Electrical Science: 2021-22

Lecture 17

Three Phase AC Circuits - Part 1

By Dr. Sanjay Vidhyadharan

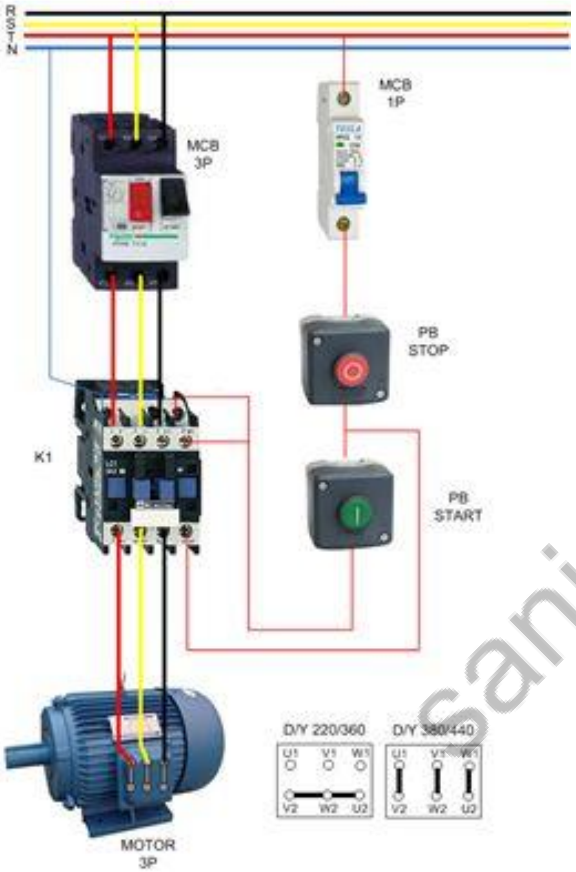
Three Phase Alternating Currents

Locomotive Engines

Electric Automobiles

Three Phase Alternating Currents

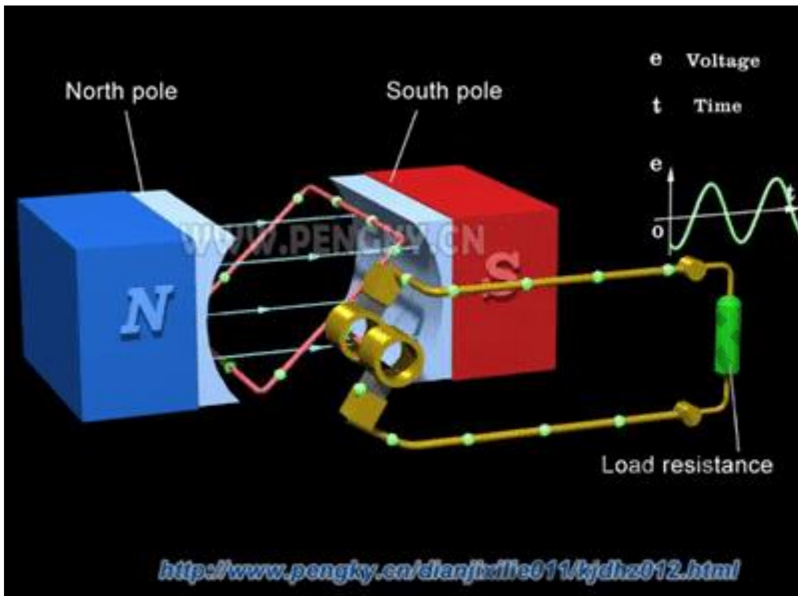
Pumps

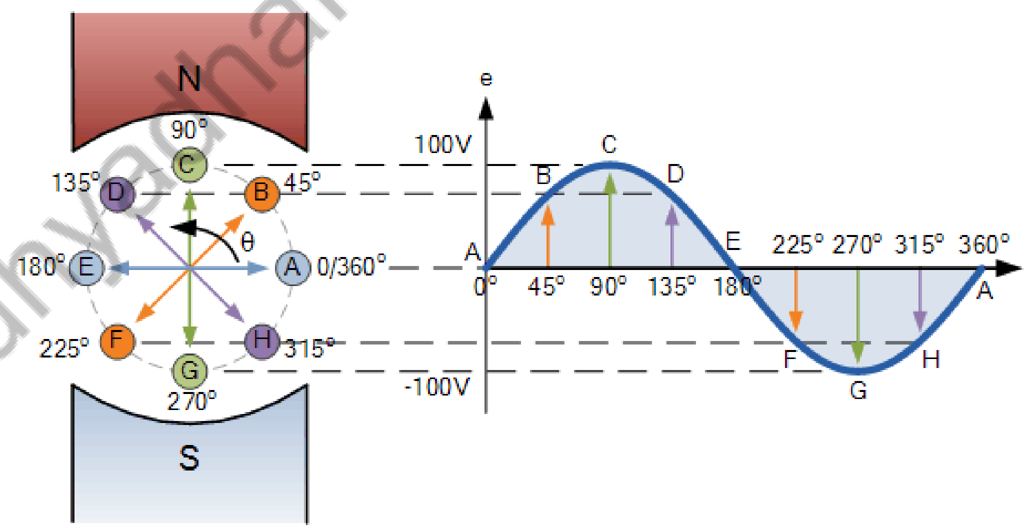


Welding Machines

Three Phase Alternating Currents

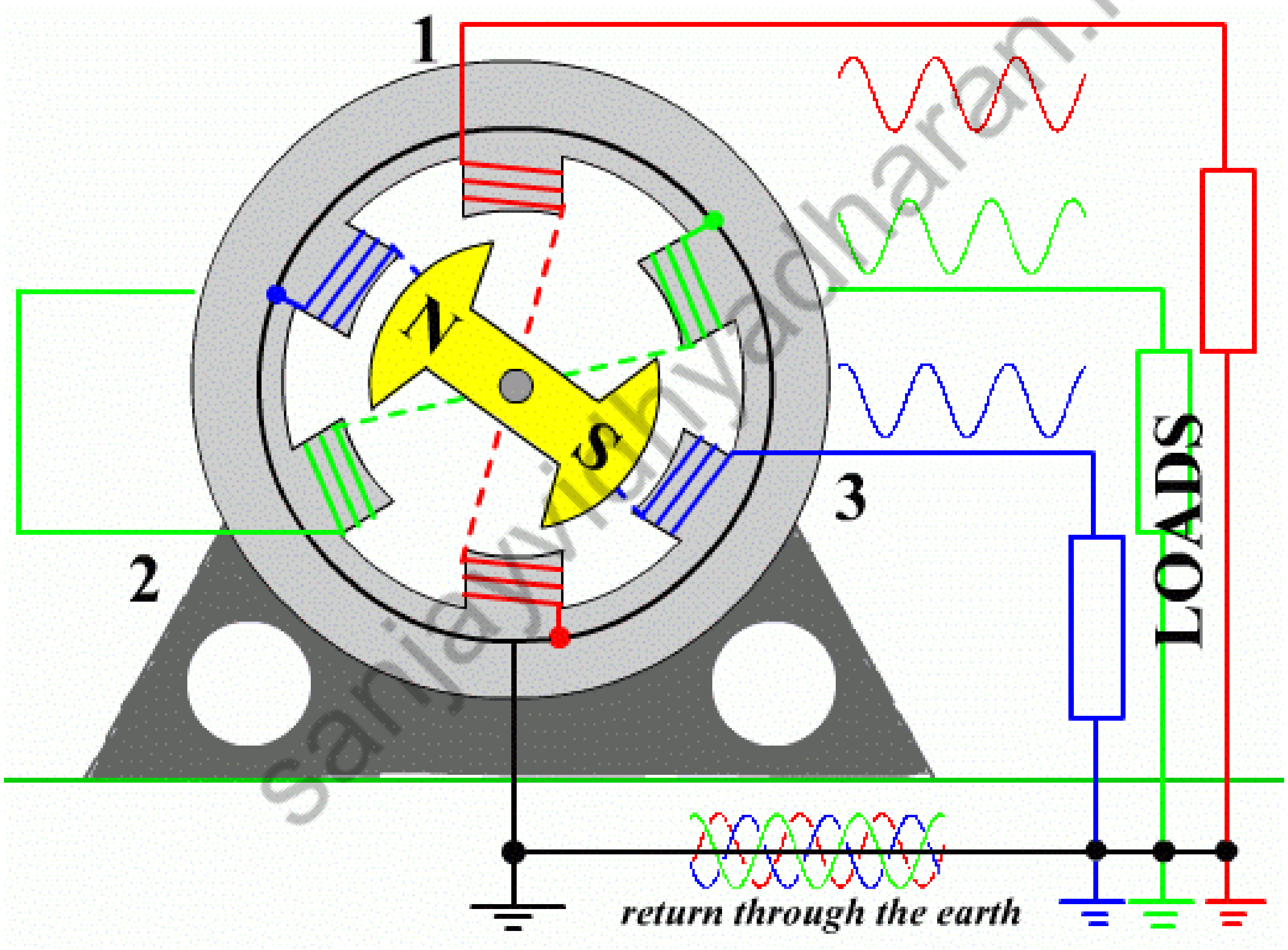
Single-Phase System:





