EE2003
Circuit Theory

Chapter 12
Three-Phase Circuit

MARATHON ELECTRIC
Mtr, 3 Ph, 1/2hp, 1725, 208-230/460, Eff 76.1

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General Purpose Motor, 3-Phase, 1/2 HP, Nameplate RPM 1725, Voltage 208-230/460, 56C Frame, Totally Enclosed Fan-Cooled, Number of Speeds 1, Full Load Amps 2.1-2.2/1.1, 60/50 Hz, Face Mounting, Thermal Protection None, Insulation Class B, Service Factor 1.25Max. Ambient Temp. 40 Degrees C, Rotation CW/CCW, Overall Length 10-15/16 In., Shaft Dia. 5/8 In., Shaft Length 1-7/8 In.

Grainger Item #	3N687
Price (ea.)	**$273.75**
Brand	MARATHON ELECTRIC
Mfr. Model #	5K35MNB114A
UNSPSC #	26101612
Ship Qty.	1
Sell Qty. (Will-Call)	1
Ship Weight (lbs.)	18.4
Availability	**Typically in Stock**
Catalog Page No.	18
Country of Origin (Country of Origin is subject to change.)	Mexico

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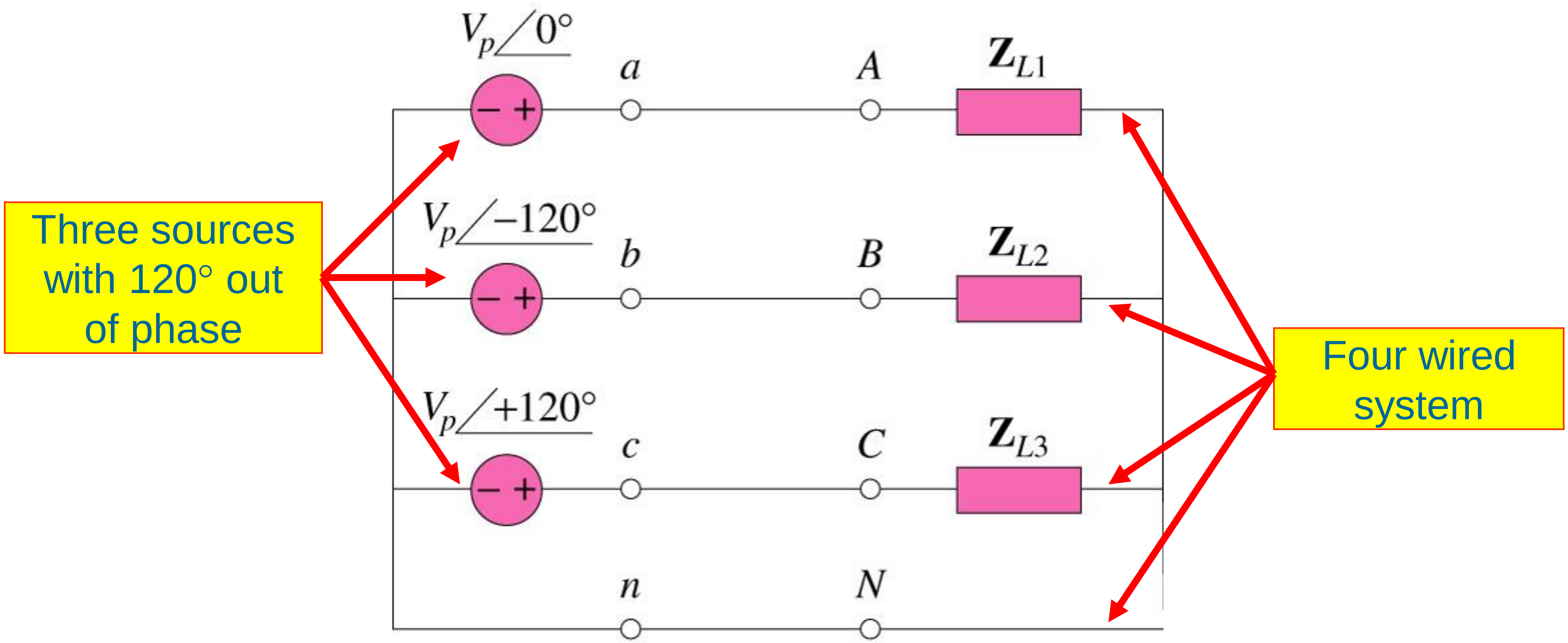
Qty.

Three-Phase Circuits
Chapter 12

12.1 What is a Three-Phase Circuit?(1)

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



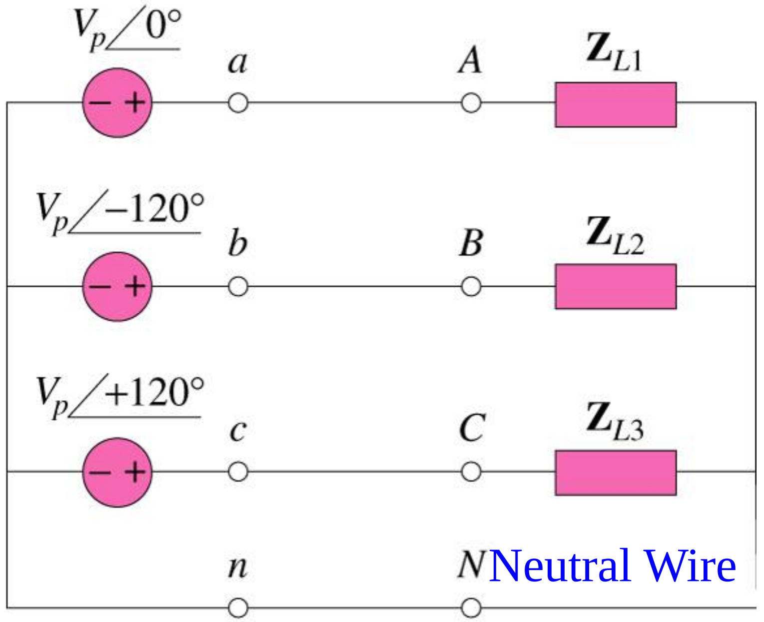
12.1 What is a Three-Phase Circuit?(2)

Advantages:

