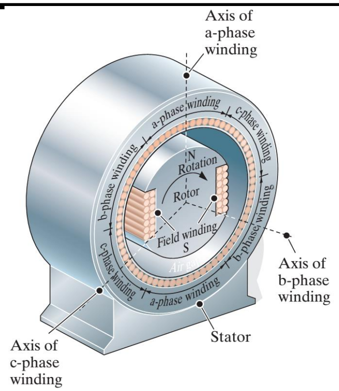
Lecture 12

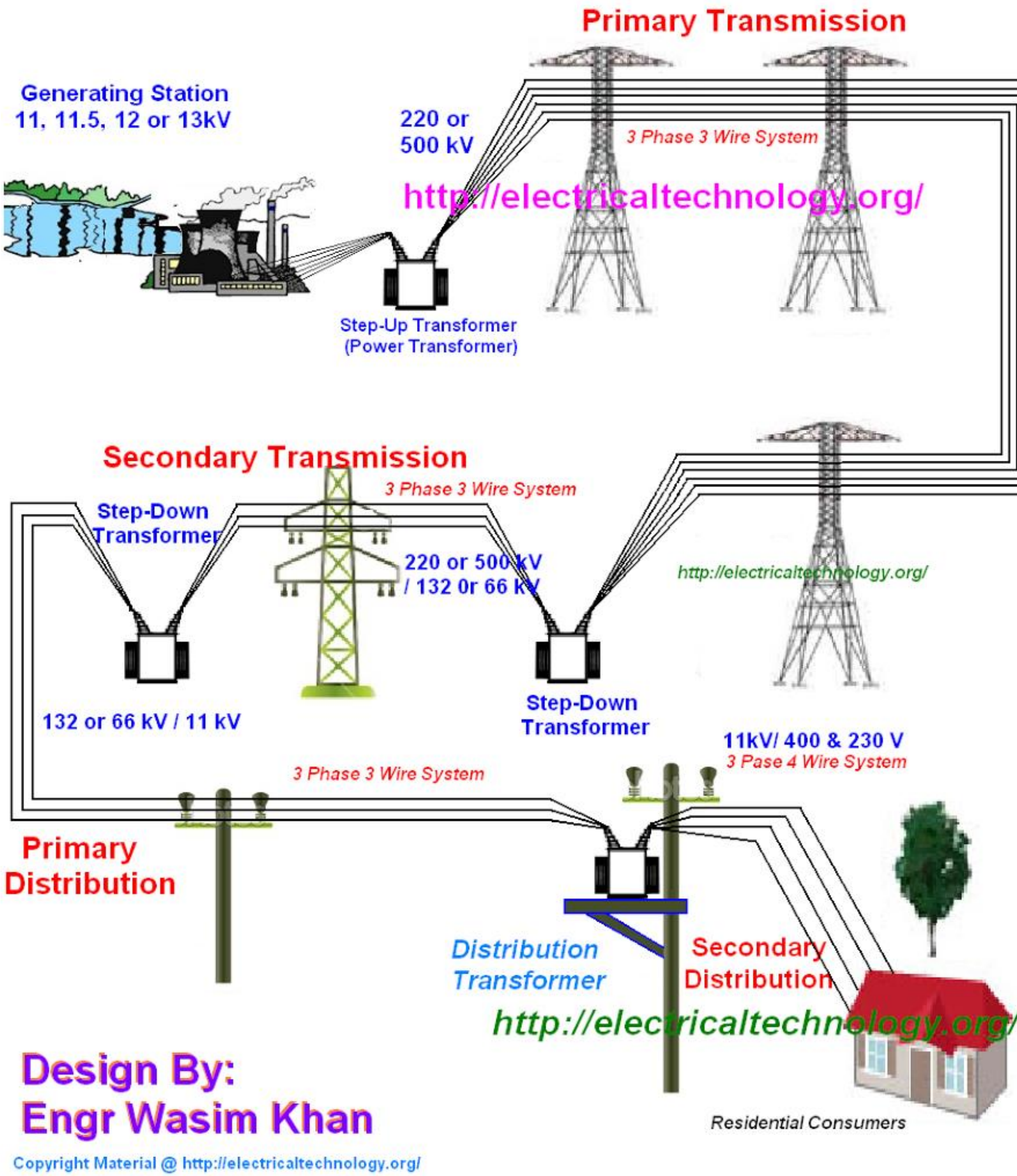
- Transformers/Three-Phase Circuits

Outline

- Balanced Three-Phase System (Wye - Wye)
  - Balanced sources
  - Balanced loads

- Circuit analysis (Wye - Wye)
  - Phase voltage/current
  - Line voltage/current

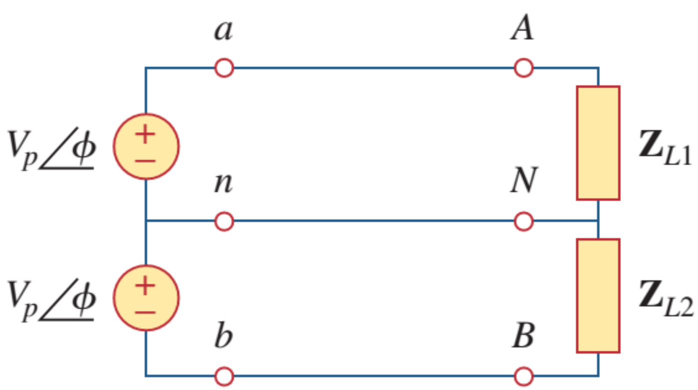

Axis of a-phase winding
a-phase winding
c-phase winding
N
Rotation
Rotor
Field winding
S
b-phase winding
c-phase winding
a-phase winding
Axis of b-phase winding
Stator
Axis of c-phase winding

