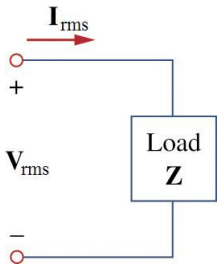
Lesson 27: 3-phase circuit analysis 1

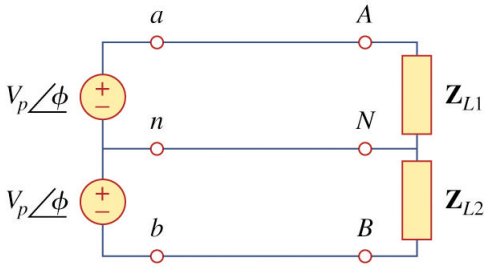
Complex power (review)
Determine the power (*P*, *Q*, and S) by load Z.



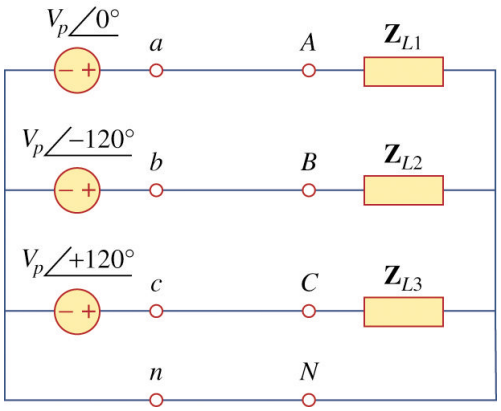
Single-phase system (2-wire)
A single-phase ac power system consists of a generator connected through a pair of wires (transmission line) to a load.

- V_P is the magnitude of the source voltage given in RMS (the subscript *P* is for phase, not peak).
- ϕ is the phase.
- This is a _____-wire system.

Single-phase system (3-wire)
A three-wire single-phase system consists of two identical sources (equal _____ and _____) connected to two loads by two outer wires and a neutral.
This is typical of power supplied to houses.

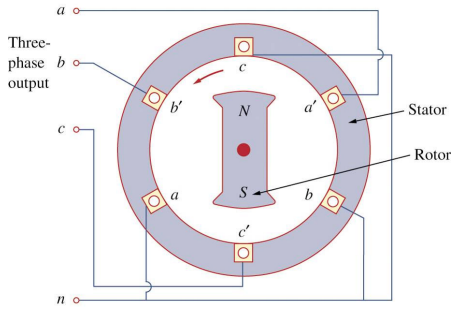


Three-phase system (4-wire)
A three-phase system is produced by three sources with the same amplitude and frequency but separated in phase by _____.



Why three-phase?

1. Nearly all power generated and distributed is 3-phase, ___ Hz (or 50 Hz outside the U.S.).
- When single phase is needed, it can simply be taken from one of the three phases.
2. The instantaneous power in 3-phase system can be _____ (not pulsating).
- Results in less _____ in 3-phase machines.
3. Three phase systems are more economical that single.
- Amount of _____ needed is less than single phase.



Balanced three-phase voltages

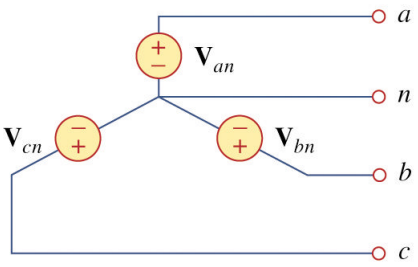
Three-phase voltages are produced by a three-phase ac generator (or alternator).

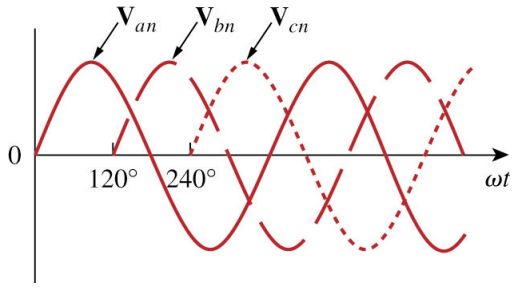
The stator contains 3 windings (*a*-*a*′, *b*-*b*′, *c*-*c*′) physically separated by _____°.

The voltages induced in the windings are equal in magnitude but out of phase by 120°.

The voltages $\mathbf{V}_{an}$, $\mathbf{V}_{bn}$, and $\mathbf{V}_{cn}$ are between lines *a*, *b* and *c* and the neutral line *n*.

These are called _____ voltages.





Balanced three-phase voltages

If the voltages are equal in magnitude but out of phase by 120° they are said to be balanced.

This implies

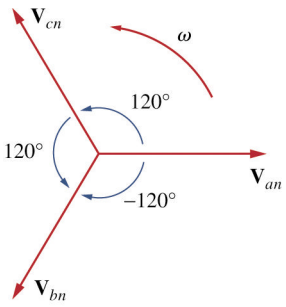
$$\mathbf{V}_{an} + \mathbf{V}_{bn} + \mathbf{V}_{cn} = 0$$

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

Positive phase sequence (*abc*)

The _____ sequence or _____ sequence.

