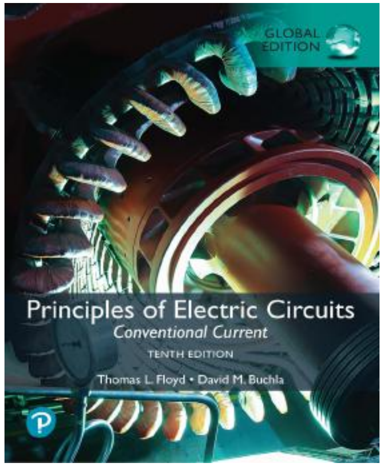
Principles of Electric Circuits: Conventional Current

Tenth Edition, Global Edition

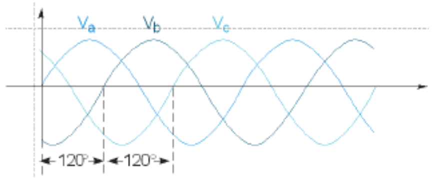


Chapter 21

Three-Phase Systems in Power Applications

Summary: Three-phase voltages

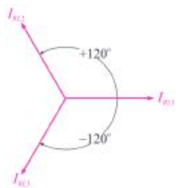
Multiple sinusoidal voltages are separated by certain constant phase angles. The most common polyphase system is called three-phase (abbreviated 3-ϕ). Three-phase voltages are illustrated; they are common in industrial applications.



Three-phase voltages are used in power applications with higher currents. In these cases, delivering power to a load as efficiently as possible is an important consideration.

Summary: Copper cross section (1 of 2)

In a balanced three-phase system the rotating phasors at any instant add to zero, and there is no current in the return line. Thus each of the three lines deliver the same current to the loads.



By contrast, a single-phase system requires two wires to deliver this same current – the return line must have the same current as the supply line. A balanced three-phase system is thus more efficient.

Copper cross section represents the total amount of copper required to deliver a certain amount of power to a load. The copper cross section for a three-phase system is therefore smaller than a single-phase system that delivers the same power.

Summary: Copper cross section (2 of 2)

Recall that power is directly proportional to the *current squared*, so reducing current is a key factor in efficiently delivering power.

Example

Compare the copper cross sections from a single phase 240 V generator to an 80 Ω load with a 240 V three-phase system that delivers the same total power to three 240 Ω loads. The power delivered in each case is 720 W.

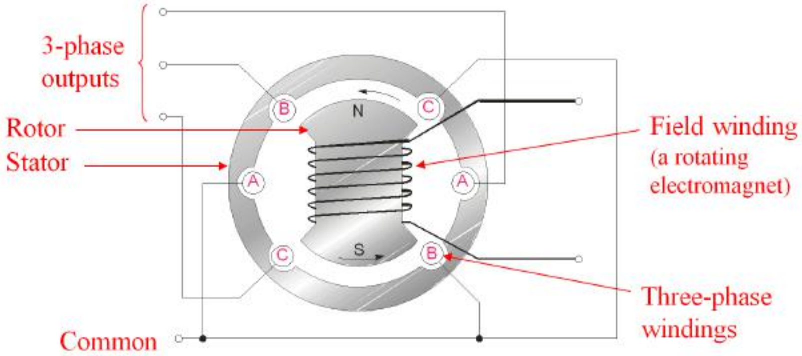
Solution

By Ohm's law, the current in the single-phase load is 30 A. Each conductor must be rated for this current. The copper cross section is 2 X 30 A = 60 A

In the balanced three-phase case, each load dissipates 240 W (⅓ of 720 W). By Ohm's law. the current in each of the three supply lines is 10 A. The return line current is zero. The copper cross section is 3 X 10 A = 30 A

Summary: Three-phase generator

Three-phase generators simultaneously produce three sinusoidal voltages that are separated by 120^{o}.
A two-pole, three-phase generator is shown.



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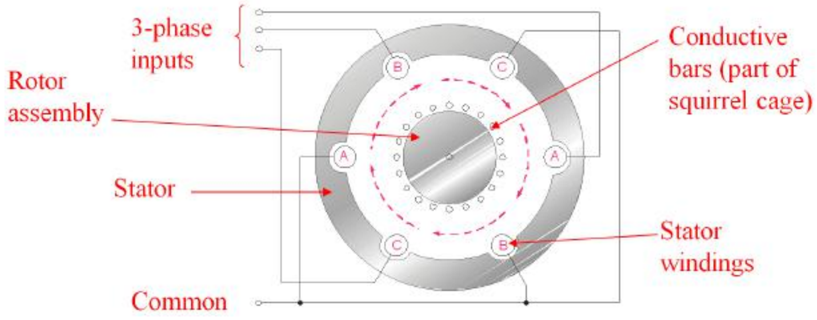
Summary: Three-phase motor (1 of 2)

Three-phase induction motors produce rotor current through induction rather than using slip rings and brushes. The induced rotor current is in conductors that are part of a squirrel-cage rotor assembly.



