Electrical Engineering 1
12026105

Chapter 12

Three-Phase Circuit

Learning Objectives

By using the information and exercises in this chapter you will be able to:

1. Understand balanced three-phase voltages.
2. Analyze balanced wye-wye circuits.
3. Understand and analyze balanced wye-delta circuits.
4. Analyze balanced delta-delta circuits.
5. Understand and analyze balanced delta-wye circuits.
6. Explain and analyze power in balanced three-phase circuits.
7. Analyze unbalanced three-phase circuits.

วัตถุประสงค์การเรียนรู้

โดยใช้ข้อมูลและแบบฝึกหัดในบทนี้ นักเรียนจะสามารถ:

1. เข้าใจสมดุลแรงดันไฟฟ้าสามเฟส
2. วิเคราะห์วงจรสมดุล Y – Y ได้
3. เข้าใจและวิเคราะห์วงจรสมดุล Y – Δ ได้
4. วิเคราะห์วงจรสมดุล Δ – Δ ได้
5. เข้าใจและวิเคราะห์วงจรสมดุล Δ – Yได้
6. อธิบายและวิเคราะห์กำลังในวงจรสมดุลสามเฟสได้
7. วิเคราะห์วงจรสามเฟสที่ไม่สมดุลได้

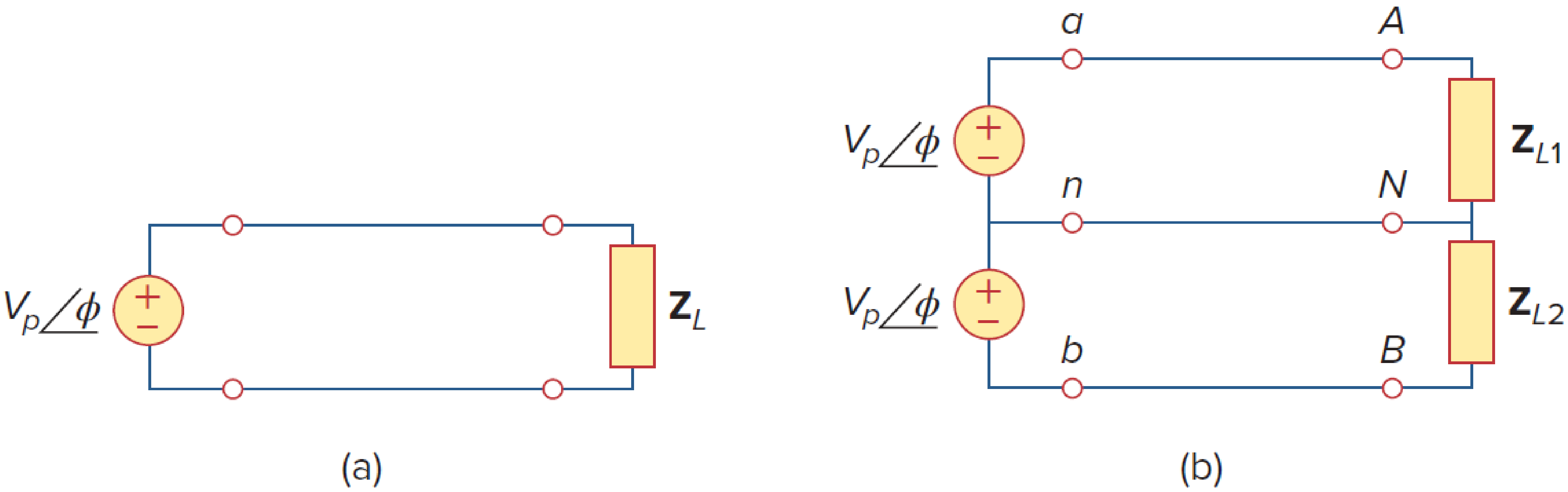
Three-Phase Circuits Chapter 12

- What is a Three-Phase Circuit?
- Balance Three-Phase Voltages
- Balance Three-Phase Connection
- Power in a Balanced System
- Unbalanced Three-Phase Systems
- Application – Residential Wiring

Nikola Tesla (1856–1943)

12.1 What is a Three-Phase Circuit?

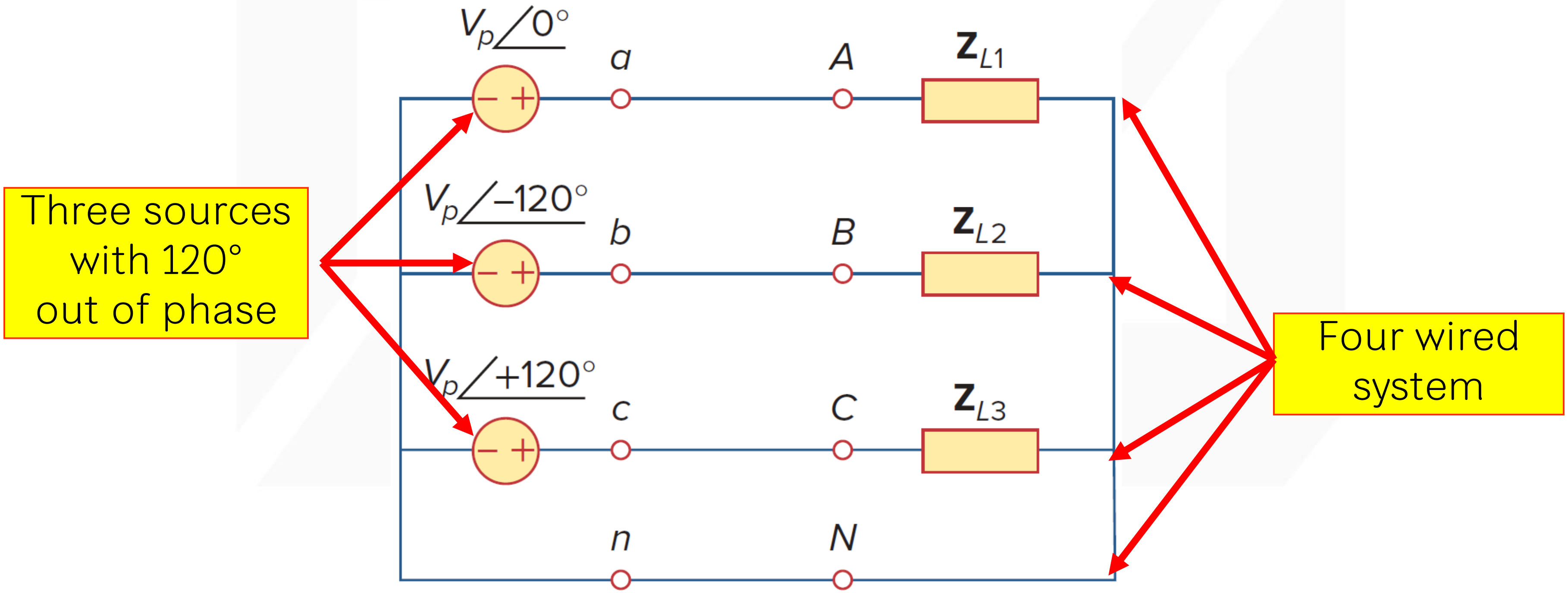
So far, we have dealt with single-phase circuits.



Single-phase systems: (a) two-wire type, (b) three-wire type.

12.1 What is a Three-Phase Circuit?

It is a system produced by a generator consisting of <u>three sources</u> having the same amplitude and frequency but <u>out of phase</u> with each other by 120°.



Three-phase four-wire system.

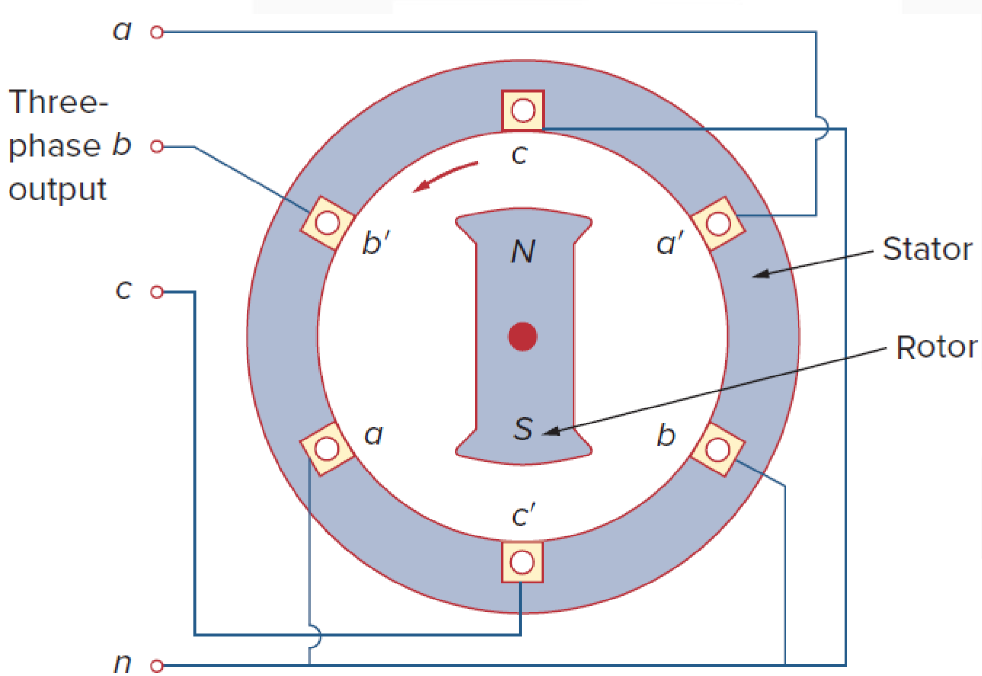
12.1 What is a Three-Phase Circuit?