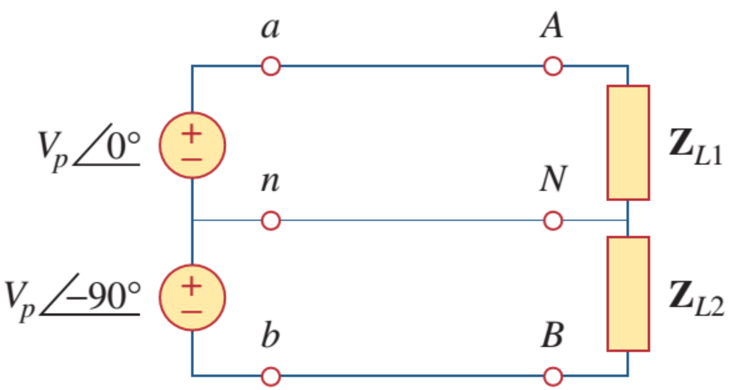

Primary Transmission
Generating Station
11, 11.5, 12 or 13kV
220 or
500 kV
3 Phase 3 Wire System
http://electricaltechnology.org/
Step-Up Transformer
(Power Transformer)
Secondary Transmission
3 Phase 3 Wire System
Step-Down
Transformer
220 or 500 kV
/ 132 0r 66 kV
http://electricaltechnology.org/
132 or 66 kV / 11 kV
Step-Down
Transformer
11kV/ 400 & 230 V
3 Pase 4 Wire System
3 Phase 3 Wire System
Primary
Distribution
Distribution
Transformer
Secondary
Distribution
http://electricaltechnology.org/
Design By:
Engr Wasim Khan
Residential Consumers
Copyright Material @ http://electricaltechnology.org/

Single Phase vs. Polyphase

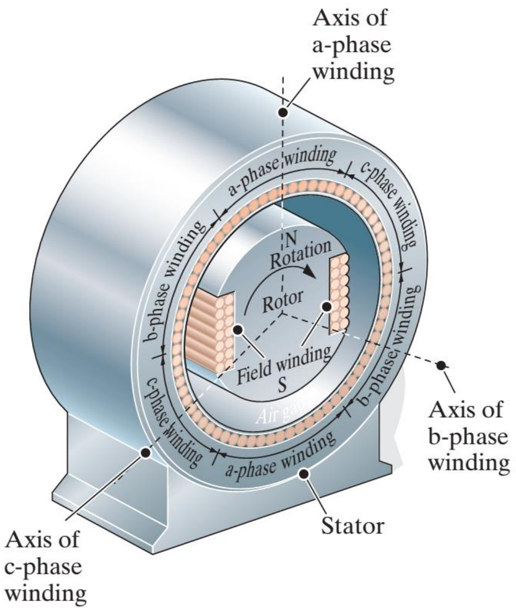
- Households have single-phase power supply
  - This typically in a three wire form

- Circuits that operate at the same frequency but with multiple sources at different phases are called polyphase.



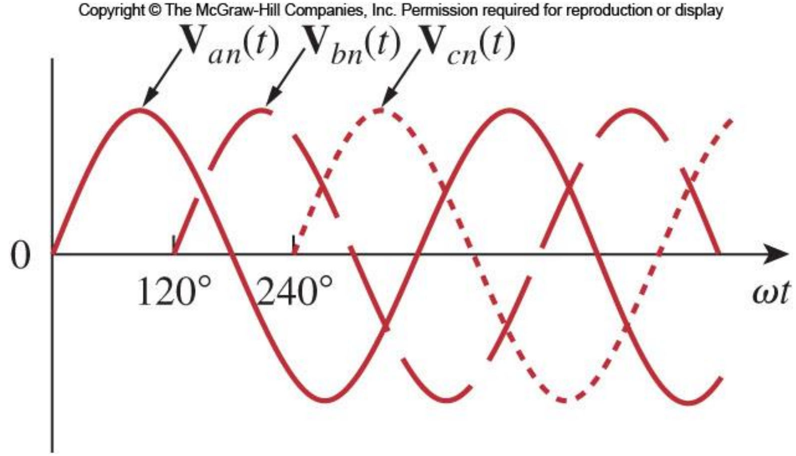


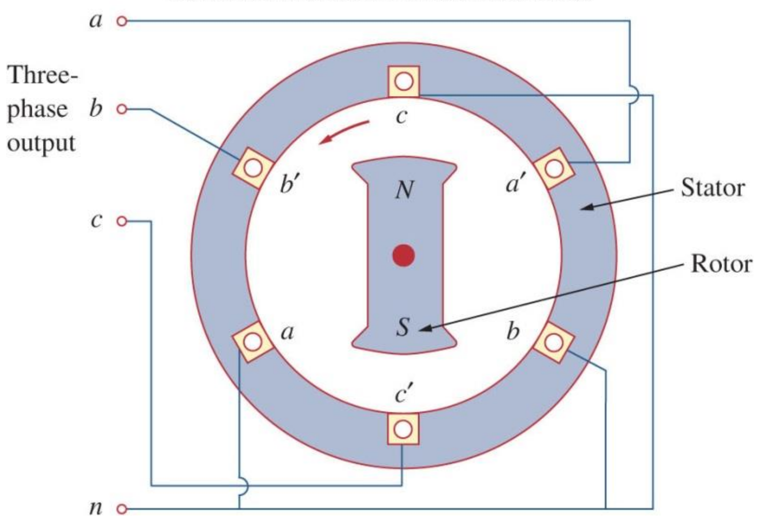
Balanced Three-Phase Sources



- Three phase voltages are typically produced by a three-phase AC generator.

