THREE PHASE SYSTEM

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- Three-phase systems differ from single-phase systems in that they use a set of three voltages instead of one.

- Three-phase systems are used for the generation and transmission of bulk electrical power. All commercial ac power systems, for example, are three-phase systems.

- Not all loads connected to a three-phase system need be three-phase, however—for example, the electric lights and appliances used in our homes require only single-phase ac.

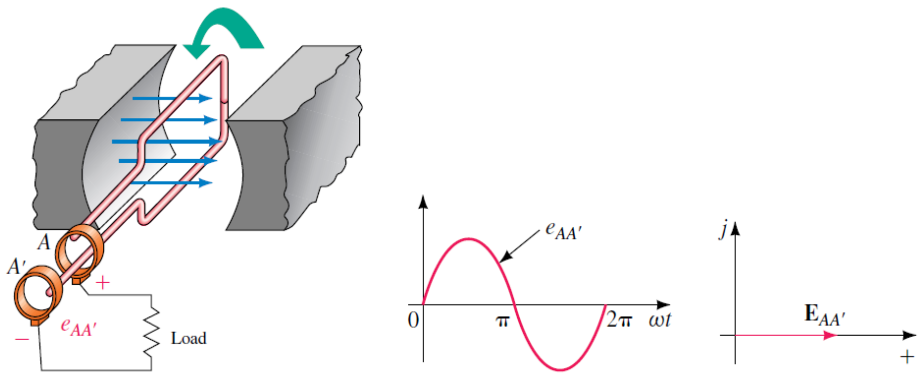
- To get single-phase ac from a three-phase system, we simply tap off one of its phases.

Three Phase Voltage Generation

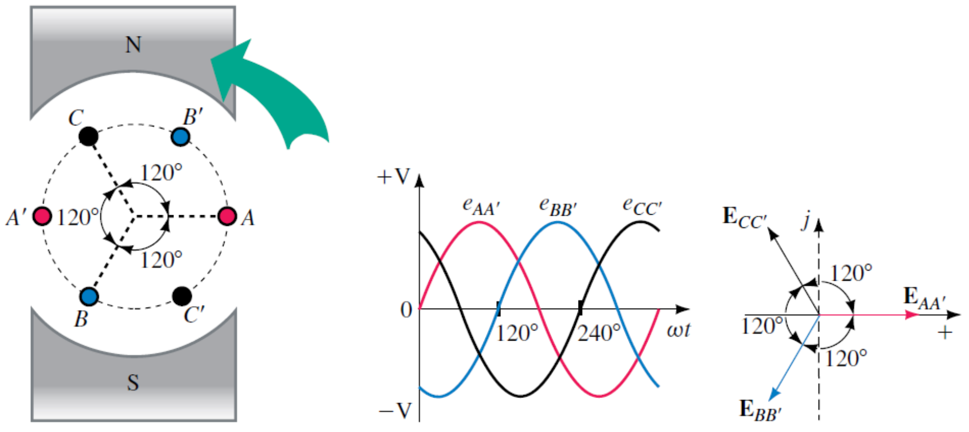
Three-phase generators have three sets of windings and thus produce three ac voltages instead of one. consider the elementary single-phase generator of Figure. As coil AA’ rotates, it produces a sinusoidal waveform $e_{AA'}$ as indicated .

If two more windings are added as in Fig, two additional voltages are generated. Since these windings are identical with *AA’* (except for their position on the rotor), they produce identical voltages. However, since coil *BB’* is placed 120° behind coil *AA’*, voltage $e_{BB'}$ lags $e_{AA'}$ by 120°; similarly, coil *CC’*, which is placed ahead of coil *AA’* by 120°, produces voltage $e_{CC'}$ that leads by 120°.

As indicated, the generated voltages are equal in magnitude and phase displaced 120°. Thus, if **E***AA’* is at 0°, then **E***BB’* will be at 120° and *ECC’* will be at 120°. Assuming an rms value of 120V and a reference position of 0° for phasor **E***AA’* for example, yields **E***AA’*=120 V $\angle$0°, **E***BB’*=120 V $\angle$-120° and **E***CC’*=120 V$\angle$120°. Such a set of voltages is said to be balanced. Because of this fixed relationship between balanced voltages, if you know one voltage, easily determine the other two.



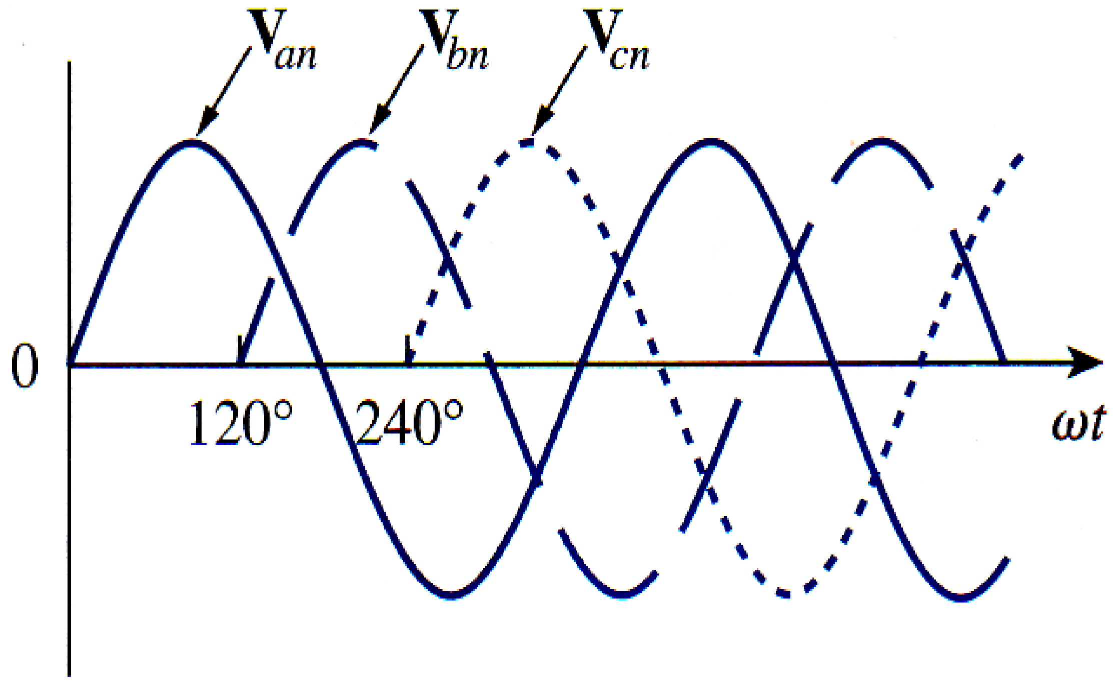
(a) Basic ac generator (b) Voltage waveform (c) Phasor



(a) Basic 3-phase generator (b) Voltage waveforms (c) Phasors

Generated Voltages

The three phase generator can supply power to both single phase and three phase loads. The three-phase system has three live conductors which supply the 440V to the large consumers. While the single-phase system has one live conductor which is used for domestic purposes.



