VINNITSA NATIONAL AGRARIAN UNIVERSITY
Department of Electric Power Engineering, Electrical Engineering and Electromechanics

THREE-PHASE ELECTRIC CIRCUITS Y CONNECTIONS

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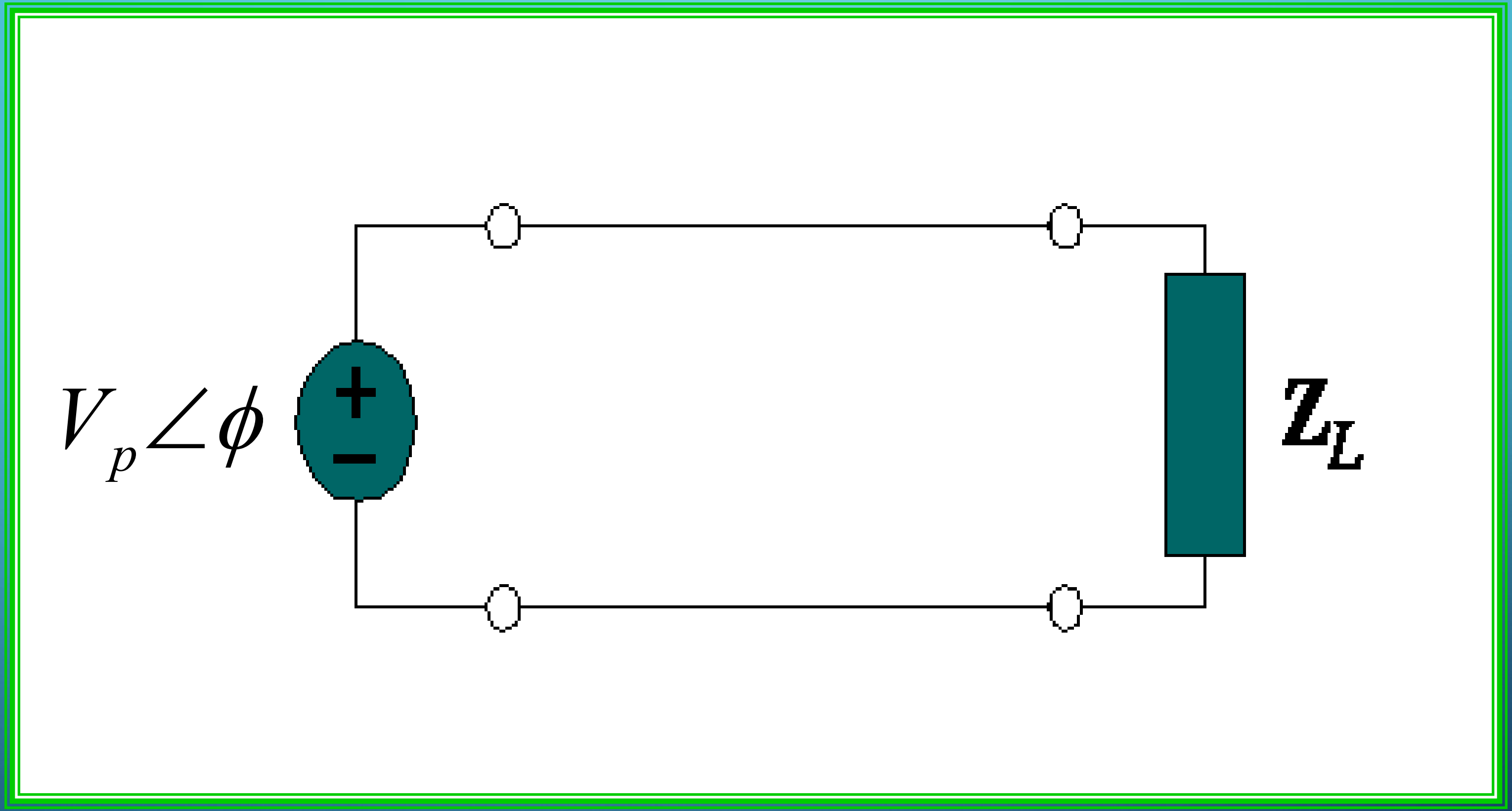
OBJECTIVES

- Explain the differences between single-phase, two-phase and three-phase.
- Compute and define the Balanced Three-Phase voltages.
- Determine the phase and line voltages/currents for Three-Phase systems.

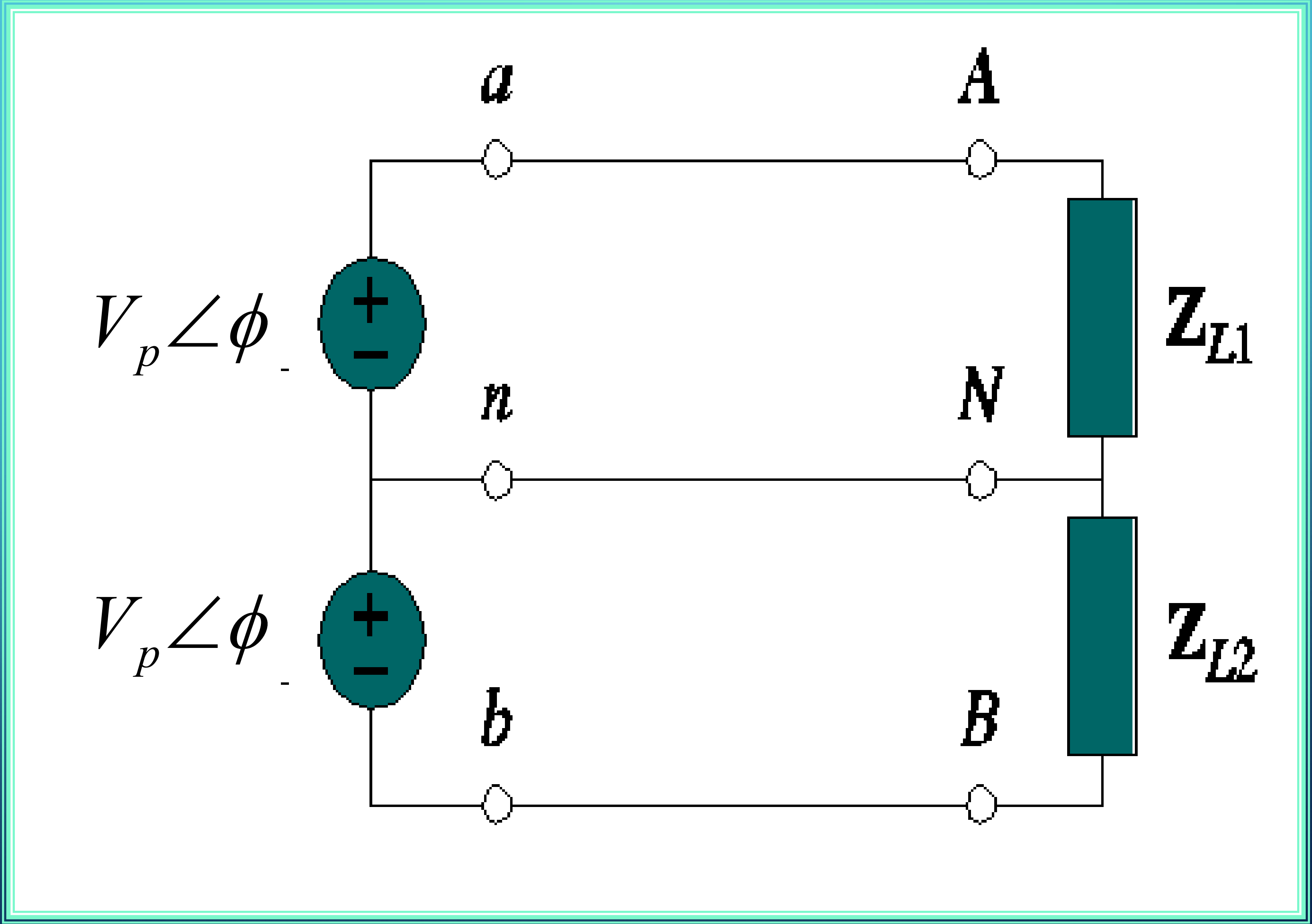
SINGLE PHASE TWO WIRE



SINGLE PHASE SYSTEM

- A generator connected through a pair of wire to a load – Single Phase Two Wire.
- V_p is the magnitude of the source voltage, and ϕ is the phase.