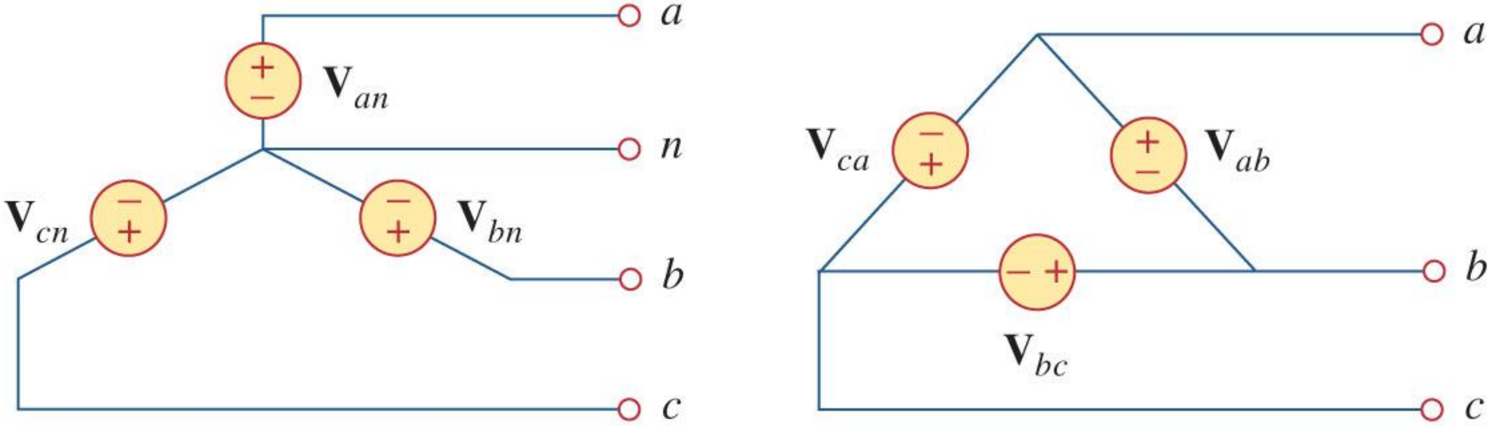
- The output voltages look like below.





Connecting the Sources

- Three phase voltage sources can be connected the loads by either three or four wire configurations.
  - Three-wire configuration accomplished by Delta connected source.
  - Four-wire system accomplished using a Y connected source.

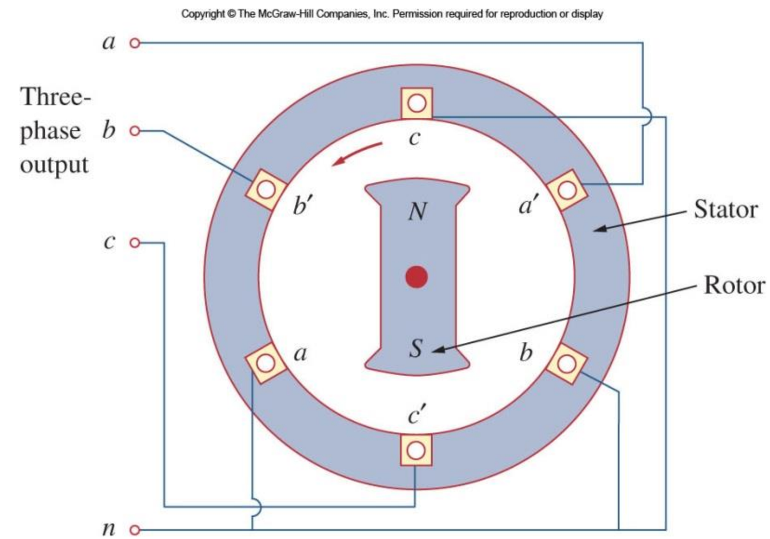


(a) (b)

Balanced Sources

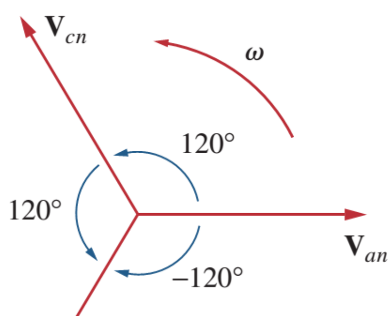
- A wye connected source is said to be balanced when

$$V_{an} + V_{bn} + V_{cn} = 0$$

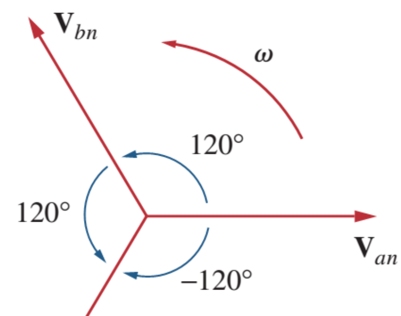


$$|V_{an}| = |V_{bn}| = |V_{cn}|$$

- Two sequences for the phases:



Positive



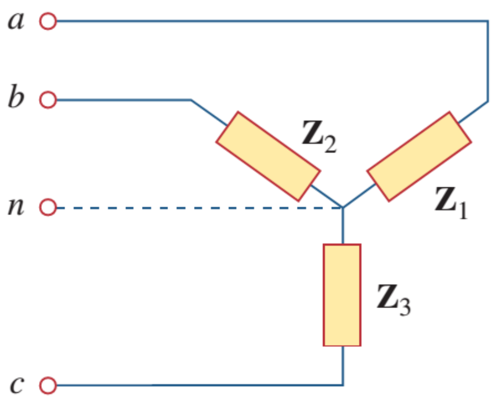
Negative

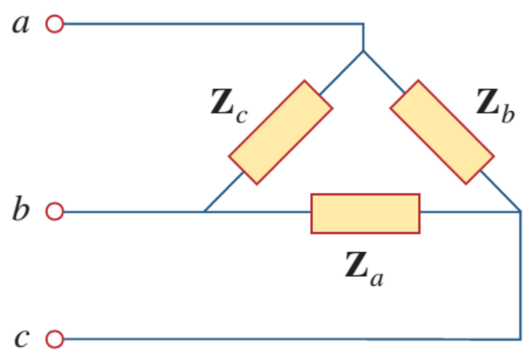
$$V_{an} = V_p \angle 0^\circ$$
$$V_{bn} = V_p \angle -120^\circ$$
$$V_{cn} = V_p \angle -240^\circ = V_p \angle +120^\circ$$

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

Balanced Loads

- Similar to the source, a <u>balanced</u> load is one that has the same impedance presented to all three voltage sources.
- They may also be connected in either Delta or wye
  - For a balanced wye connected load: $Z_1 = Z_2 = Z_3 = Z_Y$
  - For a balanced delta connected load: $Z_a = Z_b = Z_c = Z_\Delta$





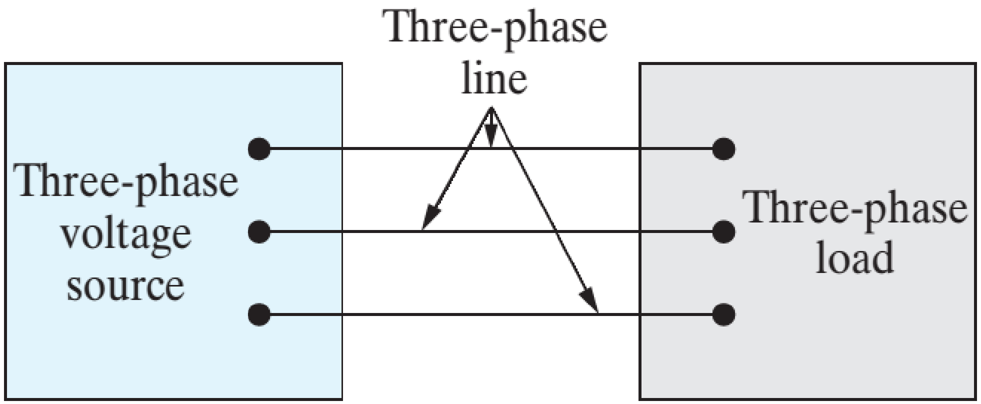
- The load impedance per phase for the two load configurations can be interchanged.

Outline

- Balanced Three-Phase System (Wye - Wye)
  - Balanced sources
  - Balanced loads

- Circuit analysis (Wye - Wye)
  - Phase voltage/current
  - Line voltage/current