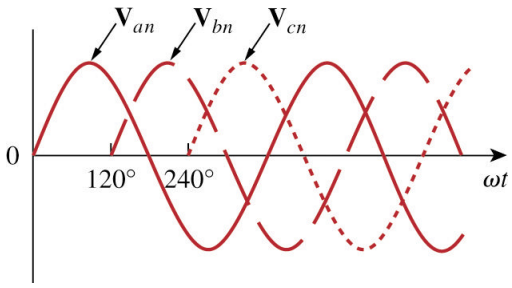
Note: V_P is the rms value of the phase voltage.



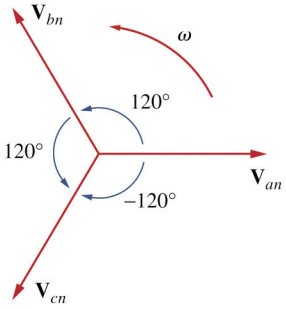
$\mathbf{V}_{an} =$

$\mathbf{V}_{bn} =$

$\mathbf{V}_{cn} =$



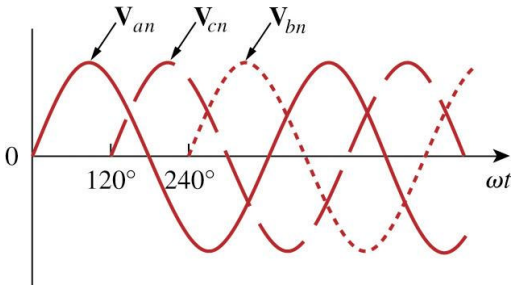
Negative phase sequence (*acb*)
The *acb* or negative sequence is produced when the generator rotates counterclockwise.



$\mathbf{V}_{an} =$

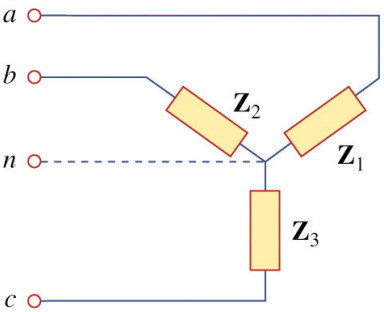
$\mathbf{V}_{cn} =$

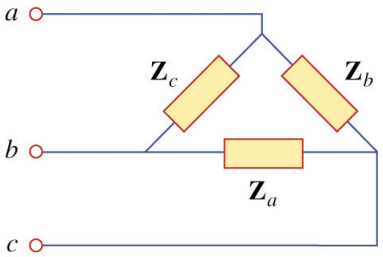
$\mathbf{V}_{bn} =$



Phase sequence
The phase sequence is the time order in which the voltages pass through their respective maximum values.
Phase sequence is important because it determines the _____ of a connected motor.

Three-phase loads
Three-phase loads can be either _____-connected or _____-connected.
Loads are said to be balanced if phase impedances ($\mathbf{Z}_1$, $\mathbf{Z}_2$, $\mathbf{Z}_3$ or $\mathbf{Z}_a$, $\mathbf{Z}_b$, $\mathbf{Z}_c$) are equal in magnitude and phase.

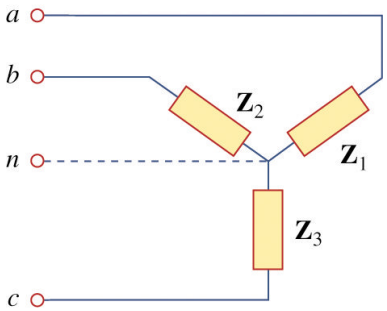




Wye-connected load
Whether a _____ line exists depends on if it is a three or four-wire system.
For a balanced wye-connected load

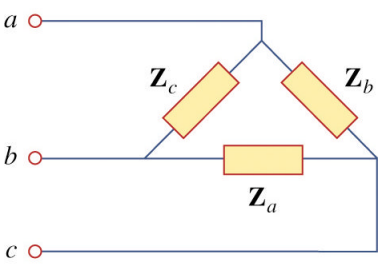
$$\mathbf{Z}_1 = \mathbf{Z}_2 = \mathbf{Z}_3 =$$

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



Delta-connected load
A neutral line cannot exist in a Δ-connected load.
For a balanced Δ-connected load (where $\mathbf{Z}_\Delta$ is the load per phase.)

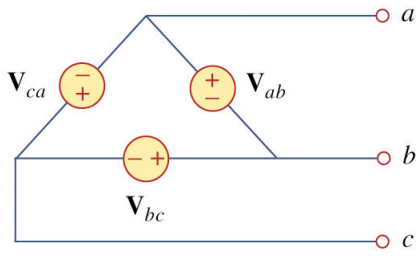
$$\mathbf{Z}_a = \mathbf{Z}_b = \mathbf{Z}_c =$$



Delta-wye transformation
How can we equate the wye- and delta-connected (balanced) loads?

For balanced loads, $\mathbf{Z}_\Delta =$ or $\mathbf{Z}_Y =$

Delta-connected sources
Sources may also be delta-connected.