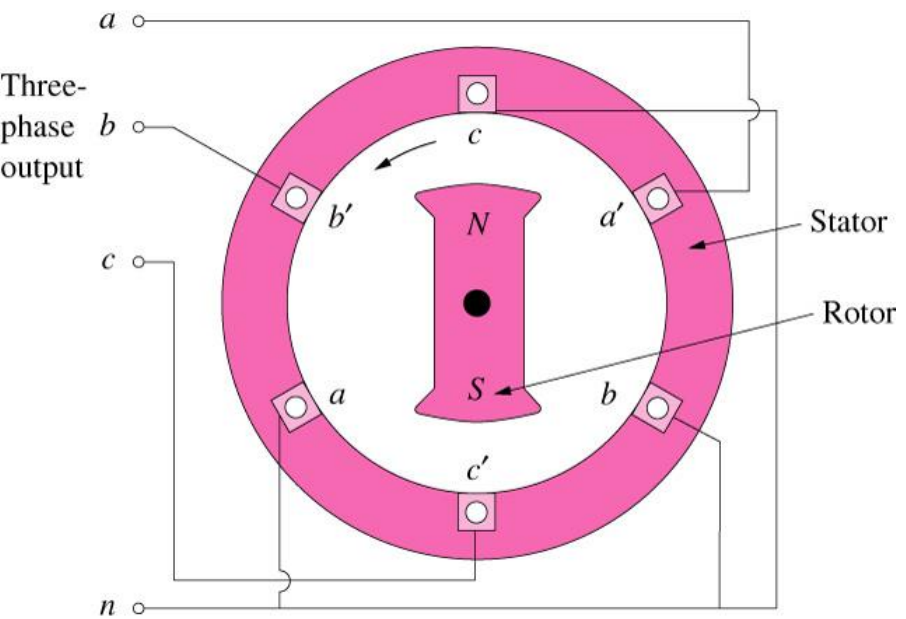
1. Most electric power is generated and distributed in three-phase.
2. The instantaneous power in a three-phase system can be constant.
3. Given the same amount of power, a three-phase system is more economical than single-phase.
4. In fact, the amount of wire required for a three-phase system is less than that required for an equivalent single-phase system.

Balanced Three-phase Voltages

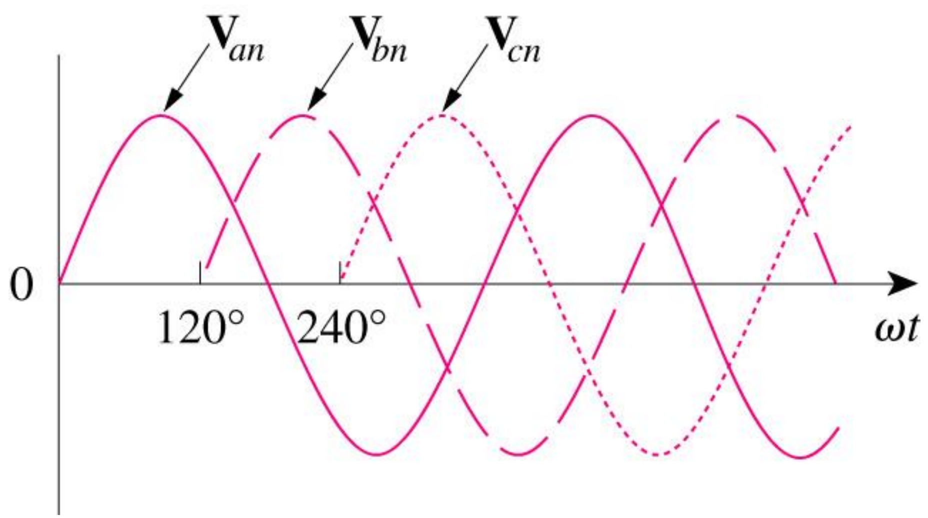
Three-phase four-wire system



A Three-phase Generator

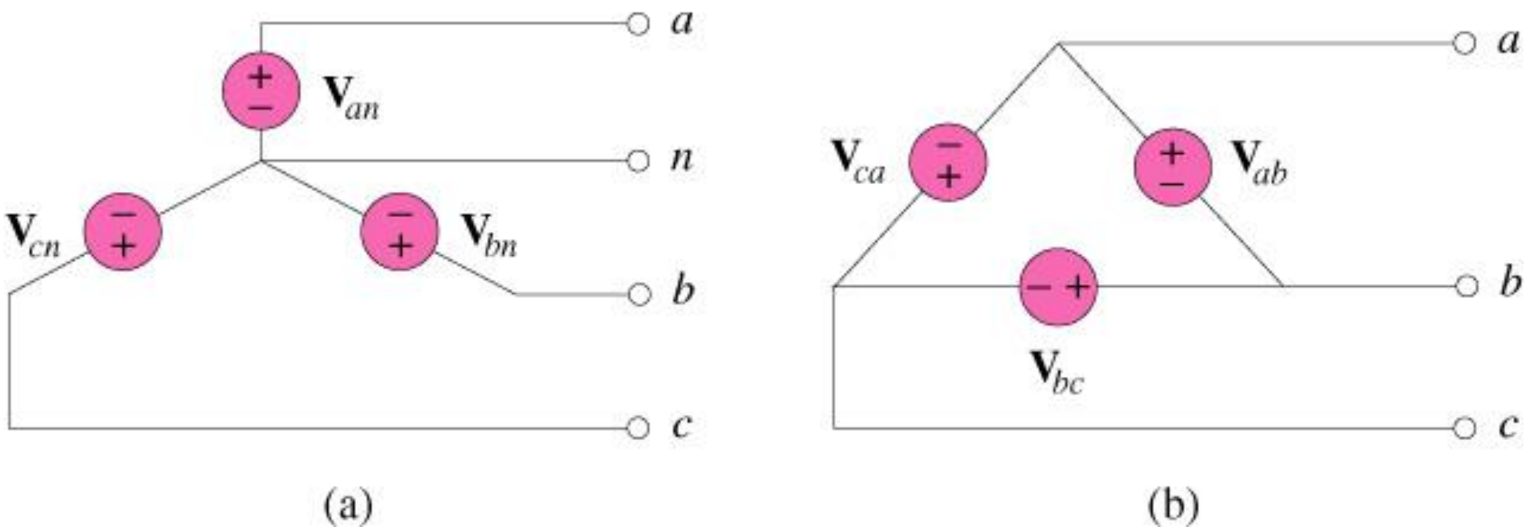


Voltages having 120° phase difference



12.2 Balance Three-Phase Voltages (2)

- Two possible configurations:



Three-phase voltage sources: (a) Y-connected ; (b) Δ-connected

12.2 Balance Three-Phase Voltages (3)

- ***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

Example 1

Determine the phase sequence of the set of voltages.

$$v_{an} = 200\cos(\omega t + 10^\circ)$$

$$v_{bn} = 200\cos(\omega t - 230^\circ)$$

$$v_{cn} = 200\cos(\omega t - 110^\circ)$$

12.2 Balance Three-Phase Voltages (5)

Solution:

The voltages can be expressed in phasor form as

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

We notice that $\mathbf{V_{an}}$ leads $\mathbf{V_{cn}}$ by 120° and $\mathbf{V_{cn}}$ in turn leads $\mathbf{V_{bn}}$ by 120°.