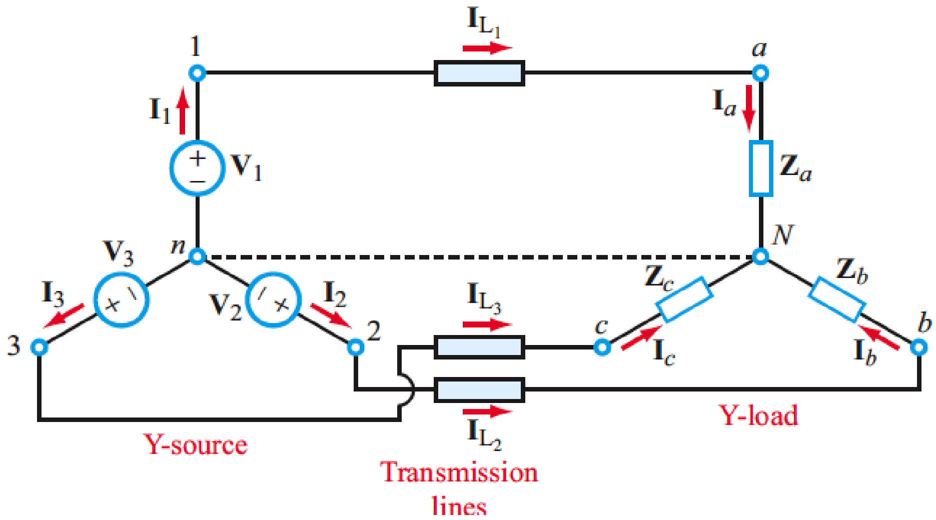
Source-Load configurations



Source	Load
Y	Y
Y	Δ
Δ	Y
Δ	Δ

Source-Load Configurations

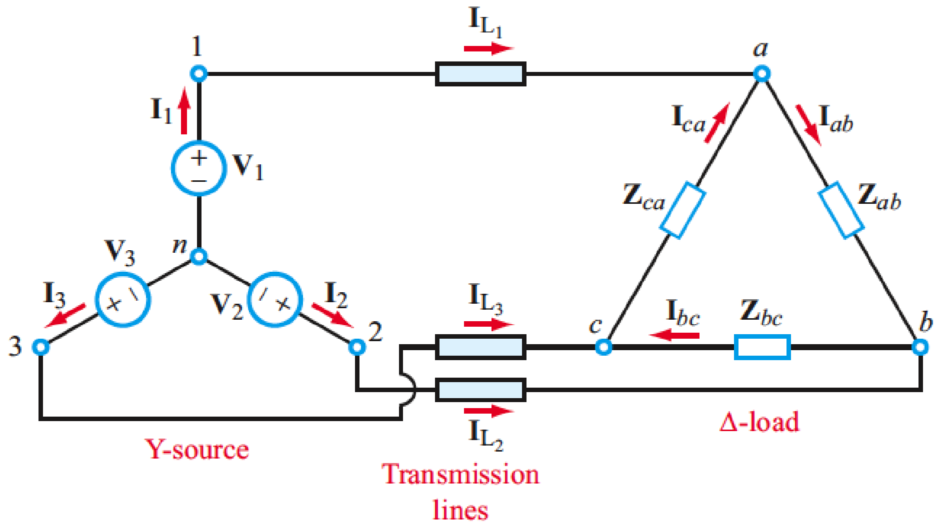
Y-Y



Load Phase Currents
I_a, I_b, I_c
(same as line currents I_{L_1}, I_{L_2}, and I_{L_3})

Load Phase Voltages
V_{aN}, V_{bN}, V_{cN}

Y-Delta

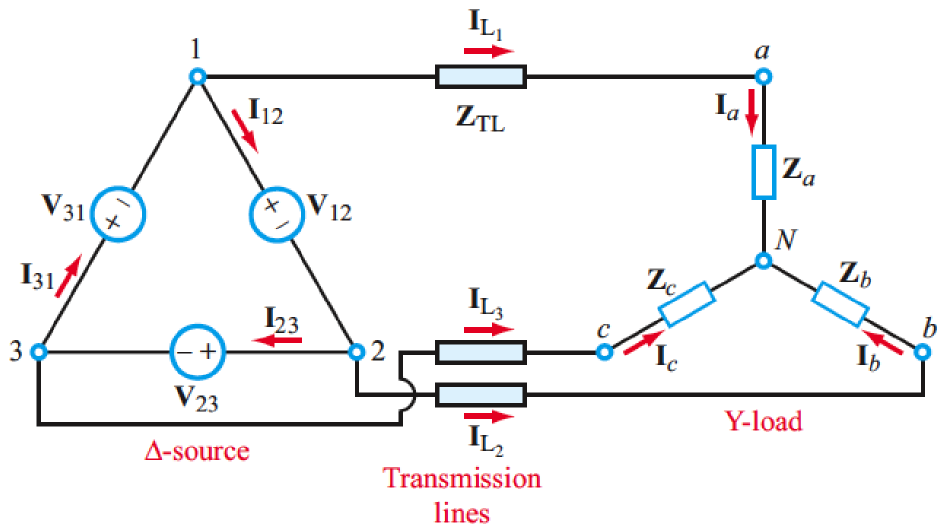


Load Phase Currents
I_{ab}, I_{bc}, I_{ca}

Load Phase Voltages
V_{ab}, V_{bc}, V_{ca}

Source-Load Configurations

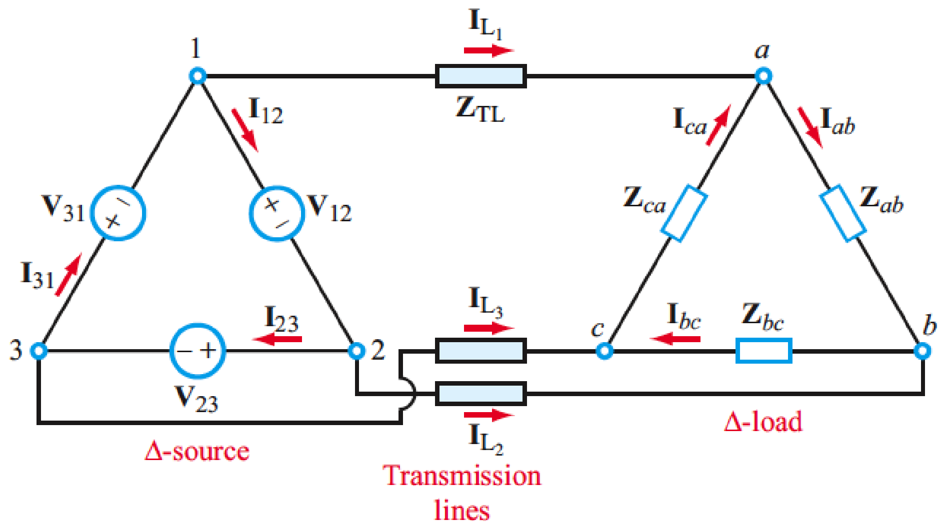
Delta-Y



Load Phase Currents
I_a, I_b, I_c
(same as line currents
I_{L_1}, I_{L_2}, and I_{L_3})

