive load.

27. Make the necessary switch settings on the Resistive Load module in order to obtain the resistance values required.

28. Turn the three-phase ac power source in the Power Supply on.

Measure and record below the voltages and currents in the circuit of Figure 7, then turn the three-phase ac power source in the Power Supply off.

CAUTION

Do not leave the three-phase ac power source on for a long time as the power the resistors dissipate exceeds their nominal power rating.

E_{R1} = ________ V E_{R2} = ________ V

E_{R3} = ________ V

I_{R1} = ________ A I_{R2} = ________ A

I_{R3} = ________ A

29. Compare the individual load voltages E_{R1}, E_{R2}, and E_{R3} measured in the previous step. Are they approximately equal?

❑ Yes ❑ No

Compare the individual load currents I_{R1}, I_{R2}, and I_{R3} measured in the previous step. Are they approximately equal?

❑ Yes ❑ No

Does this mean that the load is balanced?

❑ Yes ❑ No

30. Calculate the average phase current I_{Phase} using the phase current values recorded in step 28.

$$\text{Average } I_{Phase} = \frac{I_{R1} + I_{R2} + I_{R3}}{3} = \_\_\_\_\_\_\_\_ \text{ A}$$

31. Reconnect meter inputs *I1*, *I2*, and *I3* as shown in Figure 8 to measure the line currents in the delta-connected, three-phase circuit.

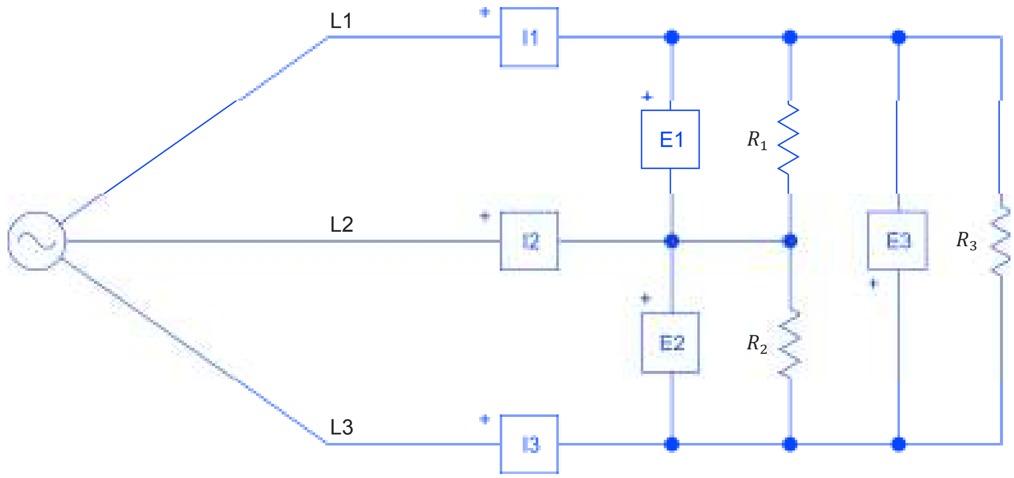


Figure 8. Line current measurements in the delta-connected, three-phase circuit.

32. Turn the three-phase ac power source in the Power Supply on.

Measure and record below the line currents in the circuit of Figure 8, then turn the three-phase ac power source in the Power Supply off. Then, determine the average value of the line currents.

CAUTION

Do not leave the three-phase ac power source on for a long time as the power the resistors dissipate exceeds their nominal power rating.

$I_{Line\ 1} =$ ________ A

$I_{Line\ 2} =$ ________ A

$I_{Line\ 3} =$ ________ A

$$\text{Average } I_{Line} = \frac{I_{Line\ 1} + I_{Line\ 2} + I_{Line\ 3}}{3} = \_\_\_\_\_\_\_\_ \text{ A}$$

33. Calculate the ratio of the average line current I_{Line} calculated in the previous step to the average phase current I_{Phase} recorded in step 30.

$$\frac{\text{Average } I_{Line}}{\text{Average } I_{Phase}} = \_\_\_\_\_\_\_\_$$

Is the ratio approximately equal to $\sqrt{3}$?

❑ Yes ❑ No

34. Calculate the active power dissipated in each phase of the circuit and the total active power P_T dissipated in the circuit using the voltages and currents recorded in step 28.

$P_{R1} = E_{R1} \times I_{R1} =$ _______ W

$P_{R2} = E_{R2} \times I_{R2} =$ _______ W

$P_{R3} = E_{R3} \times I_{R3} =$ _______ W

$P_T = P_{R1} + P_{R2} + P_{R3} =$ _______ W

35. Calculate the average phase voltage E_{Phase} using the phase voltages recorded in step 28.

$$\text{Average } E_{Phase} = \frac{E_{R1} + E_{R2} + E_{R3}}{3} = \text{\_\_\_\_\_\_\_ V}$$

36. Calculate the total active power P_T dissipated in the circuit using the average phase voltage E_{Phase} recorded in the previous step and average phase current I_{Phase} recorded in step 30, and compare the result with the total active power P_T calculated in step 34. Are both values approximately equal?

$P_T = 3\,(E_{Phase} \times I_{Phase}) =$ _______ W

❑ Yes ❑ No

37. Close LVDAC-EMS, then turn off all the equipment. Disconnect all leads and return them to their storage location.

Conclusion

In this exercise, you learned what three-phase circuits are. You saw the difference between line and phase voltages, and line and phase currents, as well as the relationship between line and phase parameter values in wye- and delta-connected three-phase circuits. You learned what the phase sequence of a three-phase circuit is. You also learned how to calculate the active power dissipated in each phase of a three-phase circuit, and how to calculate the total active power dissipated in a three-phase circuit. Finally, you used voltage and current measurements to confirm the theory and calculations presented in the exercise.

Review Questions

1. Explain the difference between the phase voltage and the line voltage in a three-phase circuit.

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2. What is the ratio between the line and phase voltages and the ratio between the line and phase currents in a wye-connected, three-phase circuit?

3. What is the ratio between the line and phase voltages and the ratio between the line and phase currents in a delta-connected, three-phase circuit?

4. The phase voltage E_{Phase} measured across a balanced, wye-connected, three-phase resistive load is 60 V. Calculate the line voltage E_{Line}, as well as the current I_N flowing in the neutral line.

5. In a balanced, delta-connected, resistive, three-phase circuit, the phase voltage E_{Phase} is 120 V and the line current I_{Line} is 3.46 A. Calculate the total active power P_T dissipated in the circuit.

Exercise 2

Three-Phase Power Measurement

EXERCISE OBJECTIVE

When you have completed this exercise, you will be able to calculate active, reactive, and apparent power in balanced, wye- or delta-connected, three-phase circuits. You will know how to use a power meter to measure power in single-phase circuits. You will also know how to measure power in three- and four-wire, three-phase circuits.