Advantages of Three Phase System

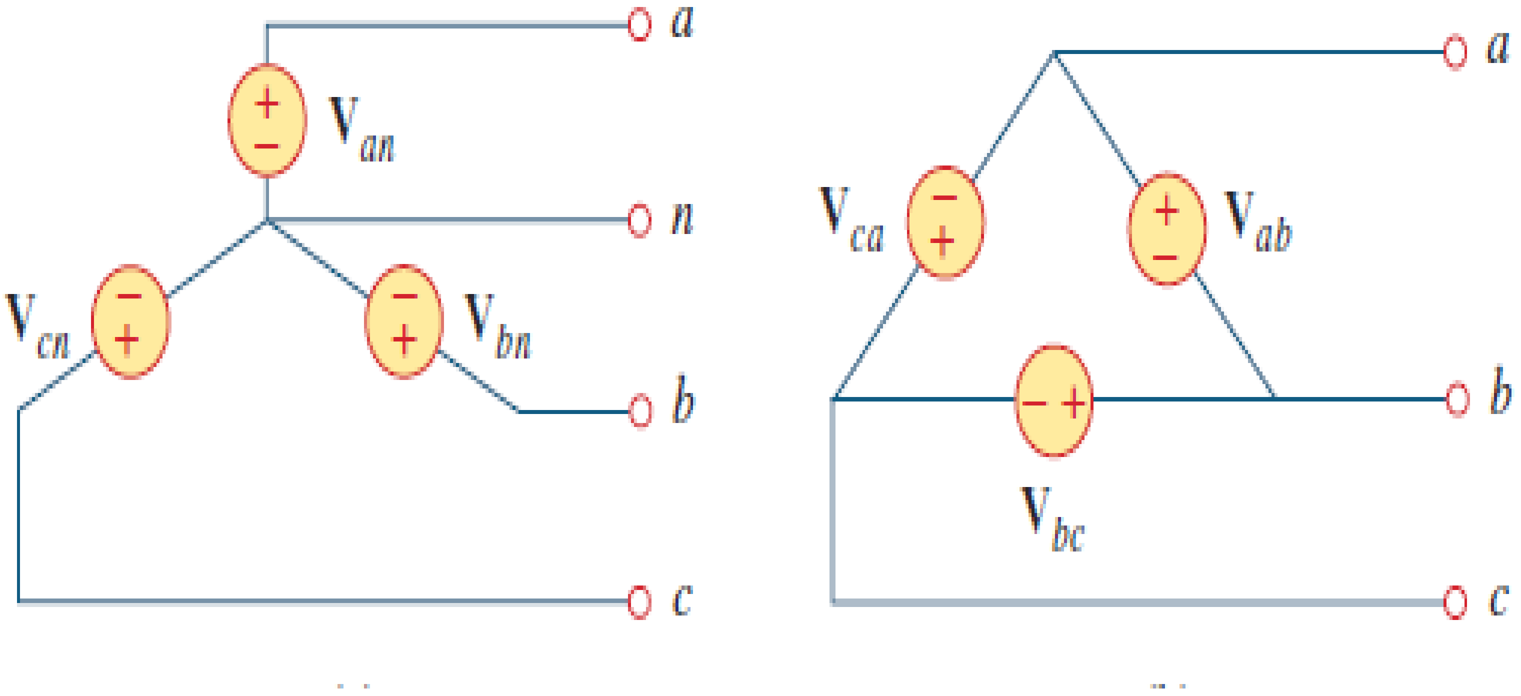
1.Thinner conductors can be used to transmit the same kVA, which reduces the amount of copper required (typically about 25% less) and in turn reduces construction and maintenance costs.

2. The lighter lines are easier to install, and the supporting structures can be less massive and farther apart.

3. Three-phase equipment and motors have preferred running and starting characteristics compared to single-phase systems because of a more even flow of power to the transducer than can be delivered with a single-phase supply.

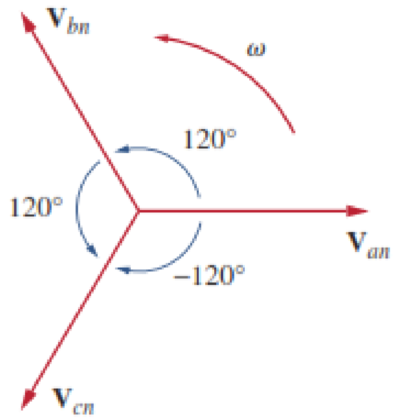
4. In general, most larger motors are three phase because they are essentially self-starting and do not require a special design or additional starting circuitry.

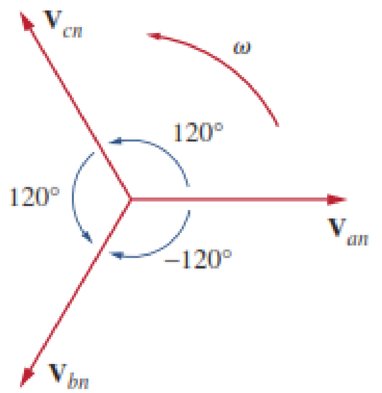
Basic Three-Phase Circuit Connections



Positive sequence - ABC

Negative Sequence - ACB





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

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

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

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

In Fig.(a), as the phasors rotate in the counterclockwise direction with frequency they pass through the horizontal axis in a sequence Thus, the sequence is *abc or bca or cab.*

Similarly, for the phasors in Fig. , as they rotate in the clockwise direction, they pass the horizontal axis in a sequence *acbacba* . . . . This describes the *acb sequence.*

The phase sequence is important in three-phase power distribution. It determines the direction of the rotation of a motor connected to the power source, Like the generator connections, a three-phase load can be either wye-connected or delta-connected, depending on the end application.

Figure shows a wye-connected load, and delta-connected load. The neutral line in Fig. may or may not be there, depending on whether the system is four- or three-wire.

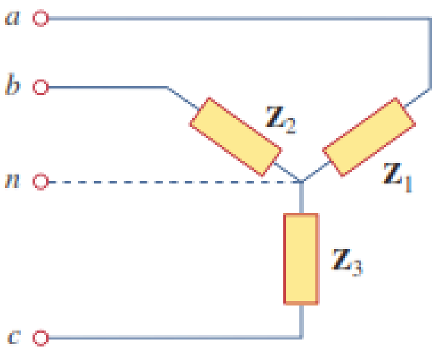
A wye- or delta-connected load is said to be unbalanced if the phase impedances are not equal in magnitude or phase.

A balanced load is one in which the phase impedances are equal in magnitude and in phase. For a **balanced wye-connected** load,

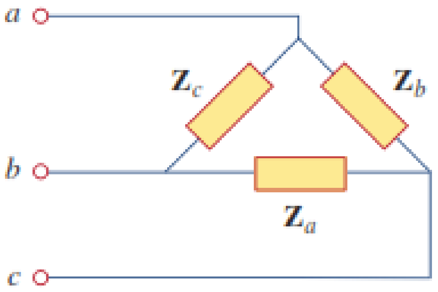
$\mathbf{Z}_1 = \mathbf{Z}_2 = \mathbf{Z}_3 = \mathbf{Z}_Y$ where **Z**Y is the load impedance per phase.

For a **balanced delta connected load,**

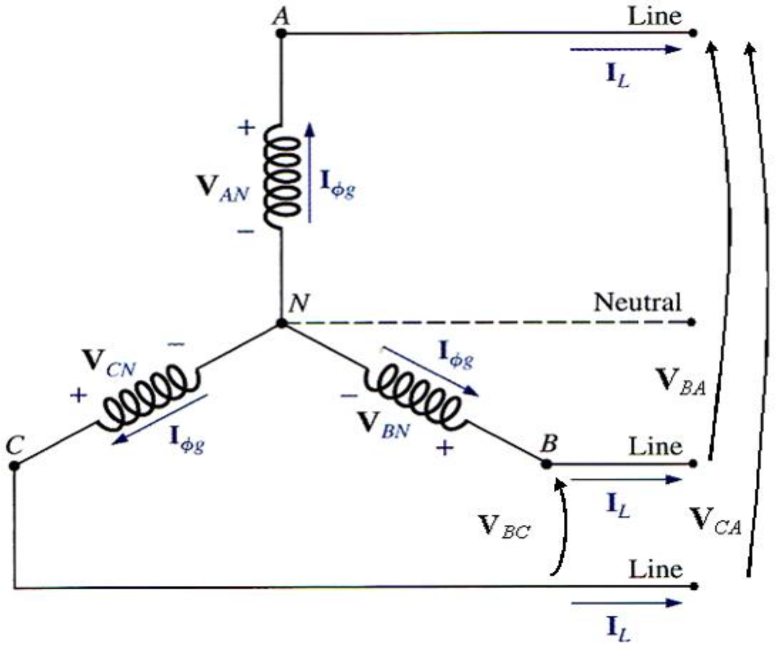
$$\mathbf{Z}_a = \mathbf{Z}_b = \mathbf{Z}_c = \mathbf{Z}_\Delta$$