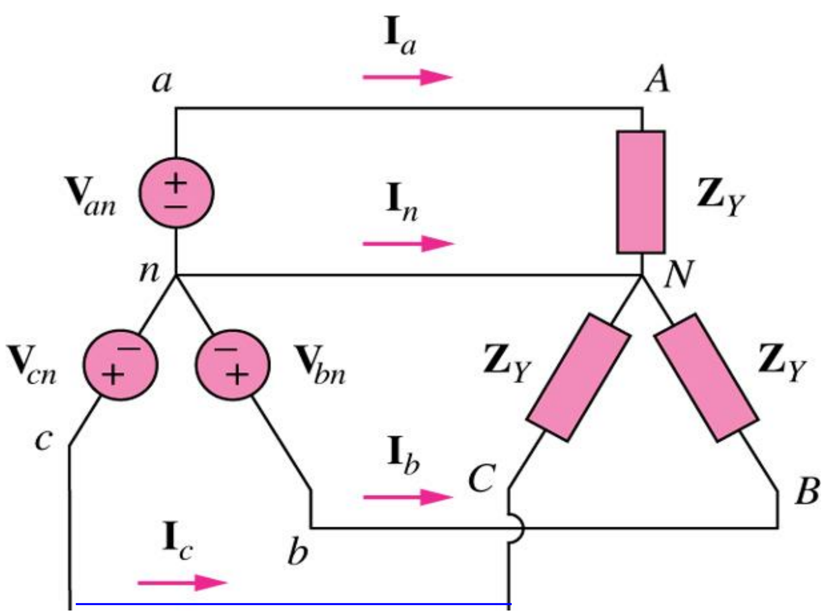
Hence, we have an acb sequence.

12.3 Balance Three-Phase Connection (1)

- 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 (2)

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



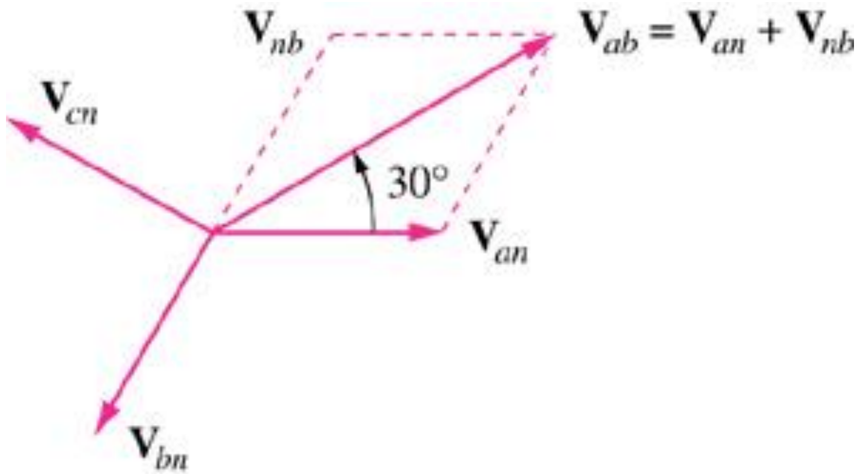
$$V_L = \sqrt{3}V_p \text{, where}$$

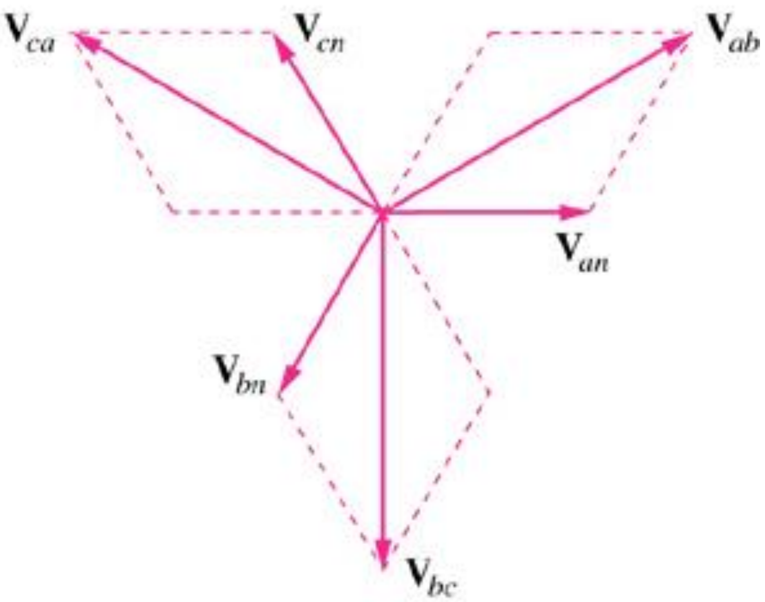
$$V_p = |\mathrm{V}_{an}| = |\mathrm{V}_{bn}| = |\mathrm{V}_{cn}|$$