DISCUSSION OUTLINE

The Discussion of this exercise covers the following points:

- Calculating power in balanced three-phase circuits
- Power measurements in single-phase circuits
- Measuring the total power in four-wire, three-phase circuits
- Measuring the total power in three-wire, three-phase circuits (two-wattmeter method)
- Measuring the total power in four-wire, three-phase circuits using the two-wattmeter method

DISCUSSION

Calculating power in balanced three-phase circuits

As seen in the previous exercise, the total active power P_T supplied to a balanced three-phase load (i.e., the total active power dissipated in a circuit) can be calculated using the following equation:

$$P_T = 3 \times P_{Phase} = 3\,(E_{Phase} \times I_{Phase} \times \cos\varphi)$$

In a wye-connected circuit, $E_{Phase} = E_{Line}/\sqrt{3}$ and the phase current I_{Phase} is equal to the line current I_{Line}. The above equation then becomes:

$$P_T = \frac{3}{\sqrt{3}} \times E_{Line} \times I_{Line} \times \cos\varphi$$

The $3/\sqrt{3}$ factor can be simplified to $\sqrt{3}$, so that the final equation for the total active power dissipated in the wye-connected circuit is:

$$P_T = \sqrt{3}\,(E_{Line} \times I_{Line} \times \cos\varphi) \qquad (3)$$

where P_T is the total active power dissipated in the three-phase circuit, expressed in watts (W)

In a delta-connected circuit, the same equation is obtained because the phase voltage E_{Phase} is equal to the line voltage E_{Line}, and $I_{Phase} = I_{Line}/\sqrt{3}$. Therefore, in either a balanced wye-connected circuit or a balanced delta-connected circuit, the total active power P_T dissipated in the three-phase circuit can be calculated using Equation (3).

Since $(E_{Phase} \times I_{Phase} \times \cos\varphi)$ is the expression representing the active power P_{Phase} dissipated in a single phase of a three-phase circuit, it follows that the expression $E_{Phase} \times I_{Phase}$ represents the apparent power in a single phase. The total apparent power S_T in a balanced, wye- or delta-connected, three-phase circuit can thus be calculated using the following equation:

$$S_T = 3\,(E_{Phase} \times I_{Phase}) \tag{4}$$

where S_T is the total apparent power in the three-phase circuit, expressed in volt-amperes (VA)

Following the same steps used to obtain the equation for calculating the total active power P_T in three-phase circuits using the line voltage E_{Line} and the line current I_{Line}, the equation for the total apparent power S_T in a three-phase circuit can be rewritten as follows:

$$S_T = \sqrt{3}\,(E_{Line} \times I_{Line})$$

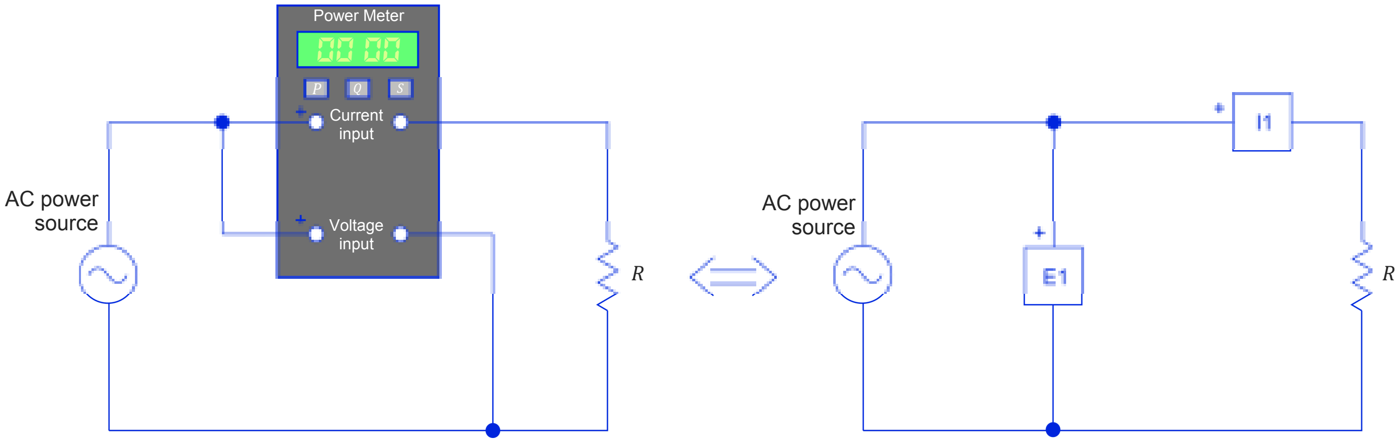
The power factor of a balanced three-phase circuit is the ratio of the total active power to the total apparent power (i.e., P_T/S_T), and the relationship between P_T, Q_T, and S_T is the same as for single-phase ac circuits (i.e., ${S_T}^2 = {P_T}^2 + {Q_T}^2$). Thus, the total reactive power Q_T in a three-phase circuit can be calculated using the following equation:

$$Q_T = \sqrt{{S_T}^2 - {P_T}^2} \tag{5}$$

where Q_T is the total reactive power in the three-phase circuit, expressed in reactive volt-amperes (var)

Power measurements in single-phase circuits

Commercial instruments are available to measure active, reactive, and apparent power directly. These instruments are referred to as power meters. A selector on the power meter usually allows the unit to measure active, reactive, or apparent power. A power meter determines power by measuring the circuit voltage and current. All power meters thus generally have at least a voltage input and a current input to measure the circuit voltage and current. Figure 9a shows the typical connections of a power meter in a single-phase circuit and Figure 9b shows the equivalent connections required to measure power using the Data Acquisition and Control Interface (DACI) module.



(a) Typical power meter connections

(b) Equivalent connections for power measurements using the DACI

Figure 9. Three-phase circuit diagrams showing the connections required for power measurements.

Measuring the total power in four-wire, three-phase circuits

Measuring the total power in a four-wire, three-phase circuit is done by first measuring the voltage and current in each phase of the circuit (i.e., the voltage across each load element and the current flowing in each load element) and calculating the active power and reactive power in each phase from the voltage and current measured in each phase of the circuit. The total active power P_T in the four-wire, three-phase circuit is simply the algebraic sum of the active power values obtained for the three phases of the circuit. Similarly, the total reactive power Q_T is simply the algebraic sum of the reactive power values obtained for the three phases of the circuit.

In other words, it is like measuring the active power and reactive power in each phase independently using three power meters and algebraically adding the three measured power (either active or reactive) values. The total apparent power S_T can then be obtained by computing the vectorial sum of the total active power P_T and the total reactive power Q_T. Figure 10 shows the connections required to measure the total power in a four-wire, three-phase circuit using the DACI. Note that, in the circuit diagram, inputs E1 and I1, inputs E2 and I2, and inputs E3 and I3 each represent a power meter.