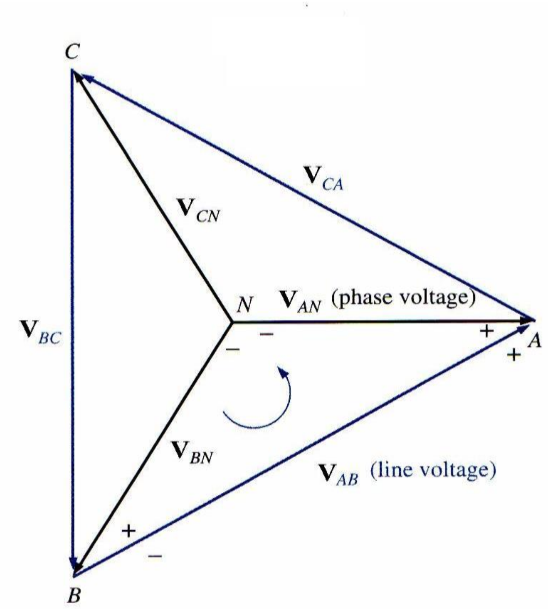


(a)



Wye Connected Generator





$$I_L = I_{\phi g}$$

Applying KVL around the indicated loop in figure above, we obtain

$$V_{AB} = V_{AN} - V_{BN} = V_{AN} + V_{NB}$$

$$V_{BC} = V_{BN} - V_{CN} = V_{BN} + V_{NC}$$

$$V_{CA} = V_{CN} - V_{AN} = V_{CN} + V_{NA}$$

For line-to-line voltage V_{AB} is given by

$$V_{AB} = V_A - V_B$$

$$= V_\phi \angle 0^0 - V_\phi \angle -120^0$$

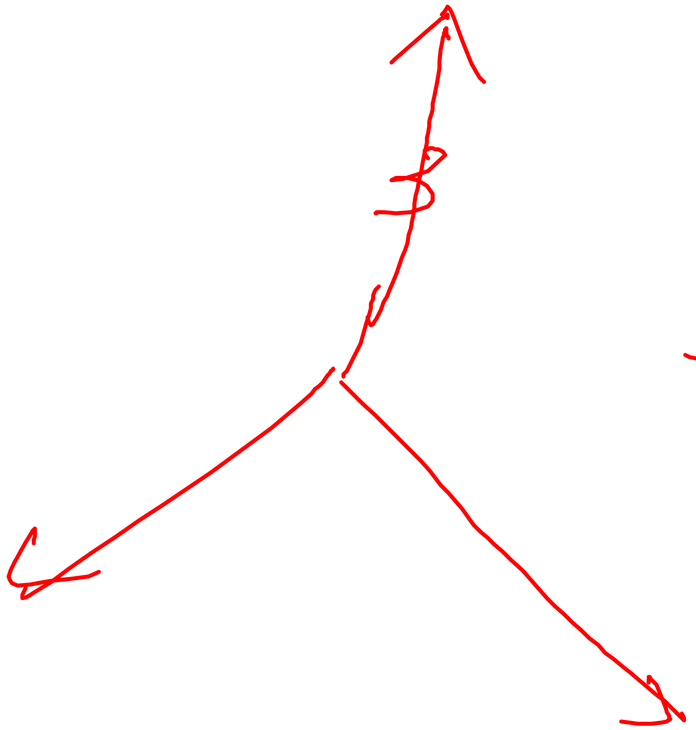
$$= V_\phi - \left(-\frac{1}{2} V_\phi - j \frac{\sqrt{3}}{2} V_\phi \right)$$

$$= \frac{3}{2} V_\phi + j \frac{\sqrt{3}}{2} V_\phi$$

$$= \sqrt{3} V_\phi \left(\frac{\sqrt{3}}{2} + j \frac{1}{2} \right) \qquad = \sqrt{3} V_\phi \angle 30^0$$