SINLGE PHASE THREE WIRE



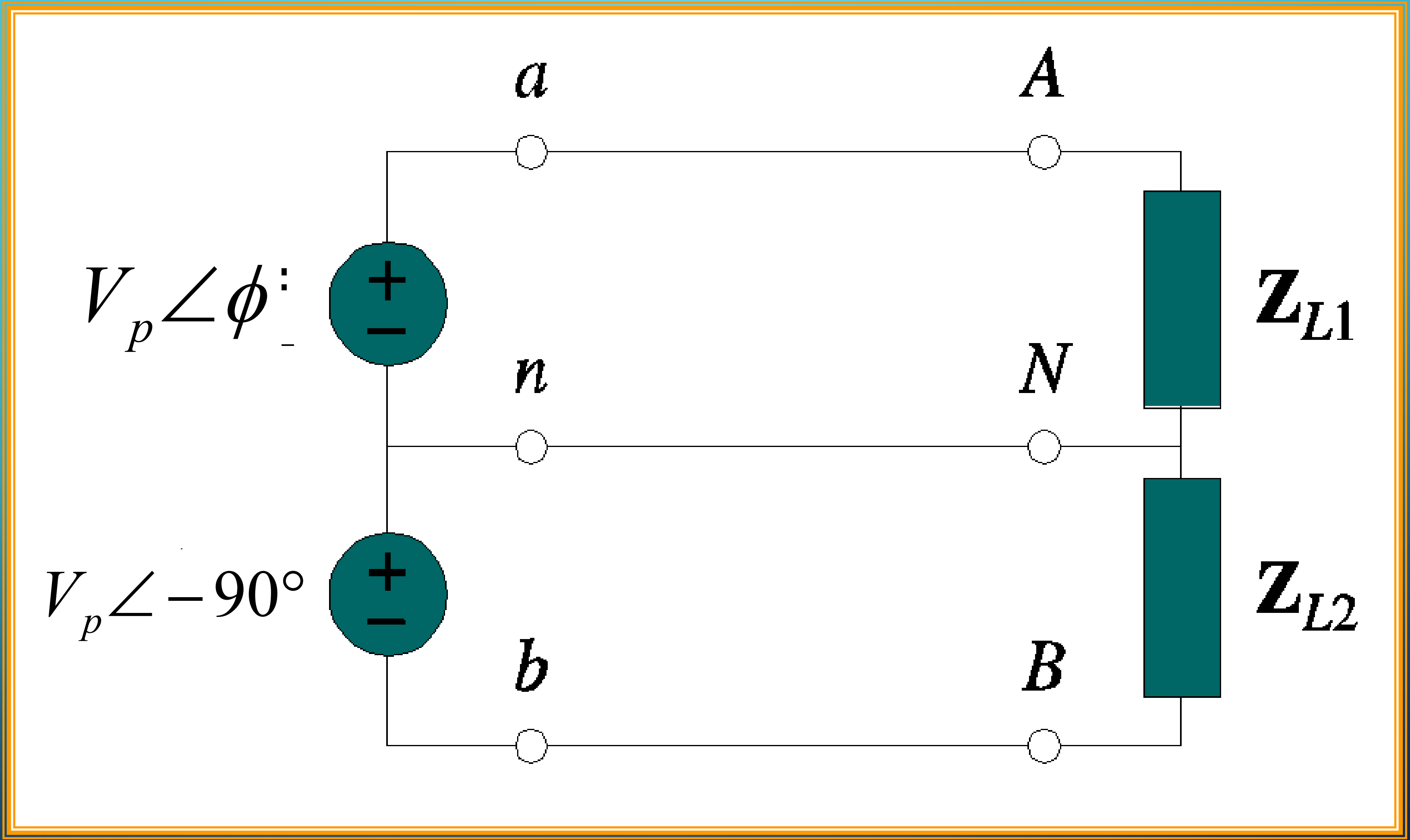
SINGLE PHASE SYSTEM

- Most common in practice: two identical sources connected to two loads by two outer wires and the neutral: Single Phase Three Wire.
- Terminal voltages have same magnitude and the same phase.

POLYPHASE SYSTEM

- Circuit or system in which AC sources operate at the same frequency but different phases are known as polyphase.

TWO PHASE SYSTEM THREE WIRE



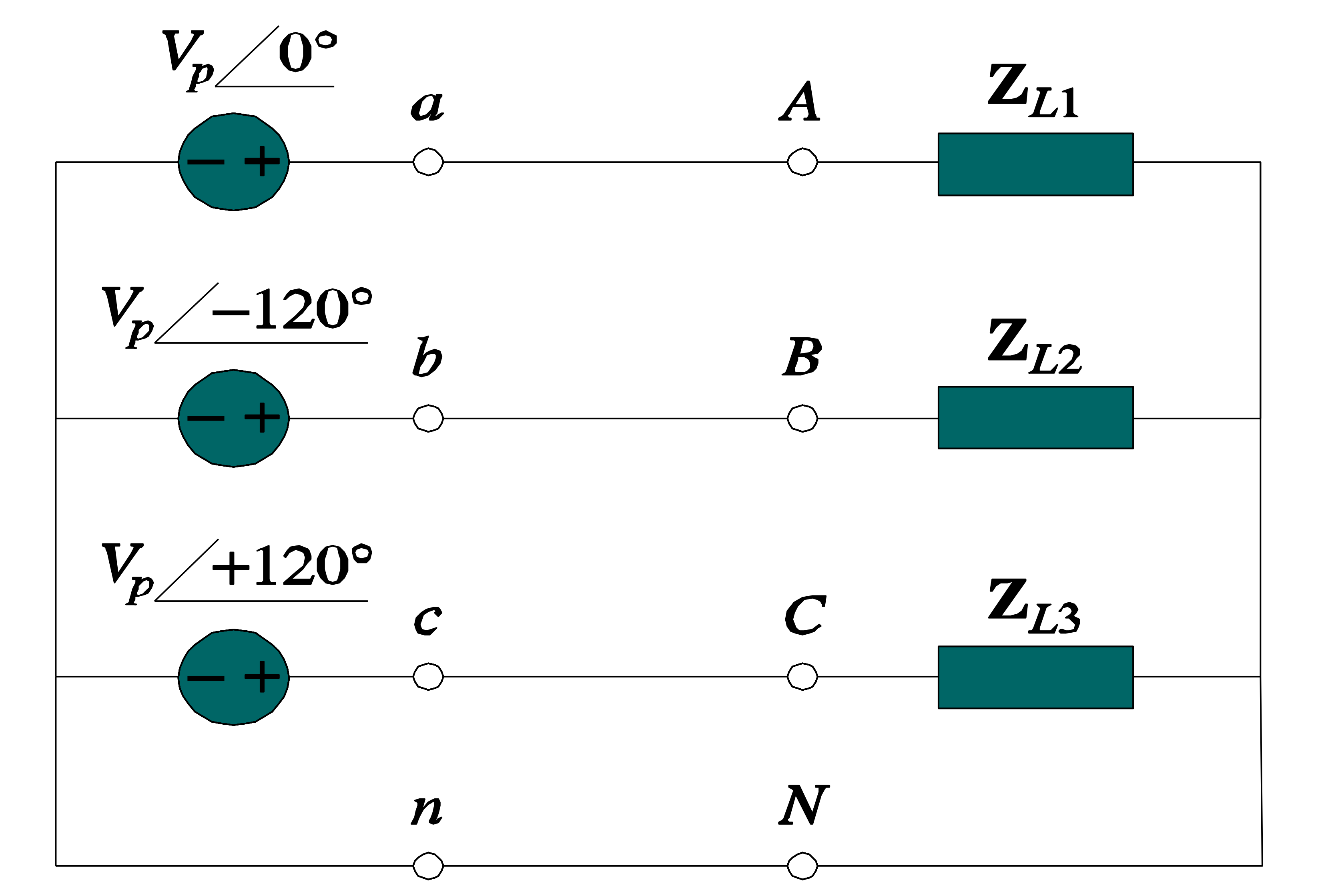
POLYPHASE SYSTEM

- Two Phase System:
  - A generator consists of two coils placed perpendicular to each other
  - The voltage generated by one lags the other by 90°.

POLYPHASE SYSTEM

- Three Phase System:
  - A generator consists of <u>three coils</u> placed 120° apart.
  - The voltage generated are equal in magnitude but, out of phase by 120°.
- Three phase is the most economical polyphase system.

THREE PHASE FOUR WIRE



IMPORTANCE OF THREE PHASE SYSTEM

- All electric power is generated and distributed in three phase.
  - One phase, two phase, or more than three phase input can be taken from three phase system rather than generated independently.
  - Melting purposes need 48 phases supply.

IMPORTANCE OF THREE PHASE SYSTEM

- Uniform power transmission and less vibration of three phase machines.
  - The instantaneous power in a 3ϕ system can be constant (not pulsating).
  - High power motors prefer a steady torque especially one created by a rotating magnetic field.