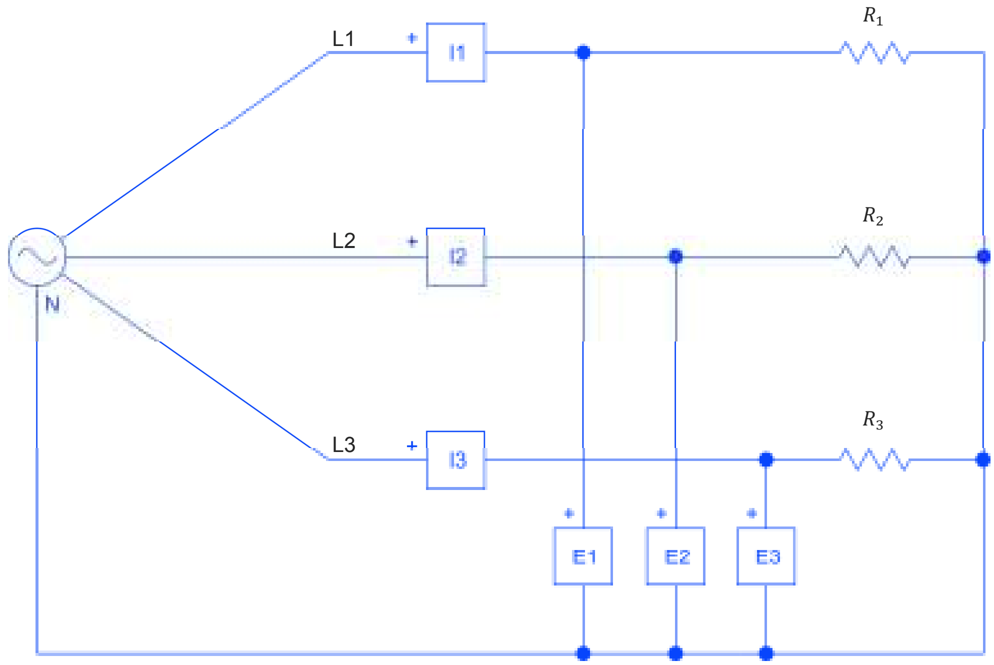


Figure 10. Three-phase power measurement using three power meters.

The method of power measurement shown in Figure 10 works whether the three-phase circuit is balanced or not.

Measuring the total power in three-wire, three-phase circuits (two-wattmeter method)

A three-wire, three-phase circuit is simply a three-phase circuit with three line conductors but no neutral conductor. Three-wire, three-phase circuits are used commonly because they allow three-phase power to be conveyed using three conductors instead of four conductors. This makes three-wire, three-phase circuits more economical than four-wire, three-phase circuits.

The method for measuring the total power in four-wire, three-phase circuits discussed in the previous section cannot be used to measure the total power in three-wire, three-phase circuits. For instance, when the load is connected in a wye configuration, the phase currents can be measured but the phase voltages (voltage across each load element) cannot because the neutral point generally is not available to connect the voltage inputs of the power meters, as Figure 11 shows.

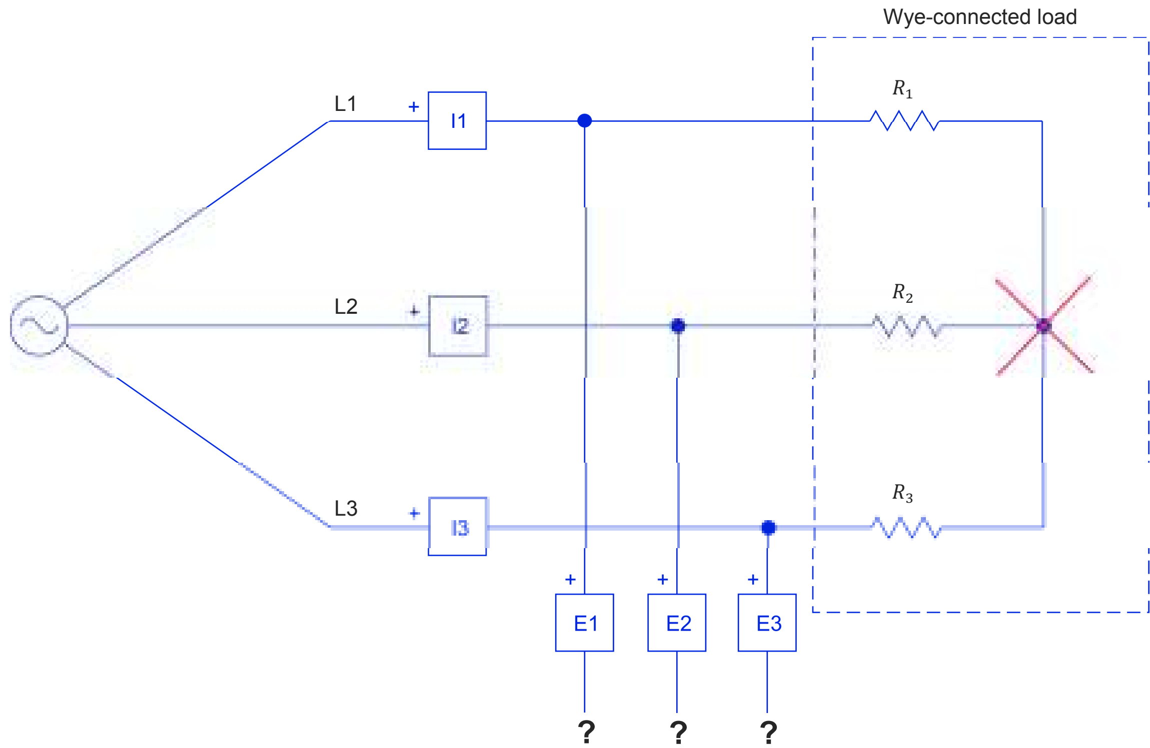


Figure 11. Diagram of a three-wire, wye-connected, three-phase circuit showing that the voltage inputs of the power meters generally cannot be connected to the neutral point of the circuit.

Similarly, when the load is connected in a delta configuration, the phase voltages can be measured but the phase currents (current flowing through each load element) cannot be measured because individual access to each load element generally is not possible (i.e., it is impossible to connect the current inputs of the power meters to measure the phase currents), as Figure 12 shows.