Advantages:

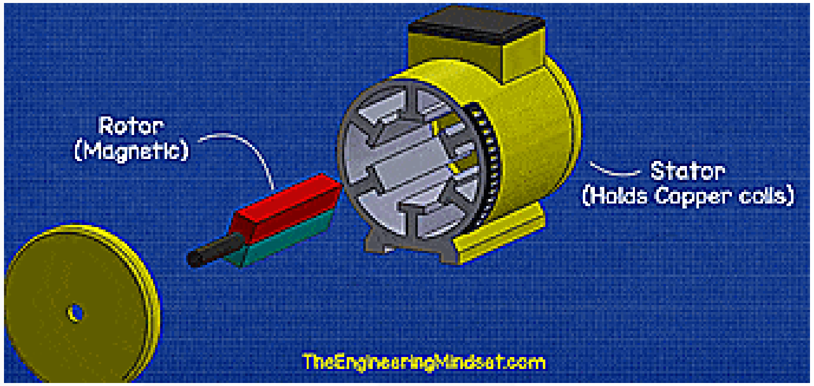
1. Nearly all electric power is generated and distributed in three-phase, at the operating frequency of 60 Hz (or ω = 377 rad/s) in the U.S. or 50 Hz (or ω = 314 rad/s) in some other parts of the world.
2. The instantaneous power in a three-phase system can be constant (not pulsating). This results in uniform power transmission and less vibration of three-phase machines.
3. For the same amount of power, the three-phase system is more economical that the single-phase. In fact, the amount of wire required for a three-phase system is less than that required for an equivalent single-phase system.

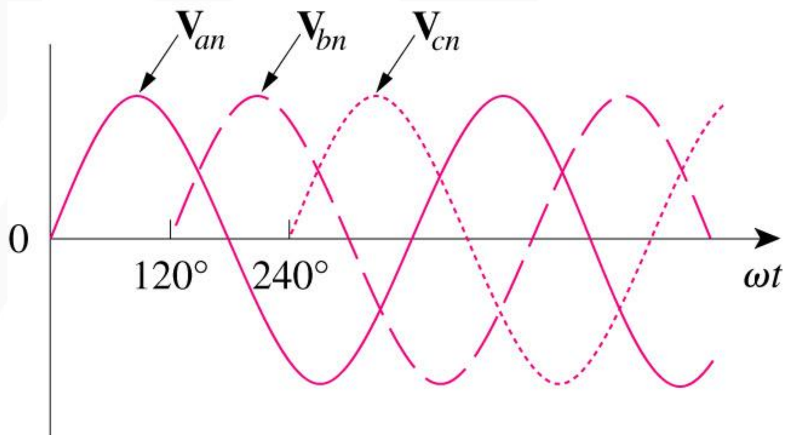
12.2 Balance Three-Phase Voltages

A three-phase ac generator (or alternator) consists of a rotating magnet (rotor) surrounded by a stationary winding (stator).



A three-phase generator

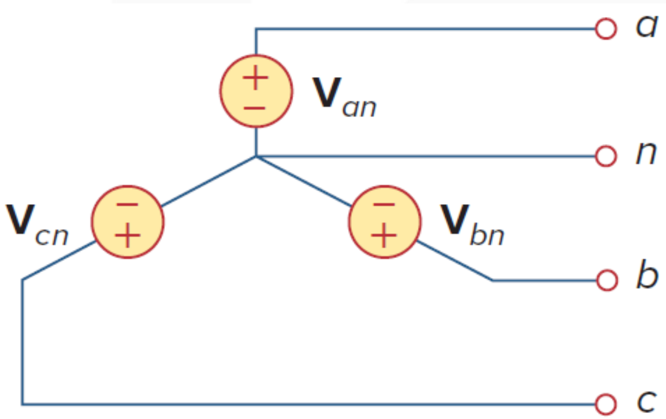




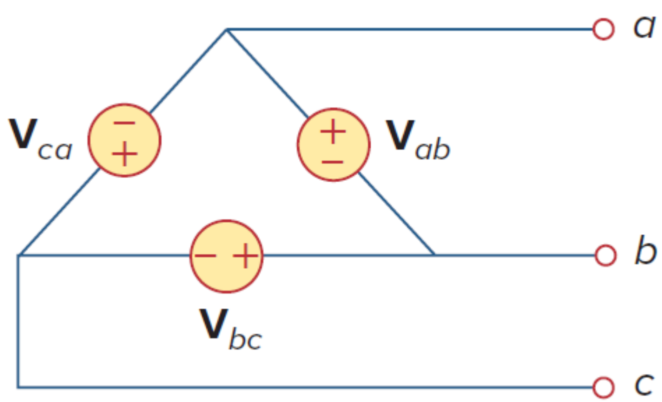
The generated voltages

12.2 Balance Three-Phase Voltages

- A typical three-phase system consists of three voltage sources connected to loads by three or four wires.
- The voltage sources can be either wye connected as shown in Fig. (a) or delta-connected as in Fig. (b).



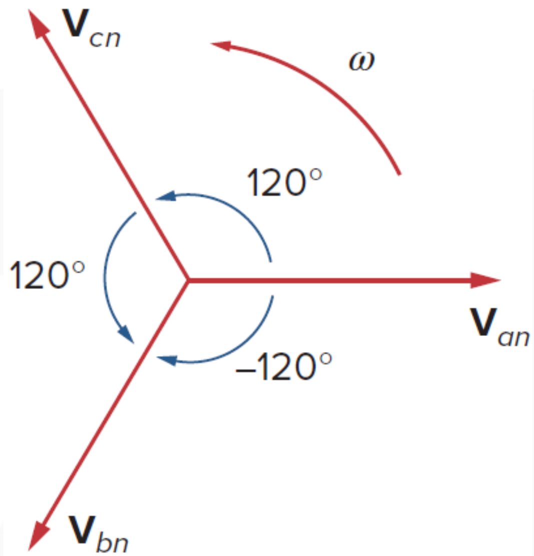
(a) Y-connected source



(b) Δ-connected source.

12.2 Balance Three-Phase Voltages

Consider the wye-connected voltages. There are two possible combinations.



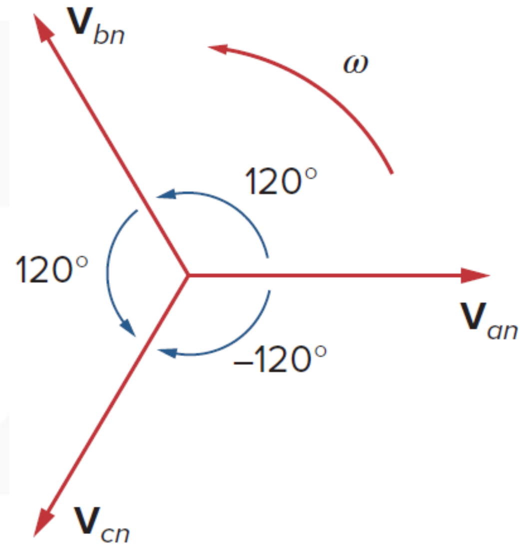
$$\mathbf{V}_{an} = V_p\angle 0^\circ$$
$$\mathbf{V}_{bn} = V_p\angle -120^\circ$$
$$\mathbf{V}_{cn} = V_p\angle -240^\circ = V_p\angle +120^\circ$$

where V_p is the effective or rms value of the phase voltages.

This is known as the *abc* sequence or positive sequence. In this phase sequence, $\mathbf{V}_{an}$ leads $\mathbf{V}_{bn}$, which in turn leads $\mathbf{V}_{cn}$. This sequence is produced when the rotor (Page8) rotates counterclockwise. As the phasors rotate in the counterclockwise direction with frequency ω, they pass through the horizontal axis in a sequence *abcabca* . . . . Thus, the sequence is *abc* or *bca* or *cab*.

12.2 Balance Three-Phase Voltages

Consider the wye-connected voltages. There are two possible combinations.



$$\mathbf{V}_{an} = V_p\angle 0^\circ$$
$$\mathbf{V}_{cn} = V_p\angle -120^\circ$$
$$\mathbf{V}_{bn} = V_p\angle -240^\circ = V_p\angle +120^\circ$$

This is called the *acb* sequence or negative sequence. In this phase sequence, $\mathbf{V}_{an}$ leads $\mathbf{V}_{cn}$, which in turn leads $\mathbf{V}_{bn}$. The *acb* sequence is produced when the rotor (Page8) rotates in the clockwise direction. As the phasors rotate in the counterclockwise direction, they pass the horizontal axis in a sequence acbacba . . . . This describes the *acb* sequence.

12.2 Balance Three-Phase Voltages

- If the voltage sources have the same amplitude and frequency ω and are out of phase with each other by 120°, the voltages are said to be balanced. This implies that

$$\mathbf{V}_{an} + \mathbf{V}_{bn} + \mathbf{V}_{cn} = 0$$

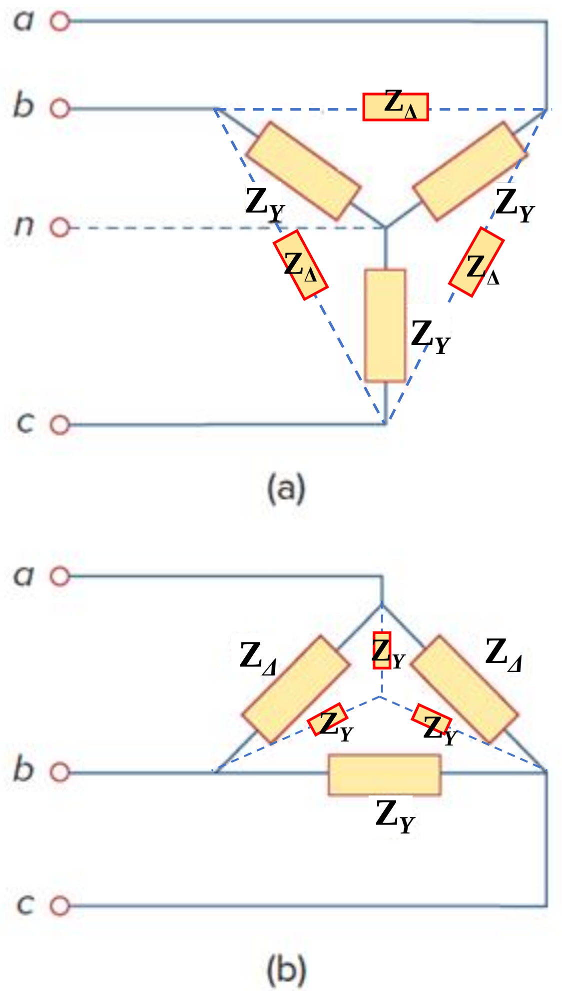
$$|\mathbf{V}_{an}| = |\mathbf{V}_{bn}| = |\mathbf{V}_{cn}|$$

Balanced phase voltages are equal in magnitude and are out of phase with each other by 120°.

$$\begin{aligned}\mathbf{V}_{an} + \mathbf{V}_{bn} + \mathbf{V}_{cn} &= V_p\underline{/0^\circ} + V_p\underline{/-120^\circ} + V_p\underline{/+120^\circ} \\ &= V_p(1.0 - 0.5 - j0.866 - 0.5 + j0.866) \\ &= 0\end{aligned}$$

12.2 Balance Three-Phase Voltages

- A wye- or delta-connected load is said to be unbalanced if the phase impedances are not equal in magnitude or phase.