Three Phase Alternating Currents

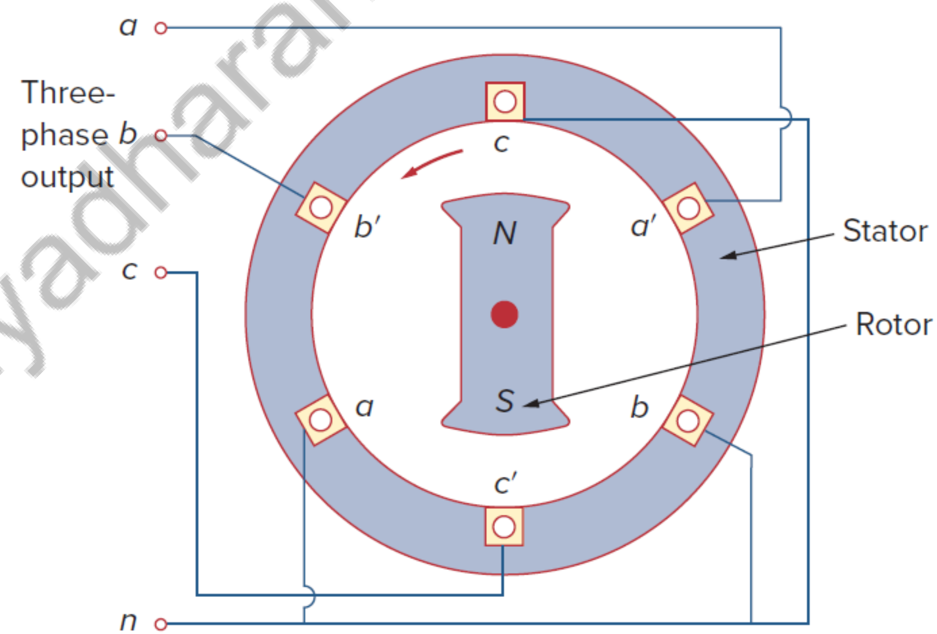
Three-Phase System:



BALANCED THREE-PHASE VOLTAGES

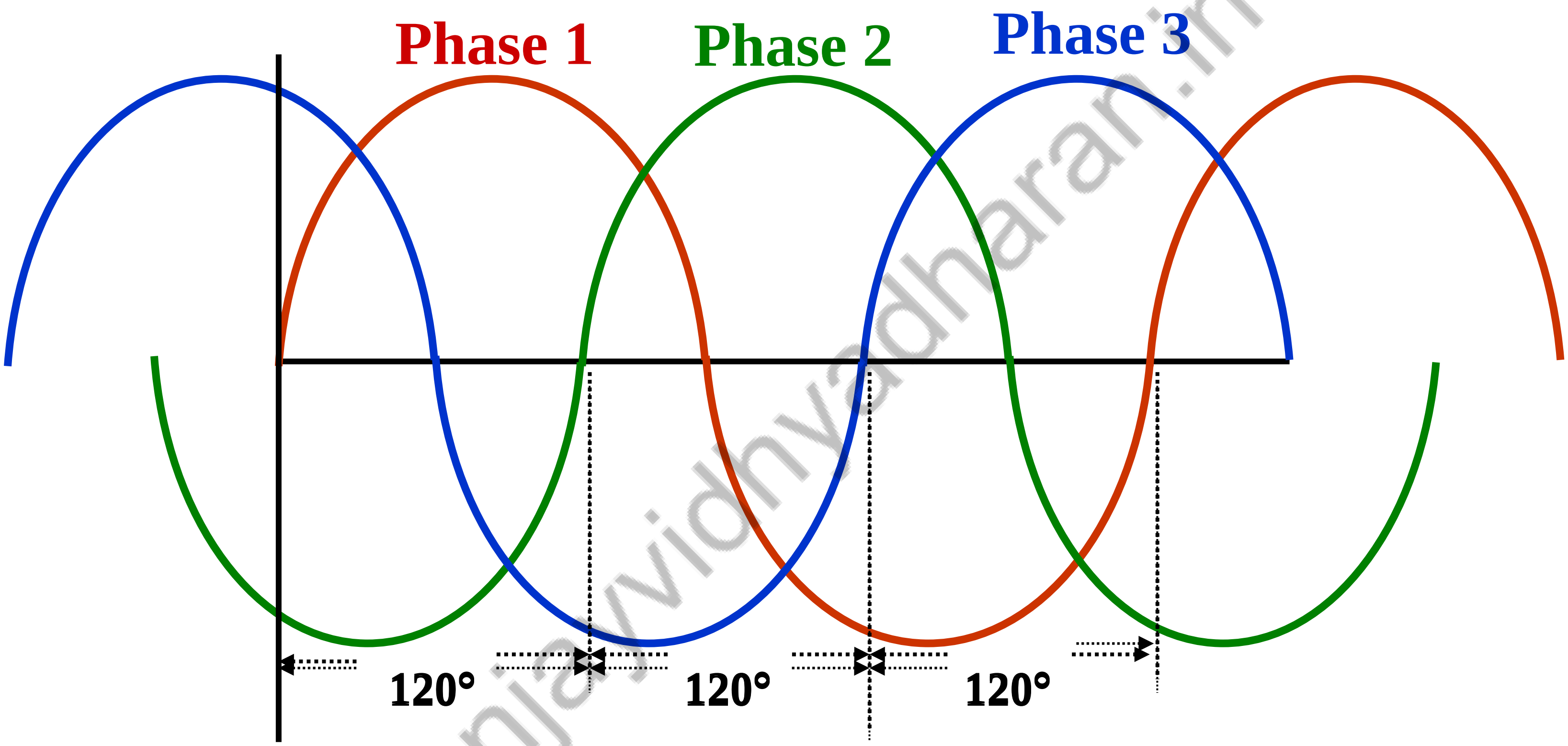
The generator basically consists of a

- Rotating magnet (called the rotor).
- Stationary winding (called the stator).
- Three separate windings or coils with terminals a-a′, b-b′, and c-c′ are physically placed 120° apart around the stator.