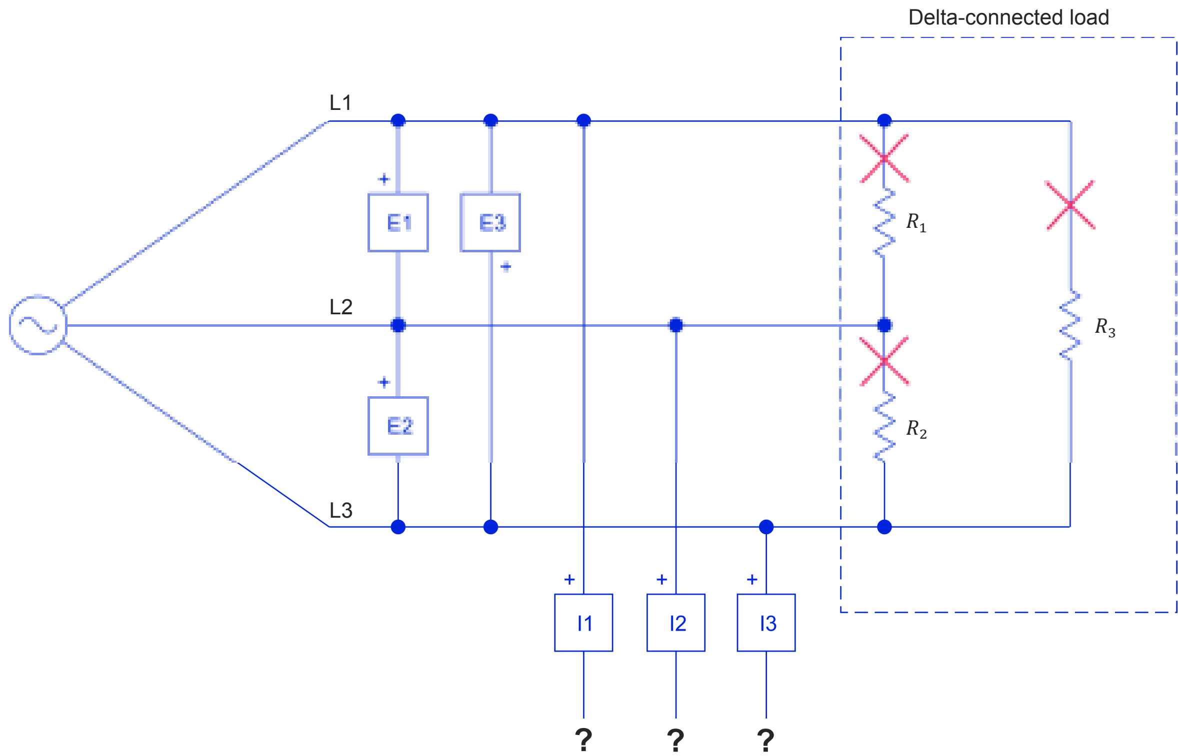


Figure 12. Diagram of a three-wire, delta-connected, three-phase circuit showing that the current inputs of the power meters cannot be connected to measure the phase currents.

To measure the total power (either the total active power P_T, the total reactive power Q_T, or the total apparent power S_T) in three-wire, three-phase circuits, a method using only two power meters can be used. This method is usually referred to as the **two-wattmeter method** because historically, it was first implemented with two wattmeters instead of two power meters. Figure 13 shows the connections of the voltage and current inputs of the two power meters required for the two-wattmeter method of measuring three-phase power. Note that the voltage and current inputs of the power meters must be connected with the polarity indicated in the figure in order to obtain correct power measurements.

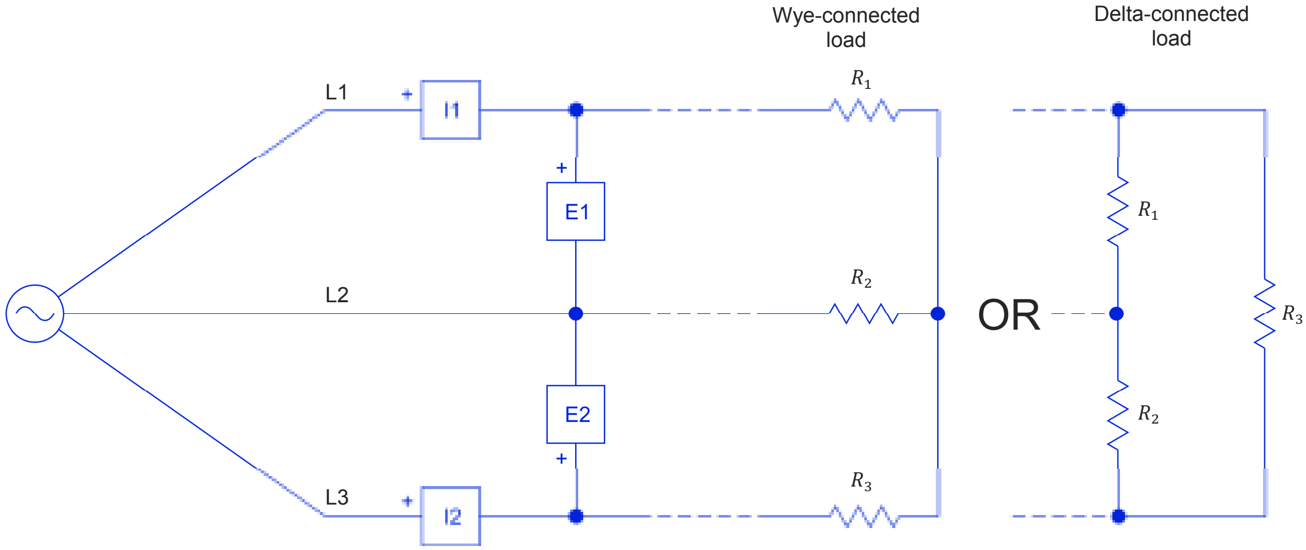


Figure 13. Connections of the voltage and current inputs of the power meters to a three-wire, three-phase circuit when measuring the total power using the two-wattmeter method.

The total active power P_T in the three-wire, three-phase circuit is simply the algebraic sum of the active power values indicated by the two power meters. Similarly, the total reactive power Q_T is simply the algebraic sum of the reactive power values indicated by the two power meters. The total apparent power S_T can then be obtained by computing the vectorial sum of the total active power P_T and the total reactive power Q_T. This method of power measurement works whether the three-phase circuit is balanced or not.

Measuring the total power in four-wire, three-phase circuits using the two-wattmeter method

The two-wattmeter method of power measurement can also be used to measure the total power (either active, reactive, or apparent) in four-wire, three-phase circuits. This can be useful because the two-wattmeter method requires only two power meters (i.e., two voltage inputs and two current inputs) instead of three power meters (i.e., three voltage inputs and three current inputs) as with the method seen earlier in this discussion. However, care must be exercised when using the two-wattmeter method to measure the total power in four-wire, three-phase circuits because the method works only with balanced circuits.

PROCEDURE OUTLINE

The Procedure is divided into the following sections:

- Setup and connections
- Measuring the total power in four-wire, three-phase circuits
- Measuring the total power in three-wire, three-phase circuits (wye configuration)
- Measuring the total power in three-wire, three-phase circuits (delta configuration)
- Measuring the total power in four-wire, three-phase circuits using the two-wattmeter method

PROCEDURE

⚠ WARNING

High voltages are present in this laboratory exercise. Do not make or modify any banana jack connections with the power on unless otherwise specified.