Two possible three-phase load configurations:
(a) a Y-connected load,(b) a Δ-connected load.

For a *balanced* wye-connected load,

$$\mathbf{Z}_1 = \mathbf{Z}_2 = \mathbf{Z}_3 = \mathbf{Z}_Y$$

where $\mathbf{Z}_Y$ is the load impedance per phase.

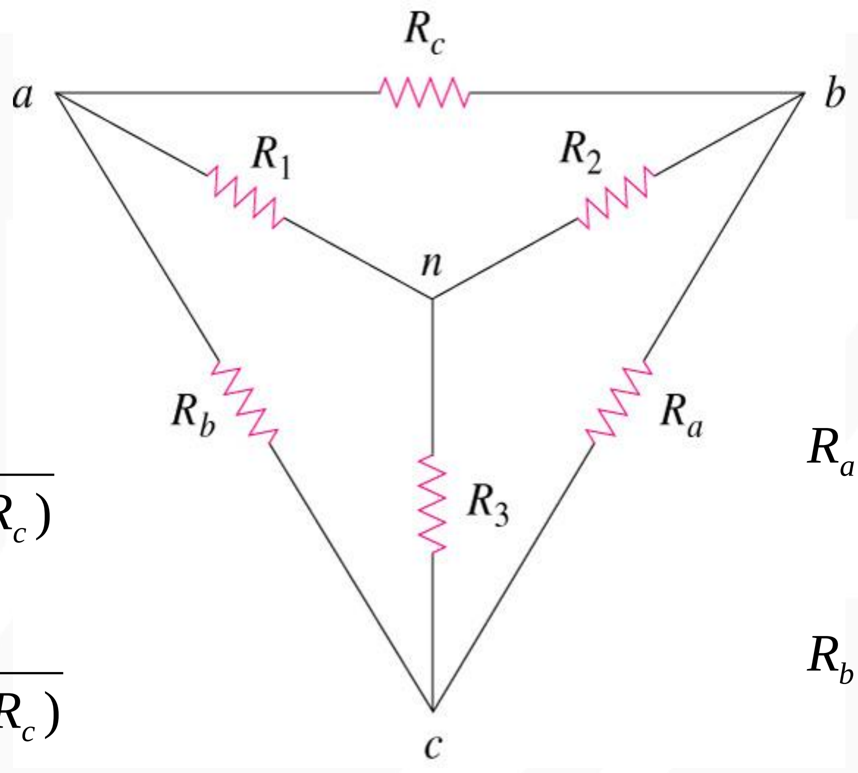
For a *balanced* delta-connected load,

$$\mathbf{Z}_a = \mathbf{Z}_b = \mathbf{Z}_c = \mathbf{Z}_\Delta$$

where $\mathbf{Z}_\Delta$ is the load impedance per phase.

$$\mathbf{Z}_\Delta = 3\mathbf{Z}_Y \qquad \text{or} \qquad \mathbf{Z}_Y = \frac{1}{3}\mathbf{Z}_\Delta$$

12.2 Balance Three-Phase Voltages
(Wye-Delta Transformations)



Delta →Star

$$R_1 = \frac{R_b R_c}{(R_a + R_b + R_c)}$$

$$R_2 = \frac{R_c R_a}{(R_a + R_b + R_c)}$$

$$R_3 = \frac{R_a R_b}{(R_a + R_b + R_c)}$$

Star → Delta

$$R_a = \frac{R_1 R_2 + R_2 R_3 + R_3 R_1}{R_1}$$

$$R_b = \frac{R_1 R_2 + R_2 R_3 + R_3 R_1}{R_2}$$

$$R_c = \frac{R_1 R_2 + R_2 R_3 + R_3 R_1}{R_3}$$

12.2 Balance Three-Phase Voltages

- Balanced phase voltages are equal in magnitude and are out of phase with each other by 120°.

- The phase sequence is the time order in which the voltages pass through their respective maximum values.

- A balanced load is one in which the phase impedances are equal in magnitude and in phase

12.2 Balance Three-Phase Voltages

Ex.1 Determine the phase sequence of the set of voltages.

$$v_{an} = 200\cos(\omega t + 10^\circ)$$
$$v_{bn} = 200\cos(\omega t - 230^\circ)$$
$$v_{cn} = 200\cos(\omega t - 110^\circ)$$

Solution:

The voltages can be expressed in phasor form as

$$\mathrm{V}_{an} = 200\angle 10^\circ \text{ V}$$
$$\mathrm{V}_{bn} = 200\angle -230^\circ \text{ V}$$
$$\mathrm{V}_{cn} = 200\angle -110^\circ \text{ V}$$

We notice that V_{an} leads V_{cn} by 120° and V_{cn} in turn leads V_{bn} by 120°. Hence, we have an *acb* sequence.

12.2 Balance Three-Phase Voltages

Ex.1.2 Given that $V_{bn} = 110\angle 30^\circ$ V, find V_{an} and V_{cn}, assuming a positive (*abc*) sequence.

Answer: $110\angle 150^\circ$ V, $110\angle -90^\circ$ V.

12.3 Balance Three-Phase Connection

Four possible connections

1. Y-Y connection (Y-connected source with a Y-connected load)
2. Y-Δ connection (Y-connected source with a Δ-connected load)
3. Δ-Δ connection
4. Δ-Y connection

12.3 Balance Three-Phase Connection

A balanced Y-Y system is a three-phase system with a balanced y-connected source and a balanced y-connected load.

V_L = *line-to-line* voltages (V_{ab} , V_{bc} , V_{ca})

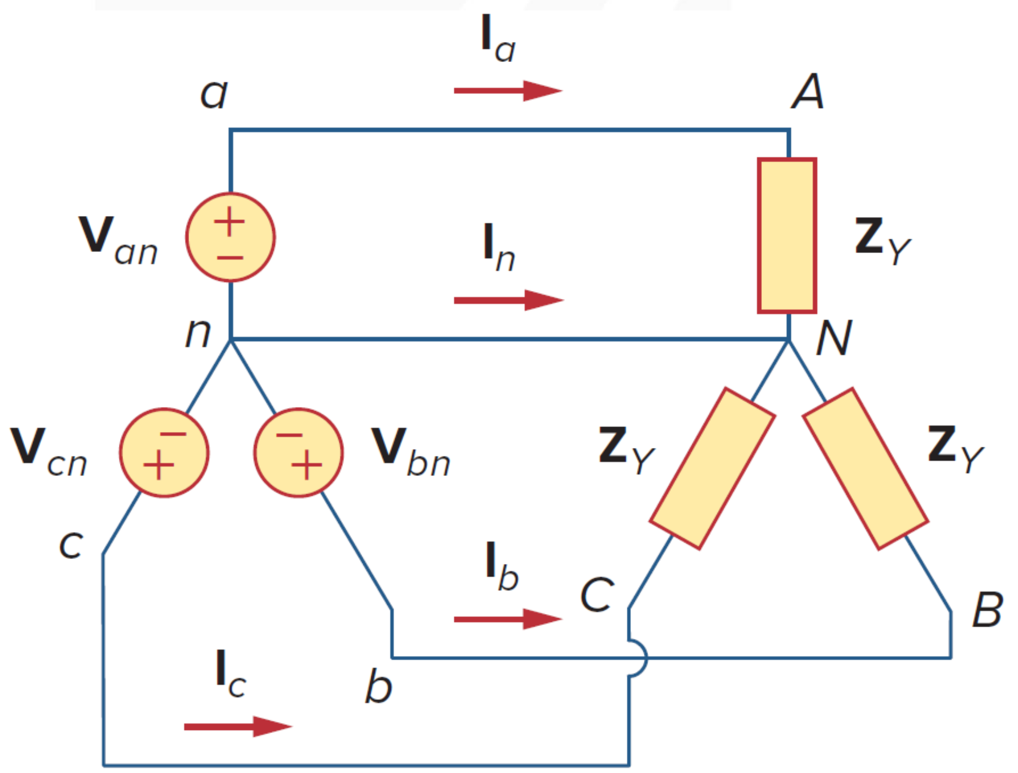
$$\mathbf{V}_{ab} = \mathbf{V}_{an} + \mathbf{V}_{nb} = \mathbf{V}_{an} - \mathbf{V}_{bn}$$
$$= V_p\underline{/0^\circ} - V_p\underline{/-120^\circ}$$
$$= V_p\left(1 + \frac{1}{2} + j\frac{\sqrt{3}}{2}\right) = \sqrt{3}V_p\underline{/30^\circ}$$