IMPORTANCE OF THREE PHASE SYSTEM

- Three phase system is more economical than the single phase.
  - The amount of wire required for a three phase system is less than required for an equivalent single phase system.
  - Conductor: Copper, Aluminum, etc

THREE PHASE GENERATION

GENERATOR WORK

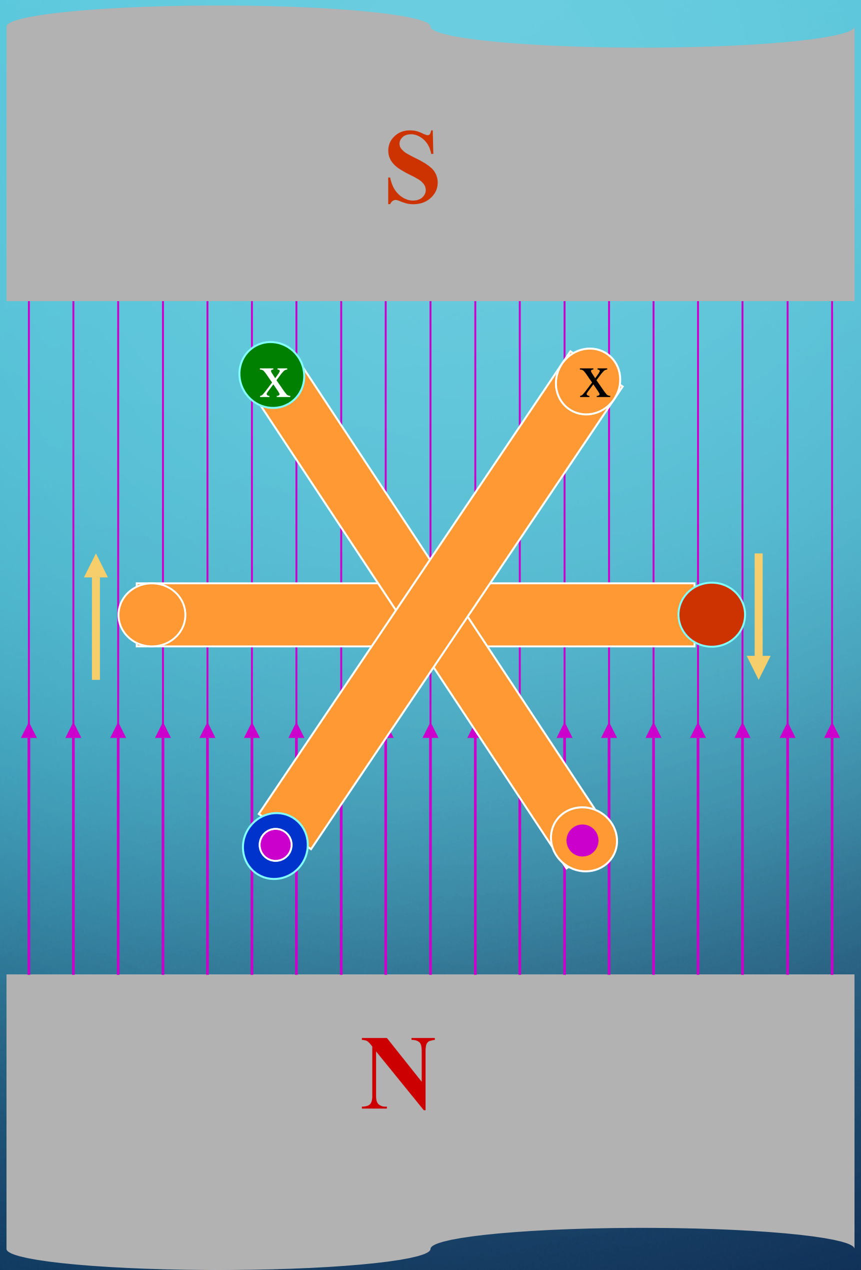
- The generator consists of a rotating magnet (rotor) surrounded by a stationary winding (stator).

- Three separate windings or coils with terminals a-a’, b-b’, and c-c’ are physically placed 120° apart around the stator.

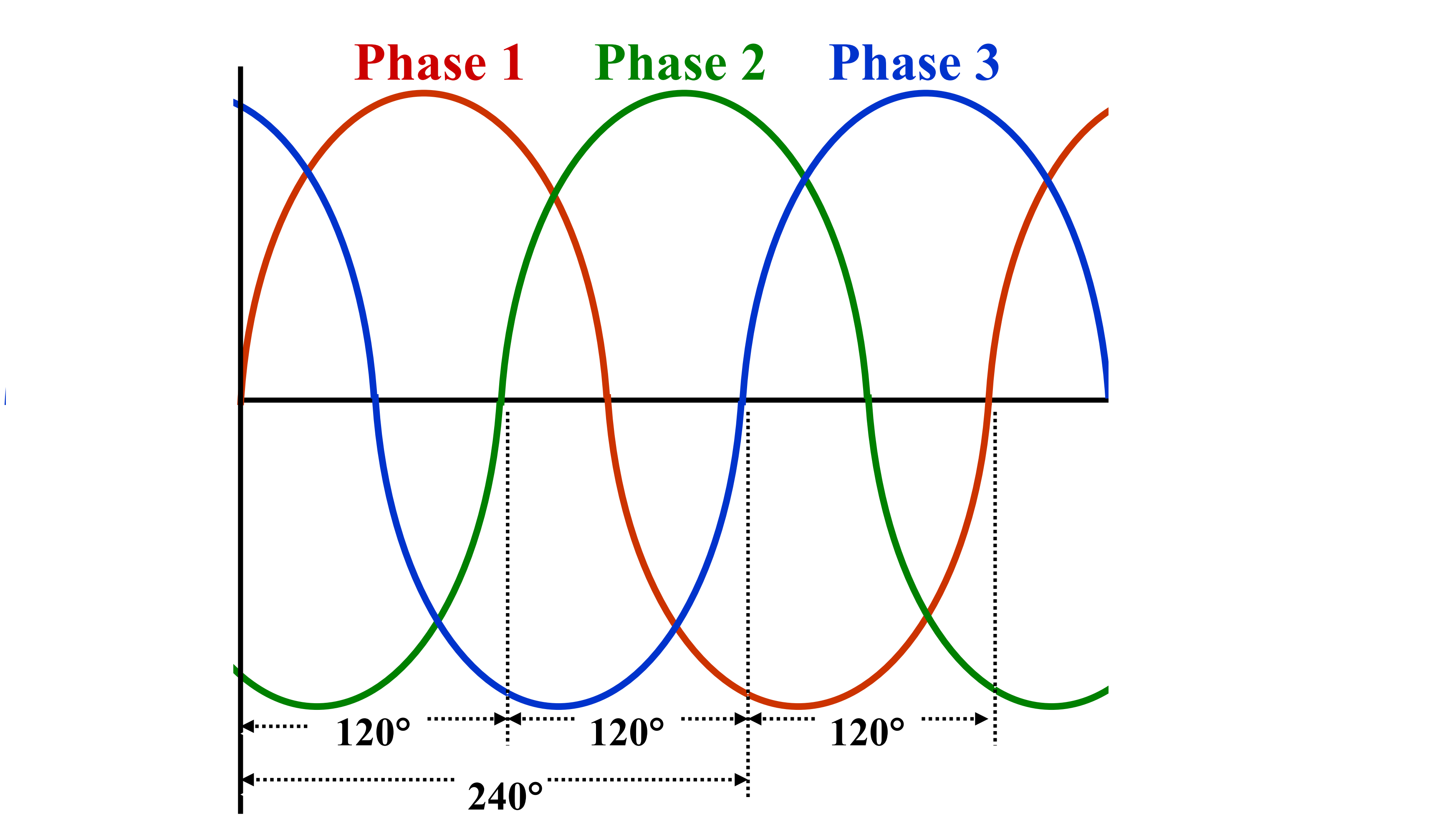
- As the rotor rotates, its magnetic field cuts the flux from the three coils and induces voltages in the coils.

- The induced voltage have equal magnitude but out of phase by 120°.