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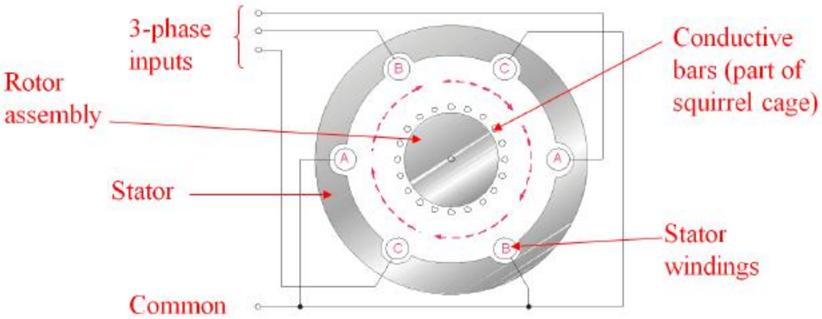
Summary: Three-phase motor (2 of 2)

As the magnetic field rotates, currents are induced in the conductors of the squirrel-cage rotor. The interaction of the induced currents and the magnetic field produces forces that cause the rotor to turn.



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Summary: Advantages of three-phase systems

Three important advantages to three-phase systems are:

- The size of the copper wire required to carry current from the generator to a load can be reduced when a three-phase rather than a single-phase system is used. This implies a smaller copper cross-section.
- Three-phase systems produce constant power in the load, which means uniform conversion of energy, an important advantage in power applications.
- Three-phase systems have a constant rotating magnetic field, which tends to keep a constant shaft speed on motors.

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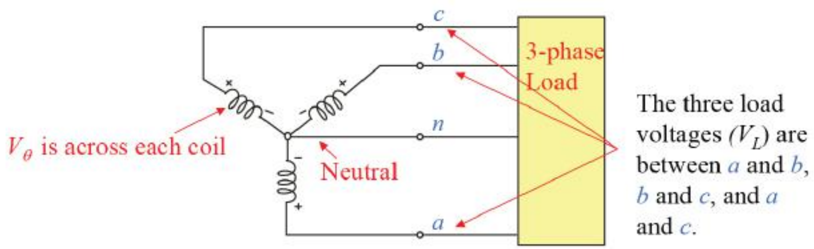
Summary: The Y-connected three-phase generator (1 of 4)

The Y-connected generator has the generator coils connected in a Y-configuration with neutral connected to the center. Voltages across the generator windings are called **phase voltages** (V_θ) and currents through the windings are called **phase currents** (I_θ).



Summary: The Y-connected three-phase generator (2 of 4)

Points about the Y-connected three-phase generator are:

The magnitude of each line current is equal to the corresponding phase current: $I_L = I_\theta$

There are three line voltages, one across each phase voltage pair.

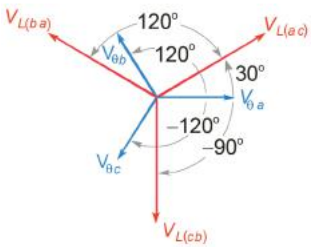
The magnitude of each line voltage is equal to $\sqrt{3}$ times the magnitude of the phase voltage.

There is a phase difference of 30° between each line voltage and the nearest phase voltage (see the following slide).

Summary: The Y-connected three-phase generator (3 of 4)

The phase diagram for a three-phase Y-connected generator is shown. Line voltages are in red; phase voltages are in blue.

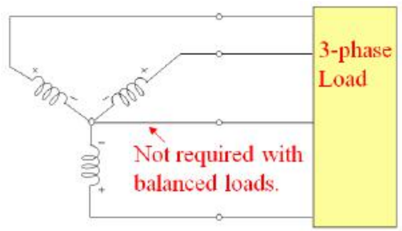
In the Y-connected generator, with 120 V_{rms} phase voltages, the line voltages will be 208 V.



Summary: The Y-connected three-phase generator (4 of 4)

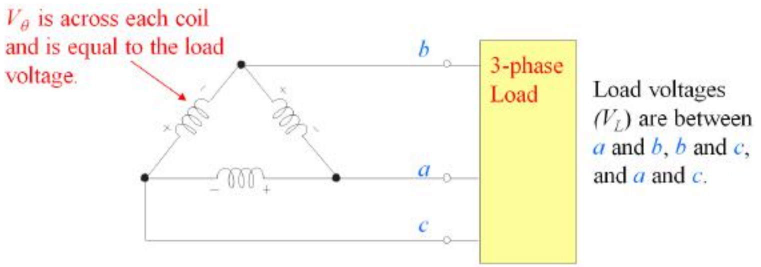
When the loads are perfectly balanced in a Y-connected three-phase generator, the neutral current is zero, so only 3-wires are required in this case.