Setup and connections

In this section, you will set up the equipment to measure power in a four-wire, three-phase circuit.

1. Refer to the Equipment Utilization Chart in Appendix A to obtain the list of equipment required to perform this exercise.

Install the required equipment in the Workstation.

Make sure that the ac and dc power switches on the Power Supply are set to the O (off) position, then connect the Power Supply to a three-phase ac power outlet.

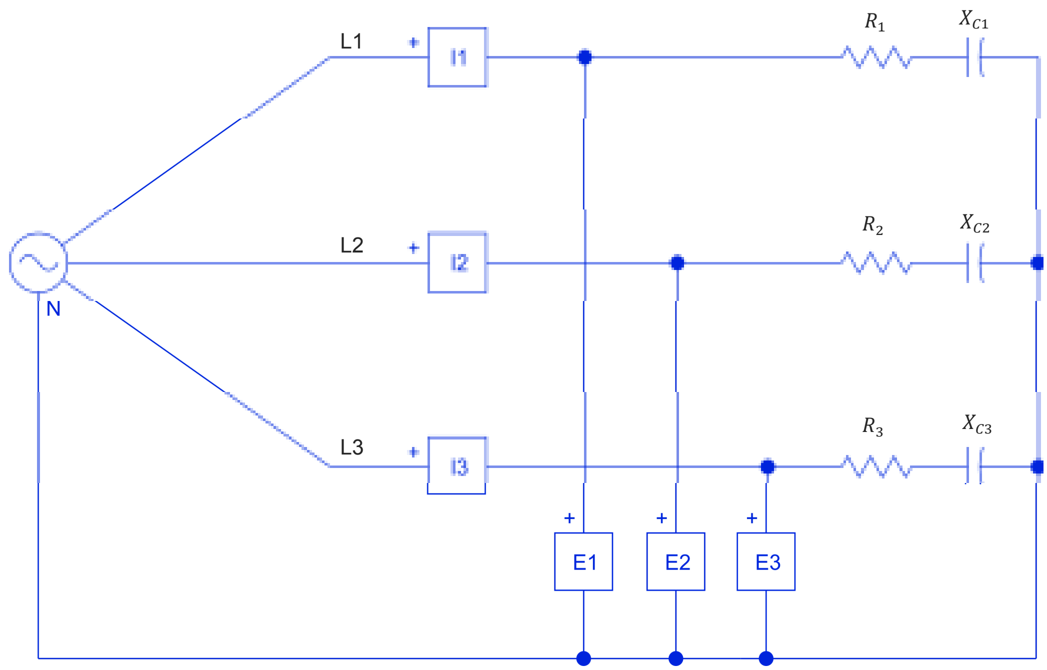
Connect the *Power Input* of the Data Acquisition and Control Interface to a 24 V ac power supply. Turn the 24 V ac power supply on.

2. Connect the USB port of the Data Acquisition and Control Interface to a USB port of the host computer.

3. Turn the host computer on, then start the LVDAC-EMS software.

In the LVDAC-EMS Start-Up window, make sure that the Data Acquisition and Control Interface is detected. Make sure that the *Computer-Based Instrumentation* function for the Data Acquisition and Control Interface is available. Select the network voltage and frequency that correspond to the voltage and frequency of your local ac power network, then click the *OK* button to close the LVDAC-EMS Start-Up window.

4. Set up the circuit shown in Figure 14.



Local ac power network		R_1, R_2, R_3 (Ω)	X_{C1}, X_{C2}, X_{C3} (Ω)
Voltage (V)	Frequency (Hz)		
120	60	171	240
220	50	629	880
240	50	686	960
220	60	629	880

Figure 14. Balanced, four-wire, wye-connected, three-phase circuit set up for power measurements.

5. Make the necessary switch settings on the Resistive Load and Capacitive Load modules in order to obtain the resistance and capacitive reactance values required.

6. In LVDAC-EMS, start the Metering application, then make the required settings in order to measure the rms values (ac) of the phase voltages E_{1-N}, E_{2-N}, and E_{3-N} (inputs *E1*, *E2*, and *E3*, respectively), and the phase currents $I_{Phase\ 1}$, $I_{Phase\ 2}$, and $I_{Phase\ 3}$ (inputs *I1*, *I2*, and *I3*, respectively). Set three other meters to measure power from inputs *E1* and *I1* (meter *PQS1*), *E2* and *I2* (meter *PQS2*), and *E3* and *I3* (meter *PQS3*). These three power meters will be used to successively measure the active powers P_1, P_2, and P_3, the reactive powers Q_1, Q_2, and Q_3, and the apparent powers S_1, S_2, and S_3 in each phase of the circuit. Set the meters to continuous refresh mode.

Measuring the total power in four-wire, three-phase circuits

In this section, you will solve the circuit you set up in the previous section by calculating the active, reactive, and apparent power values in each phase of the circuit, and the total active, reactive, and apparent power values in the circuit. You will measure the circuit's voltage, current, and power values, and confirm that the measured circuit parameters are equal to the calculated circuit parameters. You will then unbalance the three-phase circuit by modifying the impedance in one phase of the circuit, and solve the resulting unbalanced, three-phase circuit. Finally, you will measure the total active, reactive, and apparent power values in the circuit, and verify that the measured circuit parameters are equal to the calculated circuit parameters, thus confirming that the total power in both balanced and unbalanced, four-wire, three-phase circuits can be measured using three power meters.

7. Solve the circuit in Figure 14 to determine the following parameters: the active power P, reactive power Q, and apparent power S in each phase of the circuit, as well as the total active power P_T, total reactive power Q_T, and total apparent power S_T in the circuit.

8. Turn the three-phase ac power source in the Power Supply on.

Measure and record below the voltages and currents in the circuit of Figure 14, as well as the active power, reactive power, and apparent power in each phase of the circuit, then turn the three-phase ac power source in the Power Supply off.

You can change the type of power (i.e., active, reactive, or apparent) measured by a power meter in the Metering window by clicking on the meter Mode button. With this method, you can rapidly perform all active power measurements, then all reactive power measurements, and finally all apparent power measurements using the same three meters.

Voltage and current measurements:

E_{1-N} = _______ V $I_{Phase\ 1}$ = _______ A

E_{2-N} = _______ V $I_{Phase\ 2}$ = _______ A

E_{3-N} = _______ V $I_{Phase\ 3}$ = _______ A

Active, reactive, and apparent power measurements:

P_1 = _______ W P_2 = _______ W

P_3 = _______ W

Q_1 = _______ var Q_2 = _______ var

Q_3 = _______ var

S_1 = _______ VA S_2 = _______ VA

S_3 = _______ VA

9. Compare the voltage, current, and power (active, reactive, and apparent) values measured in the previous step with the parameter values calculated in step 7. Are all values approximately equal?