$$V_L = |\mathrm{V}_{ab}| = |\mathrm{V}_{bc}| = |\mathrm{V}_{ca}|$$

Balanced Wye-wye Connection

- Phasor diagram of phase and line voltages



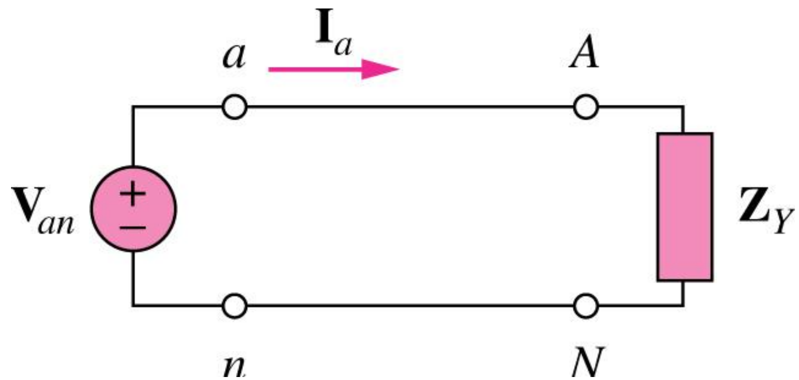


$$V_L = |V_{ab}| = |V_{bc}| = |V_{ca}|$$
$$= \sqrt{3}|V_{an}| = \sqrt{3}|V_{bn}| = \sqrt{3}|V_{cn}| = \sqrt{3}V_p$$

$$V_p = |V_{an}| = |V_{bn}| = |V_{cn}|$$

Single Phase Equivalent of Balanced Y-Y Connection

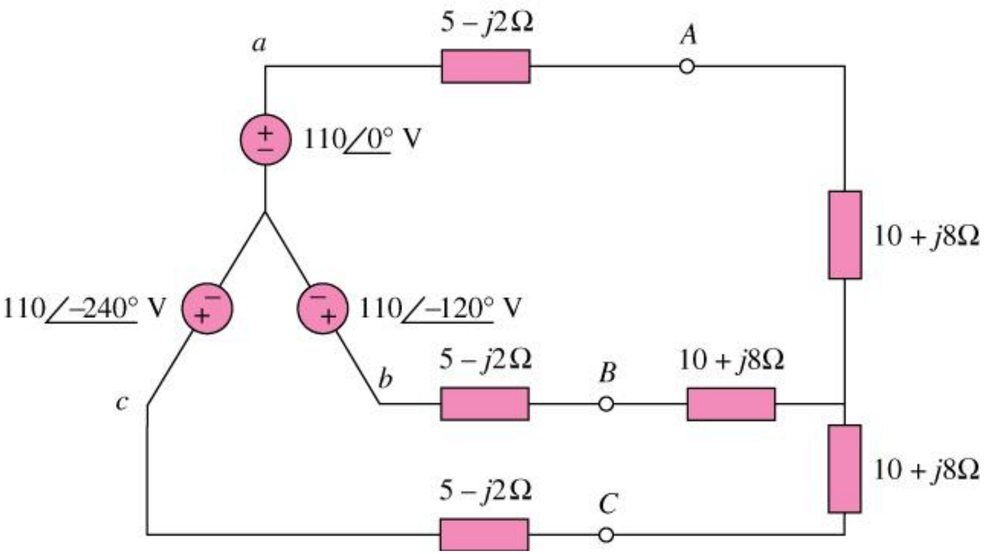
- Balanced three phase circuits can be analyzed on "per phase " basis.
- We look at one phase, say phase *a* and analyze the single phase equivalent circuit.
- Because the circuit is balanced, we can easily obtain other phase values using their phase relationships.

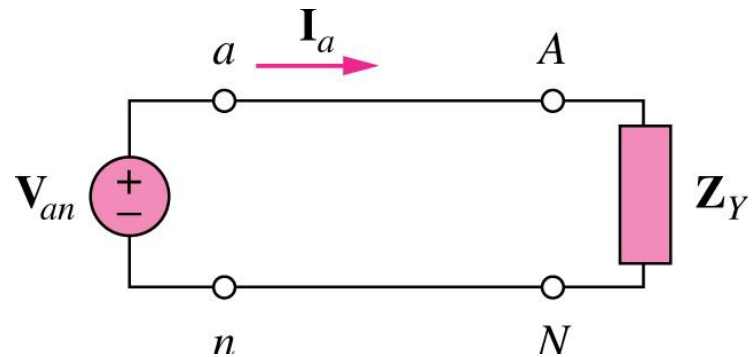


$$I_a = \frac{V_{an}}{Z_Y}$$

Example 2

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





110*ang(0)/(5-2j+10+8j) = 6.809 < -21.80

Ans

$$I_a = 6.81\angle -21.8° \text{ A}$$

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

$$I_c = 6.81\angle 98.2° \text{ A}$$

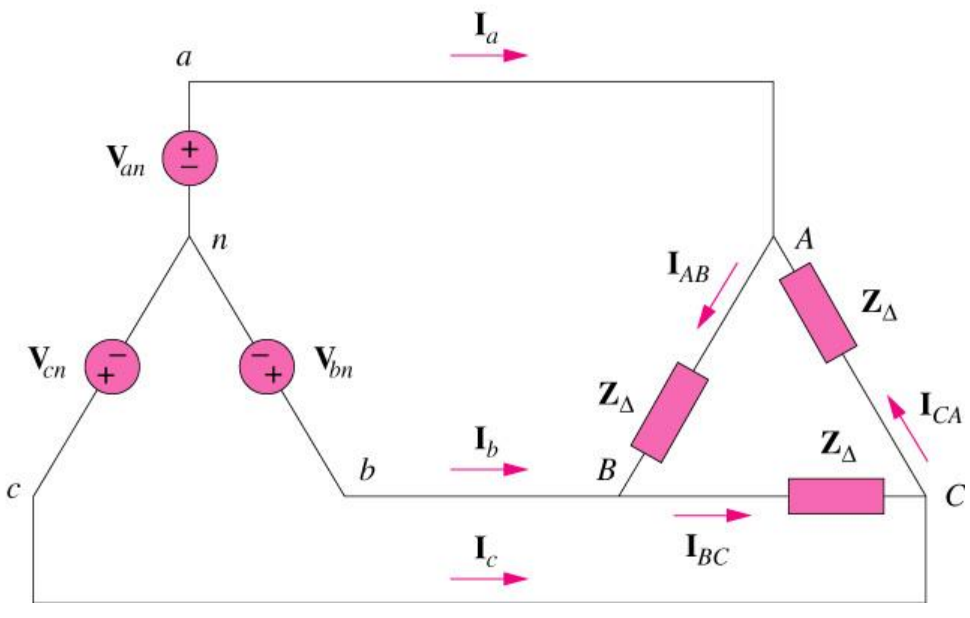
12.3 Balance Three-Phase Connection (4)