GENERATION OF THREE-PHASE AC



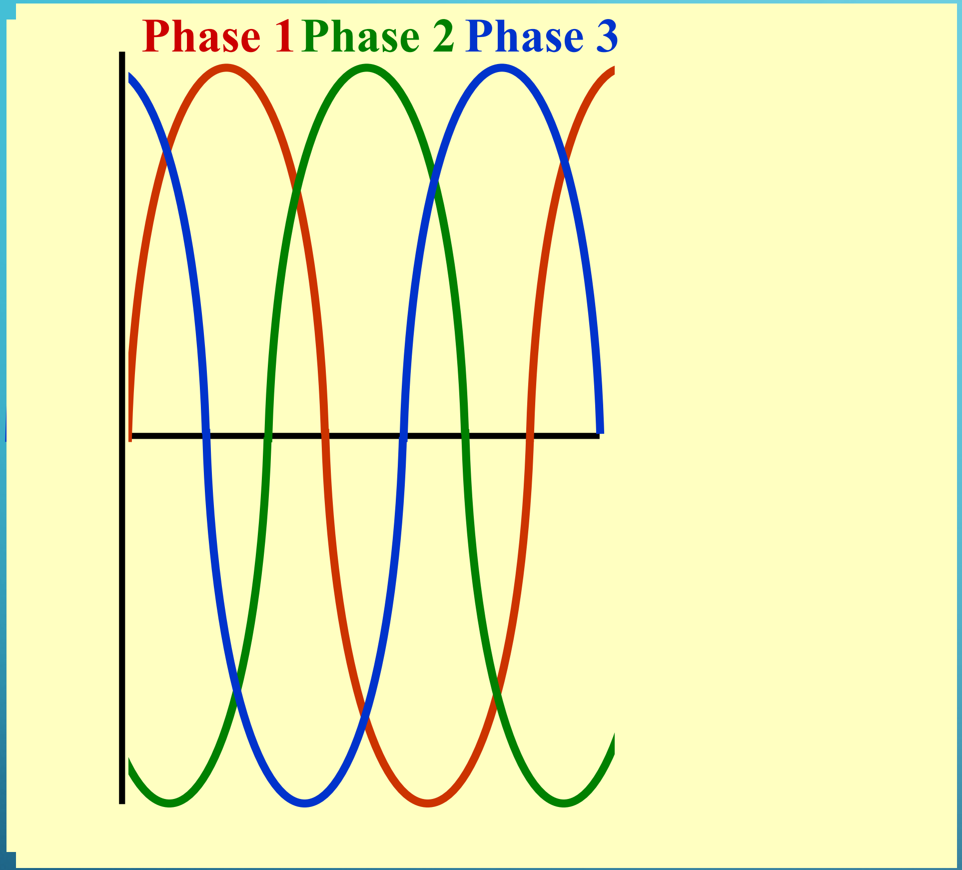
THREE-PHASE WAVEFORM

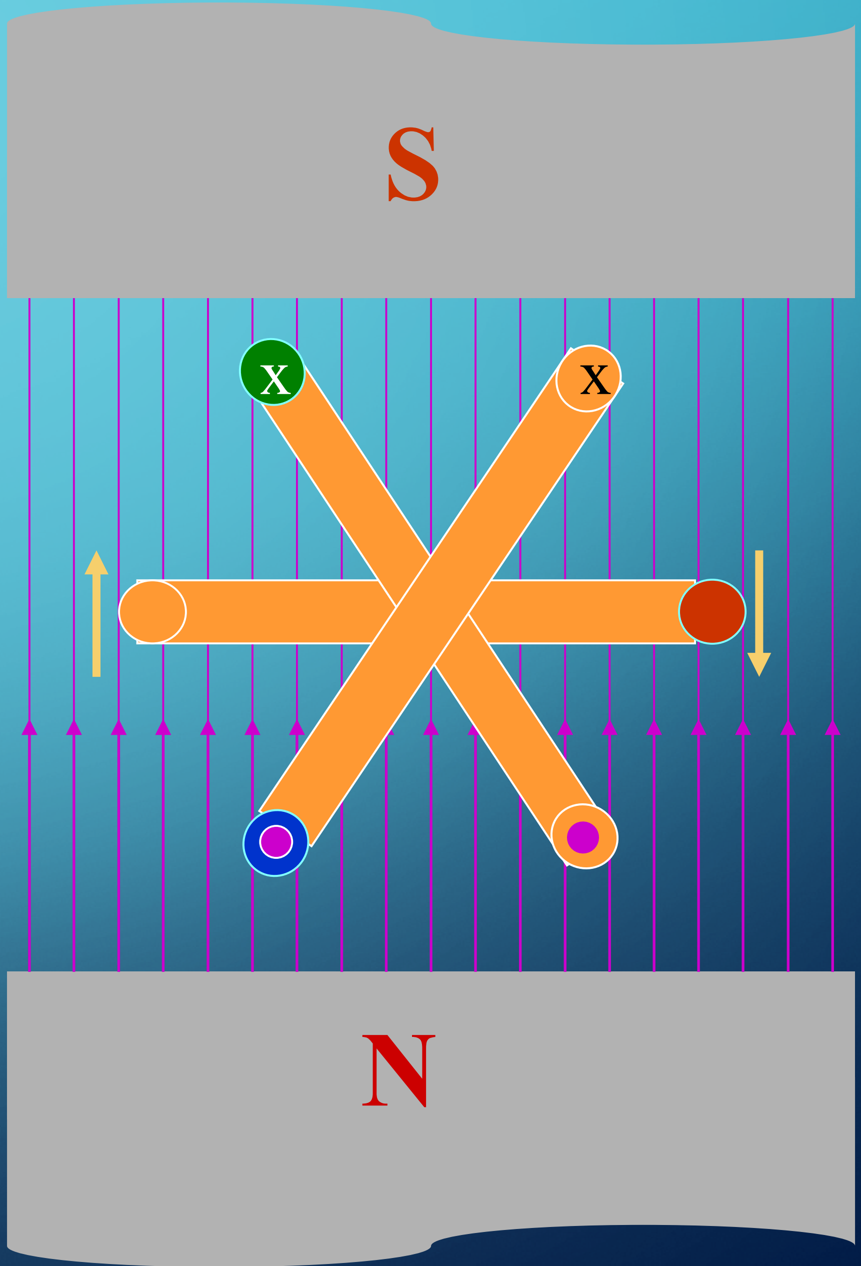


Phase 2 lags phase 1 by 120°.
Phase 3 lags phase 1 by 240°.

Phase 2 leads phase 3 by 120°.
Phase 1 leads phase 3 by 240°.

GENERATION OF 3ϕ VOLTAGES





Phase 1 is ready to go positive.
Phase 2 is going more negative.
Phase 3 is going less positive.

THREE PHASE QUANTITIES

BALANCED 3ϕ VOLTAGES

- Balanced three phase voltages:
  - same magnitude (V_M)
  - 120° phase shift

$$v_{an}(t) = V_M \cos(\omega t)$$
$$v_{bn}(t) = V_M \cos(\omega t - 120°)$$
$$v_{cn}(t) = V_M \cos(\omega t - 240°) = V_M \cos(\omega t + 120°)$$

BALANCED 3ϕ CURRENTS

- Balanced three phase currents:
  - same magnitude (I_M)
  - 120° phase shift

$$i_a(t) = I_M \cos(\omega t - \theta)$$
$$i_b(t) = I_M \cos(\omega t - \theta - 120^\circ)$$
$$i_c(t) = I_M \cos(\omega t - \theta - 240^\circ)$$

PHASE SEQUENCE

$$v_{an}(t) = V_M \cos \omega t$$
$$v_{bn}(t) = V_M \cos(\omega t - 120°)$$
$$v_{cn}(t) = V_M \cos(\omega t + 120°)$$

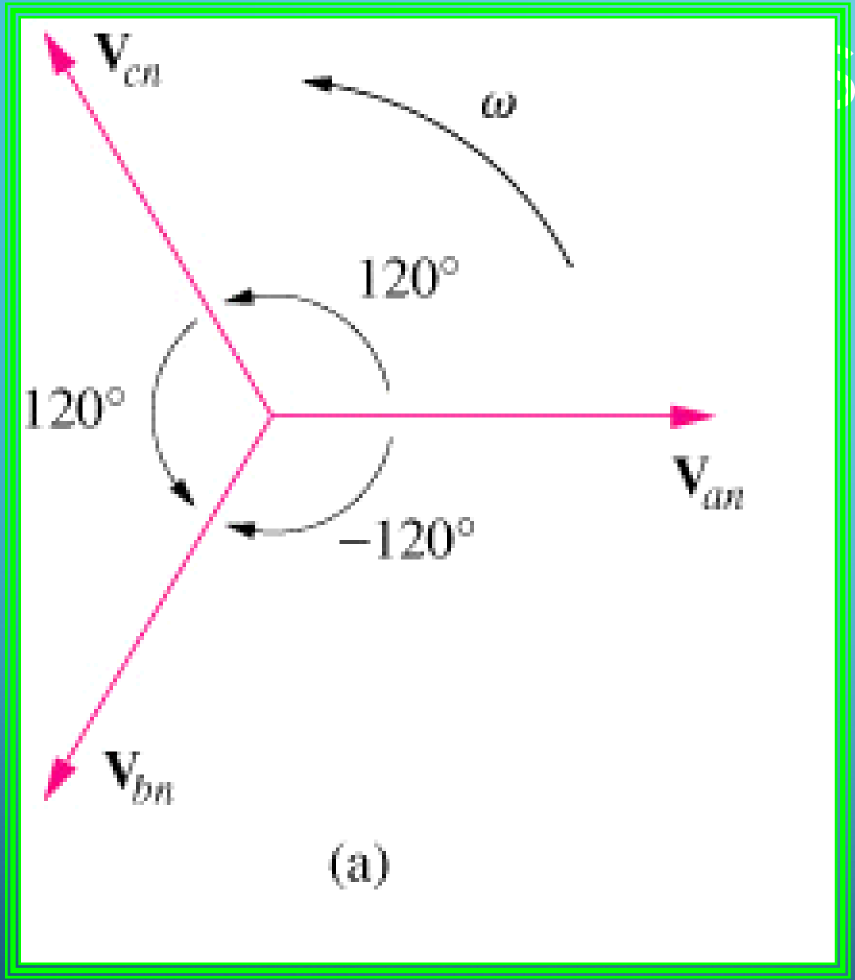
$$V_{an} = V_M \angle 0°$$
$$V_{bn} = V_M \angle -120°$$
$$V_{cn} = V_M \angle +120°$$