Similarly, we can obtain

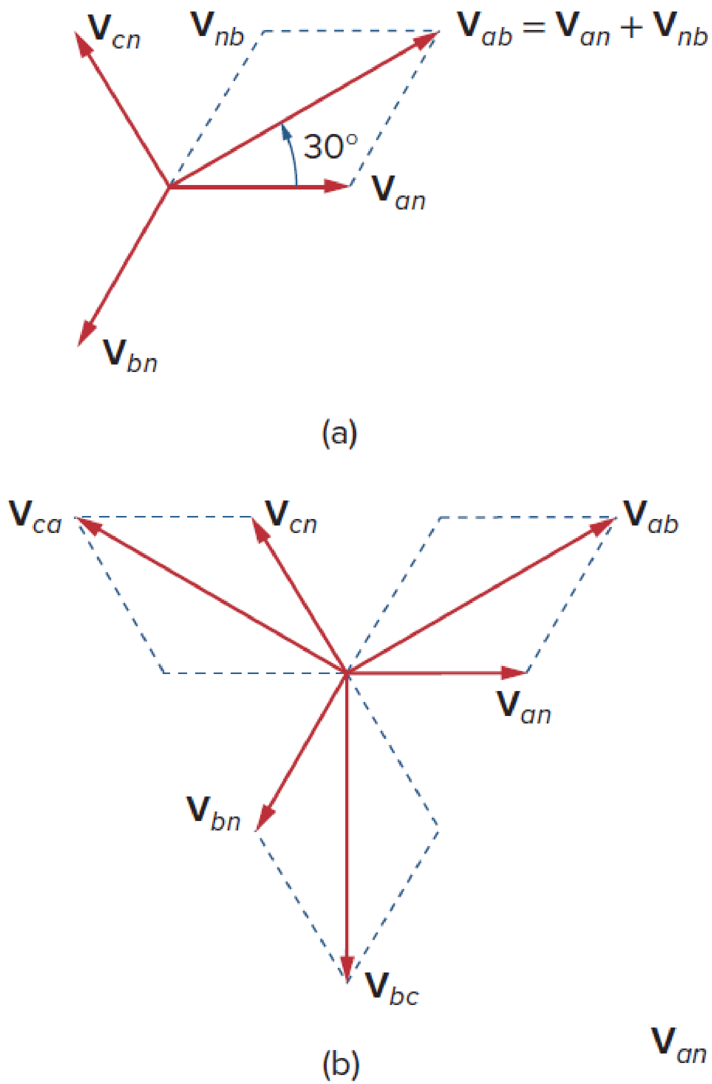
$$\mathbf{V}_{bc} = \mathbf{V}_{bn} - \mathbf{V}_{cn} = \sqrt{3}V_p\underline{/-90^\circ}$$
$$\mathbf{V}_{ca} = \mathbf{V}_{cn} - \mathbf{V}_{an} = \sqrt{3}V_p\underline{/-210^\circ}$$

$V_L = \sqrt{3}V_p$, where

$$V_p = |\mathrm{V}_{an}| = |\mathrm{V}_{bn}| = |\mathrm{V}_{cn}|$$
$$V_L = |\mathrm{V}_{ab}| = |\mathrm{V}_{bc}| = |\mathrm{V}_{ca}|$$



12.3 Balance Three-Phase Connection



Phasor diagrams illustrating the relationship between line voltages&phase voltages.

Applying KVL to each phase in Fig. 12.10, we obtain the line currents as

$$\mathbf{I}_a = \frac{\mathbf{V}_{an}}{\mathbf{Z}_Y}, \qquad \mathbf{I}_b = \frac{\mathbf{V}_{bn}}{\mathbf{Z}_Y} = \frac{\mathbf{V}_{an}\underline{/-120^\circ}}{\mathbf{Z}_Y} = \mathbf{I}_a\underline{/-120^\circ}$$

$$\mathbf{I}_c = \frac{\mathbf{V}_{cn}}{\mathbf{Z}_Y} = \frac{\mathbf{V}_{an}\underline{/-240^\circ}}{\mathbf{Z}_Y} = \mathbf{I}_a\underline{/-240^\circ}$$

We can readily infer that the line currents add up to zero,

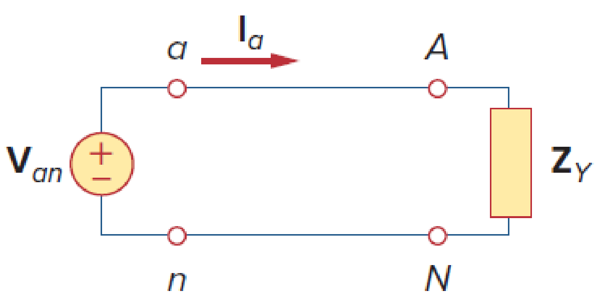
$$\mathbf{I}_a + \mathbf{I}_b + \mathbf{I}_c = 0$$

so that

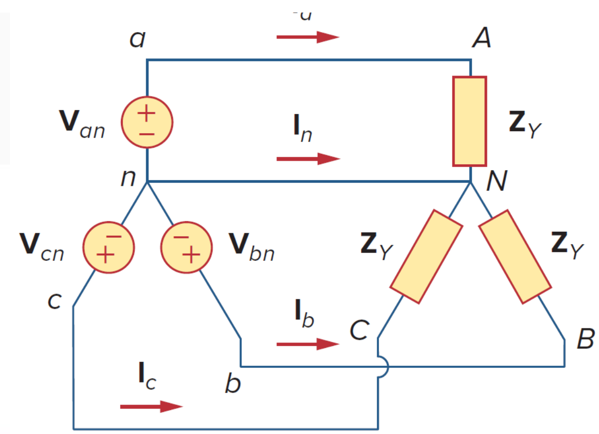
$$\mathbf{I}_n = -(\mathbf{I}_a + \mathbf{I}_b + \mathbf{I}_c) = 0$$

or

$$\mathbf{V}_{nN} = \mathbf{Z}_n\mathbf{I}_n = 0$$



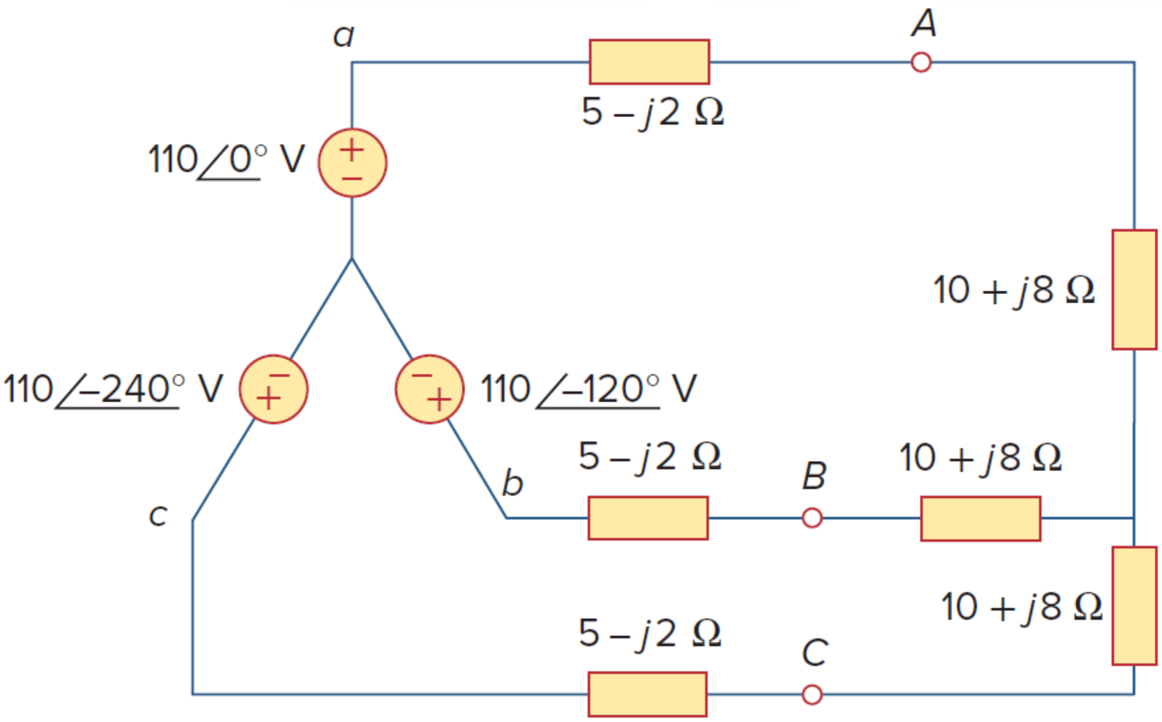
A single-phase equivalent circuit.



12.3 Balance Three-Phase Connection

Ex.2

Calculate the line currents in the three-wire Y-Y system shown below:



Ans

$$I_a = 6.81\angle -21.8° \text{ A}$$

$$I_b = 6.81\angle -141.8° \text{ A}$$

$$I_c = 6.81\angle 98.2° \text{ A}$$

*Refer to in-class illustration, textbook

12.3 Balance Three-Phase Connection

Solution

We obtain $\mathbf{I}_a$ from the single-phase analysis as

$$\mathbf{I}_a = \frac{\mathbf{V}_{an}}{\mathbf{Z}_Y}$$

where $\mathbf{Z}_Y = (5 - j2) + (10 + j8) = 15 + j6 = 16.155\underline{/21.8^\circ}$. Hence,

$$\mathbf{I}_a = \frac{110\underline{/0^\circ}}{16.155\underline{/21.8^\circ}} = 6.81\underline{/-21.8^\circ}\text{ A}$$

In as much as the source voltages in Fig. 12.13 are in positive sequence, the line currents are also in positive sequence:

$$\mathbf{I}_b = \mathbf{I}_a\underline{/-120^\circ} = 6.81\underline{/-141.8^\circ}\text{ A}$$

$$\mathbf{I}_c = \mathbf{I}_a\underline{/-240^\circ} = 6.81\underline{/-261.8^\circ}\text{ A} = 6.81\underline{/98.2^\circ}\text{ A}$$

*Refer to in-class illustration, textbook

12.3 Balance Three-Phase Connection

A balanced Y-Δ system is a three-phase system with a balanced y-connected source and a balanced Δ-connected load.