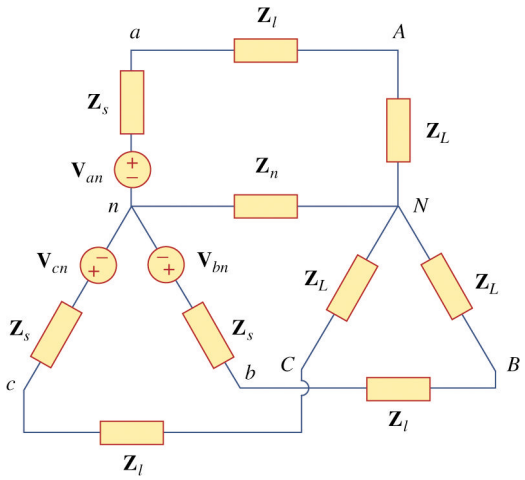


In practice, this is rarely done because slight imbalances in the voltages result in a circulating current in the delta-mesh

Three-phase systems
Given that both loads and sources can be Y-connected and Δ-connected, we have 4 possible combinations to consider

- Y-Y connection
- Y-Δ connection
- Δ-Δ connection
- Δ-Y connection

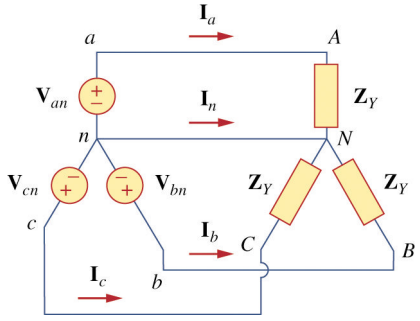
In reality, the most common configuration is _____ .



Balanced Y-Y connection
We will consider a four-wire Y-Y system.

$\mathbf{Z}_Y =$

The impedance $\mathbf{Z}_Y$ can be thought of as the sum of the _____, _____ and _____ impedances.

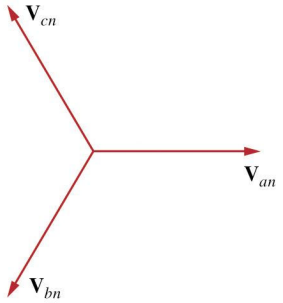


Balanced Y-Y connection
Because $\mathbf{Z}_S$ and $\mathbf{Z}_l$ are often quite small compared to $\mathbf{Z}_L$, we will assume $\mathbf{Z}_Y = \mathbf{Z}_L$, simplifying our Y-Y system.

Source-load labeling convention
_____ are labeled using lowercase letters.
_____ are labeled using uppercase letters.

Line voltages

How are the line voltages ($\mathbf{V}_{ab}$, $\mathbf{V}_{bc}$, $\mathbf{V}_{ca}$) related to the phase voltages ($\mathbf{V}_{an}$, $\mathbf{V}_{bn}$, $\mathbf{V}_{an}$) ?



$$\mathbf{V}_{ab} = \mathbf{V}_{ab} - \mathbf{V}_{bn} =$$

$$\mathbf{V}_{bc} = \sqrt{3}V_P\angle$$

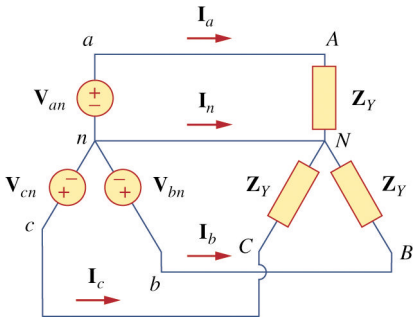
$$\mathbf{V}_{ca} = \sqrt{3}V_P\angle$$

Line voltage are _____ times larger and lead their respective phase voltages by ____.

Line currents

What are the line currents ($\mathbf{I}_a$, $\mathbf{I}_b$, $\mathbf{I}_c$)?

What is the neutral line current ($\mathbf{I}_n$)?



Line currents are given

$$\mathbf{I}_a =$$

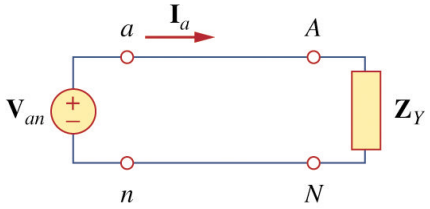
$$\mathbf{I}_b = \frac{\mathbf{V}_{bn}}{\mathbf{Z}_Y} = \frac{\mathbf{V}_{an}\angle -120°}{\mathbf{Z}_Y} =$$

$$\mathbf{I}_c = \frac{\mathbf{V}_{cn}}{\mathbf{Z}_Y} = \frac{\mathbf{V}_{an}\angle -240°}{\mathbf{Z}_Y} =$$

Since $\mathbf{I}_a + \mathbf{I}_b + \mathbf{I}_c = 0$, if follows that $\mathbf{I}_n$ = _____ .

Single-phase equivalent

In analyzing a balanced Y-Y system, it is sufficient to examine just one of the phases and apply the results to the other two phases (with appropriate phase delays).



Example Problem 1

Determine the phase sequence of the set of voltages.

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

Example Problem 2

Calculate the line currents in the three-wire Y-Y system.