❑ Yes ❑ No

10. In the Metering window, set an additional meter to measure the total power (either active, reactive, or apparent) from the values provided by the meters measuring the power in each phase of the circuit.

The PQS1 + PQS2 + PQS3 function (accessible through the Meter Settings window of the Metering application) allows the sum (either algebraic or vectorial) of the power values measured by meters PQS1, PQS2, and PQS3. The total power meter can be set to indicate either the active, reactive, or apparent power value.

11. Turn the three-phase ac power source in the Power Supply on.

Measure and record successively the total active power P_T, total reactive power Q_T, and total apparent power S_T in the circuit using the total power meter set in the previous step, then turn the three-phase ac power source in the Power Supply off.

P_T = _______ W Q_T = _______ var

S_T = _______ VA

Compare the total power values you just measured with the total active power P_T, total reactive power Q_T, and total apparent power S_T calculated in step 7. Are all values approximately equal?

❑ Yes ❑ No

12. Modify the switch settings on the Resistive Load and Capacitive Load modules in the circuit of Figure 14 in order to obtain the resistance and capacitive reactance values indicated in Table 1. Due to these modifications, the three-phase load is now unbalanced (i.e., the first phase of the circuit has a different impedance from that of the second and third phases).

Table 1. Resistance and capacitive reactance values used for unbalancing the four-wire, wye-connected, three-phase circuit of of Figure 14.

Local ac power network		R_1 (Ω)	R_2, R_3 (Ω)	X_{C1} (Ω)	X_{C2}, X_{C3} (Ω)
Voltage (V)	Frequency (Hz)				
120	60	300	171	600	240
220	50	1100	629	2200	880
240	50	1200	686	2400	960
220	60	1100	629	2200	880

13. Solve the circuit in Figure 14 using the resistance and capacitive reactance values indicated in Table 1, to determine the following parameters: the total active power P_T, total reactive power Q_T, and total apparent power S_T in the circuit.

14. Turn the three-phase ac power source in the Power Supply on.

Successively measure and record the active power P_T, reactive power Q_T, and apparent power S_T in the circuit using the total power meter you set up before, then turn the three-phase ac power source in the Power Supply off.

$P_T =$ _______ W $Q_T =$ _______ var

$S_T =$ _______ VA

15. Compare the total active power P_T, total reactive power Q_T, and total apparent power S_T measured in the previous step with the total power values calculated in step 13. Are all values approximately equal?

❑ Yes ❑ No

Do the circuit measurements performed in this section confirm that the total power in both balanced and unbalanced, four-wire, three-phase circuits can be measured using three power meters?

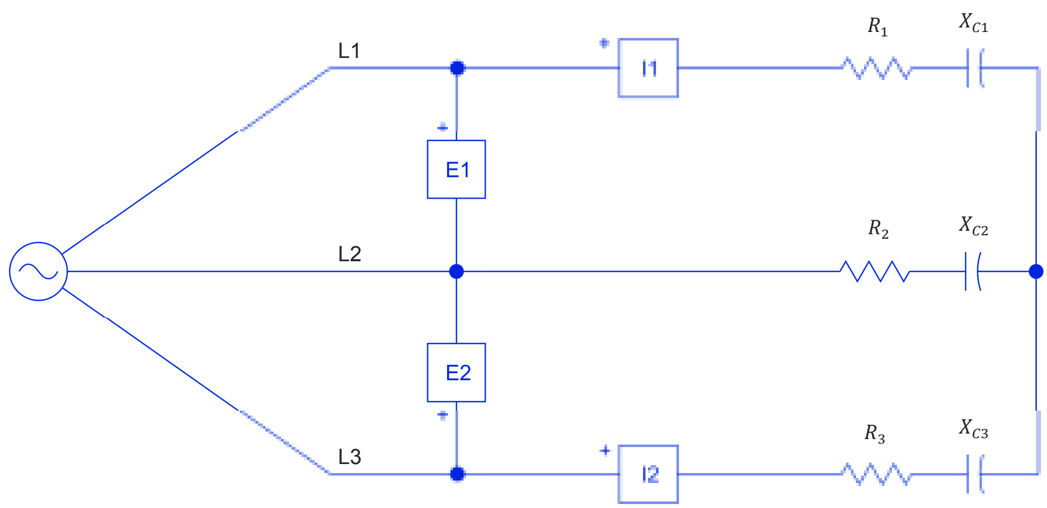
❑ Yes ❑ No

Measuring the total power in three-wire, three-phase circuits (wye configuration)

In this section, you will set up a balanced, three-wire, wye-connected, three-phase circuit. You will measure the total active, reactive, and apparent power values in the circuit using the two-wattmeter method, and verify that the measured power values are equal to the calculated power values, thus confirming that the two-wattmeter method of power measurement works for measuring the total power in balanced, three-wire, three-phase circuits.

16. Set up the circuit shown in Figure 15.

The balanced, three-phase load in the circuit of Figure 15 is identical to the balanced, three-phase load used in the previous section of this exercise. The total active power P_T, total reactive power Q_T, and total apparent power S_T are thus equal to those calculated in the previous section (see step 7) of the exercise.



Local ac power network		R_1, R_2, R_3 (Ω)	X_{C1}, X_{C2}, X_{C3} (Ω)
Voltage (V)	Frequency (Hz)		
120	60	171	240
220	50	629	880
240	50	686	960
220	60	629	880

Figure 15. Balanced, three-wire, wye-connected, three-phase circuit set up for power measurements using the two-wattmeter method.

17. Make the necessary switch settings on the Resistive Load and Capacitive Load modules in order to obtain the resistance and capacitive reactance values required.

18. In the Metering window, make the required settings in order to measure the rms values (ac) of the line voltages E_{1-2} and E_{3-2} (inputs *E1* and *E2*, respectively), and the line currents $I_{Line\ 1}$ and $I_{Line\ 3}$ (inputs *I1* and *I2*). Set two meters to measure power from inputs *E1* and *I1* (meter *PQS1*) and inputs *E2* and *I2* (meter *PQS2*). Set another meter to measure the total power from the power values provided by meters *PQS1* and *PQS2*.

The PQS1 + PQS2 function (accessible through the Meter Settings window of the Metering application) allows the sum (either algebraic or vectorial) of the power values measured by meters PQS1 and PQS2. The total power meter can be set to indicate either the active, reactive, or apparent power value.

19. Turn the three-phase ac power source in the Power Supply on.

Successively measure and record the total active power P_T, total reactive power Q_T, and total apparent power S_T in the circuit using the meter you set up for total power measurement, then turn the three-phase ac power source in the Power Supply off.