Load Phase Voltages
V_{aN}, V_{bN}, V_{cN}

Delta-Delta



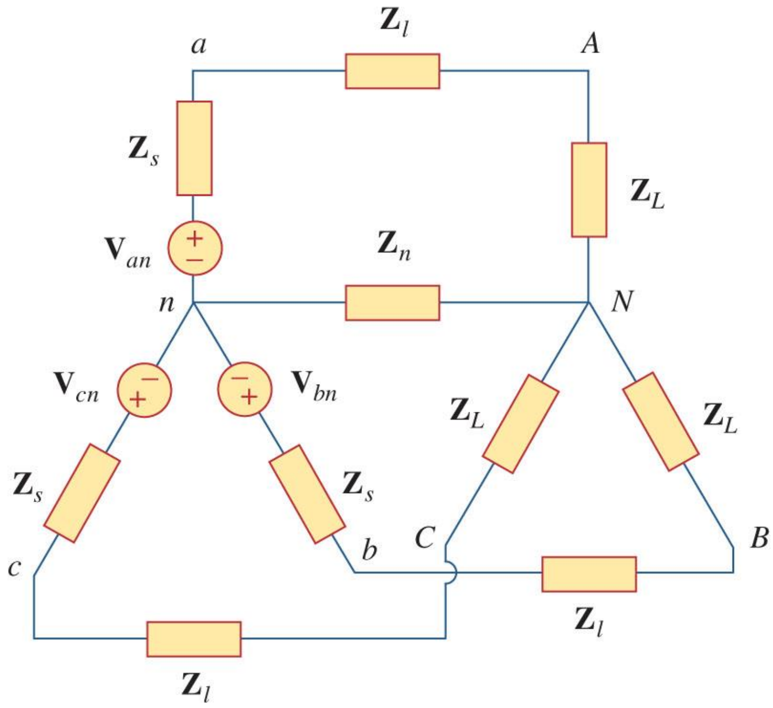
Load Phase Currents
I_{ab}, I_{bc}, I_{ca}

Load Phase Voltages
V_{ab}, V_{bc}, V_{ca}
(same as source voltages
if Z_{TL} is negligible)

Balanced Y-Y connection

- Any three-phase system can be reduced to an equivalent Y-Y system.
- The load impedances Z_y will be assumed to be balanced.
  - This can be the source Z_s, line Z_l and load Z_L together.

$$\mathbf{Z}_Y = \mathbf{Z}_s + \mathbf{Z}_\ell + \mathbf{Z}_L$$



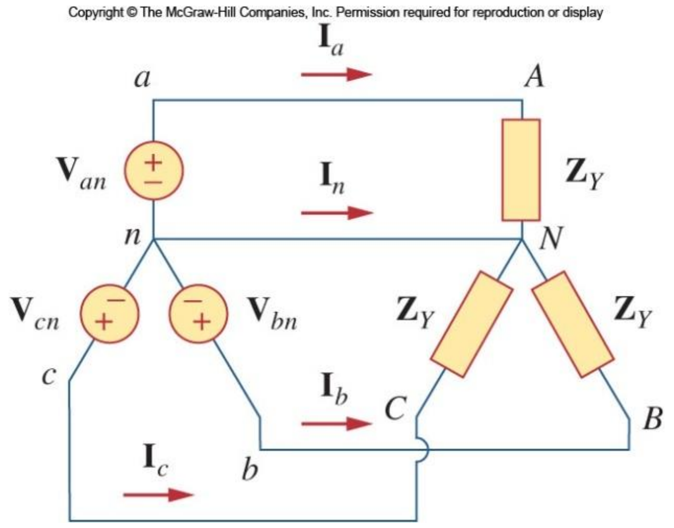
Line-to-Line Voltage

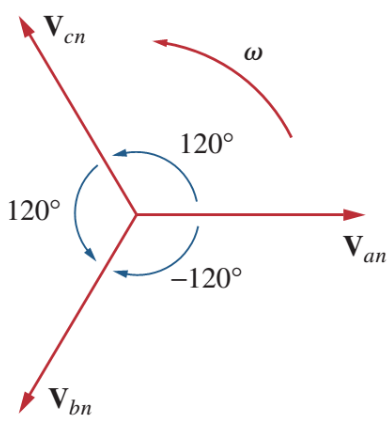
- Use the positive sequence:

$$V_{an} = V_p \angle 0^\circ$$

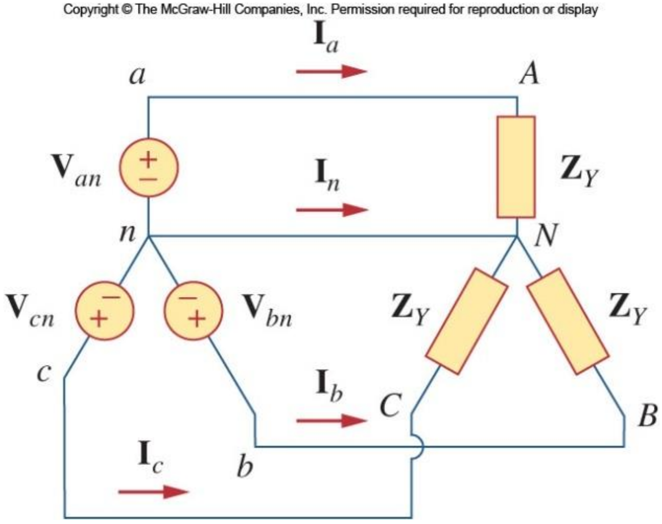
$$V_{bn} = V_p \angle -120^\circ \quad V_{cn} = V_p \angle +120^\circ$$