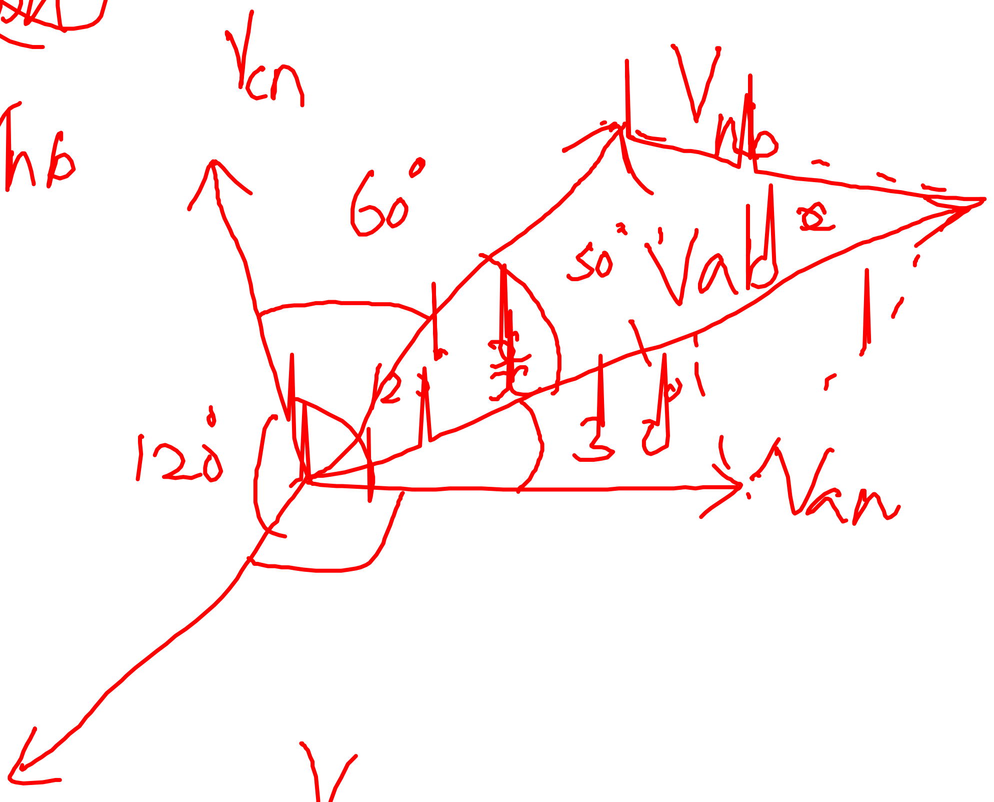
$V_{ab} = V_{an} - V_{bn}$

$= V_{an} + V_{nb}$



V_{bn}

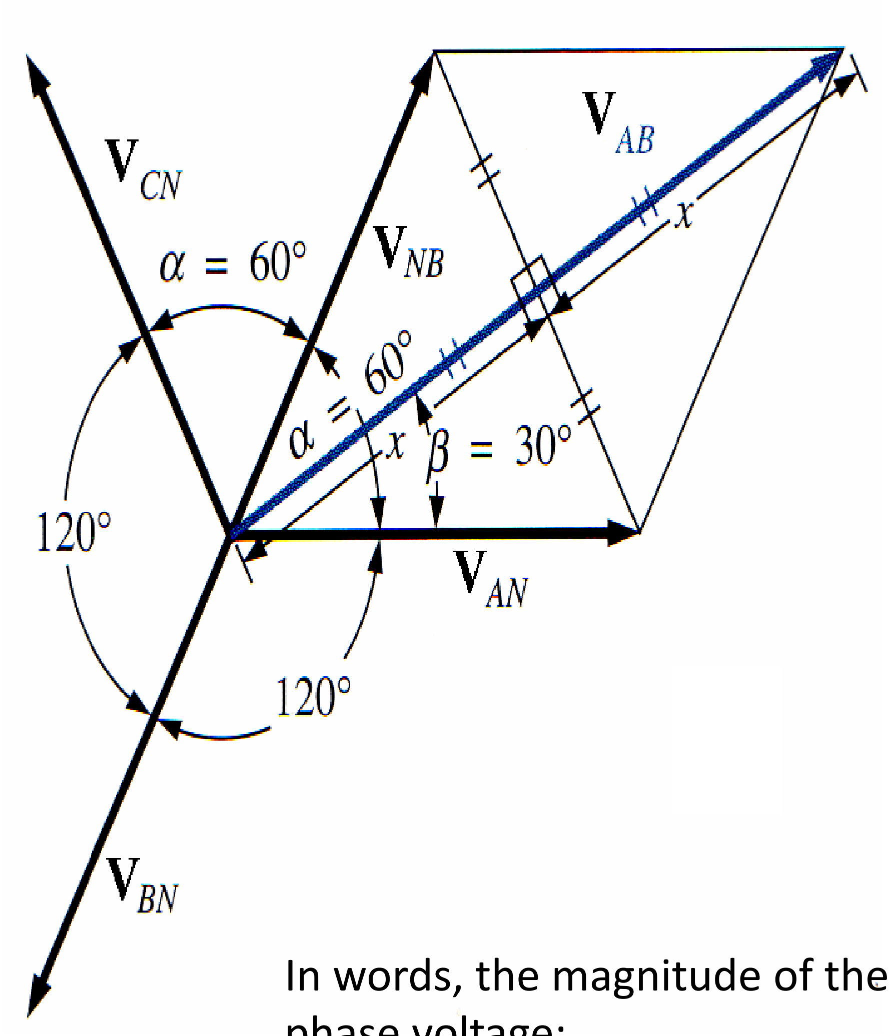
$V_{nb} = -V_{bn}$



V_{bn}

$V_{ab} = 2x$

Phasor Diagram



The phasor diagram is redrawn to find $\mathbf{E}_{AB}$ as shown in Fig. Since each phase voltage, when reversed ($\mathbf{E}_{NB}$), will bisect the other two, 60°. The angle β is 30°

$$x = E_{AN} \cos 30° = \frac{\sqrt{3}}{2} E_{AN}$$

$$E_{AB} = 2x = (2)\frac{\sqrt{3}}{2} E_{AN} = \sqrt{3} E_{AN}$$

Noting from the phasor diagram that θ of $\mathbf{V}_{AB}$ = β= 30°, the result is

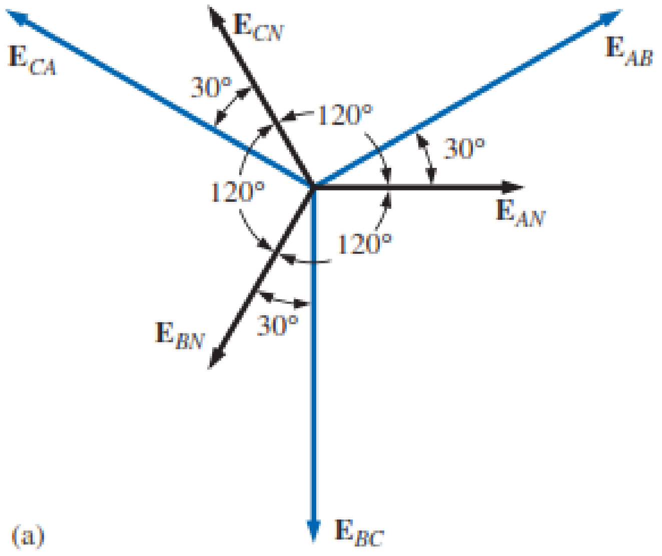
$$V_{AB} = V_{AB}\angle 30^0 = \sqrt{3} V_{AN} \angle 30^0$$

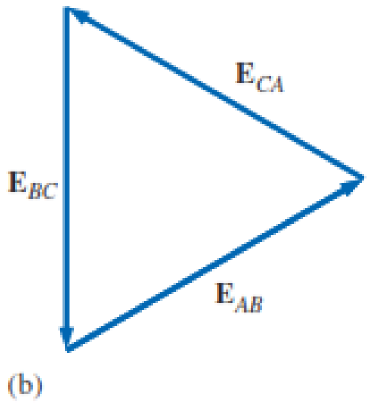
$$V_{CA} = \sqrt{3} V_{CN} \angle 150^0$$

$$V_{BC} = \sqrt{3} V_{BN} \angle 270^0$$

In words, the magnitude of the line voltage of a Y-connected generator is √3 times the phase voltage:

$$E_L = \sqrt{3} E_\phi$$





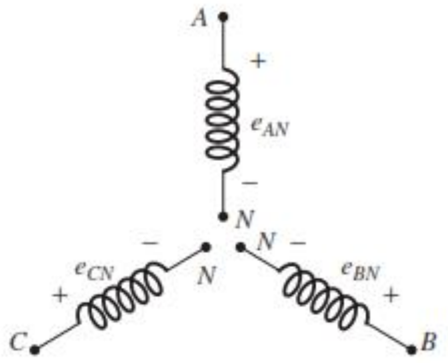
(a) Phasor diagram of the line and phase voltages of a three-phase generator; (b) demonstrating that the vector sum of the line voltages of a three-phase system is zero.

Delta Connected Generator

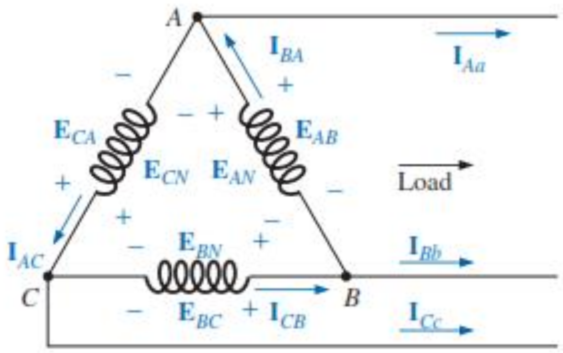
If we rearrange the coils of the generator as shown in Fig. the system is referred to as a *three-phase, three-wire,* **Δ-connected ac generator. In this system, the phase and line voltages** are equivalent and equal to the voltage induced across each coil of the generator; that is,

$$\left.\begin{array}{lll} \mathbf{E}_{AB} = \mathbf{E}_{AN} & \text{and} & e_{AN} = \sqrt{2}E_{AN}\sin\omega t \\ \mathbf{E}_{BC} = \mathbf{E}_{BN} & \text{and} & e_{BN} = \sqrt{2}E_{BN}\sin(\omega t - 120^\circ) \\ \mathbf{E}_{CA} = \mathbf{E}_{CN} & \text{and} & e_{CN} = \sqrt{2}E_{CN}\sin(\omega t + 120^\circ) \end{array}\right\} \begin{array}{l}\text{Phase} \\ \text{sequence} \\ ABC\end{array}$$

$$\boxed{\mathbf{E}_L = \mathbf{E}_{\phi g}}$$



(a)