$P_T =$ _______ W $\quad$ $Q_T =$ _______ var

$S_T =$ _______ VA

20. Compare the total active power P_T, total reactive power Q_T, and total apparent power S_T measured in the previous step with the total power values calculated in step 7. Are all values approximately equal?

❑ Yes ❑ No

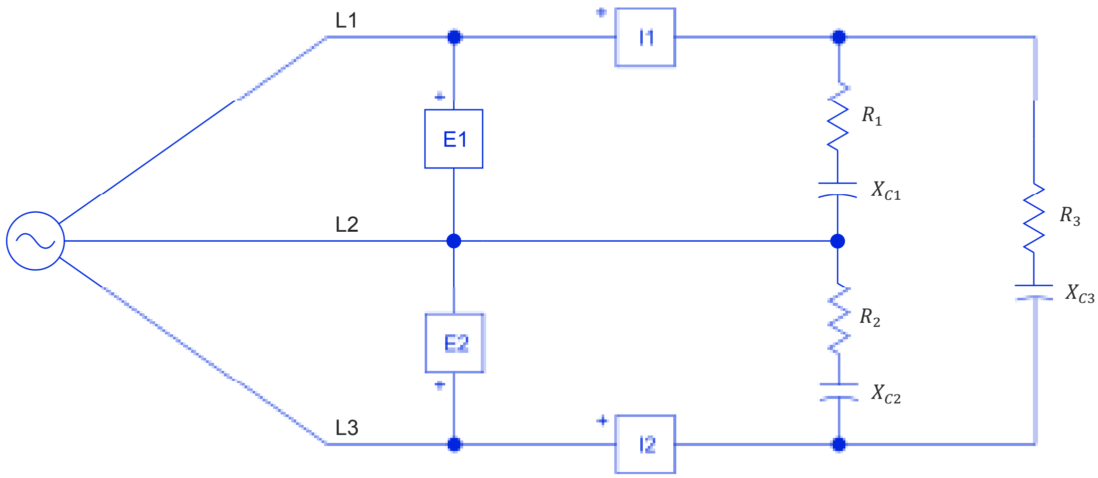
Do the circuit measurements performed in this section confirm that the two-wattmeter method of power measurement can be used to measure the total power in balanced, three-wire, wye-connected, three-phase circuits?

❑ Yes ❑ No

Measuring the total power in three-wire, three-phase circuits (delta configuration)

In this section, you will set up a balanced, three-wire, delta-connected, three-phase circuit. You will solve the circuit by calculating the active, reactive, and apparent power values in each phase of the circuit, and the total active, reactive, and apparent power values in the circuit. You will measure the total active, reactive, and apparent power values in the circuit using the two-wattmeter method, and confirm that the measured values are equal to the calculated values. You will then unbalance the three-phase circuit by modifying the impedance in one phase of the circuit, and solve the resulting unbalanced three-phase circuit. Finally, you will measure the total active, reactive, and apparent power values in the circuit using the two-wattmeter method, and verify that the measured values are equal to the calculated values, thus confirming that the two-wattmeter method of power measurement can be used to measure the total power in both balanced and unbalanced, three-wire, three-phase circuits.

21. Set up the circuit shown in Figure 16.



Local ac power network		R_1, R_2, R_3 (Ω)	X_{C1}, X_{C2}, X_{C3} (Ω)
Voltage (V)	Frequency (Hz)		
120	60	171	240
220	50	629	880
240	50	686	960
220	60	629	880

Figure 16. Balanced, three-wire, delta-connected, three-phase circuit set up for power measurements using the two-wattmeter method.

22. Make the necessary switch settings on the Resistive Load and Capacitive Load modules in order to obtain the resistance and capacitive reactance values required.

23. Solve the circuit in Figure 16 to determine the following parameters: the active power P, reactive power Q, and apparent power S in each phase of the circuit, as well as the total active power P_T, total reactive power Q_T, and total apparent power S_T in the circuit.

24. Turn the three-phase ac power source in the Power Supply on.

Successively measure and record the total active power P_T, total reactive power Q_T, and total apparent power S_T in the circuit using the meter you set up for total power measurement, then turn the three-phase ac power source in the Power Supply off.

$P_T =$ _______ W $\qquad Q_T =$ _______ var

$S_T =$ _______ VA

25. Compare the total active power P_T, total reactive power Q_T, and total apparent power S_T measured in the previous step with the total power values calculated in step 23. Are all values approximately equal?

❑ Yes ❑ No

26. Modify the switch settings on the Resistive Load and Capacitive Load modules in the circuit of Figure 16 in order to obtain the resistance and capacitive reactance values indicated in Table 2. Due to these modifications, the three-phase load is now unbalanced (i.e., the first phase of the circuit has a different impedance from that of the second and third phases).

Table 2. Resistance and capacitive reactance values used for unbalancing the three-wire, delta-connected, three-phase circuit in Figure 16.

Local ac power network		R_1 (Ω)	R_2, R_3 (Ω)	X_{C1} (Ω)	X_{C2}, X_{C3} (Ω)
Voltage (V)	Frequency (Hz)				
120	60	300	171	600	240
220	50	1100	629	2200	880
240	50	1200	686	2400	960
220	60	1100	629	2200	880

27. Solve the circuit in Figure 16 using the resistance and capacitive reactance values indicated in Table 2, to determine the following parameters: the total active power P_T, total reactive power Q_T, and total apparent power S_T in the circuit.

28. Turn the three-phase ac power source in the Power Supply on.

Successively measure and record the total active power P_T, total reactive power Q_T, and total apparent power S_T in the circuit using the meter you set up for total power measurement, then turn the three-phase ac power source in the Power Supply off.

$P_T =$ _______ W $\qquad$ $Q_T =$ _______ var

$S_T =$ _______ VA

29. Compare the total active power P_T, total reactive power Q_T, and total apparent power S_T measured in the previous step with the total power values calculated in step 27. Are all values approximately equal?