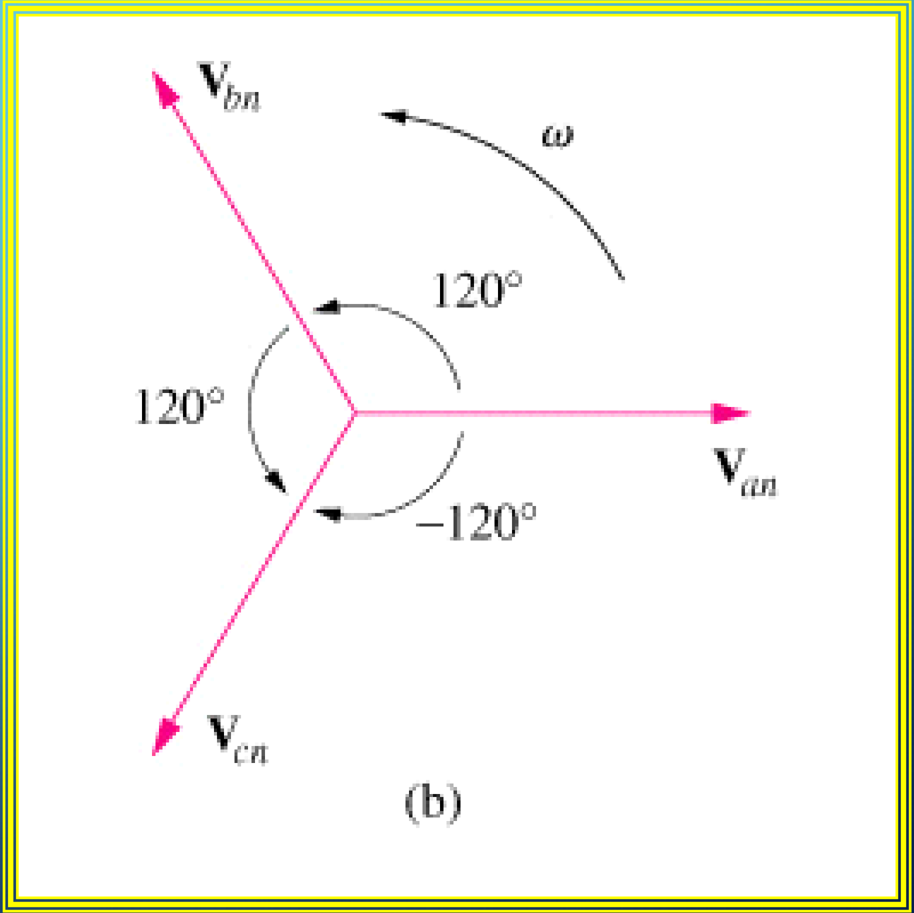
POSITIVE SEQUENCE

$$V_{an} = V_M \angle 0°$$
$$V_{bn} = V_M \angle +120°$$
$$V_{cn} = V_M \angle -120°$$

NEGATIVE SEQUENCE

SEQUENCE





EXAMPLE # 1

- Determine the phase sequence of the set voltages:

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

BALANCED VOLTAGE AND LOAD

- Balanced Phase Voltage: all phase voltages are equal in magnitude and are out of phase with each other by 120°.
- Balanced Load: the phase impedances are equal in magnitude and in phase.

THREE PHASE CIRCUIT

- POWER
  - The instantaneous power is constant

$$p(t) = p_a(t) + p_b(t) + p_c(t)$$

$$= 3\frac{V_M I_M}{2}\cos(\theta)$$

$$= 3V_{rms} I_{rms} \cos(\theta)$$

THREE PHASE CIRCUIT

- Three Phase Power,

$$\mathbf{S}_T = \mathbf{S}_A + \mathbf{S}_B + \mathbf{S}_C = 3\,\mathbf{S}_\phi$$

THREE PHASE QUANTITIES

QUANTITY	SYMBOL
Phase current	I_{ϕ}
Line current	I_L
Phase voltage	V_{ϕ}
Line voltage	V_L

PHASE VOLTAGES AND LINE VOLTAGES

- Phase voltage is measured between the neutral and any line: line to neutral voltage
- Line voltage is measured between any two of the three lines: line to line voltage.

PHASE CURRENTS AND LINE CURRENTS

- Line current (I_L) is the current in each line of the source or load.
- Phase current (I_ϕ) is the current in each phase of the source or load.

THREE PHASE CONNECTION

SOURCE-LOAD CONNECTION

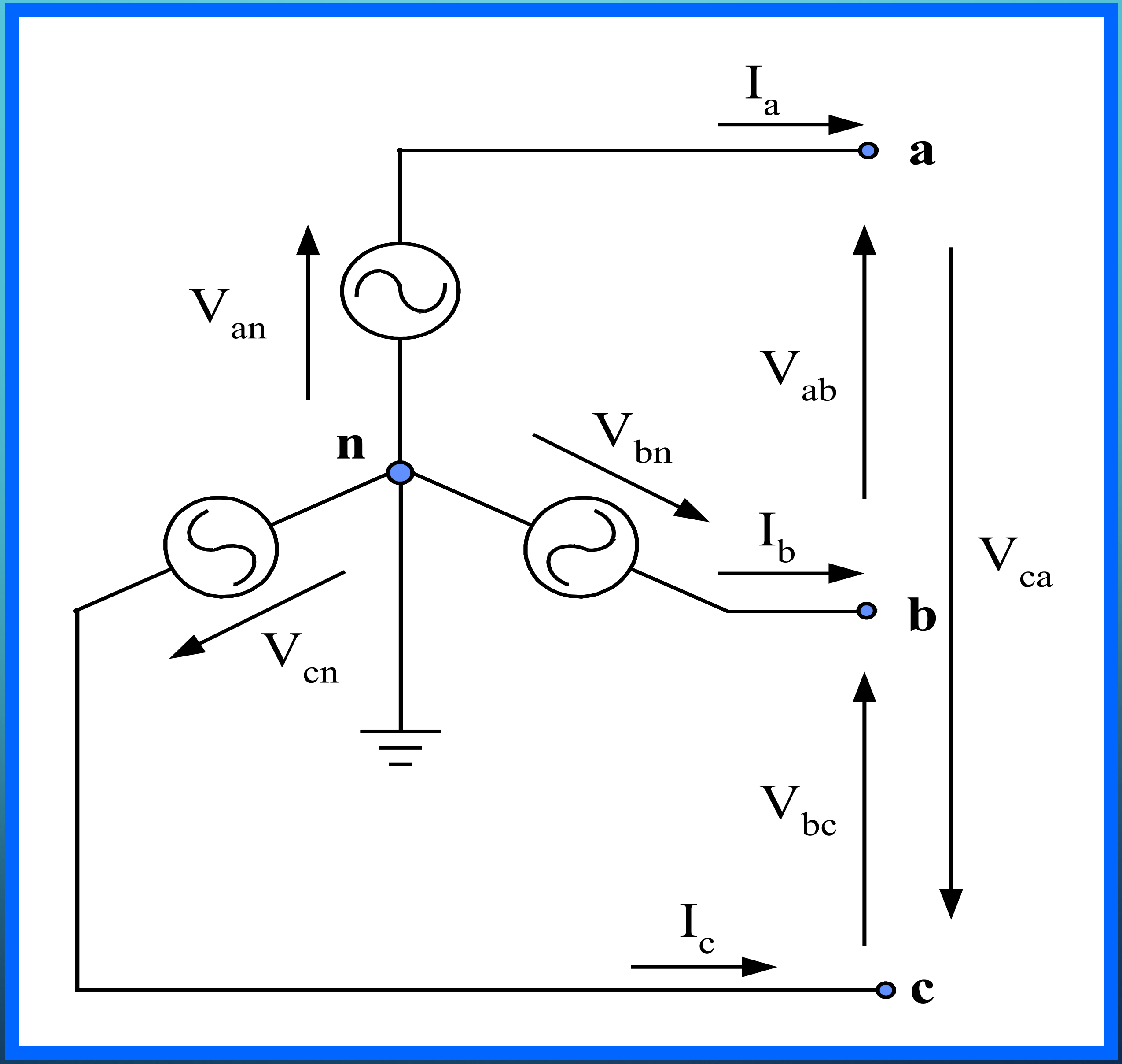
SOURCE	LOAD	CONNECTION
Wye	Wye	Y-Y
Wye	Delta	Y-Δ
Delta	Delta	Δ- Δ
Delta	Wye	Δ-Y