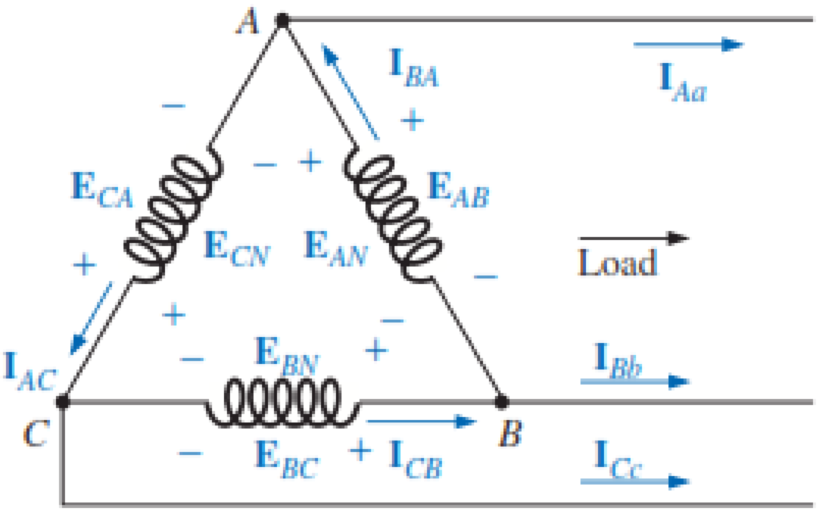


(b)

Unlike the line current for the Y-connected generator, the line current for the Δ-connected system is not equal to the phase current.

Delta Connected Generator

For line-to-line current I_{AB} is given by



$$V_{LL} = V_{\phi}$$

$$I_{\mathrm{Aa}} = I_{BA} - I_{AC}$$

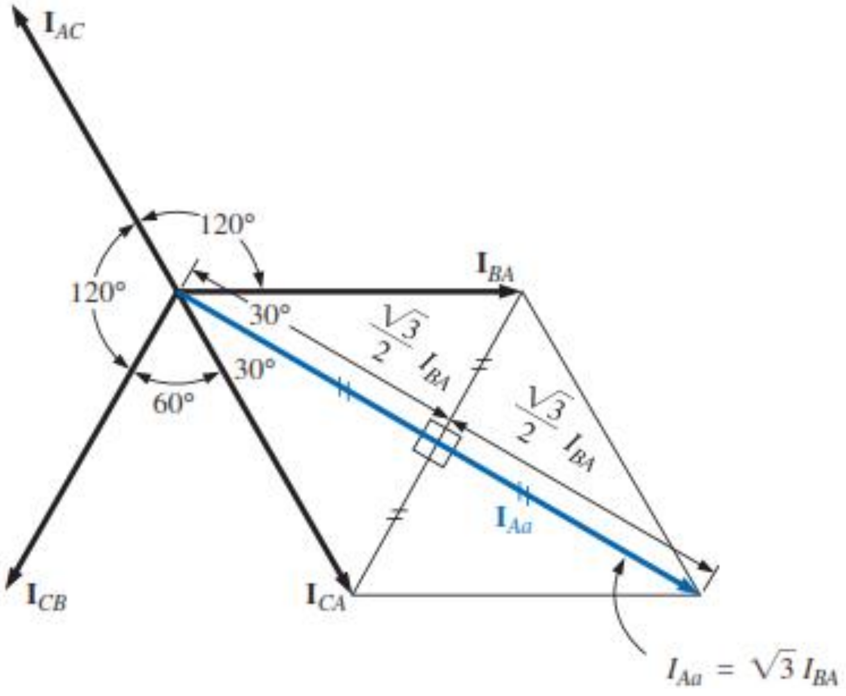
$$= I_{\phi}\angle 0^0 - I_{\phi}\angle -240^0$$

$$= I_{\phi} - \left(-\frac{1}{2}I_{\phi} + j\frac{\sqrt{3}}{2}I_{\phi}\right)$$

$$= \frac{3}{2}I_{\phi} - j\frac{\sqrt{3}}{2}I_{\phi}$$

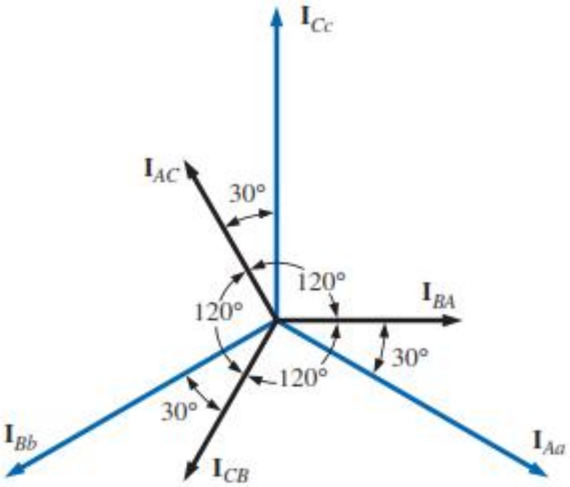
$$= \sqrt{3}I_{\phi}\left(\frac{\sqrt{3}}{2} - j\frac{1}{2}\right)$$

$$= \sqrt{3}I_{\phi}\angle -30^0$$



$$I_{Aa} = \sqrt{3} I_{BA} \angle -30°$$
$$I_{Bb} = \sqrt{3} I_{CB} \angle -150°$$
$$I_{Cc} = \sqrt{3} I_{AC} \angle 90°$$