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

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

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

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



Example 3

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

Solution

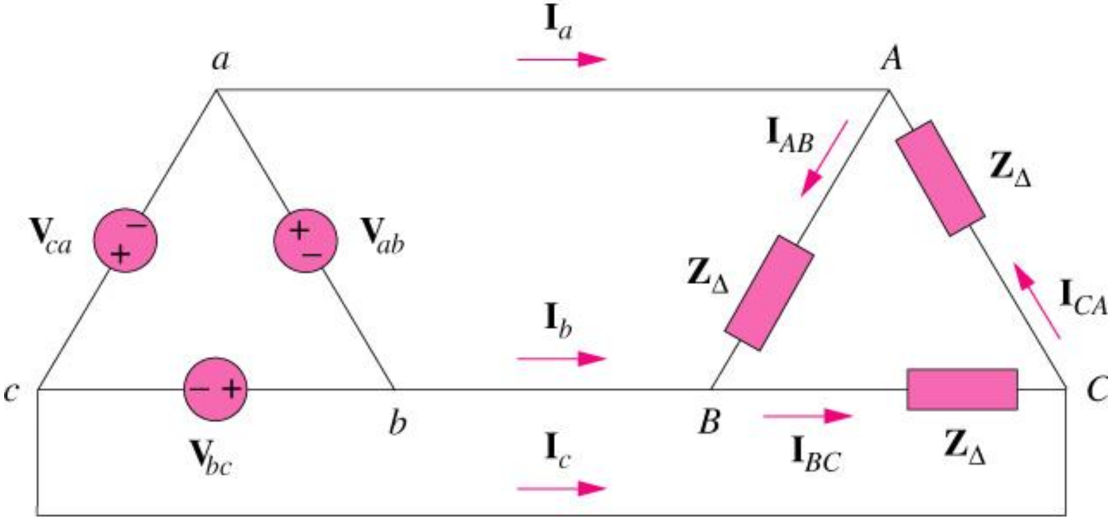
```
Van = 100*ang(10)
Vbn = 100*ang(10-120)
Vcn = 100*ang(10+120)

Vab = Van - Vbn =173.205 < 40.00

Vbc = Vbn - Vcn =173.205 < -80.00

Vca = Vcn - Van =173.205 < 160.00

Iab = Vab/(8+4j)        =19.365 < 13.43
Ica = Vca/(8+4j)        =19.365 < 133.43
Ia = Iab - Ica)         =33.541 < -16.57
```

$$I_a = \frac{V_{an}}{Z_\Delta / 3} = \frac{100\angle 10^\circ}{2.981\angle 26.57^\circ} = 33.54\angle -16.57^\circ \text{ A}$$

Other line currents are obtained using the *abc* phase sequence

12.3 Balance Three-Phase Connection (6)

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



Example 4

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

Ans:

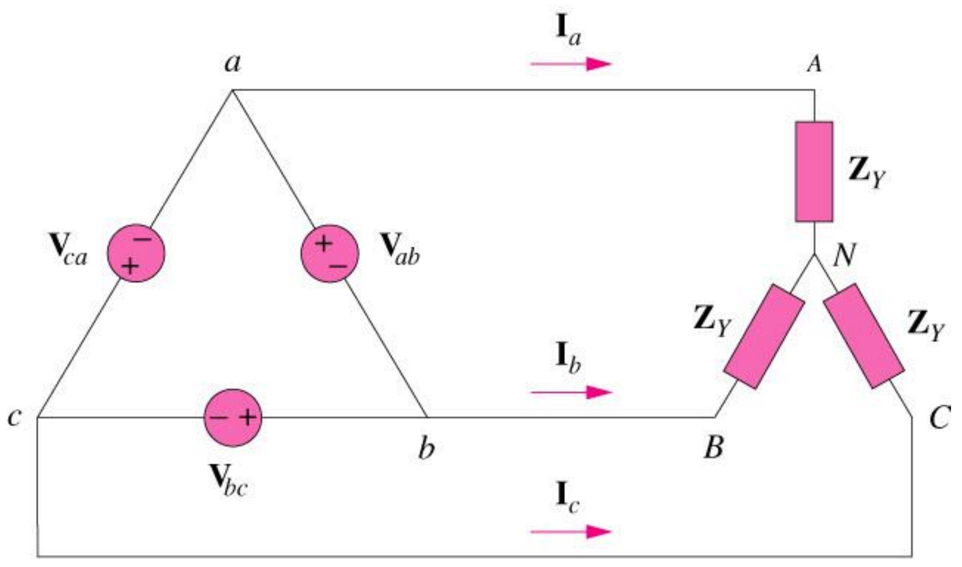
```
Iab = 110*ang(0)/(5-2j+10+8j)    = 13.200 < 36.87
Ibc =                            = 13.200 < -81.13
Ica =                            = 13.200 < 156.87

Ia = Iab - Ica                   =  22.86<6.87
```

$$I_{AB} = 13.2\angle 36.87^\circ \text{ A}; I_{BC} = 13.2\angle -81.13^\circ \text{ A}; I_{AB} = 13.2\angle 156.87^\circ \text{ A}$$

$$I_a = 22.86\angle 6.87^\circ \text{ A}; I_b = 22.86\angle -113.13^\circ \text{ A}; I_c = 22.86\angle 126.87^\circ \text{ A}$$