The line to line (or line in short) voltages:



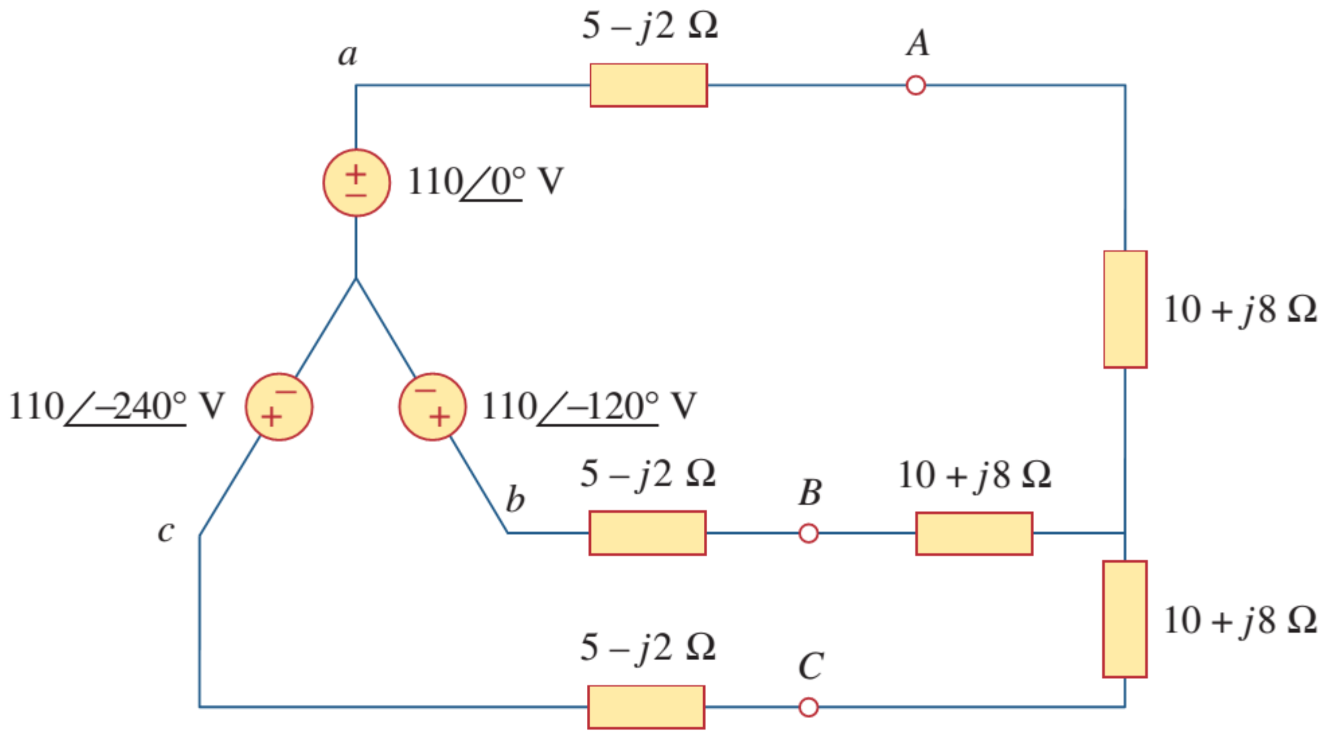


Line Currents



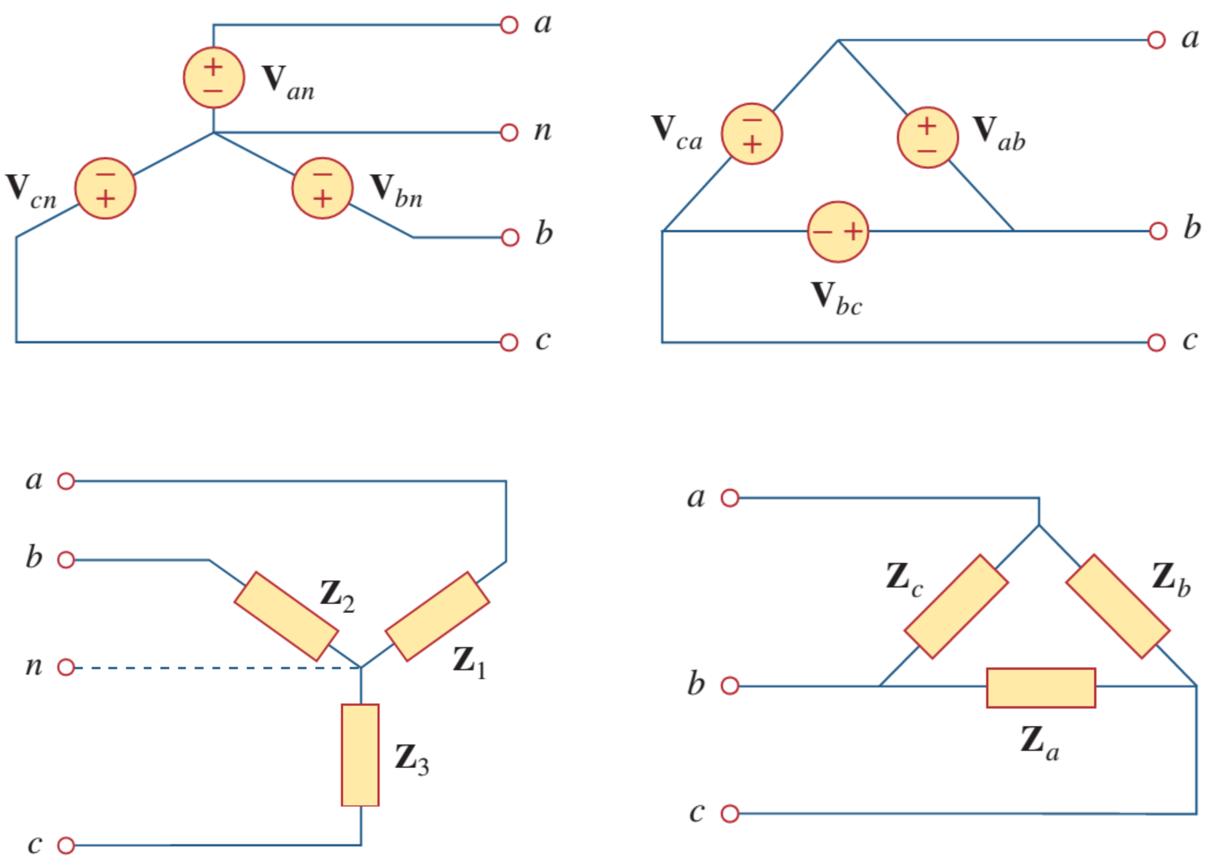
Example

- Calculate the line currents.



Connection	Phase voltages/currents	Line voltages/currents
Y-Y	$\mathbf{V}_{an} = V_p\angle 0^\circ$ $\mathbf{V}_{bn} = V_p\angle -120^\circ$ $\mathbf{V}_{cn} = V_p\angle +120^\circ$	$\mathbf{V}_{ab} = \sqrt{3}V_p\angle 30^\circ$ $\mathbf{V}_{bc} = \mathbf{V}_{ab}\angle -120^\circ$ $\mathbf{V}_{ca} = \mathbf{V}_{ab}\angle +120^\circ$
	Same as line currents	$\mathbf{I}_a = \mathbf{V}_{an}/\mathbf{Z}_Y$ $\mathbf{I}_b = \mathbf{I}_a\angle -120^\circ$ $\mathbf{I}_c = \mathbf{I}_a\angle +120^\circ$
Y-Δ	$\mathbf{V}_{an} = V_p\angle 0^\circ$ $\mathbf{V}_{bn} = V_p\angle -120^\circ$ $\mathbf{V}_{cn} = V_p\angle +120^\circ$	$\mathbf{V}_{ab} = \mathbf{V}_{AB} = \sqrt{3}V_p\angle 30^\circ$ $\mathbf{V}_{bc} = \mathbf{V}_{BC} = \mathbf{V}_{ab}\angle -120^\circ$ $\mathbf{V}_{ca} = \mathbf{V}_{CA} = \mathbf{V}_{ab}\angle +120^\circ$