$$\boxed{I_L = \sqrt{3} I_{\phi g}}$$

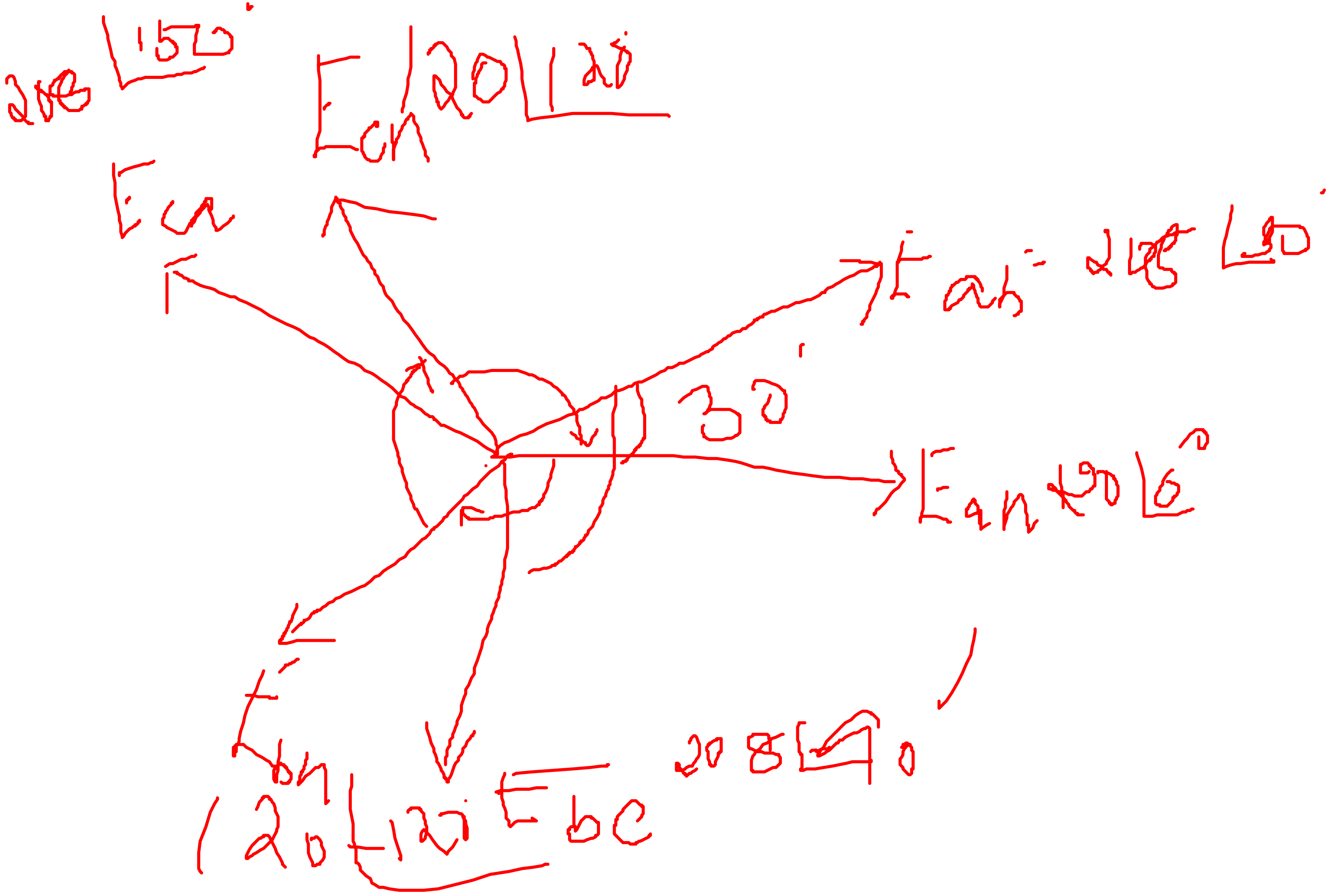


Example 1: For the circuits of Y, suppose E_{AN} $=120\ V\angle 0°$.

a. Determine the phase voltages at the load.

b. Determine the line voltages at the load.

c. Show all voltages on a phasor diagram.



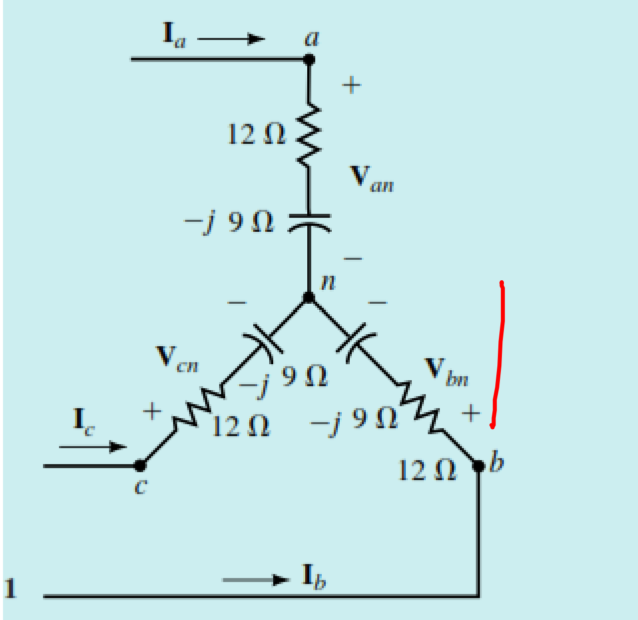
208∠150°
Eca
Ecn 120∠120°
Ean = 208∠30°
30°
Ean 120∠0°
Ebn
120∠-120°
Ebc
208∠-90°

EXAMPLE 2 **For Figure, suppose V_{an}** $=120\ V\angle 0°$.

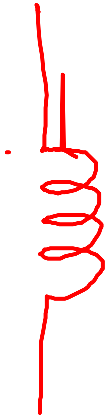
a. Compute $\mathbf{I}_a$, then determine $\mathbf{I}_b$ and $\mathbf{I}_c$ by inspection.

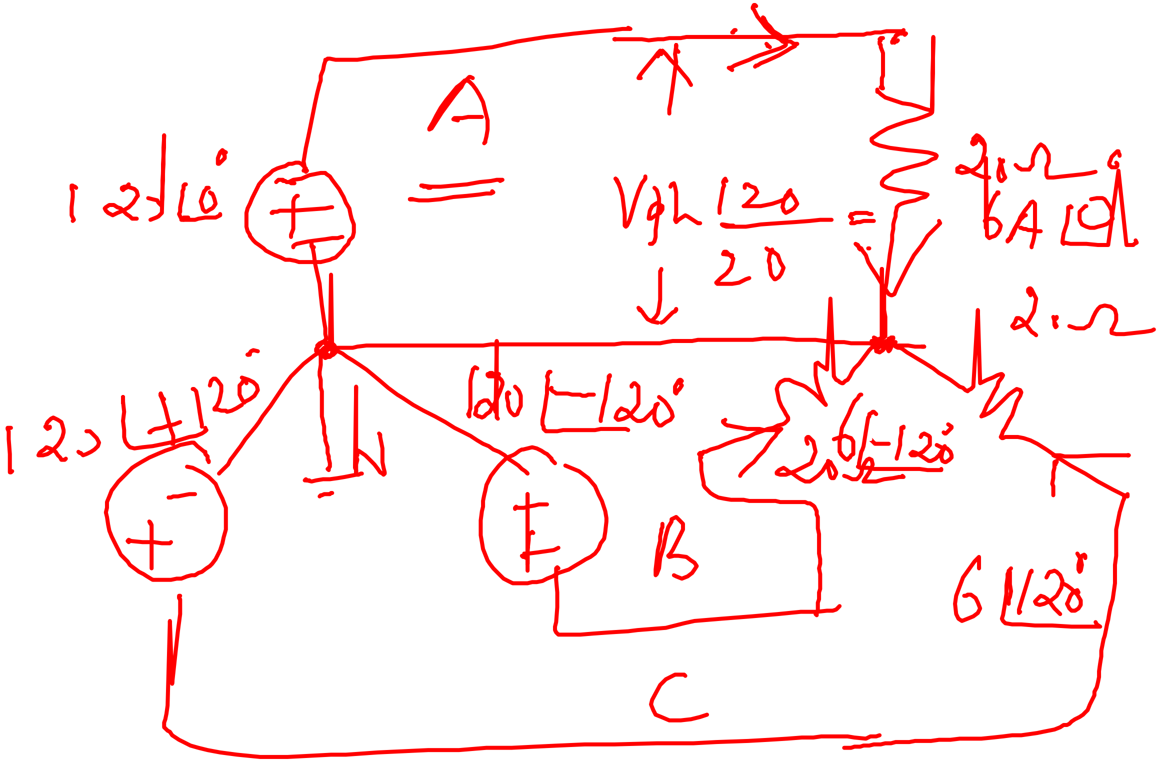
b. Verify by direct computation.