❑ Yes ❑ No

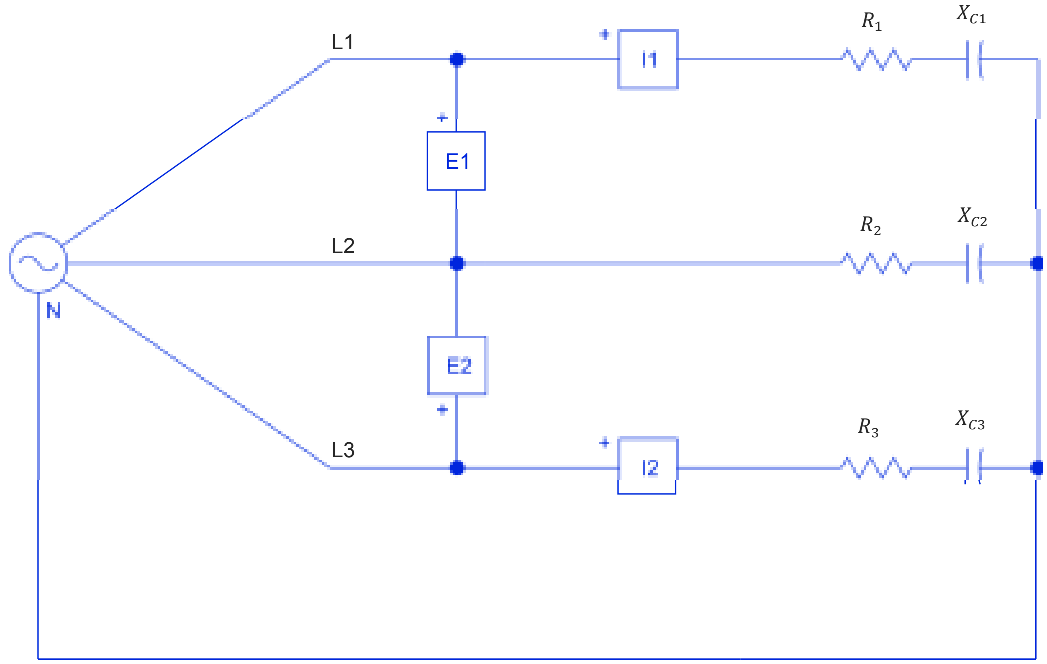
Do the circuit measurements performed in this section confirm that the two-wattmeter method of power measurement can be used to measure the total power in both balanced and unbalanced, three-wire, delta-connected, three-phase circuits?

❑ Yes ❑ No

Measuring the total power in four-wire, three-phase circuits using the two-wattmeter method

In this section, you will set up a balanced, four-wire, wye-connected, three-phase circuit similar (same load but voltage and current inputs connected for total power measurement using the two-wattmeter method) to the one you set up in the "Measuring the total power in four-wire, three-phase circuits" section of this exercise. You will measure the total active, reactive, and apparent power values in the circuit using the two-wattmeter method, and confirm that the measured values are equal to the values calculated for this balanced, three-phase circuit in the "Measuring the total power in four-wire, three-phase circuits" section of this exercise. You will then unbalance the three-phase circuit by modifying the impedance in one phase of the circuit. Finally, you will measure the total active, reactive, and apparent power values in the circuit, and verify that the measured values differ from the values calculated for this unbalanced, three-phase circuit in the "Measuring the total power in four-wire, three-phase circuits" section of this exercise. You will confirm that the two-wattmeter method of power measurement can only be used to measure power in four-wire, three-phase circuits that are balanced.

30. Set up the circuit shown in Figure 17.



Local ac power network		R_1, R_2, R_3 (Ω)	X_{C1}, X_{C2}, X_{C3} (Ω)
Voltage (V)	Frequency (Hz)		
120	60	171	240
220	50	629	880
240	50	686	960
220	60	629	880

Figure 17. Four-wire, wye-connected, three-phase circuit set up for power measurements using the two-wattmeter method.

31. Make the necessary switch settings on the Resistive Load and Capacitive Load modules in order to obtain the resistance and capacitive reactance values required.

The balanced, three-phase circuit you just set up corresponds to the balanced, four-wire three-phase circuit set up in the "Measuring the total power in four-wire, three-phase circuits" section of this exercise. The calculations required for solving the circuit are identical and do not need to be repeated.

32. Turn the three-phase ac power source in the Power Supply on.

Successively measure and record the total active power P_T, total reactive power Q_T, and total apparent power S_T in the circuit using the meter you set up for total power measurement, then turn the three-phase ac power source in the Power Supply off.

$P_T =$ _______ W $Q_T =$ _______ var

$S_T =$ _______ VA

33. Compare the total active power P_T, total reactive power Q_T, and total apparent power S_T measured in the previous step with the total power values calculated in step 7. Are all values approximately equal?

❑ Yes ❑ No

34. Modify the switch settings on the Resistive Load and Capacitive Load modules in the circuit of Figure 17 in order to obtain the resistance and capacitive reactance values indicated in Table 3. Due to these modifications, the three-phase load is now unbalanced (i.e., the first phase of the circuit has a different impedance from that of the second and third phases).

Table 3. Resistance and capacitive reactance values used for unbalancing the four-wire, wye-connected, three-phase circuit.

Local ac power network		R_1 (Ω)	R_2, R_3 (Ω)	X_{C1} (Ω)	X_{C2}, X_{C3} (Ω)
Voltage (V)	Frequency (Hz)				
120	60	300	171	600	240
220	50	1100	629	2200	880
240	50	1200	686	2400	960
220	60	1100	629	2200	880

The unbalanced, three-phase circuit you just set up corresponds to the unbalanced, four-wire, three-phase circuit set up in the "Measuring the total power in four-wire, three-phase circuits" section of this exercise. The calculations required for solving the circuit are identical and do not need to be repeated.

35. Turn the three-phase ac power source in the Power Supply on.

Successively measure and record the total active power P_T, total reactive power Q_T, and total apparent power S_T in the circuit using the meter you set up for total power measurement, then turn the three-phase ac power source in the Power Supply off.

$P_T =$ _______ W $Q_T =$ _______ var

$S_T =$ _______ VA

36. Compare the total active power P_T, total reactive power Q_T, and total apparent power S_T values measured in the previous step with the total power values calculated in step 13. Are all values equal?

❑ Yes ❑ No

What conclusions can you draw concerning the two-wattmeter method of power measurement when measuring power in four-wire, three-phase circuits?

37. Close LVDAC-EMS, then turn off all the equipment. Disconnect all leads and return them to their storage location.

Conclusion

In this exercise, you learned how to calculate active, reactive, and apparent power in balanced, wye- and delta-connected, three-phase circuits. You also learned how to use power meters to measure power in three-phase circuits. You saw how to measure power in three- and four-wire, three-phase circuits, as well as when it is possible to use the two-wattmeter method of power measurement to measure power in a three-phase circuit.

Review Questions

1. A balanced, delta-connected, purely resistive, three-phase circuit has a line voltage E_{Line} of 100 V and a line current I_{Line} of 1.5 A. Calculate the total active power P_T dissipated in the resistive load of the circuit.

2. Explain how to connect the two power meters to the lines of a three-wire, three-phase circuit when using the two-wattmeter method of power measurement.

3. A balanced, wye-connected, resistive and capacitive, three-phase circuit has a phase voltage E_{Phase} of 80 V and a phase current I_{Phase} of 2.5 A. Calculate the total apparent power S_T in the circuit.

4. A balanced, three-wire, resistive and capacitive, three-phase circuit is connected to two power meters set up to measure power using the two-wattmeter method of power measurement. The two power meters indicate active power readings of 175 W and -35 W. Calculate the total active power P_T dissipated in the circuit.

5. In which type of three-phase circuits does the two-wattmeter method of power measurement not work to measure the total power in the circuit?