SOURCE-LOAD CONNECTION

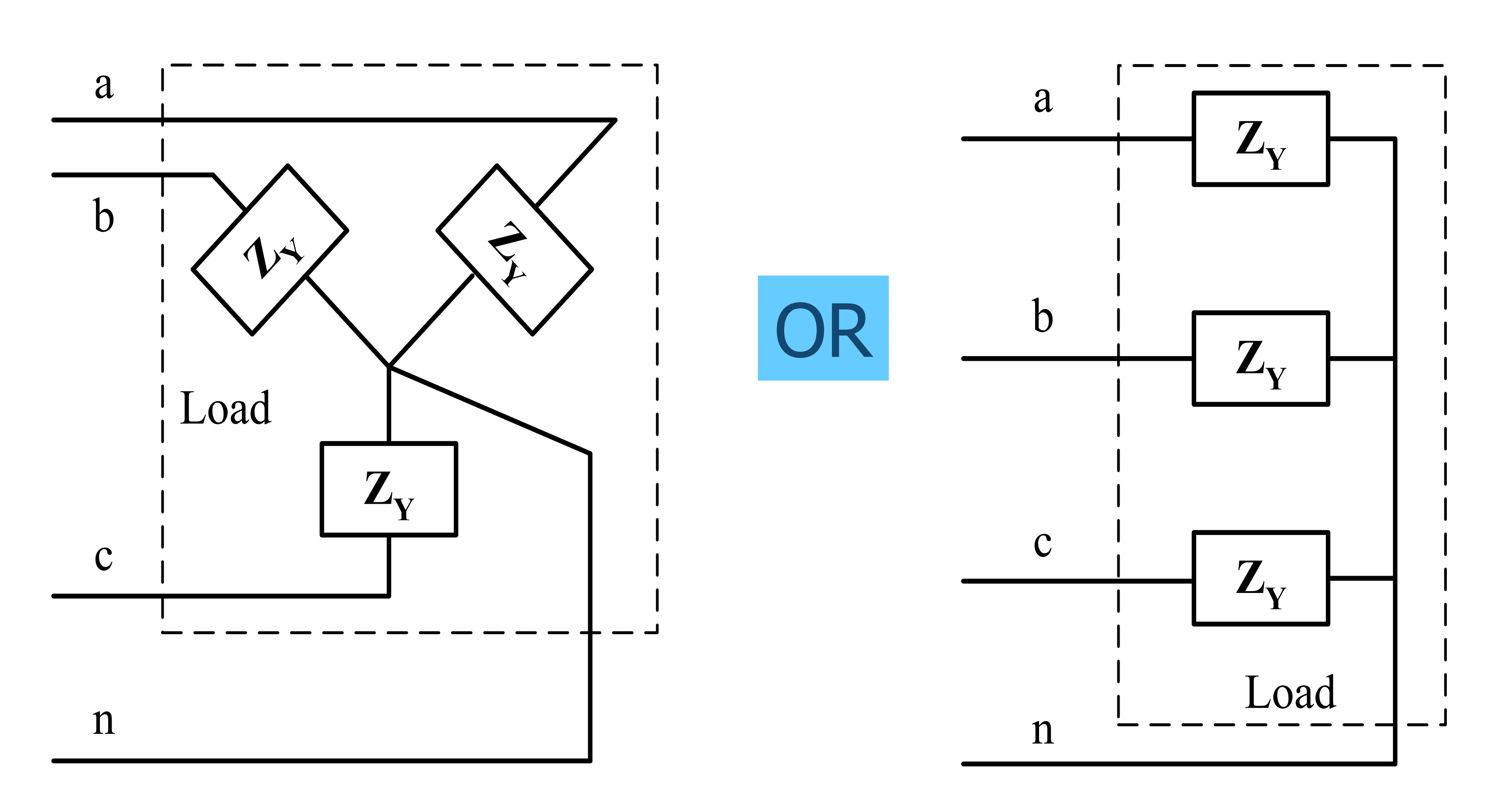
- Common connection of source: WYE
  - Delta connected sources: the circulating current may result in the delta mesh if the three phase voltages are slightly unbalanced.
- Common connection of load: DELTA
  - Wye connected load: neutral line may not be accessible, load can not be added or removed easily.