Assuming the positive sequence, the phase voltages are

$$\mathbf{V}_{an} = V_p\angle 0^\circ$$

$$\mathbf{V}_{bn} = V_p\angle -120^\circ$$

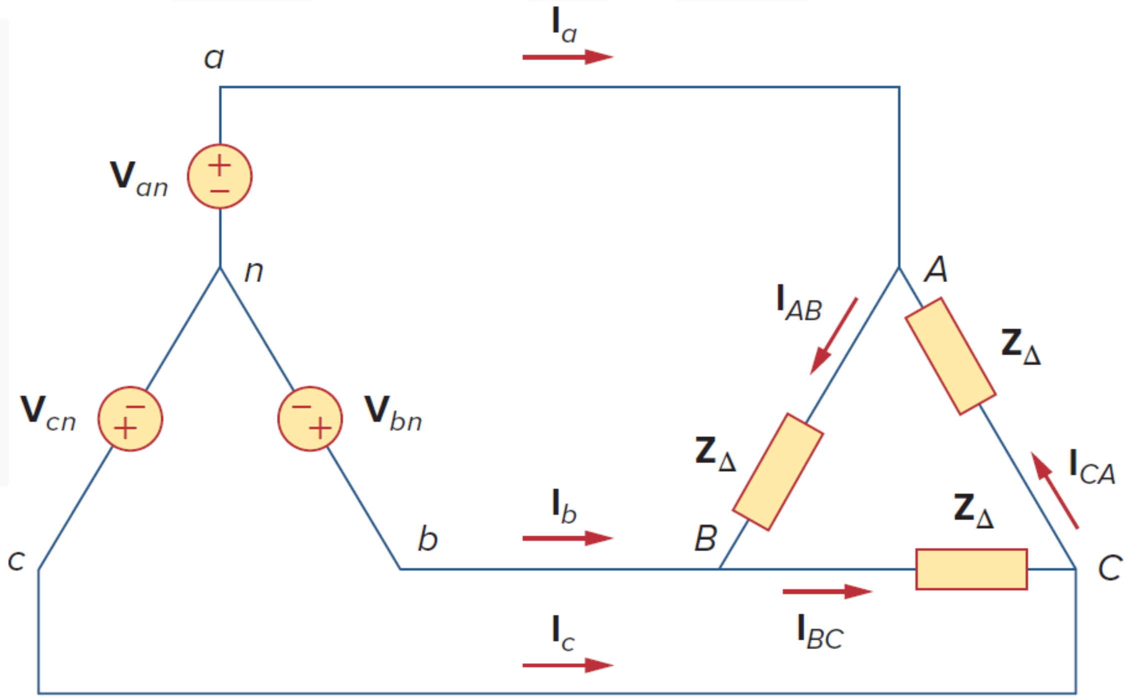
$$\mathbf{V}_{cn} = V_p\angle +120^\circ$$

The line voltages are

$$\mathbf{V}_{ab} = \sqrt{3}V_p\angle 30^\circ = \mathbf{V}_{AB}$$

$$\mathbf{V}_{bc} = \sqrt{3}V_p\angle -90^\circ = \mathbf{V}_{BC}$$

$$\mathbf{V}_{ca} = \sqrt{3}V_p\angle 150^\circ = \mathbf{V}_{CA}$$

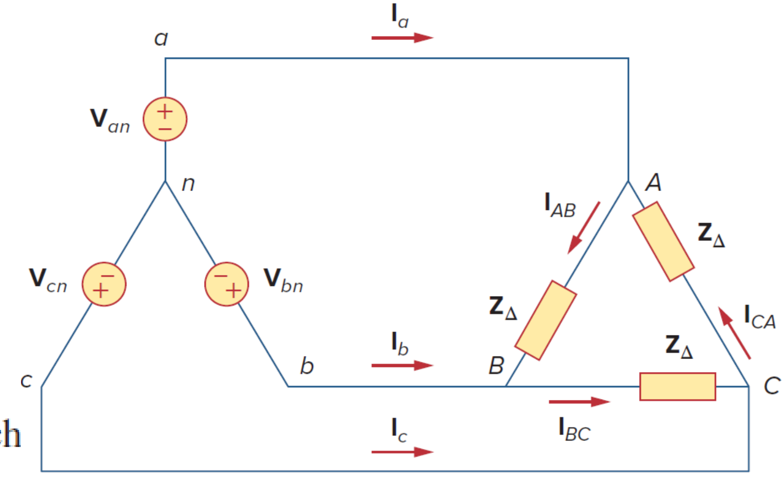


$I_L = \sqrt{3}I_p$, where

$$I_L = |\mathbf{I}_a| = |\mathbf{I}_b| = |\mathbf{I}_c|$$

$$I_p = |\mathbf{I}_{AB}| = |\mathbf{I}_{BC}| = |\mathbf{I}_{CA}|$$

12.3 Balance Three-Phase Connection



From these voltages, we can obtain the phase currents as

$$\mathbf{I}_{AB} = \frac{\mathbf{V}_{AB}}{\mathbf{Z}_\Delta}, \qquad \mathbf{I}_{BC} = \frac{\mathbf{V}_{BC}}{\mathbf{Z}_\Delta}, \qquad \mathbf{I}_{CA} = \frac{\mathbf{V}_{CA}}{\mathbf{Z}_\Delta}$$

These currents have the same magnitude but are out of phase with each other by 120° by applying KVL around loop *aABbna* gives

$$-\mathbf{V}_{an} + \mathbf{Z}_\Delta \mathbf{I}_{AB} + \mathbf{V}_{bn} = 0 \quad \text{or} \quad \mathbf{I}_{AB} = \frac{\mathbf{V}_{an} - \mathbf{V}_{bn}}{\mathbf{Z}_\Delta} = \frac{\mathbf{V}_{ab}}{\mathbf{Z}_\Delta} = \frac{\mathbf{V}_{AB}}{\mathbf{Z}_\Delta}$$

The line currents are obtained from the phase currents by applying KCL at nodes *A*, *B*, and *C*. Thus,

$$\mathbf{I}_a = \mathbf{I}_{AB} - \mathbf{I}_{CA}, \qquad \mathbf{I}_b = \mathbf{I}_{BC} - \mathbf{I}_{AB}, \qquad \mathbf{I}_c = \mathbf{I}_{CA} - \mathbf{I}_{BC}$$

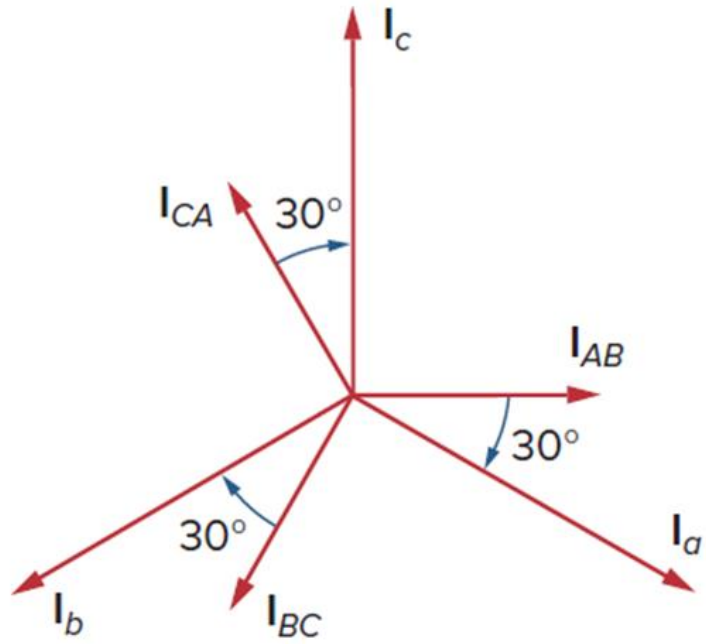
Since $\mathbf{I}_{CA} = \mathbf{I}_{AB}\underline{/-240^\circ}$,

$$\mathbf{I}_a = \mathbf{I}_{AB} - \mathbf{I}_{CA} = \mathbf{I}_{AB}(1 - 1\underline{/-240^\circ}) = \mathbf{I}_{AB}(1 + 0.5 - j0.866) = \mathbf{I}_{AB}\sqrt{3}\underline{/-30^\circ}$$

showing that the magnitude I_L of the line current is $\sqrt{3}$ times the magnitude I_p of the phase current

$$\boxed{I_L = \sqrt{3} I_p}$$

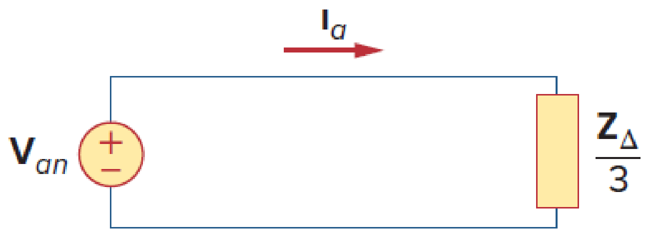
12.3 Balance Three-Phase Connection



Phasor diagram illustrating the relationship between phase and line currents.

An alternative way of analyzing the Y-Δ circuit is to transform the Δ-connected load to an equivalent Y-connected load. Using the Δ-Y transformation formula in Eq. (12.8),

$$\boxed{\mathbf{Z}_Y = \frac{\mathbf{Z}_\Delta}{3}}$$



A single-phase equivalent circuit of a balanced Y-Δ circuit.

12.3 Balance Three-Phase Connection

Example 3

A balanced abc-sequence Y-connected source with ($\mathbf{V_{an}} = \mathbf{100\angle 10°}$) is connected to a Δ-connected load (8+j4) Ω per phase. Calculate the phase and line currents.