Three-phase generator

BALANCED THREE-PHASE VOLTAGES

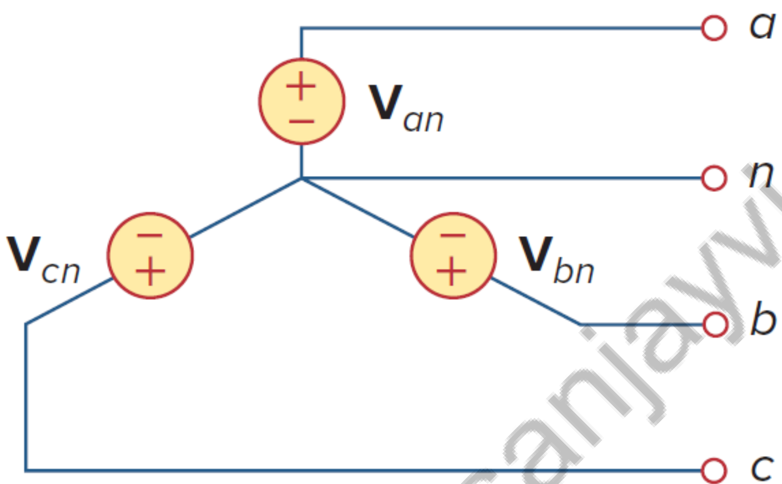


Phase 2 lags phase 1 by 120°.   Phase 2 leads phase 3 by 120°.

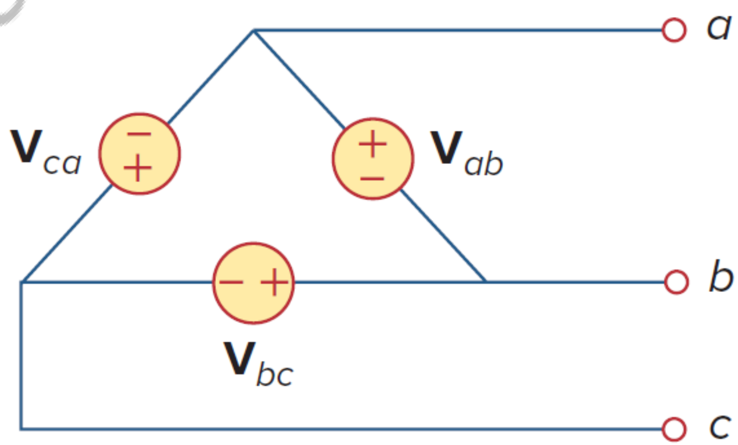
THREE-PHASE VOLTAGES

A typical three-phase system consists of three voltage sources connected to loads by three or four wires (or transmission lines).

The voltage sources can be either wye connected or delta-connected.



Y-connected source



Δ-connected source

THREE-PHASE VOLTAGES

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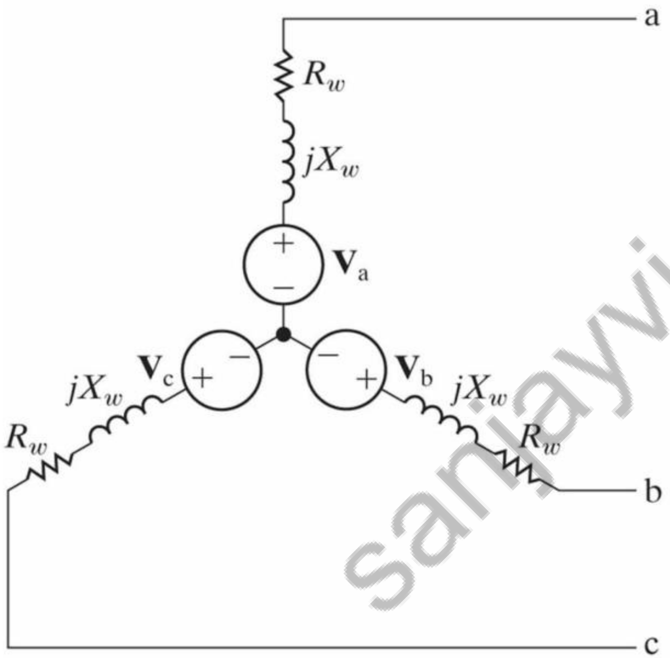
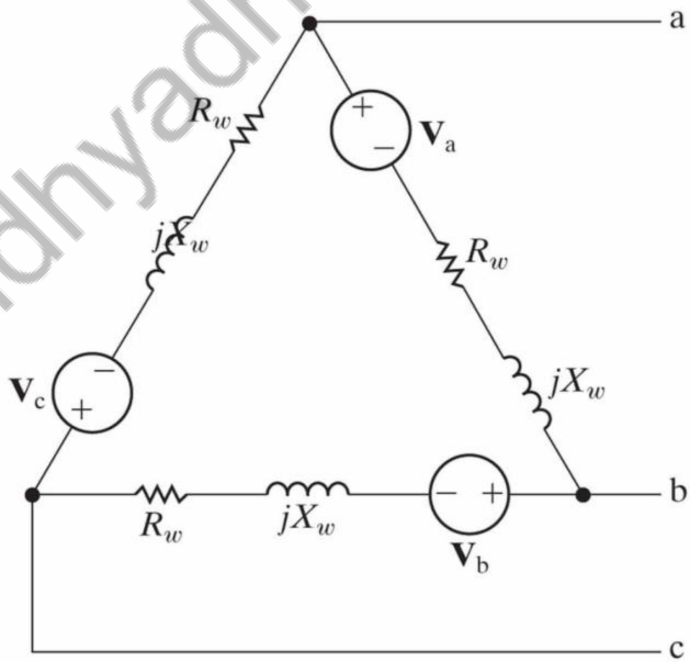


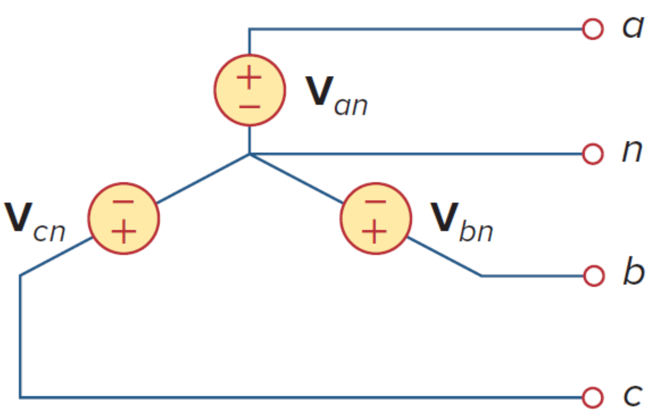
Y-connected source

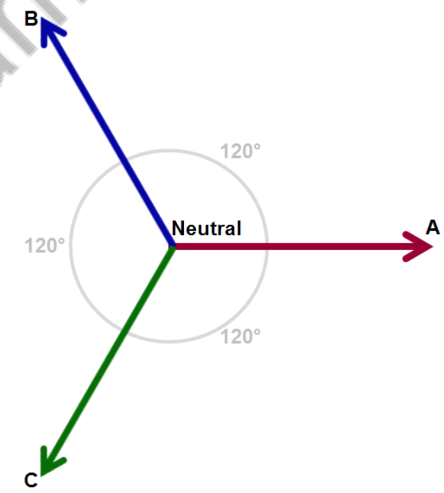


Δ-connected source

WYE CONNECTED THREE-PHASE SYSTEM

Balanced Phase Voltage





Phase voltages: voltages between lines a, b, and c and the neutral line n (V_{an} , V_{bn} , and V_{cn}).

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.