	$\mathbf{I}_{AB} = \mathbf{V}_{AB}/\mathbf{Z}_\Delta$ $\mathbf{I}_{BC} = \mathbf{V}_{BC}/\mathbf{Z}_\Delta$ $\mathbf{I}_{CA} = \mathbf{V}_{CA}/\mathbf{Z}_\Delta$	$\mathbf{I}_a = \mathbf{I}_{AB}\sqrt{3}\angle -30^\circ$ $\mathbf{I}_b = \mathbf{I}_a\angle -120^\circ$ $\mathbf{I}_c = \mathbf{I}_a\angle +120^\circ$
Δ-Δ	$\mathbf{V}_{ab} = V_p\angle 0^\circ$ $\mathbf{V}_{bc} = V_p\angle -120^\circ$ $\mathbf{V}_{ca} = V_p\angle +120^\circ$	Same as phase voltages
	$\mathbf{I}_{AB} = \mathbf{V}_{ab}/\mathbf{Z}_\Delta$ $\mathbf{I}_{BC} = \mathbf{V}_{bc}/\mathbf{Z}_\Delta$ $\mathbf{I}_{CA} = \mathbf{V}_{ca}/\mathbf{Z}_\Delta$	$\mathbf{I}_a = \mathbf{I}_{AB}\sqrt{3}\angle -30^\circ$ $\mathbf{I}_b = \mathbf{I}_a\angle -120^\circ$ $\mathbf{I}_c = \mathbf{I}_a\angle +120^\circ$
Δ-Y	$\mathbf{V}_{ab} = V_p\angle 0^\circ$ $\mathbf{V}_{bc} = V_p\angle -120^\circ$ $\mathbf{V}_{ca} = V_p\angle +120^\circ$	Same as phase voltages
	Same as line currents	$\mathbf{I}_a = \dfrac{V_p\angle -30^\circ}{\sqrt{3}\mathbf{Z}_Y}$ $\mathbf{I}_b = \mathbf{I}_a\angle -120^\circ$ $\mathbf{I}_c = \mathbf{I}_a\angle +120^\circ$

Y and Δ, Which One Better?



http://www.allaboutcircuits.com/textbook/alternating-current/chpt-10/three-phase-y-delta-configurations/