When the loads are not equal, a neutral is required to provide a return current path, because the neutral current is not zero.



Summary: The Δ-connected three-phase generator (1 of 3)

The Δ-connected generator has the generator coils connected in triangular configuration with no neutral.



Although line and phase voltages are equal, the line currents and phase currents are not.

Summary: The Δ-connected three-phase generator (2 of 3)

Points about the Δ-connected three-phase generator are:

The magnitude of each line voltage is equal to the corresponding phase voltage: $V_L = V_\theta$

Only a single voltage magnitude is available.

The magnitude of each line current is equal to $\sqrt{3}$ times the magnitude of the phase current.

There is a phase difference of 30° between each line current and the nearest phase current (see the following slide).

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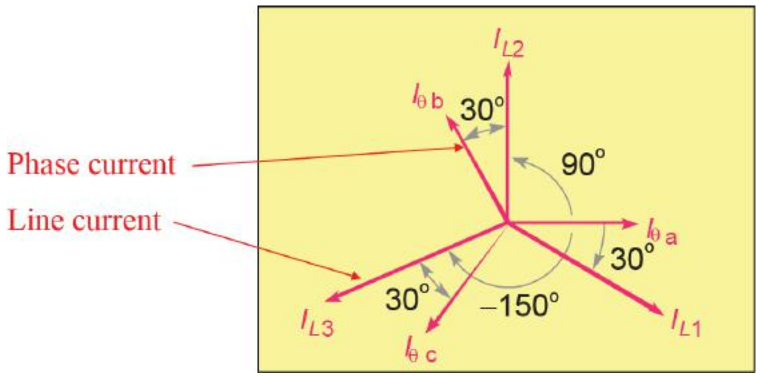
Summary: The Δ-connected three-phase generator (3 of 3)

The current phasors for a three-phase Δ-connected generator are shown.



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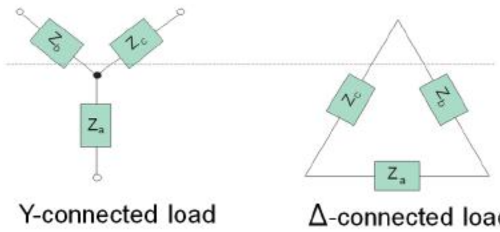
Summary: Three-phase source/load analysis

Blocks Z_a, Z_b, and Z_c represent load impedances, which can be resistive, reactive or both.



Either of these load configurations can be connected to a Y- or Δ-source to complete the system.

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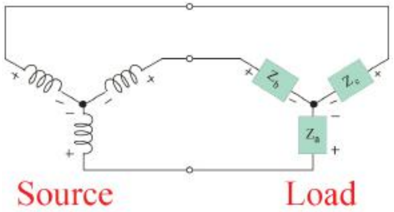
Summary: The Y-Y system

With a Y-connected source, two different values of 3-phase voltage are available: the phase voltage and the line voltage. The Y-connected load is connected to the phase voltages. In a standard power system, the loads are all 120 V. (A Δ-connected load could be connected to obtain 208 V).

For a balanced load, all the phase currents are equal, and the neutral current is zero; an unbalanced load has neutral current.

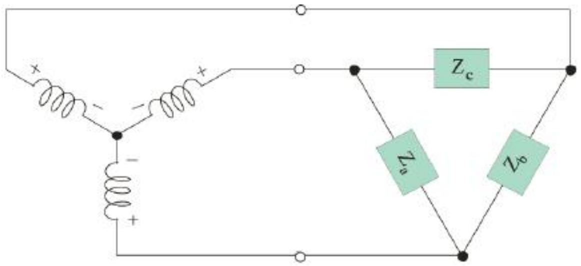


Summary: The Y-Δ system

Each phase of the load has the full line voltage across it. In a standard power system, the line voltages are all 208 V.

Line currents are equal to the corresponding phase currents, and each line current divides into two load currents.

For a balanced load, the current in each load is: $I_L = \sqrt{3}\ I_Z$

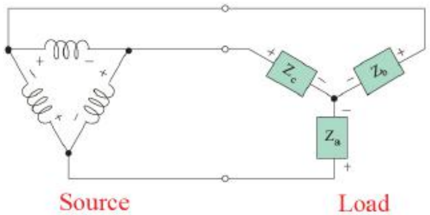


Summary: The Δ-Δ system (1 of 2)

Because of the Δ-source, the line voltages are equal to the corresponding phase voltages. Each phase voltage equals the difference between the corresponding load voltages.