12.3 Balance Three-Phase Connection (8)

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



12.3 Balanced Three-Phase Connection (9)

Example 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

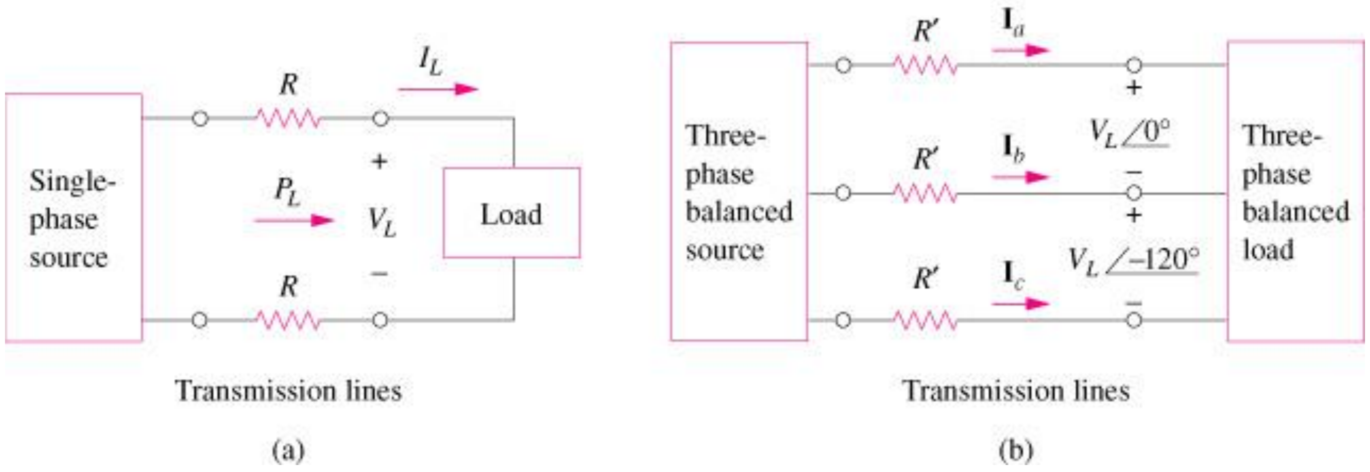
The phase currents

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

*Refer to in-class illustration, textbook

12.4 Power in a Balanced System (1)

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



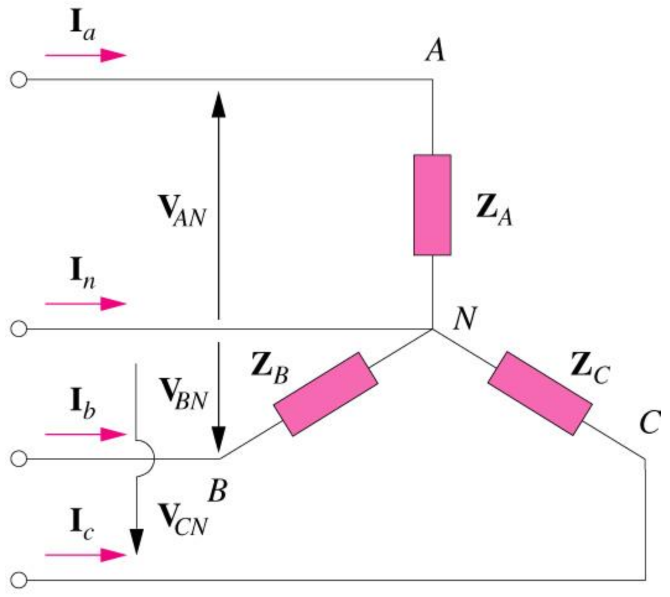
$$P'_{loss} = 2R\frac{P_L^2}{V_L^2}, \text{single - phase}$$

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

- 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 (1)

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



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

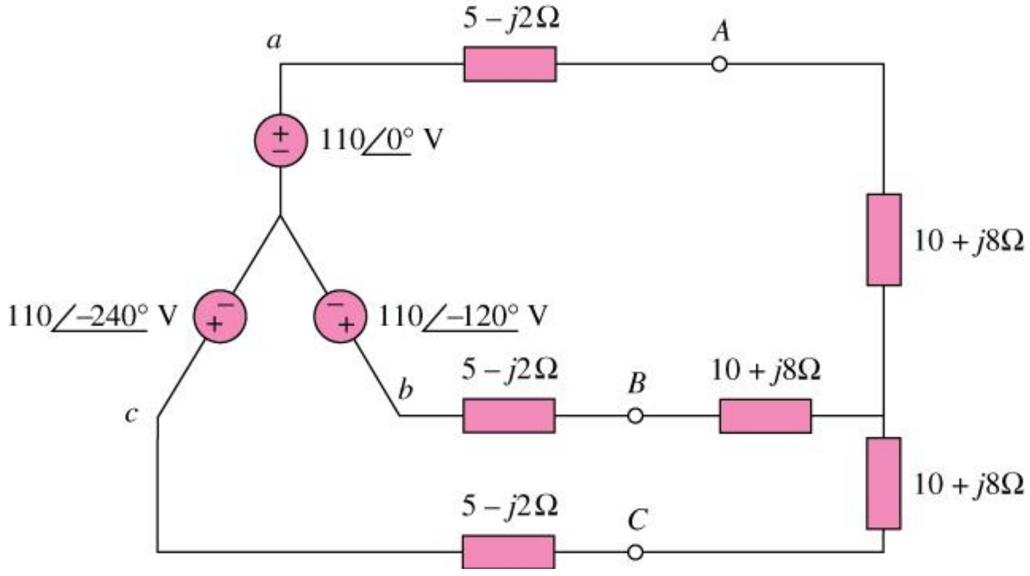
$$I_n = -(I_a + I_b + I_c)$$

- 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.

12.3 Unbalanced Three-Phase Systems (2)

Example 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:

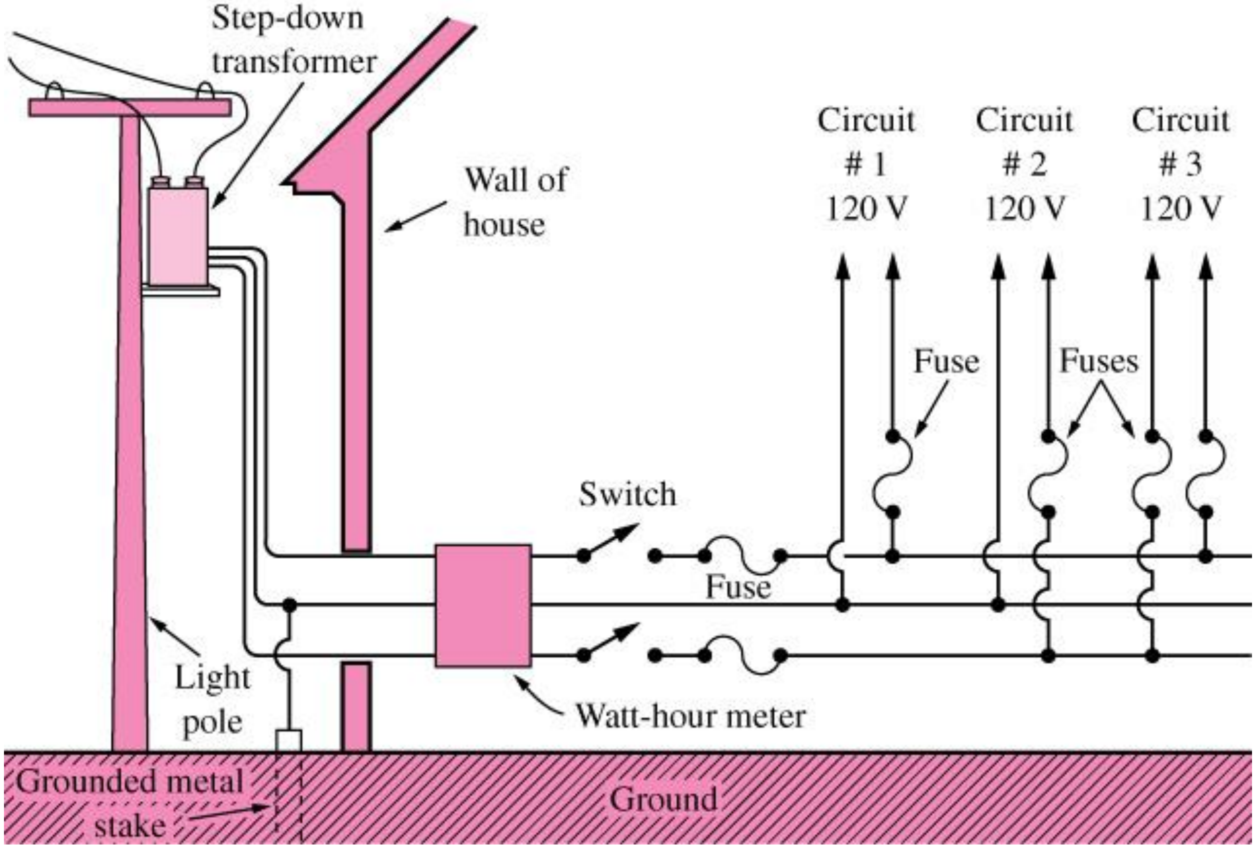
S_L = (1392 + j1113) VA

P_a = 1392W

P_r = 1113VAR

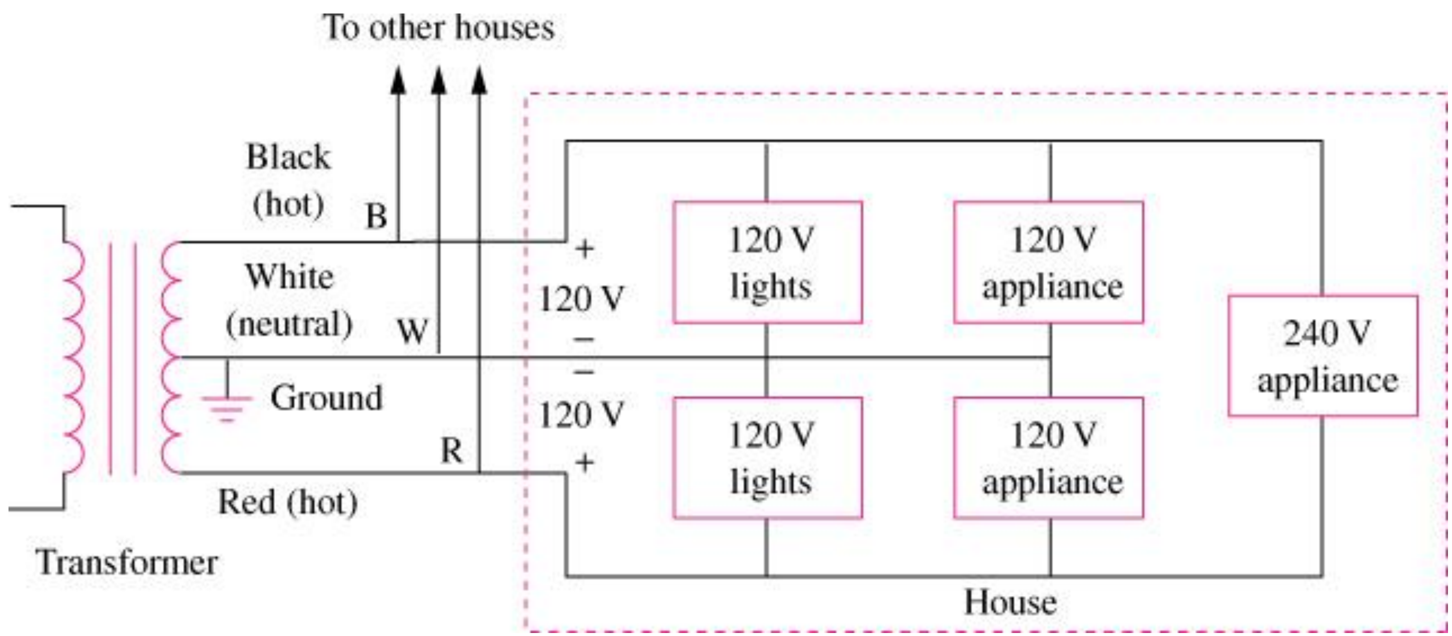
*Refer to in-class illustration, textbook