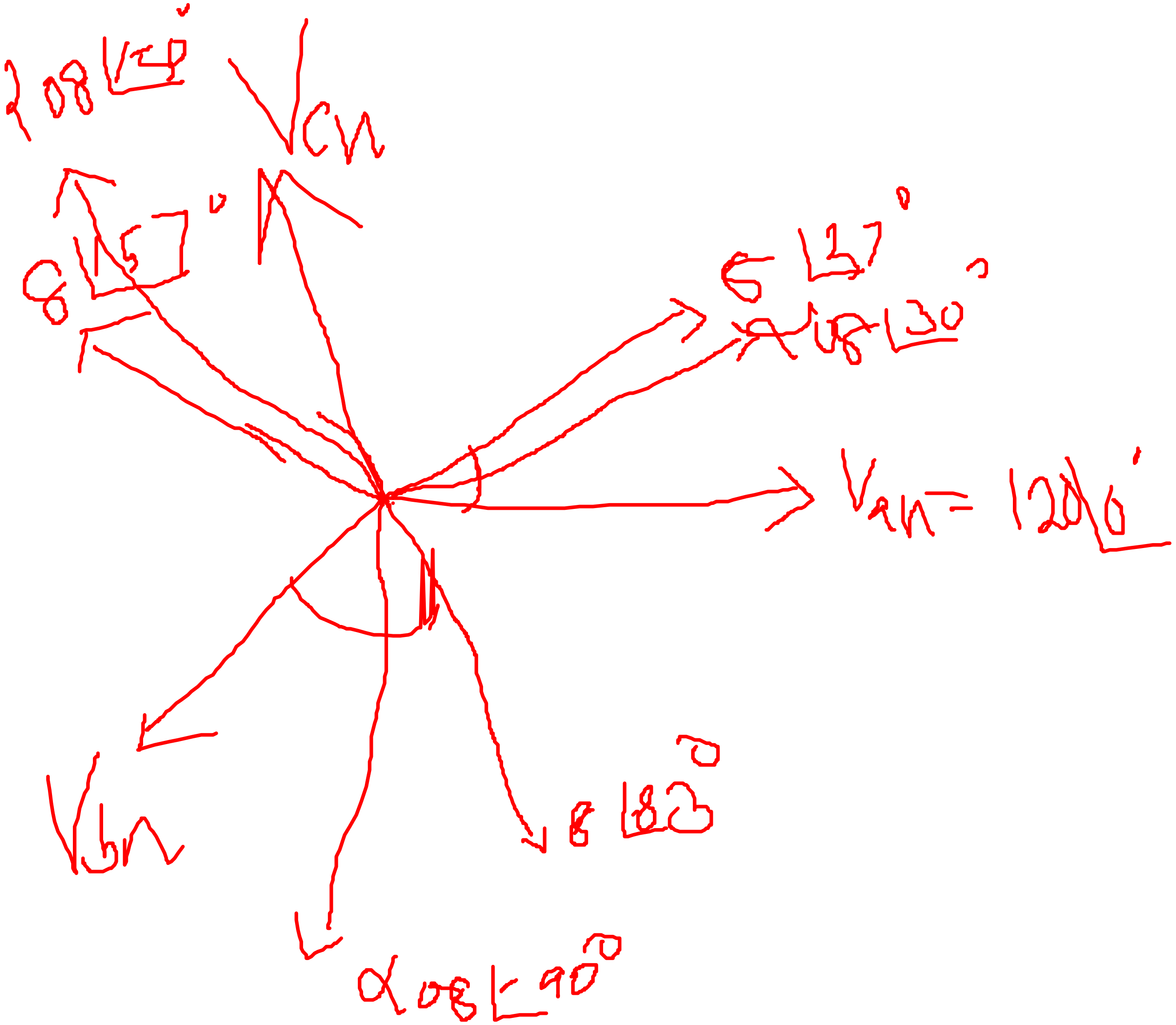
Y-Y



350uF





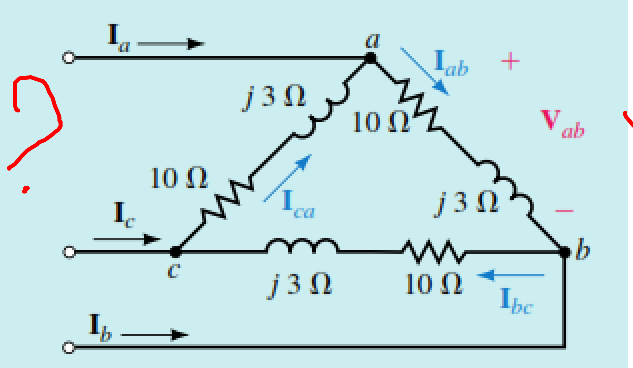

208∠150°
Vcn
8∠157°
8∠37°
208∠30°
Van = 120∠0°
Vbn
8∠83°
208∠-90°

EXAMPLE 3: **Suppose V_{ab}** $=240\ V\angle 15°$ for the circuit of Figure .

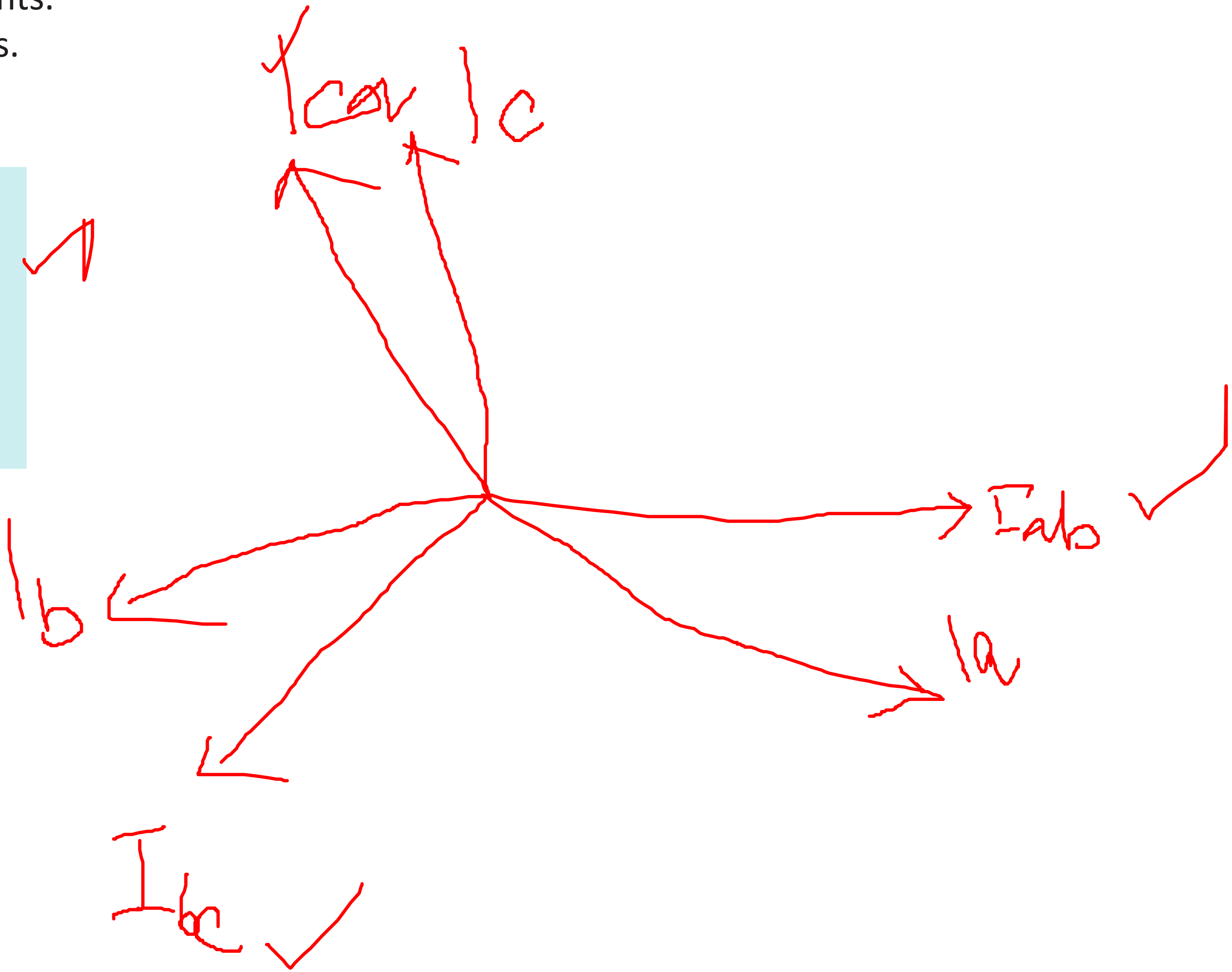
a. Determine the phase currents.

b. Determine the line currents.

c. Sketch the phasor diagram.