Solution

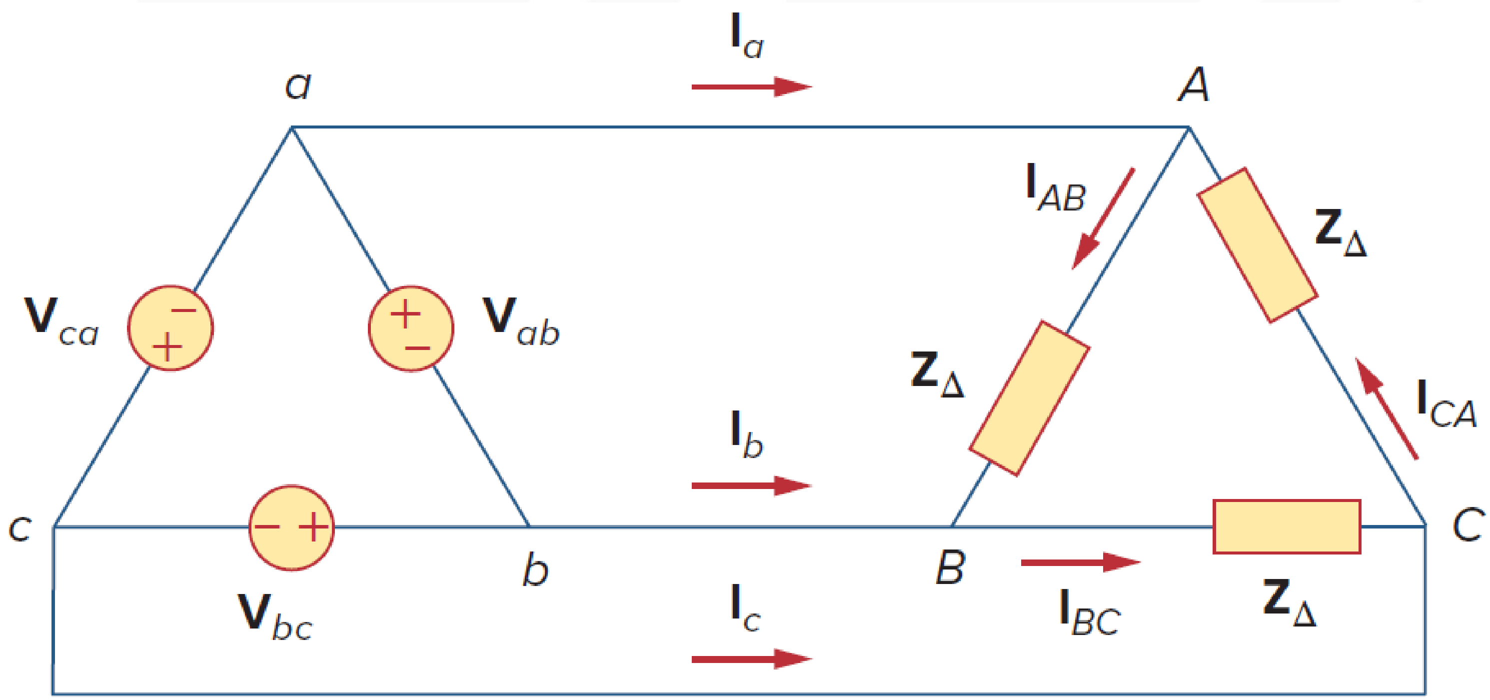
Using single-phase analysis,

$$\mathrm{I}_a = \frac{\mathrm{V_{an}}}{\mathrm{Z}_\Delta / 3} = \frac{100\angle 10°}{2.981\angle 26.57°} = 33.54\angle -16.57°\ \mathrm{A}$$

Other line currents are obtained using the abc phase sequence

12.3 Balance Three-Phase Connection

A balanced Δ-Δ system is a three-phase system with a balanced Δ -connected source and a balanced Δ -connected load.



12.3 Balance Three-Phase Connection

Assuming a positive sequence, the phase voltages for a delta-connected source are

$$\mathbf{V}_{ab} = V_p\angle 0^\circ$$
$$\mathbf{V}_{bc} = V_p\angle -120^\circ$$
$$\mathbf{V}_{ca} = V_p\angle +120^\circ$$

The line voltages are the same as the phase voltages. From Fig. 12.17, assuming there is no line impedances, the phase voltages of the delta-connected source are equal to the voltages across the impedances; that is,

$$\mathbf{V}_{ab} = \mathbf{V}_{AB}, \qquad \mathbf{V}_{bc} = \mathbf{V}_{BC}, \qquad \mathbf{V}_{ca} = \mathbf{V}_{CA}$$

Hence, the phase currents are

$$\mathbf{I}_{AB} = \frac{\mathbf{V}_{AB}}{Z_\Delta} = \frac{\mathbf{V}_{ab}}{Z_\Delta}, \qquad \mathbf{I}_{BC} = \frac{\mathbf{V}_{BC}}{Z_\Delta} = \frac{\mathbf{V}_{bc}}{Z_\Delta}$$
$$\mathbf{I}_{CA} = \frac{\mathbf{V}_{CA}}{Z_\Delta} = \frac{\mathbf{V}_{ca}}{Z_\Delta}$$

12.3 Balance Three-Phase Connection

Because the load is delta-connected just as in the previous section, some of the formulas derived there apply here. The line currents are obtained from the phase currents by applying KCL at nodes A, B, and C, as we did in the previous section:

$$\mathbf{I}_a = \mathbf{I}_{AB} - \mathbf{I}_{CA}, \qquad \mathbf{I}_b = \mathbf{I}_{BC} - \mathbf{I}_{AB}, \qquad \mathbf{I}_c = \mathbf{I}_{CA} - \mathbf{I}_{BC}$$

Also, as shown in the last section, each line current lags the corresponding phase current by 30°; the magnitude I_L of the line current is $\sqrt{3}$ times the magnitude I_p of the phase current,

$$I_L = \sqrt{3} I_p$$

An alternative way of analyzing the Δ-Δ circuit is to convert both the source and the load to their Y equivalents. We already know that $\mathbf{Z}_Y = \mathbf{Z}_\Delta/3$. To convert a Δ-connected source to a Y-connected source, see the next section.

12.3 Balance Three-Phase Connection

Example 4

A balanced Δ-connected load having an impedance 20-j15 Ω is connected to a Δ-connected positive-sequence generator having ($\mathbf{V_{ab}} = \mathbf{330\angle 0°}$ V). Calculate the phase currents of the load and the line currents.

Ans:

The phase currents

$$\mathrm{I}_{AB} = 13.2\angle 36.87°\ \mathrm{A};\ \mathrm{I}_{BC} = 13.2\angle -81.13°\ \mathrm{A};\ \mathrm{I}_{AB} = 13.2\angle 156.87°\ \mathrm{A}$$

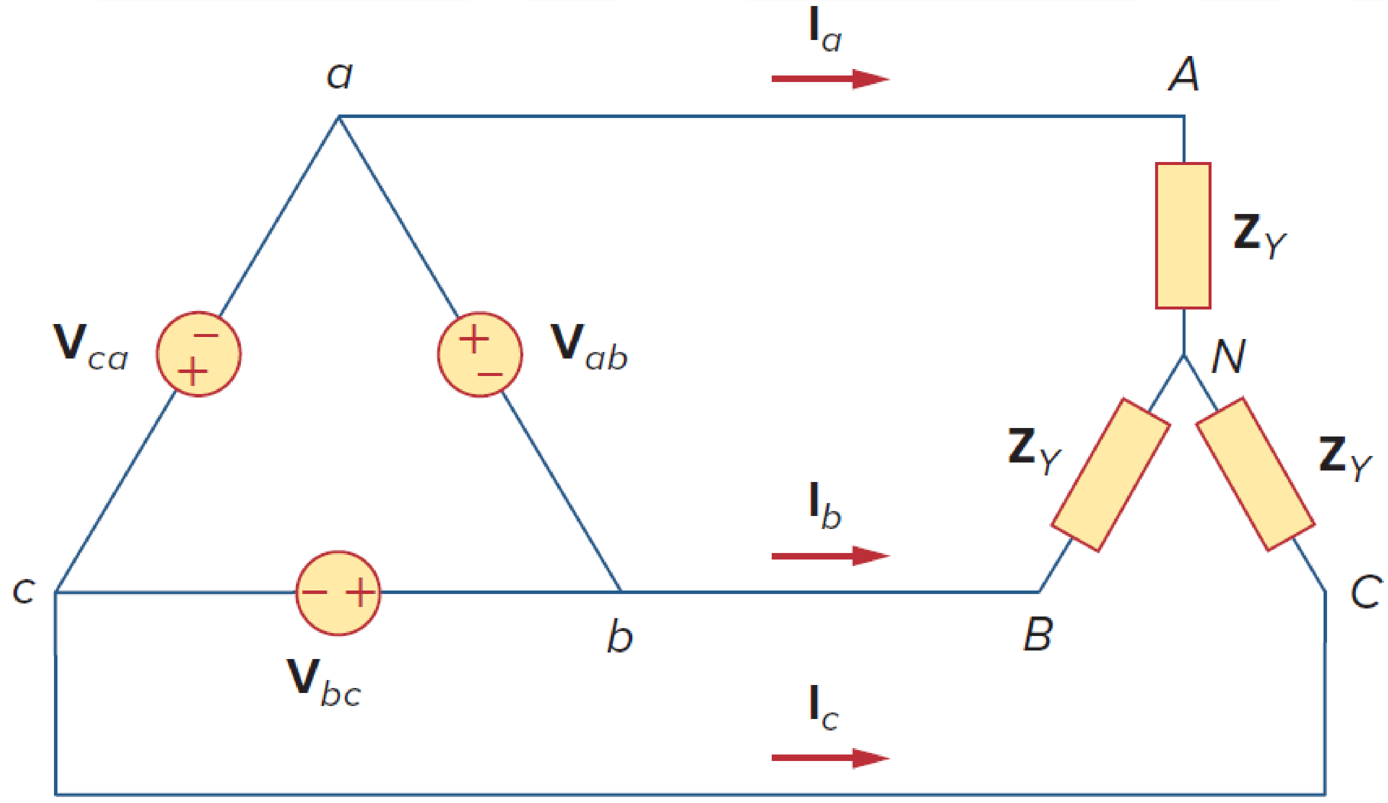
The line currents

$$\mathrm{I}_a = 22.86\angle 6.87°\ \mathrm{A};\ \mathrm{I}_b = 22.86\angle -113.13°\ \mathrm{A};\ \mathrm{I}_c = 22.86\angle 126.87°\ \mathrm{A}$$

*Refer to in-class illustration, textbook

12.3 Balance Three-Phase Connection

A balanced Δ-Y system is a three-phase system with a balanced y-connected source and a balanced y-connected load.