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

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

WYE CONNECTED THREE-PHASE SYSTEM

Balanced Phase Voltage

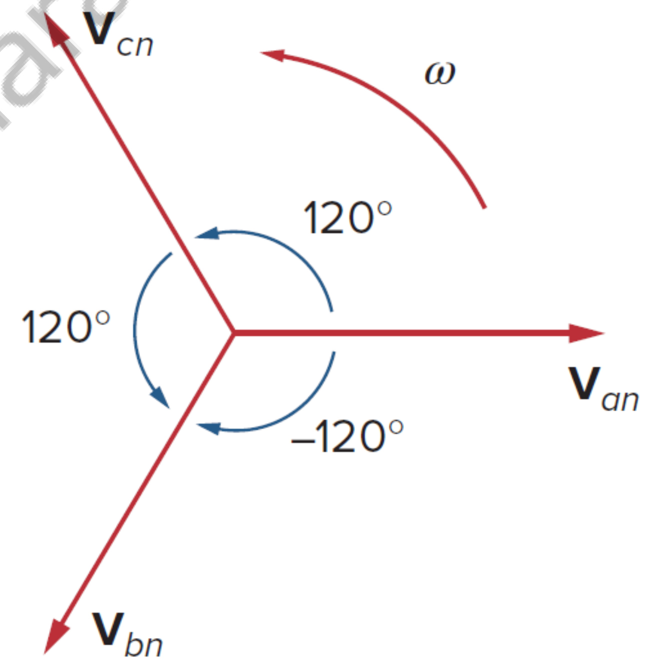
abc Sequence or Positive Sequence

Rotor has to rotate counter-clockwise.

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

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

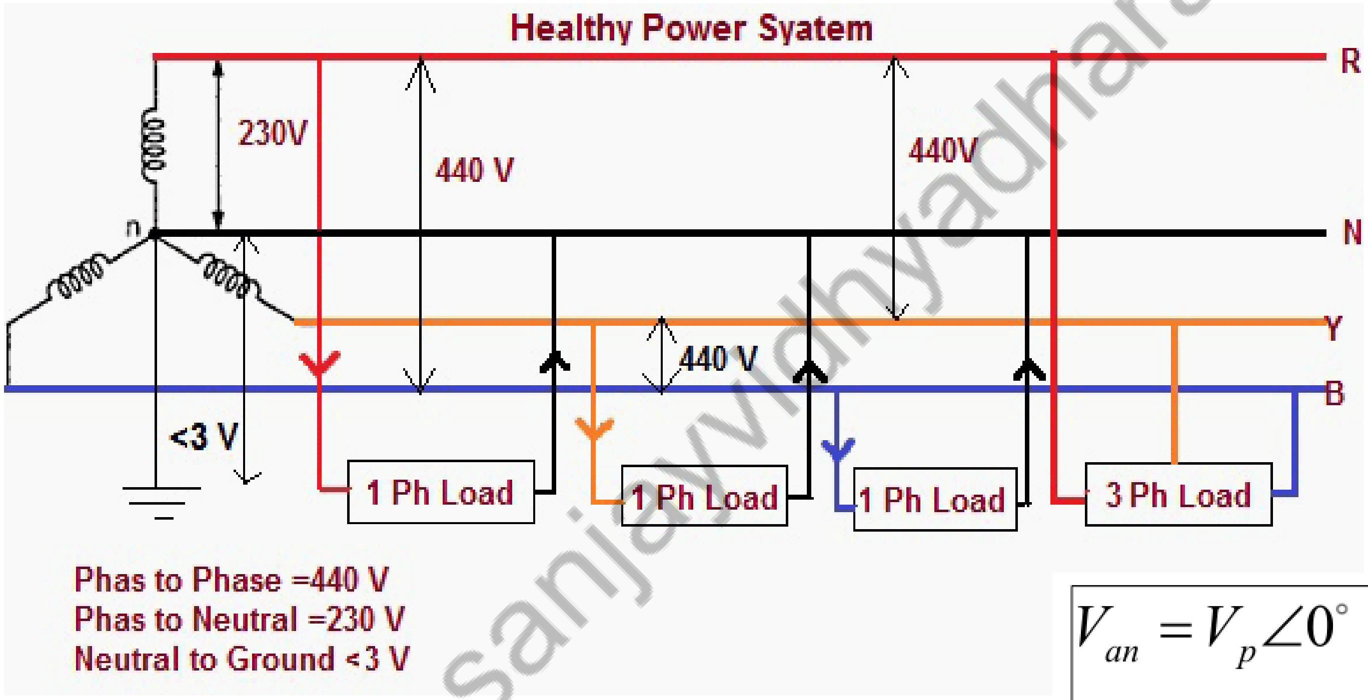
$$V_{cn} = V_p \angle -240^\circ = V_p \angle +120^\circ$$



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

WYE CONNECTED PHASE VOLTAGE

Phase voltage is measured between the neutral and any line: line to neutral voltage



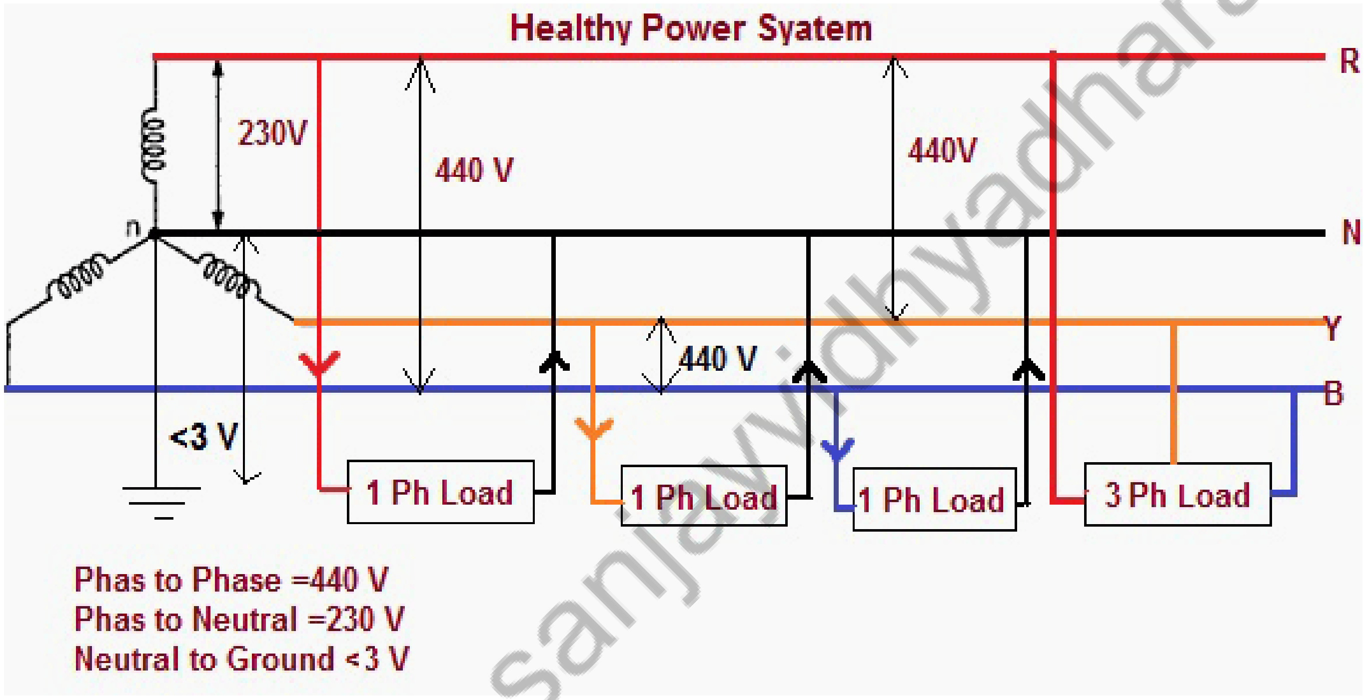
$$V_{an} = V_p \angle 0^\circ$$

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

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

WYE CONNECTED LINE VOLTAGE

Line voltage is measured between any two of the three lines: line to line voltage.