9.5mH

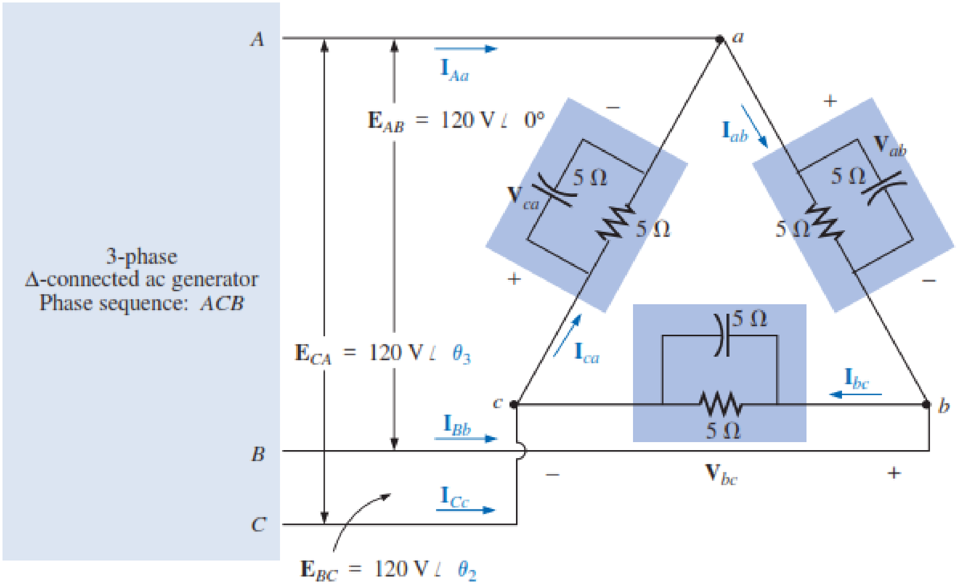


For the Δ-Δ system shown in Fig.

a. Find the phase angles θ_2 and θ_3 for the specified phase sequence.

b. Find the current in each phase of the load.

c. Find the magnitude of the line currents.



Eab = 120 (0)

Eba= 120 (-180)

Eac= 120 (-180+120) = -120 (-60)

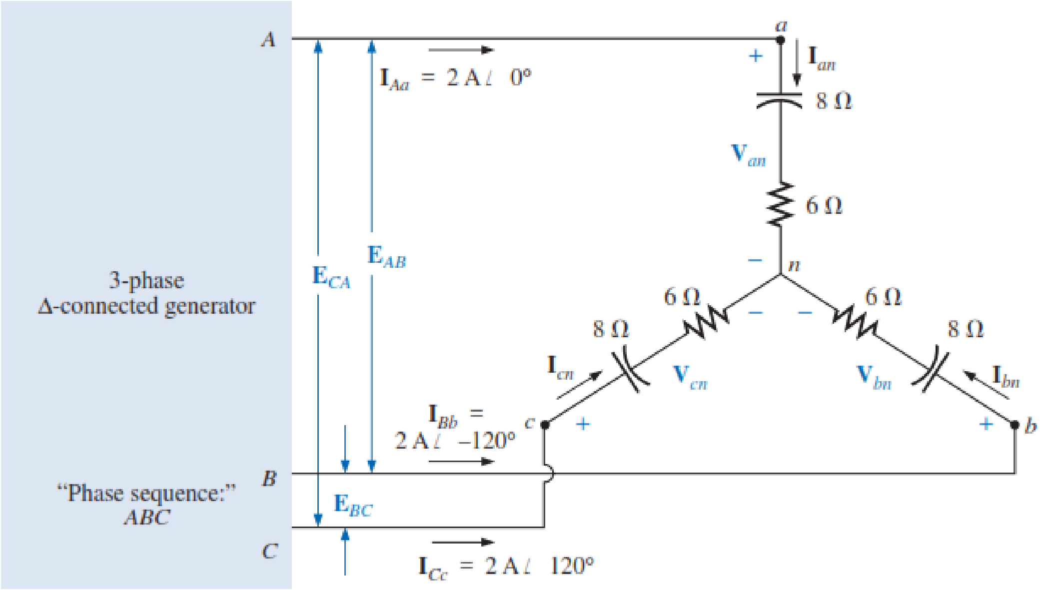
Ecb= 120 (-180+240) = -120 (60)

Eab = 120(0)
Ebc=120(-120)
Eca=120(-240)

EXAMPLE : For the Δ-Y system shown in Fig. :

a. Find the voltage across each phase of the load.

b. Find the magnitude of the line voltages.



400uF

120 → ABC → R_{cs} → 20Ω

1) Y - Y → V_L, V_p, I_{ph}

2) Y - Δ → RC RL 10Ω, j3Ω ↓ 9.5mH → V_L, I_p, I_L

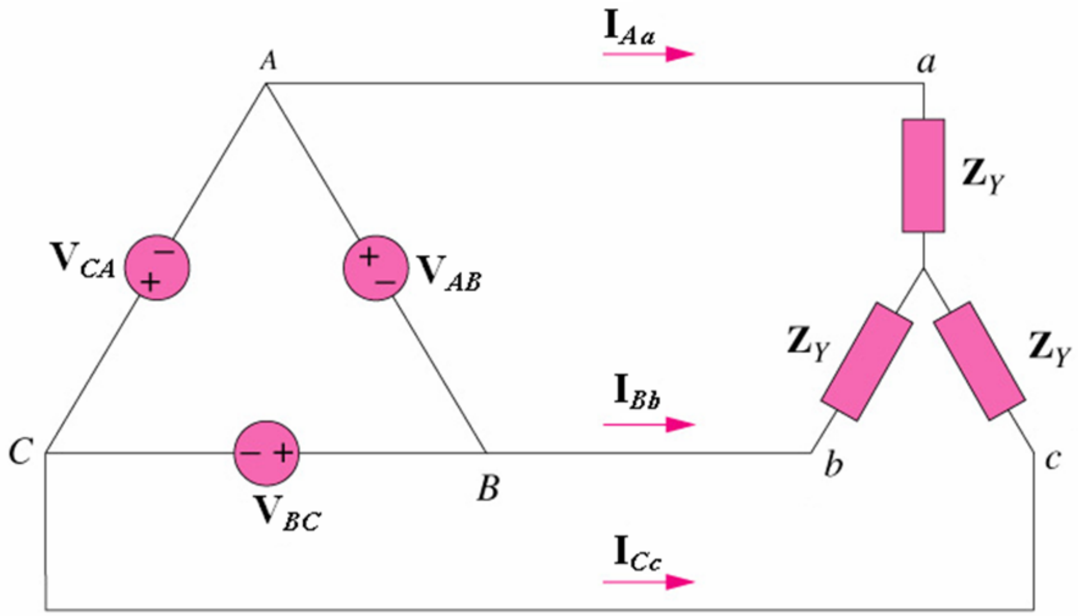
$\frac{V_L}{Z_{ph}} = I_{pL}$

3) Δ - Δ → 10Ω, j3Ω ↓ 9.5mH → V_p, I_p, I_L

$I_p = \frac{V_p}{Z}$

4) Δ - Y → 6Ω, j8Ω ↳ 400μF → V_L, $I_L = I_p = V_L/Z$ V_L, I_p, I_L

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.



The load impedance, Z_Y and the source voltage, V_{AB} are

$$\Rightarrow Z_Y = 40 + j25 = 47.17\angle 32^\circ\ \Omega$$

$$\Rightarrow V_{AB} = 210\angle 0^\circ\ V$$