12.3 Balance Three-Phase Connection

Consider the Δ-Y circuit in Fig. 12.18. Again, assuming the *abc* sequence, the phase voltages of a delta-connected source are

$$\mathbf{V}_{ab} = V_p\underline{/0^\circ}, \qquad \mathbf{V}_{bc} = V_p\underline{/-120^\circ}$$
$$\mathbf{V}_{ca} = V_p\underline{/+120^\circ}$$

These are also the line voltages as well as the phase voltages.

We can obtain the line currents in man y ways. One way is to apply KVL to loop *aANBba* in Fig. 12.18, writing

$$-\mathbf{V}_{ab} + \mathbf{Z}_Y\mathbf{I}_a - \mathbf{Z}_Y\mathbf{I}_b = 0$$

or

$$\mathbf{Z}_Y(\mathbf{I}_a - \mathbf{I}_b) = \mathbf{V}_{ab} = V_p\underline{/0^\circ}$$

Thus,

$$\mathbf{I}_a - \mathbf{I}_b = \frac{V_p\underline{/0^\circ}}{\mathbf{Z}_Y}$$

12.3 Balance Three-Phase Connection

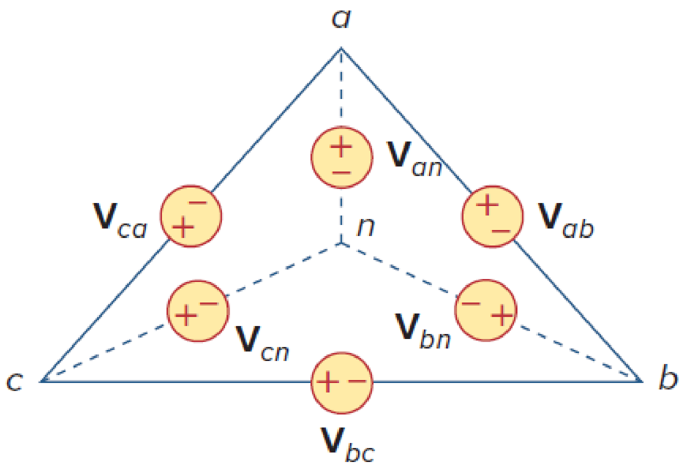
But $\mathbf{I}_b$ lags $\mathbf{I}_a$ by 120°, since we assumed the *abc* sequence; that is, $\mathbf{I}_b = \mathbf{I}_a \angle -120°$. Hence,

$$\mathbf{I}_a - \mathbf{I}_b = \mathbf{I}_a(1 - 1\angle -120°)$$

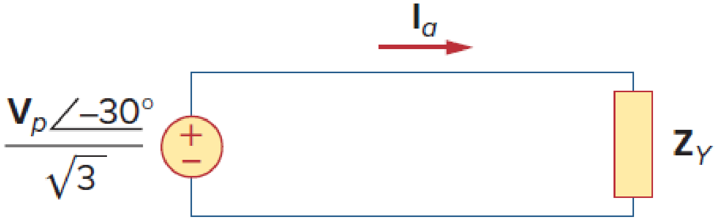
$$= \mathbf{I}_a\left(1 + \frac{1}{2} + j\frac{\sqrt{3}}{2}\right) = \mathbf{I}_a\sqrt{3}\angle 30°$$

Substituting Eq. (12.36) into Eq. (12.35) gives

$$\mathbf{I}_a = \frac{V_p/\sqrt{3}\angle -30°}{\mathbf{Z}_Y}$$



Transforming a Δ-connected source to an equivalent Y-connected source.



The single-phase equivalent circuit.

12.3 Balance Three-Phase Connection

Ex.5 A balanced Y-connected load with a phase impedance 40+j25 Ω is supplied by a balanced, positive-sequence Δ-connected source with a line voltage of 210V. Calculate the phase currents. Use V_{ab} as reference.

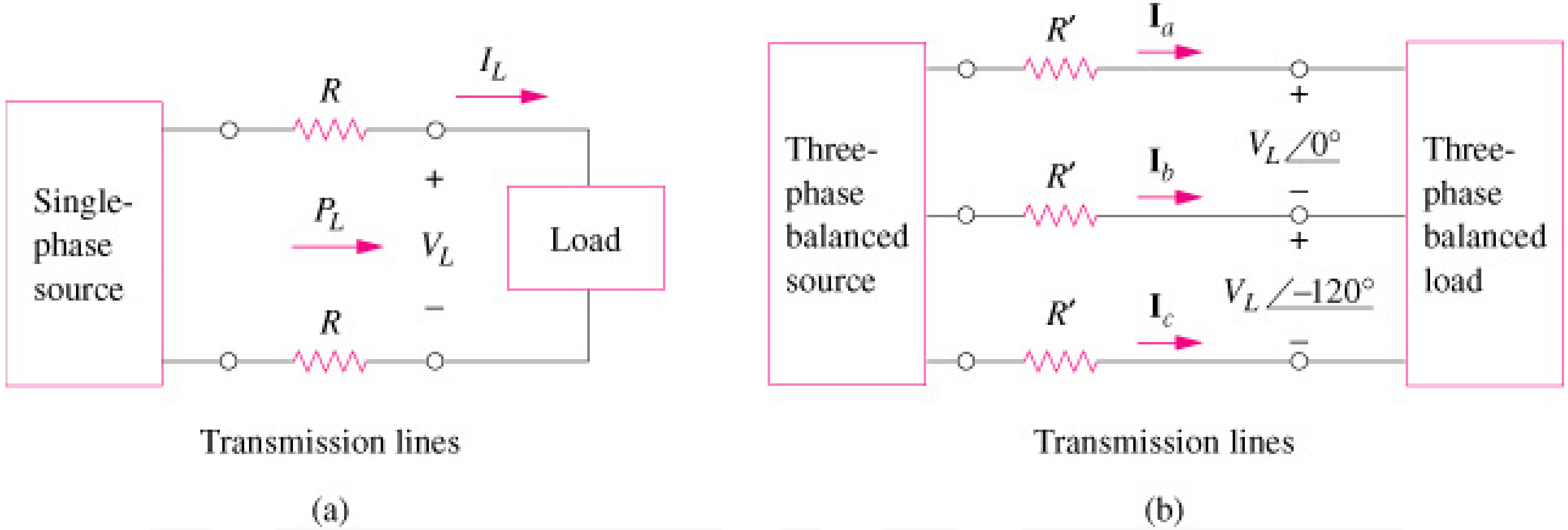
Answer

The phase currents

$$I_{AN} = 2.57\angle -62^\circ \text{ A};$$
$$I_{BN} = 2.57\angle -178^\circ \text{ A};$$
$$I_{CN} = 2.57\angle 58^\circ \text{ A};$$

12.4 Power in a Balanced System

Comparing the power loss in (a) a single-phase system, and (b) a three-phase system



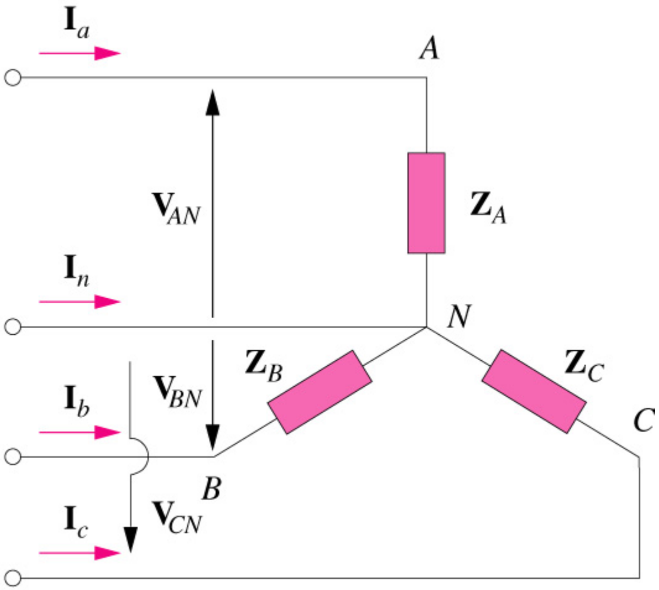
$$P'_{loss} = 2R\frac{P_L^2}{V_L^2}, \text{single-phase}$$

$$P'_{loss} = R'\frac{P_L^2}{V_L^2}, \text{three-phase}$$

If same power loss is tolerated in both system, three-phase system use only 75% of materials of a single-phase system

12.5 Unbalanced Three-Phase Systems

An unbalanced system is due to unbalanced voltage sources or an unbalanced load.



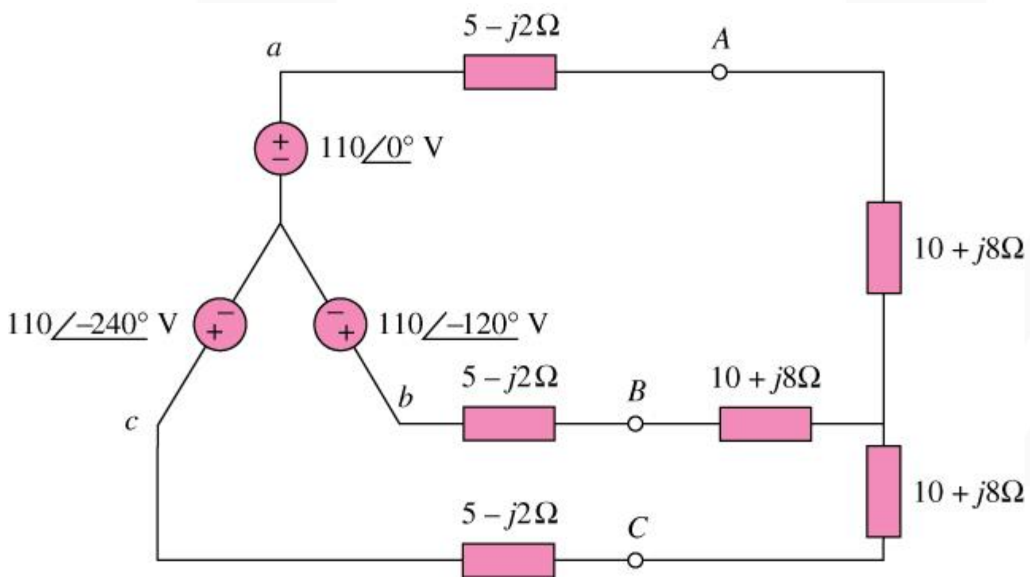
$$I_a = \frac{V_{AN}}{Z_A},\ I_b = \frac{V_{BN}}{Z_B},\ I_c = \frac{V_{CN}}{Z_C},$$

$$I_n = -(I_a + I_b + I_{c)}$$

- To calculate power in an unbalanced three-phase system requires that we find the power in each phase.
- The total power is not simply three times the power in one phase but the sum of the powers in the three phases.