WYE CONNECTION

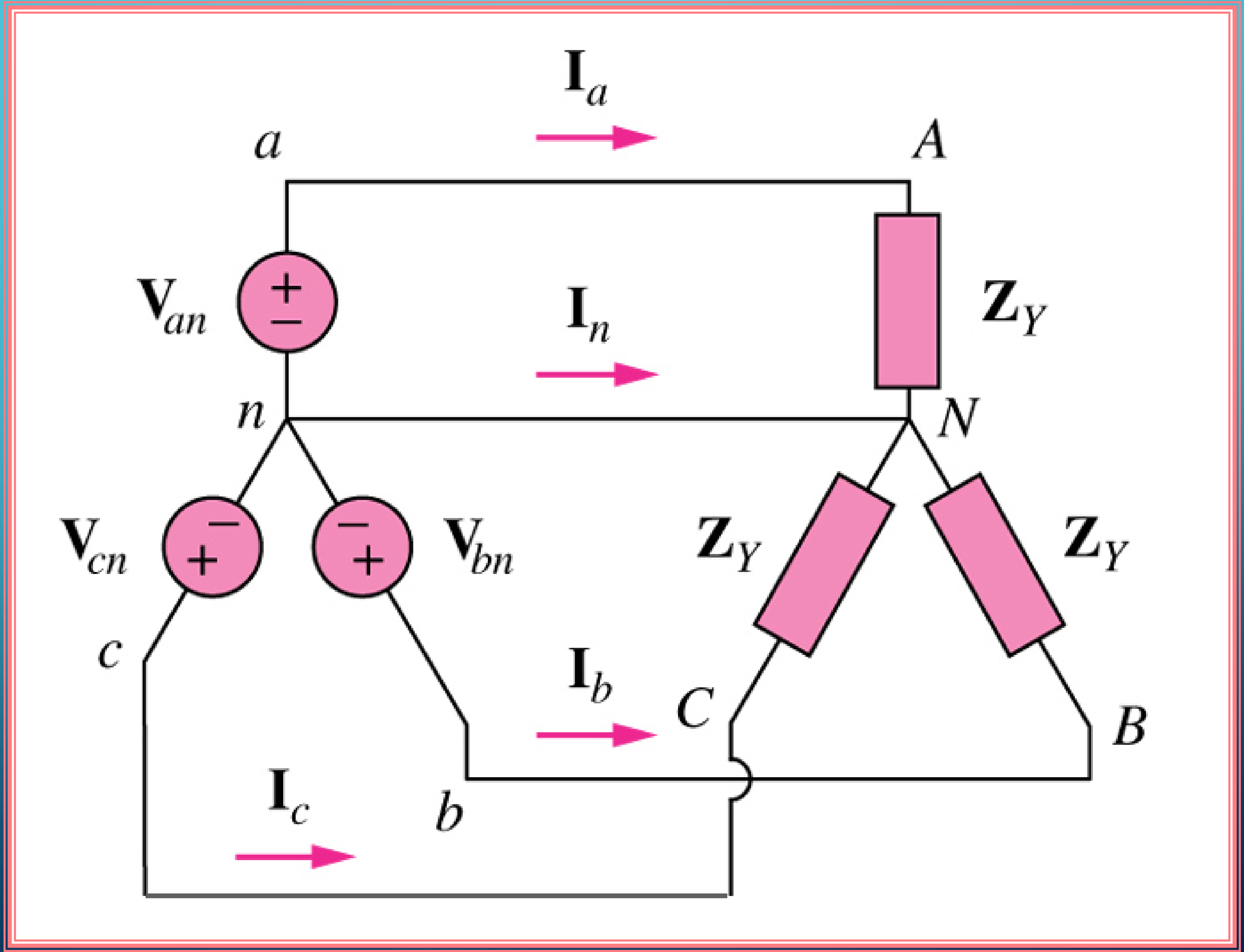
WYE CONNECTED GENERATOR



WYE CONNECTED LOAD



BALANCED Y-Y CONNECTION



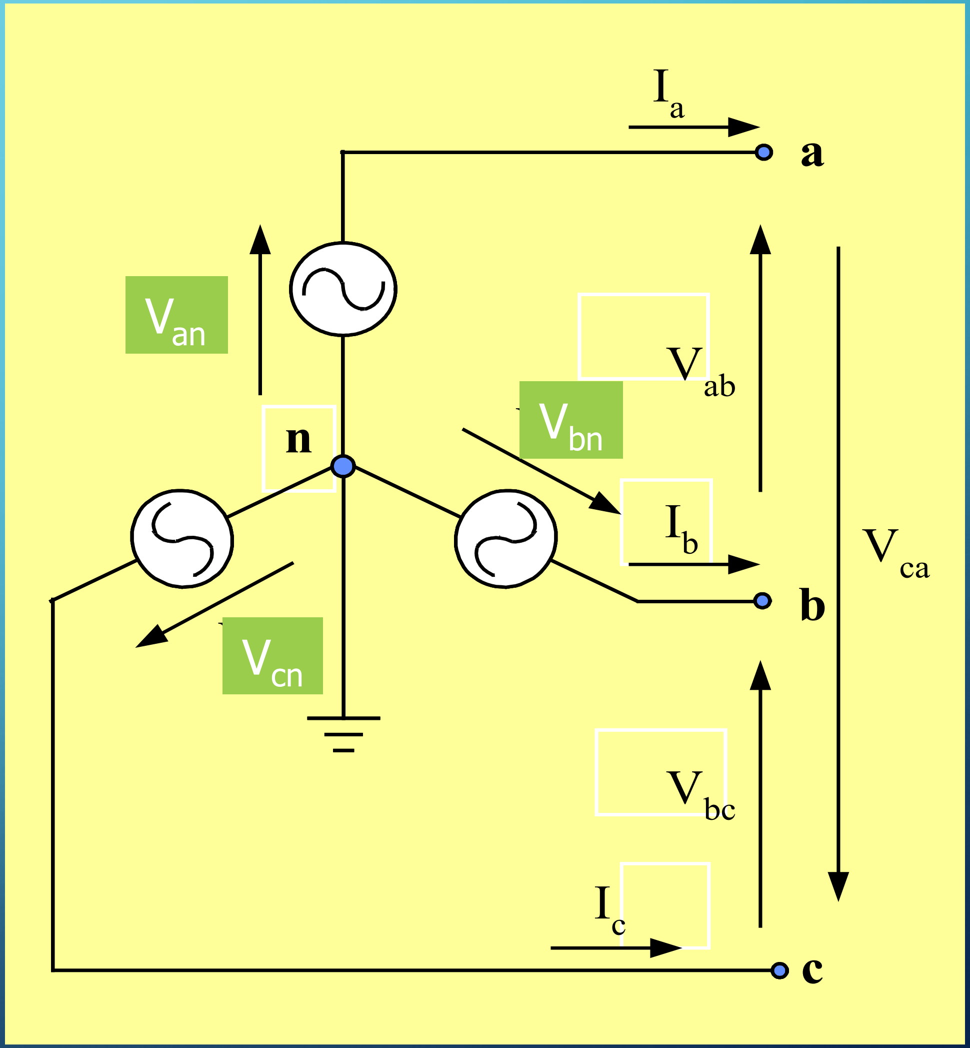
PHASE CURRENTS AND LINE CURRENTS

- In Y-Y system:

$$I_L = I_\varphi$$

PHASE VOLTAGES, V_ϕ

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



PHASE VOLTAGES, V_{ϕ}

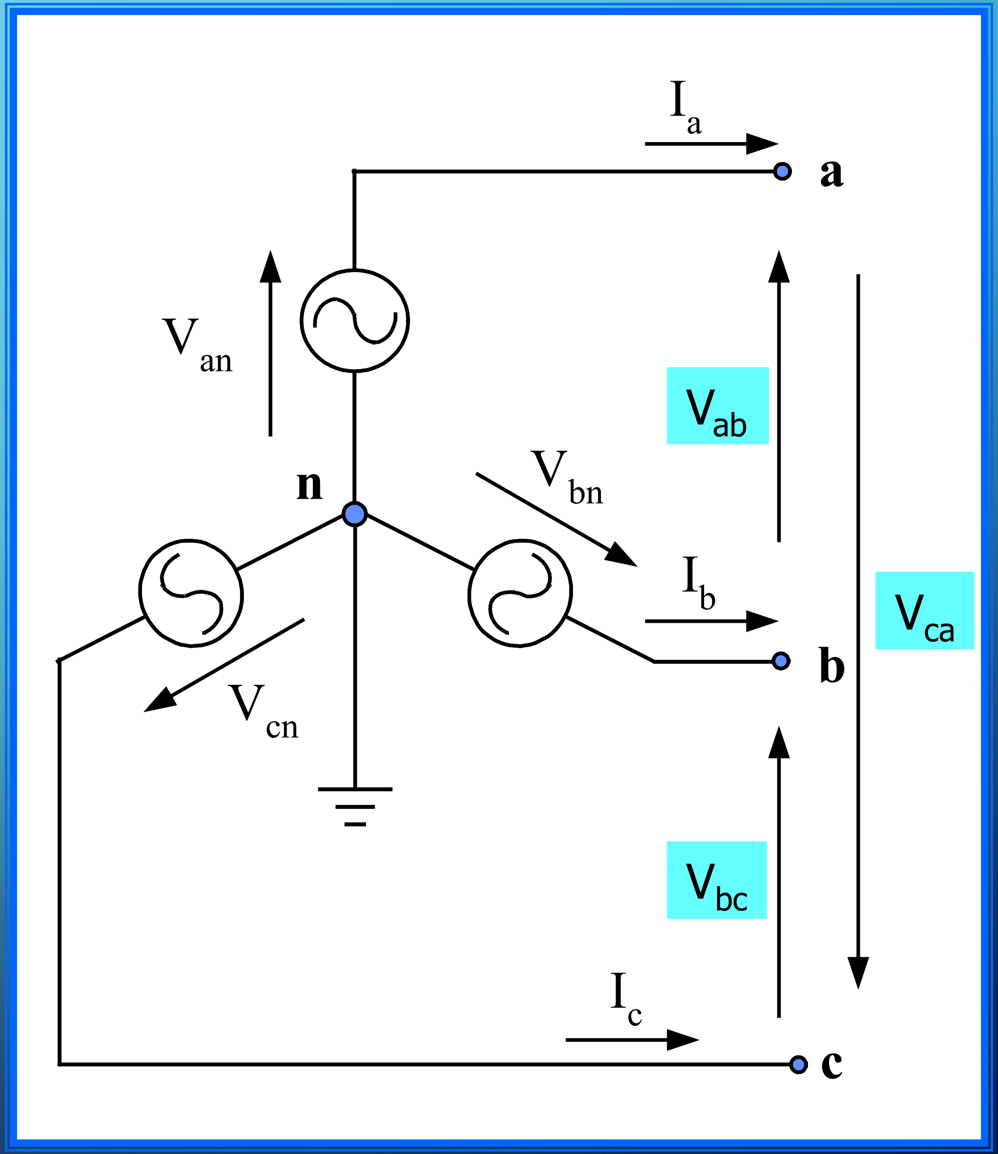
$$V_{an} = V_M \angle 0^\circ \quad \text{volt}$$

$$V_{bn} = V_M \angle -120^\circ \quad \text{volt}$$

$$V_{cn} = V_M \angle 120^\circ \quad \text{volt}$$

LINE VOLTAGES, V_L

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



LINE VOLTAGES, V_L

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

$$V_{bc} = V_{bn} - V_{cn}$$

$$V_{ca} = V_{cn} - V_{an}$$

$$V_{ab} = \sqrt{3} V_M \angle 30°$$

$$V_{bc} = \sqrt{3} V_M \angle -90°$$

$$V_{ca} = \sqrt{3} V_M \angle 150°$$

$$V_{an} = V_M \angle 0^\circ \quad \text{volt}$$

$$V_{bn} = V_M \angle -120^\circ \quad \text{volt}$$

$$V_{cn} = V_M \angle 120^\circ \quad \text{volt}$$

PHASE VOLTAGE (V_ϕ)