12.6 Application – Residential Wiring (1)



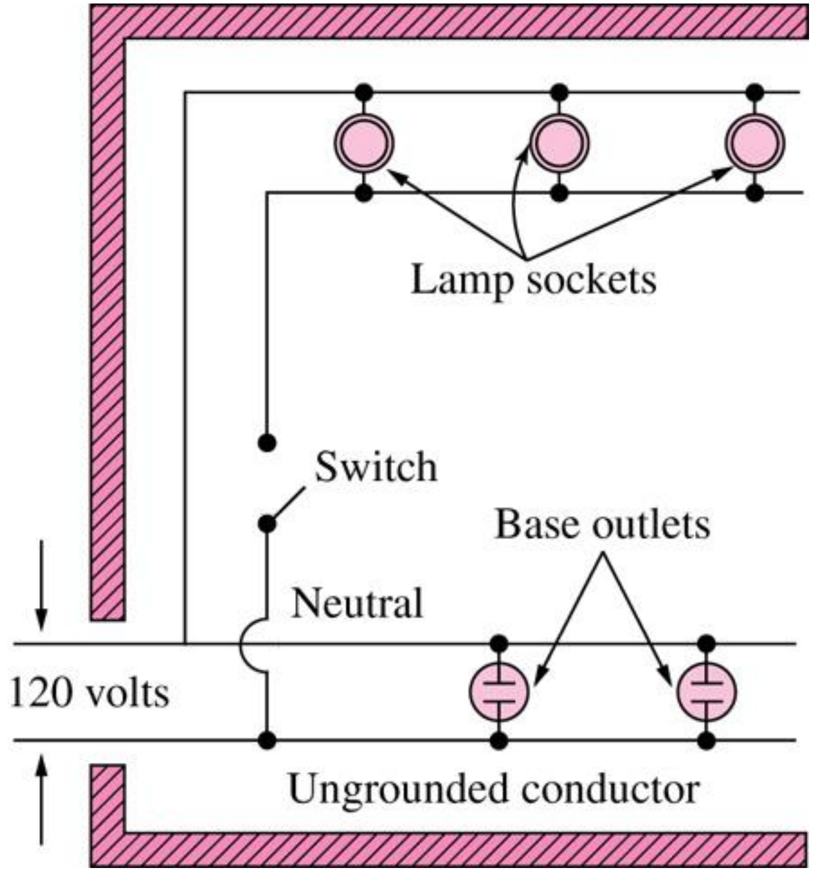
A 120/240 household power system

12.6 Application – Residential Wiring (2)



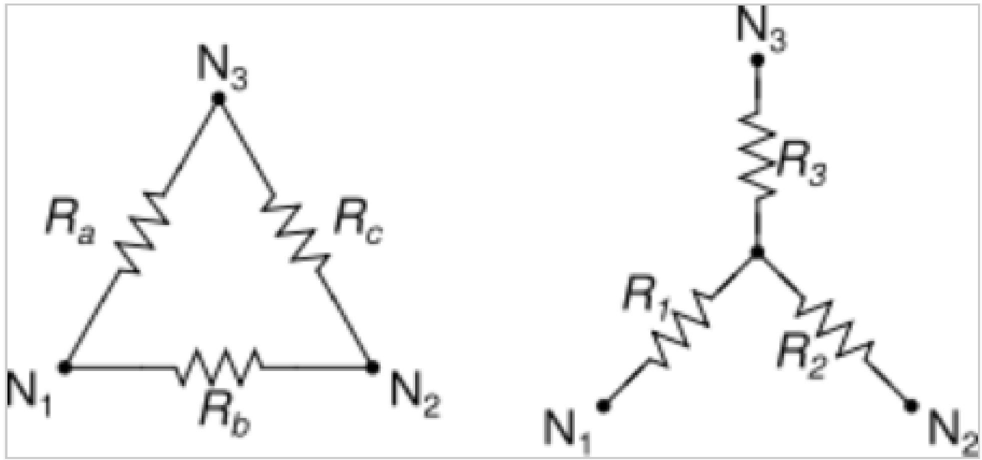
Single-phase three-wire residential wiring

12.6 Application – Residential Wiring (3)



A typical wiring diagram of a room

General Delta to Wye conversion



Delta to Wye

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

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

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

Wye to Delta

$$R_1 = \frac{R_b R_a}{R_T}$$

$$R_2 = \frac{R_b R_c}{R_T}$$

$$R_3 = \frac{R_a R_c}{R_T}$$

where $R_T = R_a + R_b + R_c$

works the same way for complex impedances

HANDOUTS

Example 1

Determine the phase sequence of the set of voltages.

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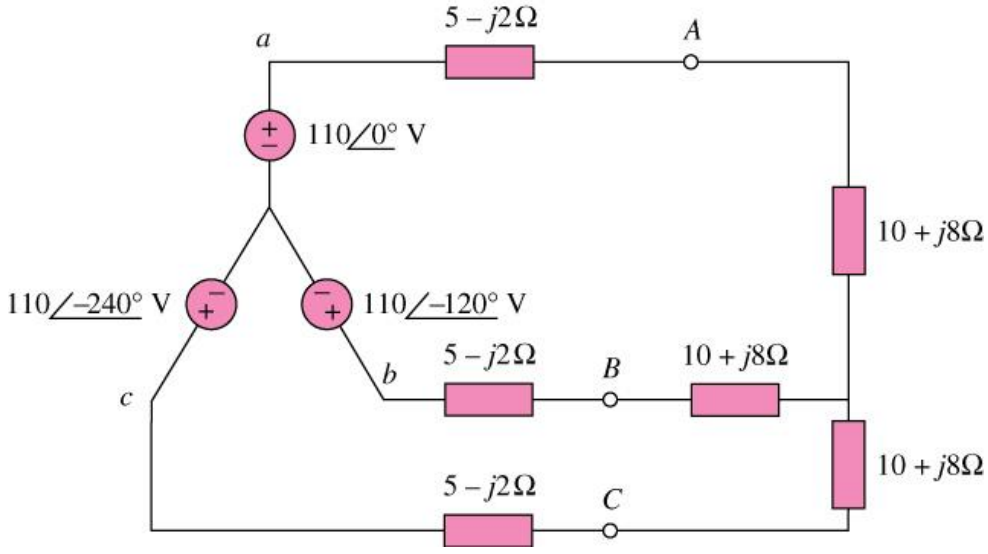

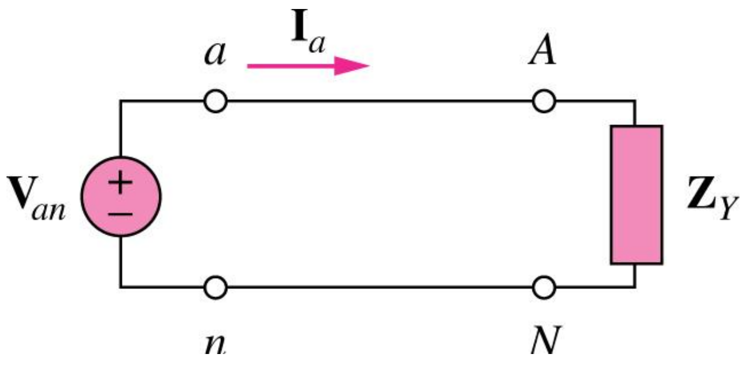

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