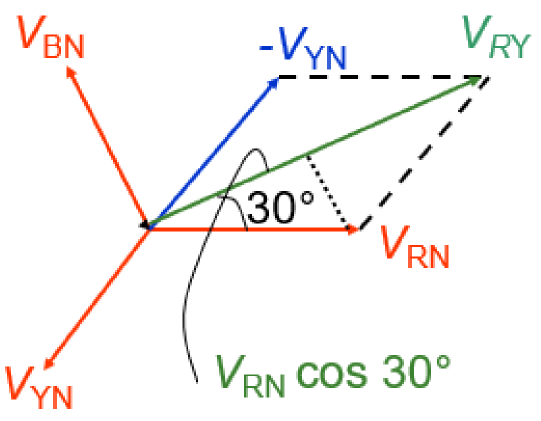
$$V_L = \sqrt{3} V_p$$

WYE CONNECTED LINE VOLTAGE

Line voltage is measured between any two of the three lines: line to line voltage.

$$V_{an} = V_p \angle 0 \,,\; V_{bn} = V_p \angle -120 \,,\; V_{cn} = V_p \angle +120$$

$$V_{ab} = V_{an} + V_{nb} = V_{an} - V_{bn} = V_p \angle 0^\circ - V_p \angle -120^\circ$$
$$= V_p \left(1 + \frac{1}{2} + j\frac{\sqrt{3}}{2}\right) = \sqrt{3} V_p \angle 30^\circ$$



$$V_{bc} = V_{bn} - V_{cn} = \sqrt{3} V_p \angle -90^\circ$$

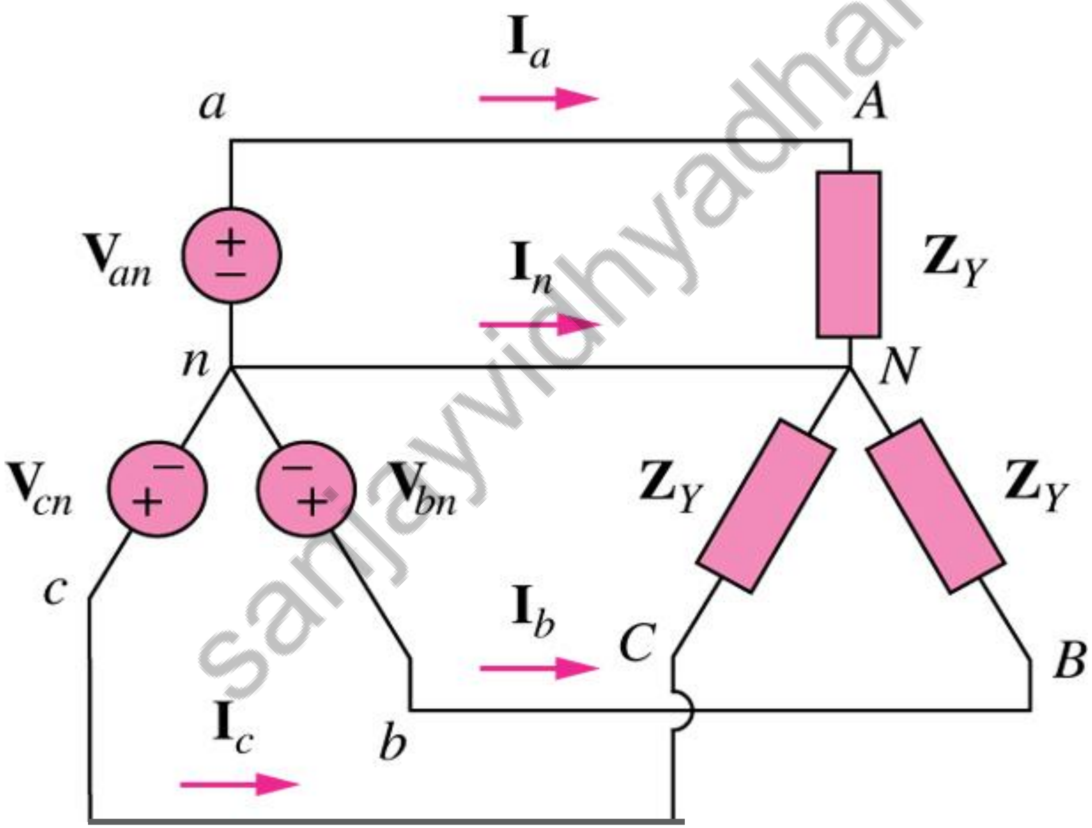
$$V_{ca} = V_{cn} - V_{an} = \sqrt{3} V_p \angle -210^\circ$$

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

WYE-WYE CONNECTED THREE-PHASE SYSTEM

Balanced Load

The phase impedances are equal in magnitude and in phase.



WYE-WYE CONNECTED THREE-PHASE SYSTEM

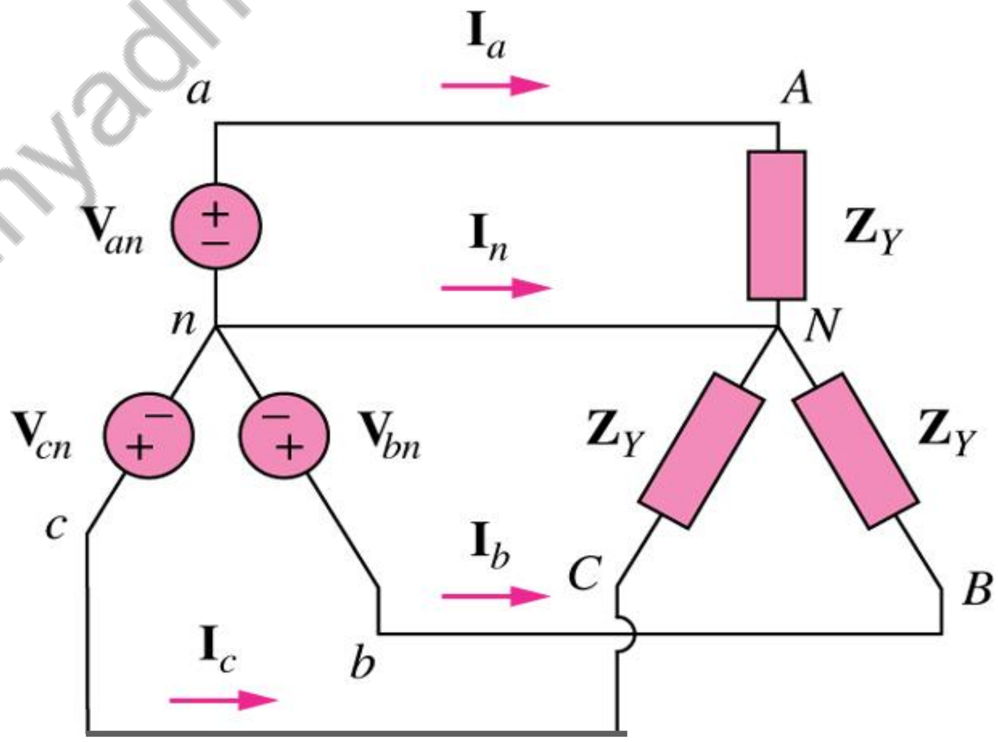
Balanced Load

The phase impedances are equal in magnitude and in phase.