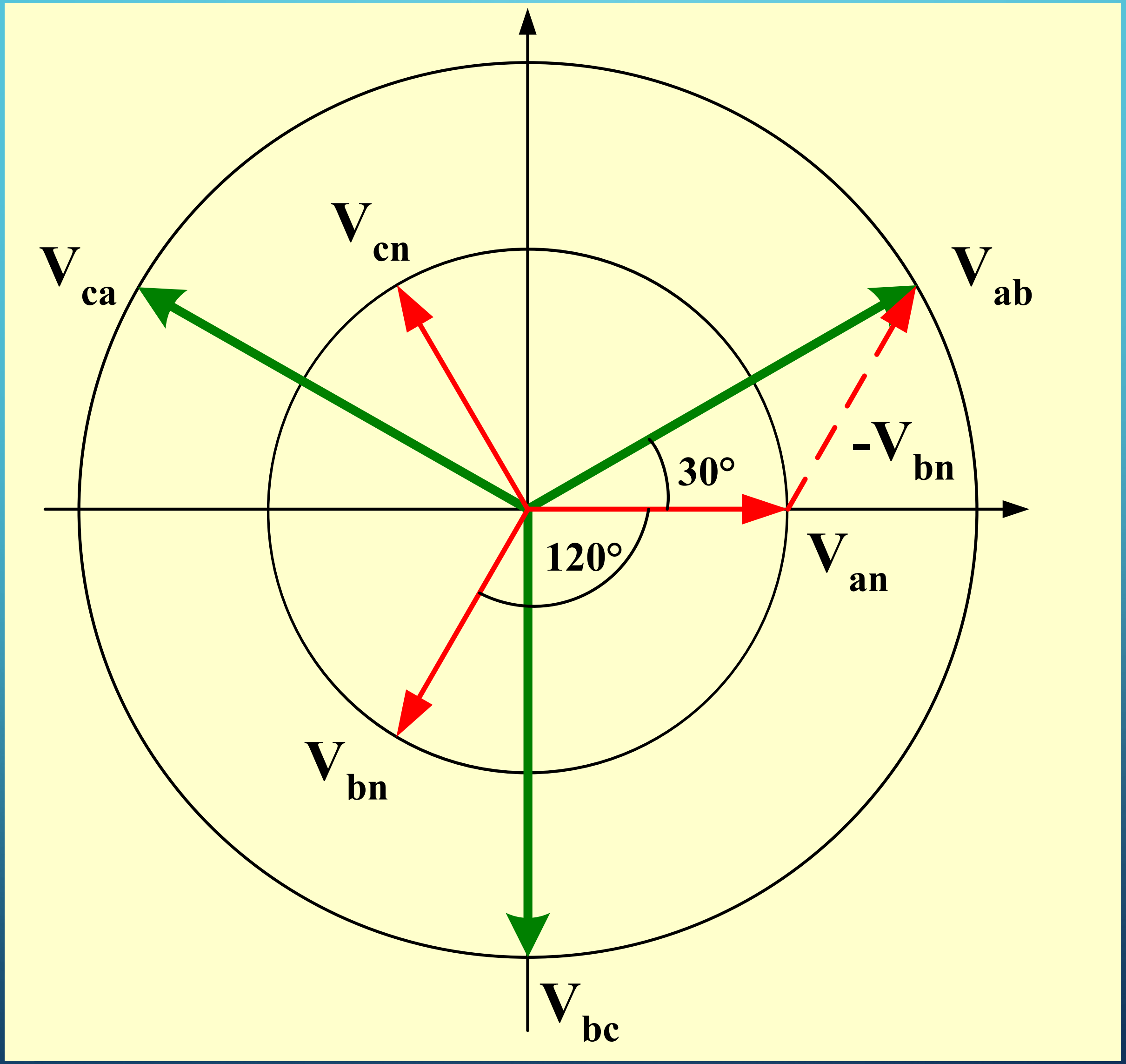
LINE VOLTAGE (V_L)

$$V_{ab} = \sqrt{3}\ V_M \angle 30^\circ \quad \text{volt}$$

$$V_{bc} = \sqrt{3}\ V_M \angle -90^\circ \quad \text{volt}$$

$$V_{ca} = \sqrt{3}\ V_M \angle 150^\circ \quad \text{volt}$$

PHASE DIAGRAM OF V_L AND V_ϕ



PROPERTIES OF PHASE VOLTAGE

- All phase voltages have the same magnitude,

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

- Out of phase

PROPERTIES OF LINE VOLTAGE

- All line voltages have the same magnitude,

$$V_L = |V_{ab}| = |V_{bc}| = |V_{ca}|$$

- Out of phase with each other by 120°

RELATIONSHIP BETWEEN V_ϕ AND V_L

1. Magnitude

$$|V_L| = \sqrt{3}\,|V_\phi|$$

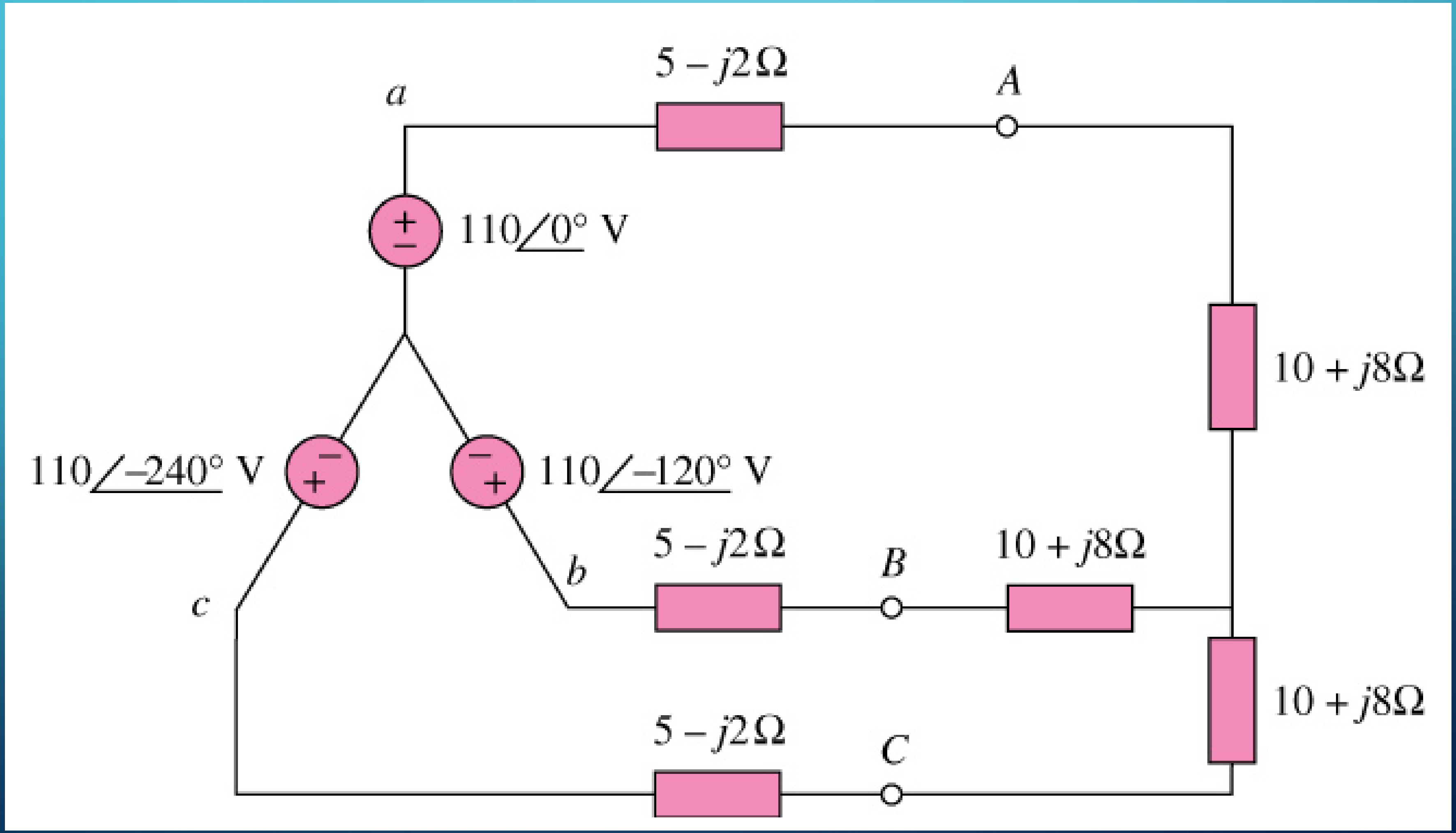
2. Phase

- V_L LEAD their corresponding V_ϕ by 30°

$$\angle V_L = \angle V_\phi + 30^\circ$$

EXAMPLE 1

- Calculate the line currents



THANK FOR YOUR ATTENTION!