For the Y-connected load, each load current equals the corresponding line current if the loads are balanced ($I_L = I_Z$).

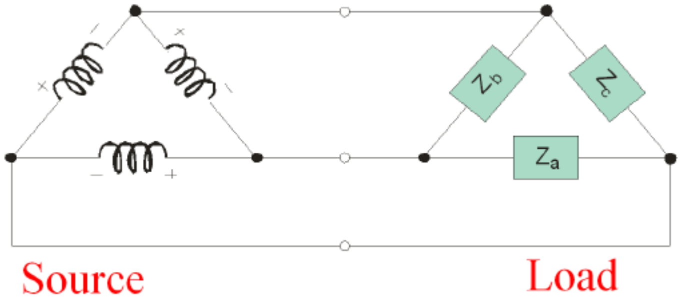
The relationship between the load voltages and the corresponding phase voltages is: $V_\theta = \sqrt{3} V_Z$



Summary: The Δ-Δ system (2 of 2)

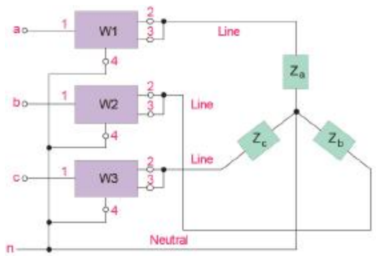
Load voltage, line voltage, and source phase voltage are all equal for a given phase.

When the load is balanced, all voltages are equal. With this condition, $I_L = \sqrt{3} I_Z$

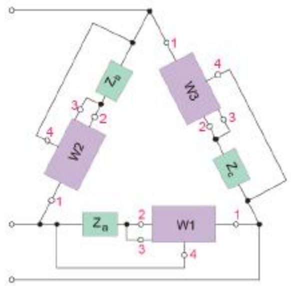


Summary: Three-phase power measurement

Power can be measured in a 3-phase load of either Y or Δ type using three wattmeters as shown.



Y-connected load



Δ-connected load

Key Terms (1 of 2)

Rotor The rotating assembly in a generator or motor.

Alternator An electromechanical ac generator.

Field winding The winding on the rotor of an ac generator.

Stator The stationary outer part of a generator or motor.

Balanced load A condition where all of the load currents are equal and the neutral current is zero.

Key Terms (2 of 2)

Phase voltage (V_θ) The voltage across a generator winding.

Phase current (I_θ) The current through a generator winding.

Line current (I_L) The current through a line feeding a load.

Line voltage (V_L) The voltage between lines feeding a load.

Quiz (1 of 11)

1. The angle between phases in a three-phase system is
   a. 90°
   b. 120°
   c. 270°
   d. none of the above

Quiz (2 of 11)

2. To produce rotor current, a three phase-induction motor uses
   - a. one set of slip rings and brushes
   - b. two sets of slip rings and brushes
   - c. three sets of slip rings and brushes
   - d. transformer action

Quiz (3 of 11)

3. The conducting bars in the rotor of an induction motor
   - a. are connected to the load
   - b. develop a magnetic field from circulating current
   - c. are used to start the motor
   - e. all of the above

Quiz (4 of 11)

4. A Y-configured generator will have neutral current
   - a. always
   - b. only of the load is unbalanced
   - c. only if the load is resistive
   - d. never

Quiz (5 of 11)

5. Voltages that are across a generator’s windings are called
   - a. phase voltages
   - b. line voltages
   - c. load voltages
   - d. field voltages

Quiz (6 of 11)

6. Current in a generator windings are called
   - a. phase currents
   - b. line currents
   - c. load currents
   - d. field currents

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Quiz (7 of 11)

7. The phase angle between the phase voltage and the line voltage of a Y-connected generator is
   - a. 0°
   - b. 30°
   - c. 60°
   - d. 90°

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Quiz (8 of 11)

8. On a Δ configured generator, the magnitude of each line voltage equals
   - a. V_θ
   - b. $\sqrt{3}V_\theta$
   - c. $2V_\theta$
   - d. $V_\theta / \sqrt{3}$

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Quiz (9 of 11)

9. In a Y-connected generator, with 120 Vrms phase voltages, the line voltages will be
   - a. 90 V
   - b. 120 V
   - c. 208 V
   - d. 260 V

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Quiz (10 of 11)

10. Load voltage, line voltage, and source phase voltage are all equal for a given phase and a balanced load with a
    a. Y-Y system
    b. Δ-Y system
    c. Y-Δ system
    d. Δ-Δ system

Quiz (11 of 11)

Answers:

1. b
2. d
3. b
4. b
5. a
6. a
7. b
8. a
9. c
10. d