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

$$I_b = \frac{V_{bn}}{Z_Y} = \frac{V_{an}\angle -120^\circ}{Z_Y} = I_a\angle -120^\circ$$

$$I_c = \frac{V_{cn}}{Z_Y} = \frac{V_{an}\angle -240^\circ}{Z_Y} = I_a\angle -240^\circ$$



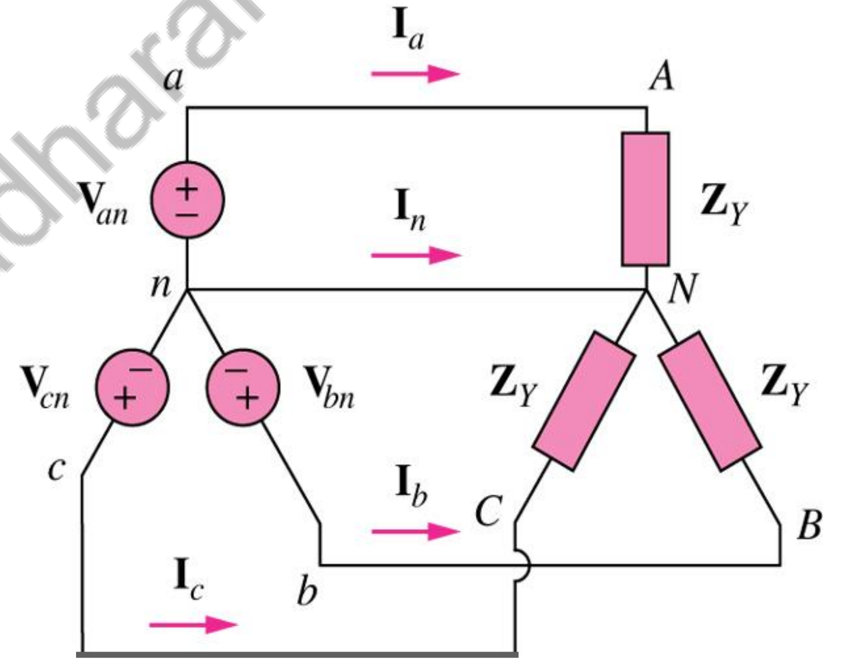
WYE CONNECTED THREE-PHASE SYSTEM

Balanced Load

The phase impedances are equal in magnitude and in phase.

$$I_a + I_b + I_c = 0$$

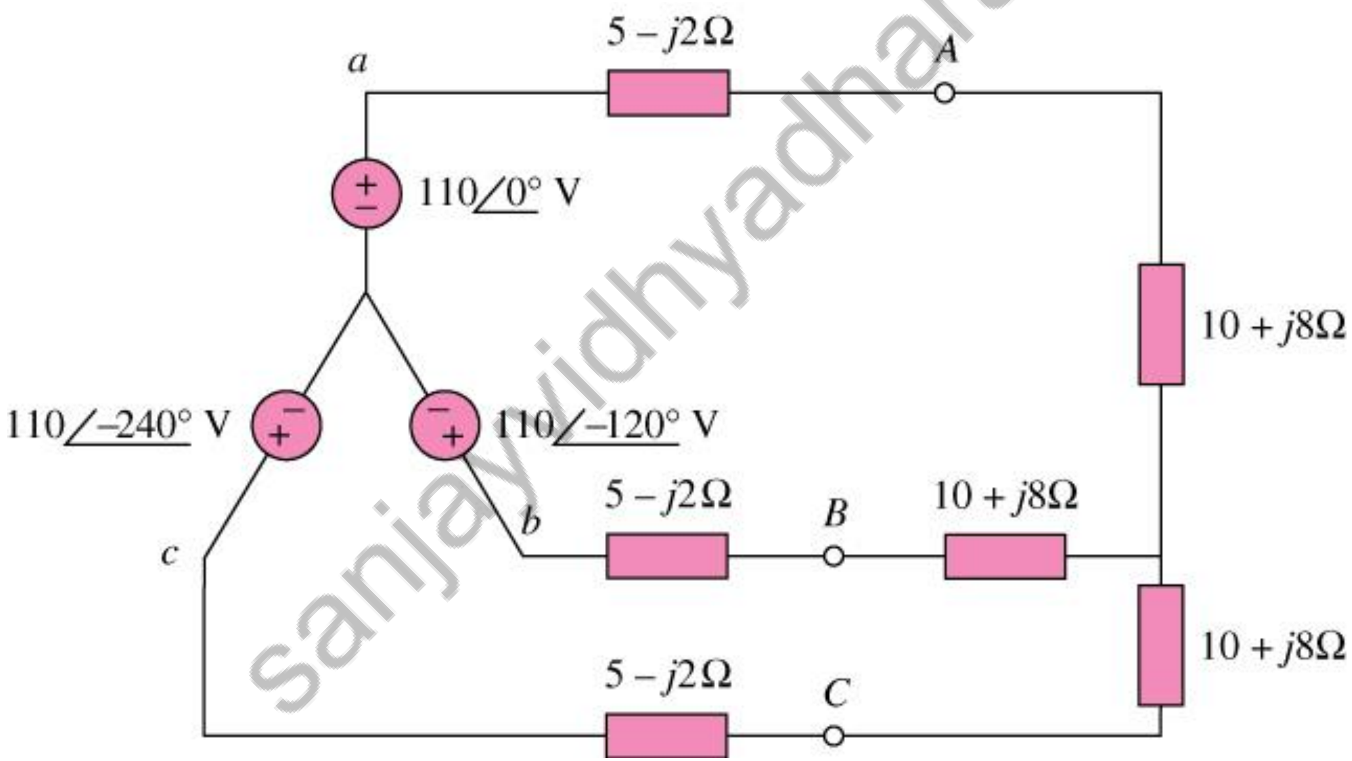
$$I_n = -\left(I_a + I_b + I_c\right) = 0$$



The line current is the current in each line, the phase current is the current in each phase of the source or load.
In the Y-Y system, the line current is the same as the phase current.