12.5 Unbalanced Three-Phase Systems

Ex.6 Determine the total average power, reactive power, and complex power at the source and at the load



Ans

At the source:

S_s = -(2087 + j834.6) VA

P_a = -2087W

P_r = -834.6VAR

At the load:

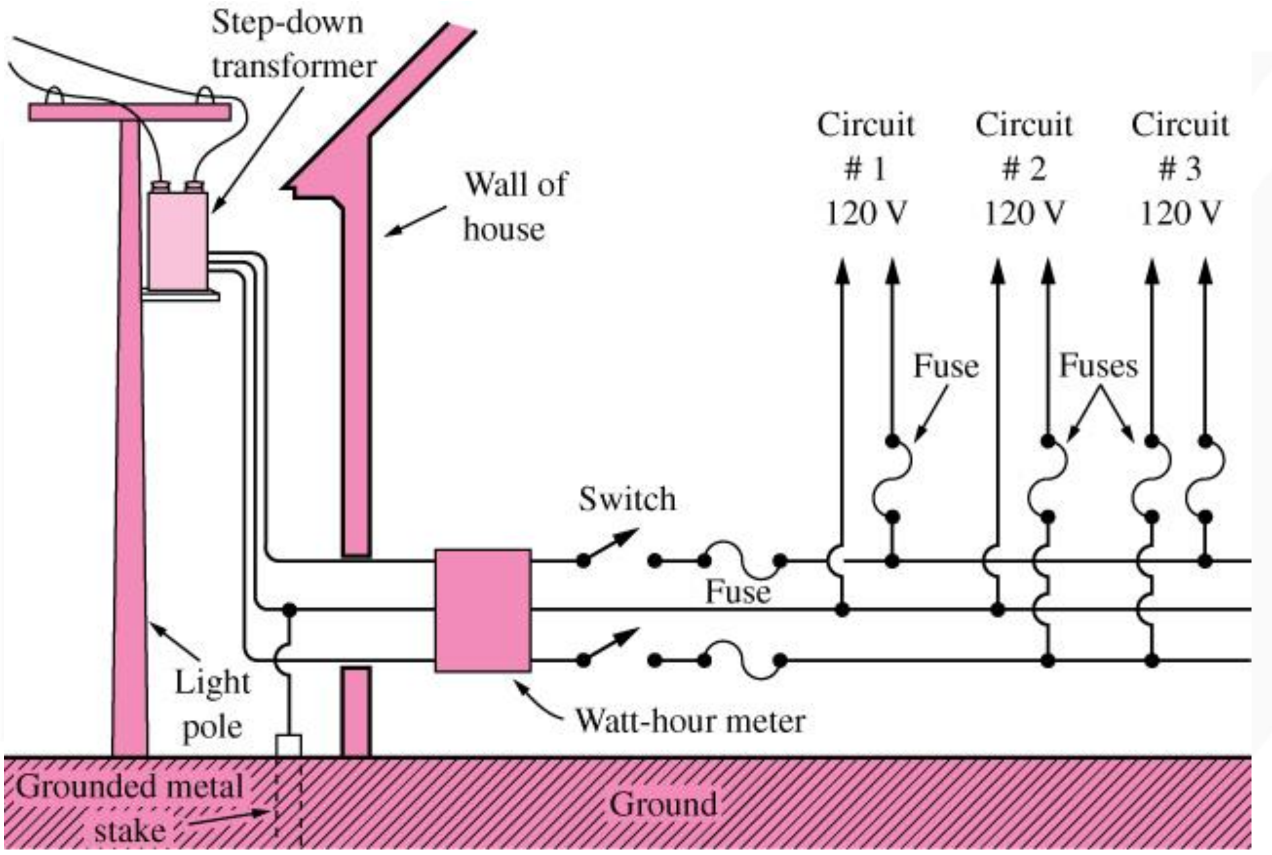
S_L = (1392 + j1113) VA

P_a = 1392W

P_r = 1113VAR

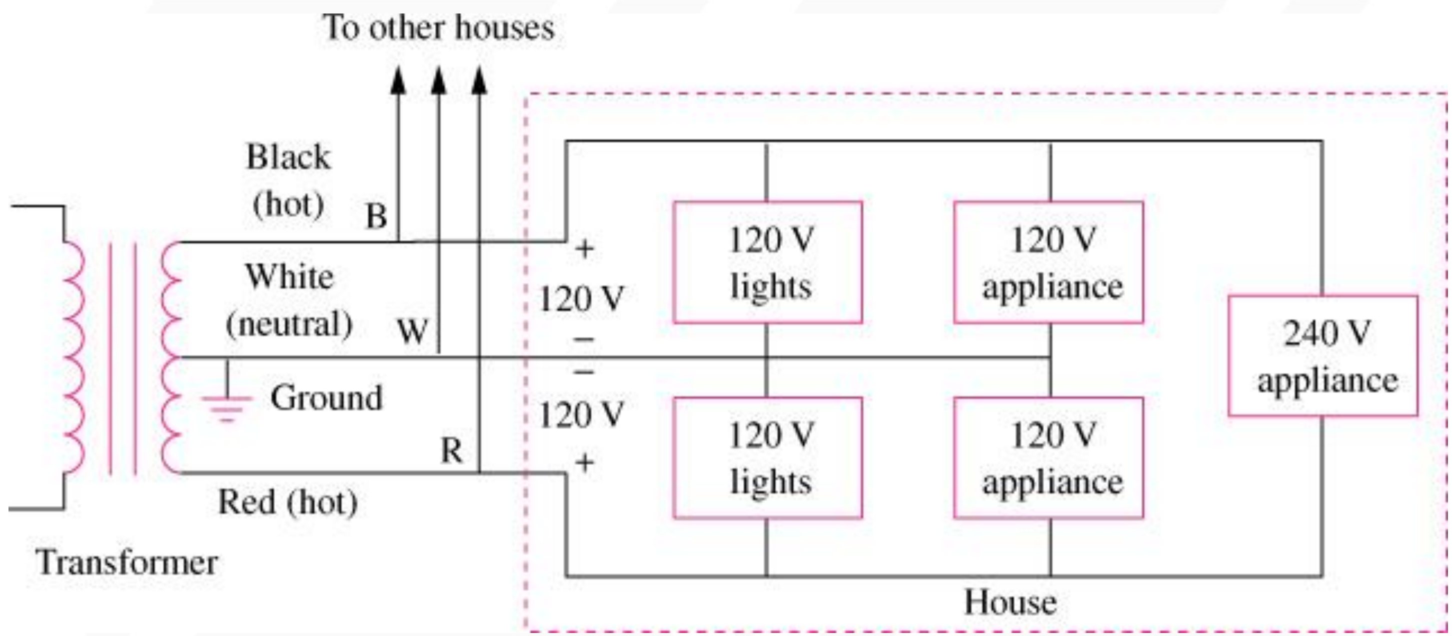
*Refer to in-class illustration, textbook

12.6 Application Residential Wiring



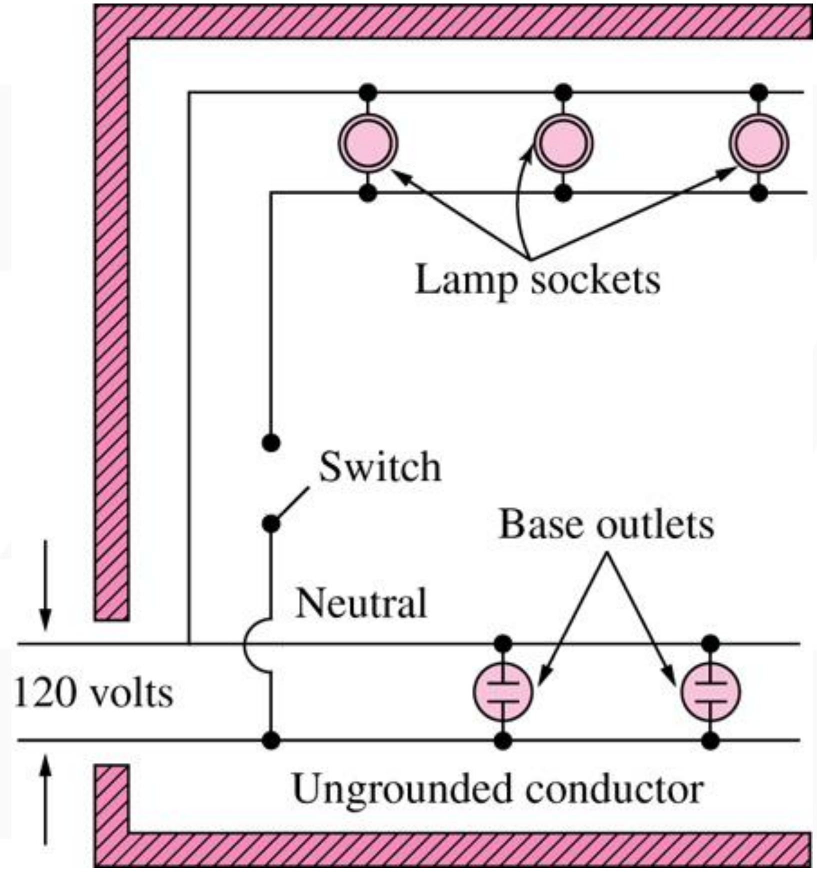
A 120/240 household power system

12.6 Application Residential Wiring



Single-phase three-wire residential wiring

12.6 Application Residential Wiring



A typical wiring diagram of a room