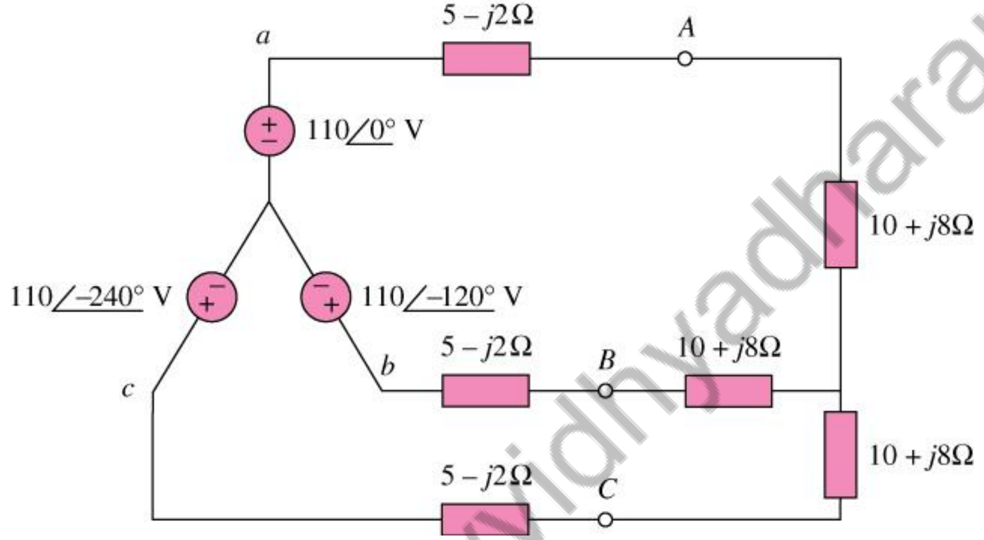
WYE CONNECTED THREE-PHASE SYSTEM

Example 1: Calculate the line currents in the three-wire Y-Y system



WYE CONNECTED THREE-PHASE SYSTEM

Example 1: Calculate the line currents in the three-wire Y-Y system



$$Z_Y = (5 - j2) + (10 + j8) = (15 + j6)$$

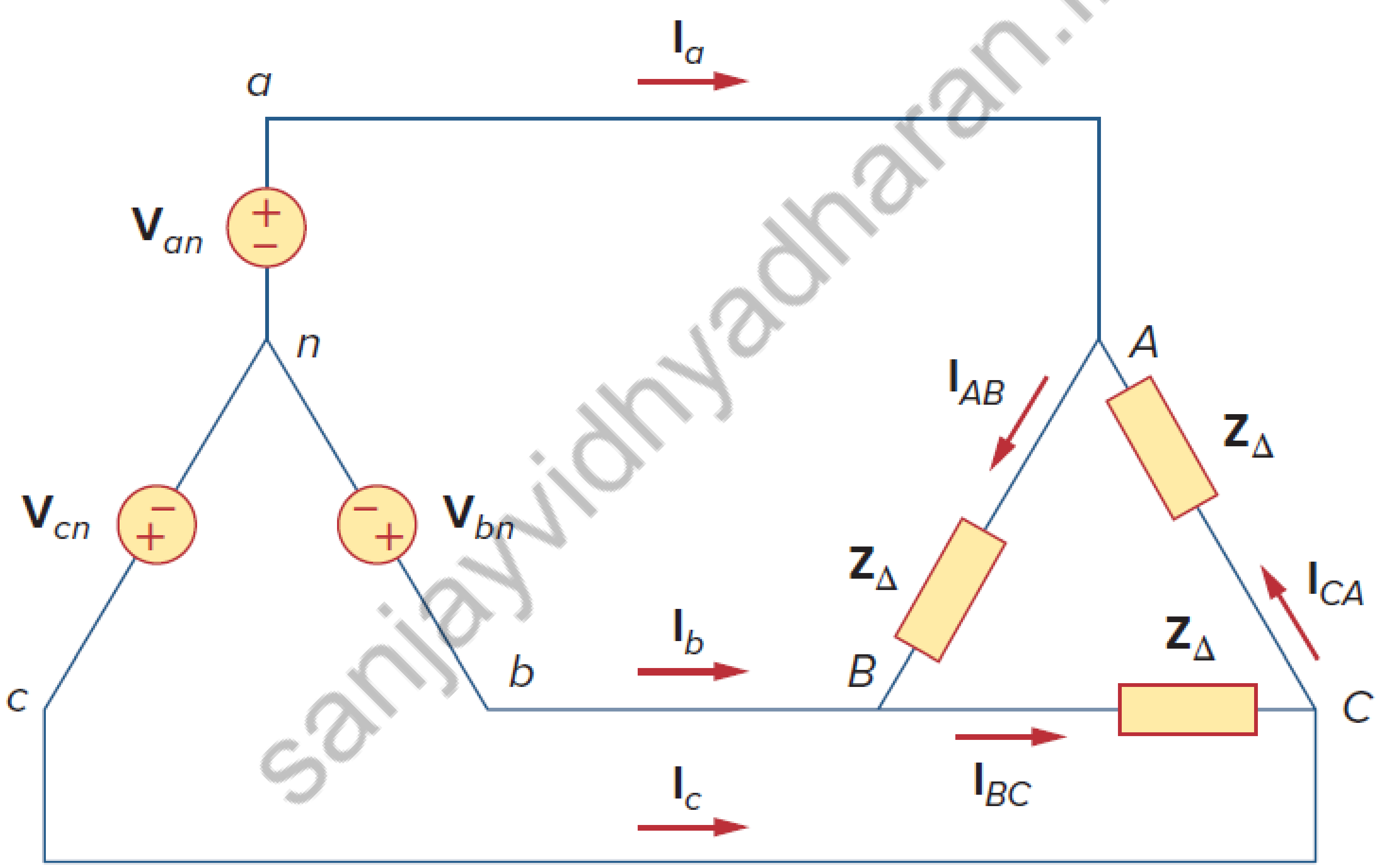
$$= 16.155\angle 21.8^0$$

$$I_a = \frac{110\angle 0^0}{16.155\angle 21.8^0} = 6.81\angle -21.8^0 \text{ A}$$

$$I_b = I_a\angle -120^0 = 6.81\angle -141.8^0 \text{ A}$$

$$I_c = I_a\angle -240^0 = 6.81\angle 98.2^0 \text{ A}$$

Balanced Wye-Delta Connection



Balanced Wye-Delta Connection

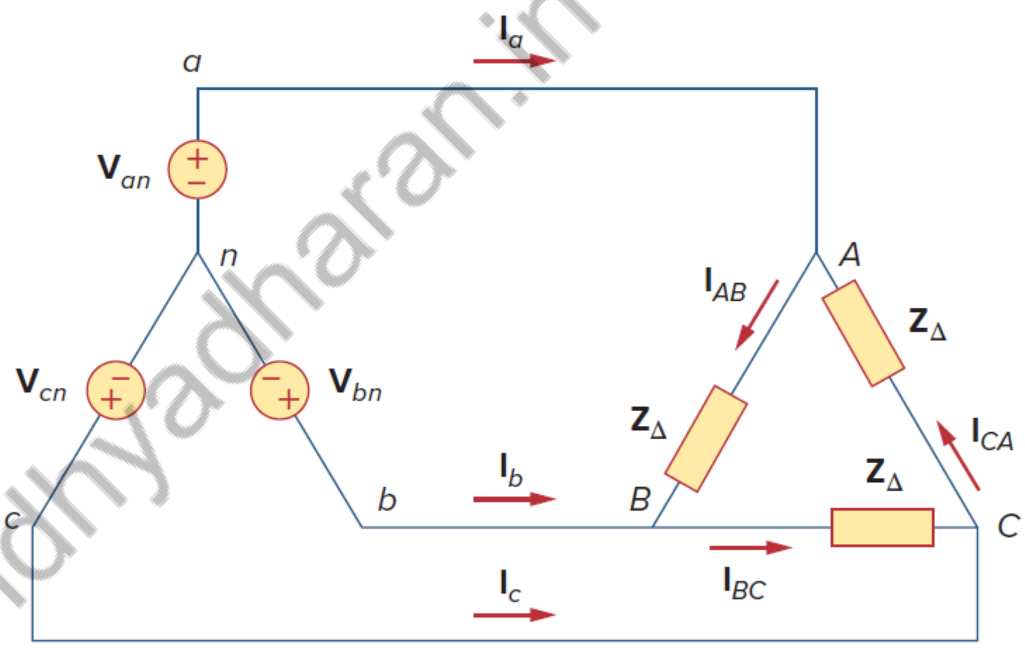
$$V_{an} = V_p\angle 0^\circ,\ V_{bn} = V_p\angle -120^\circ,$$
$$V_{cn} = V_p\angle +120^\circ$$

The line voltages are:

$$V_{ab} = \sqrt{3}V_p\angle 30^\circ = V_{AB}$$

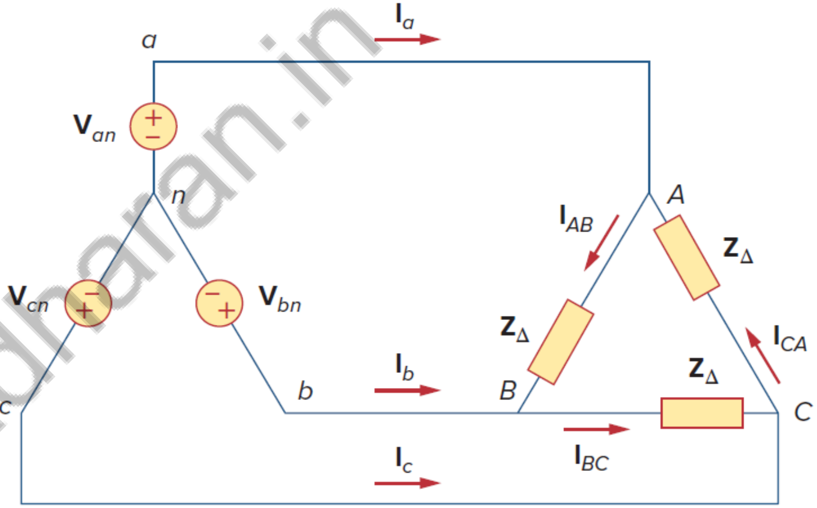
$$V_{bc} = \sqrt{3}V_p\angle -90^\circ = V_{BC}$$

$$V_{ca} = \sqrt{3}V_p\angle 150^\circ = V_{CA}$$



Balanced Wye-Delta Connection

$$I_{AB} = \frac{V_{AB}}{Z_\Delta},\ I_{BC} = \frac{V_{BC}}{Z_\Delta},\ I_{CA} = \frac{V_{CA}}{Z_\Delta}$$

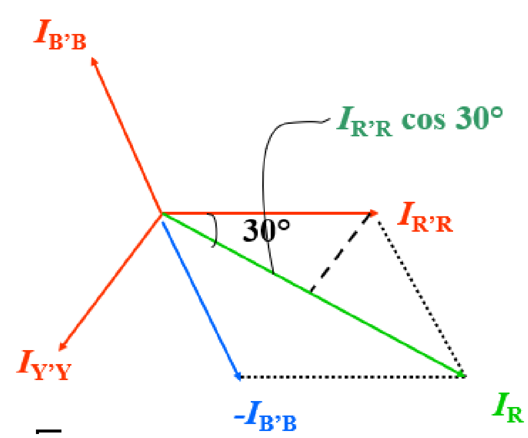


These currents have the same magnitude but are out of phase with each other by 120°. The line currents are obtained from the phase currents by applying KCL at Nodes A, B, and C. Thus,

$$I_a = I_{AB} - I_{CA},\ I_b = I_{BC} - I_{AB},\ I_c = I_{CA} - I_{BC}$$

$$\begin{aligned} I_a = I_{AB} - I_{CA} &= I_{AB}\left(1 - 1\angle -240^\circ\right) \\ &= I_{AB}\left(1 + 0.5 - j0.866\right) \\ &= I_{AB}\sqrt{3}\angle -30^\circ \end{aligned}$$

Since $I_{CA} = I_{AB}\angle -240^\circ$,



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

Balanced Wye-Delta Connection

Example 2: A balanced abc-sequence Y-connected source which is connected to a Δ-connected balanced load (8 + j4) Ω per phase. Calculate the phase and line currents. $V_{an} = 100\angle 10^0 \text{ V}$

The load impedance is:

$$Z_\Delta = 8 + j4 = 8.944\angle 26.57^0 \Omega$$

If the phase voltage $V_{an} = 100\angle 10^0$ V, then the line voltage is

$$V_{ab} = V_{an}\sqrt{3}\angle 30^0 = 173.2\angle 40^0 \text{ V} = V_{AB}$$

Balanced Wye-Delta Connection

Example 2: A balanced abc-sequence Y-connected source with is connected to a Δ-connected balanced load (8 + j4) Ω per phase. Calculate the phase and line currents. $V_{an} = 100\angle 10^0 \text{ V}$

The phase currents are,

$$I_{AB} = \frac{V_{AB}}{Z_\Delta} = \frac{173.2\angle 40^0}{8.944\angle 26.57^0} = 19.36\angle 13.43^0 \text{ A}$$

$$I_{BC} = I_{AB}\angle -120^0 = 19.36\angle -106.57^0 \text{ A}$$

$$I_{CA} = I_{AB}\angle +120^0 = 19.36\angle 133.43^0 \text{ A}$$

The line currents are,

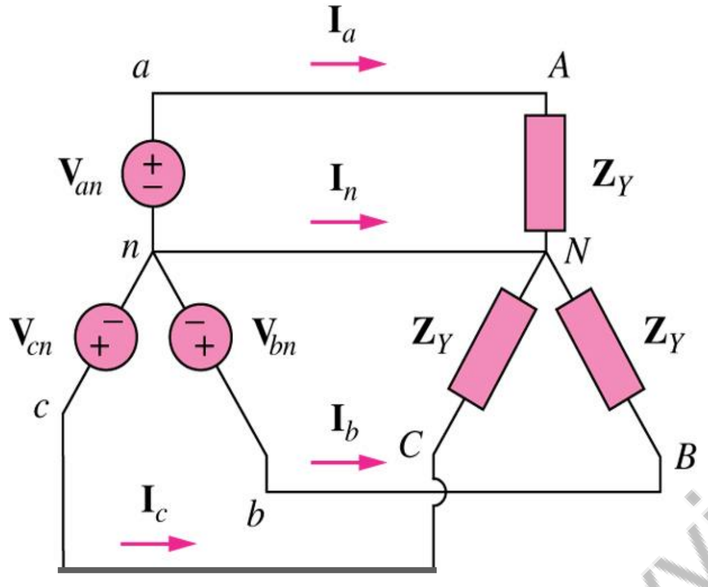
$$I_a = I_{AB}\sqrt{3}\angle -30^0 = 33.53\angle -16.57^0 \text{ A}$$

$$I_b = I_a\angle -120^0 = 33.53\angle -136.57^0 \text{ A}$$

$$I_c = I_a\angle +120^0 = 33.53\angle 103.43^0 \text{ A}$$

Summary

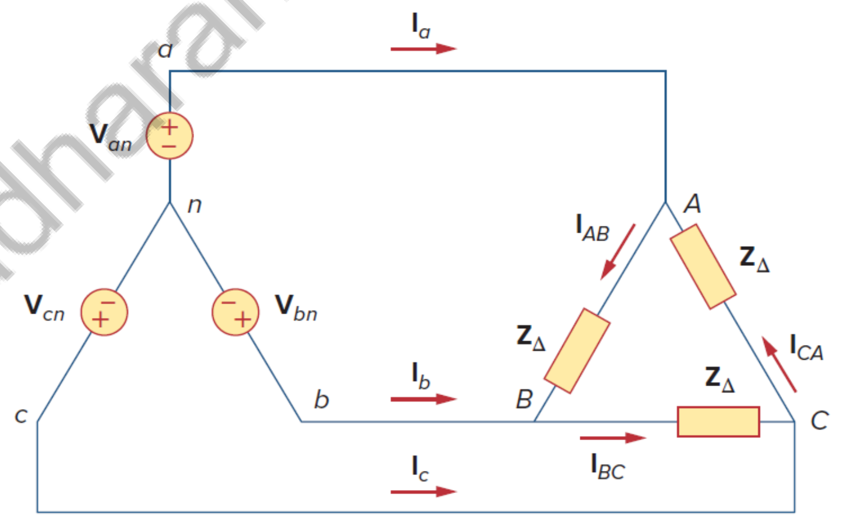
WYE-WYE



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

$$I_P = I_L$$

WYE-DELTA



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

$$I_P = \sqrt{3}\, I_L$$

Transmission Lines

Loads to be balanced for minimise Transmission loss

High Torque Motors

Thank you