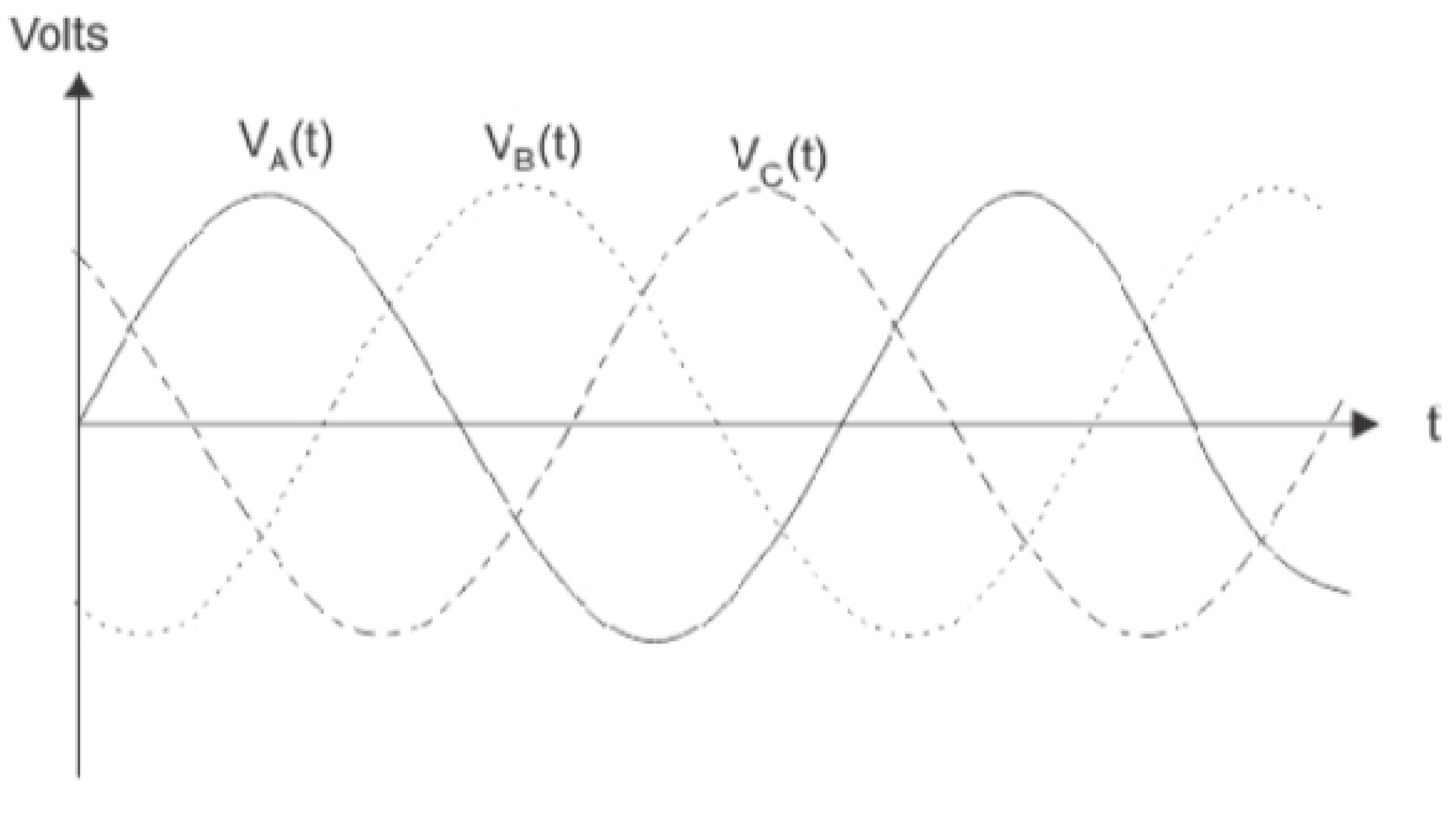
Three Phase Circuit | Star and Delta System

There are two types of system available in electric circuit, single phase and **three phase system**. In single phase circuit, there will be only one phase, i.e the current will flow through only one wire and there will be one return path called neutral line to complete the circuit. So in single phase minimum amount of power can be transported.

In 1882, new invention has been done on polyphase system, that more than one phase can be used for generating, transmitting and for load system. **Three phase circuit** is the polyphase system where three phases are send together from the generator to the load.

Each phase are having a phase difference of 120^o, i.e 120^o angle electrically. So from the total of 360^o, three phases are equally divided into 120^o each. The power in **three phase system** is continuous as all the three phases are involved in generating the total power. The sinusoidal waves for 3 phase system is shown below-

The three phases can be used as single phase each. So if the load is single phase, then one phase can be taken from the **three phase circuit** and the neutral can be used as ground to complete the circuit.



In three phase circuit, connections can be given in two types:

1. Star connection
2. Delta connection

Less commonly, there is also an open delta connection where two single-phase transformers are used to provide a three-phase supply. These are generally only used in emergency conditions, as their efficiency is low when compared to delta-delta (closed delta) systems (which are used during standard operations).

Star Connection

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Star Connection

In **star connection**, there is four wire, three wires are phase wire and fourth is neutral which is taken from the star point. Star connection is preferred for long distance power transmission because it is having the neutral point. In this we need to come to the concept of balanced and unbalanced current in power system.

When equal current will flow through all the three phases, then it is called as balanced current. And when the current will not be equal in any of the phase, then it is unbalanced current. In this case, during balanced condition there will be no current flowing through the neutral line and hence there is no use of the neutral terminal. But when there

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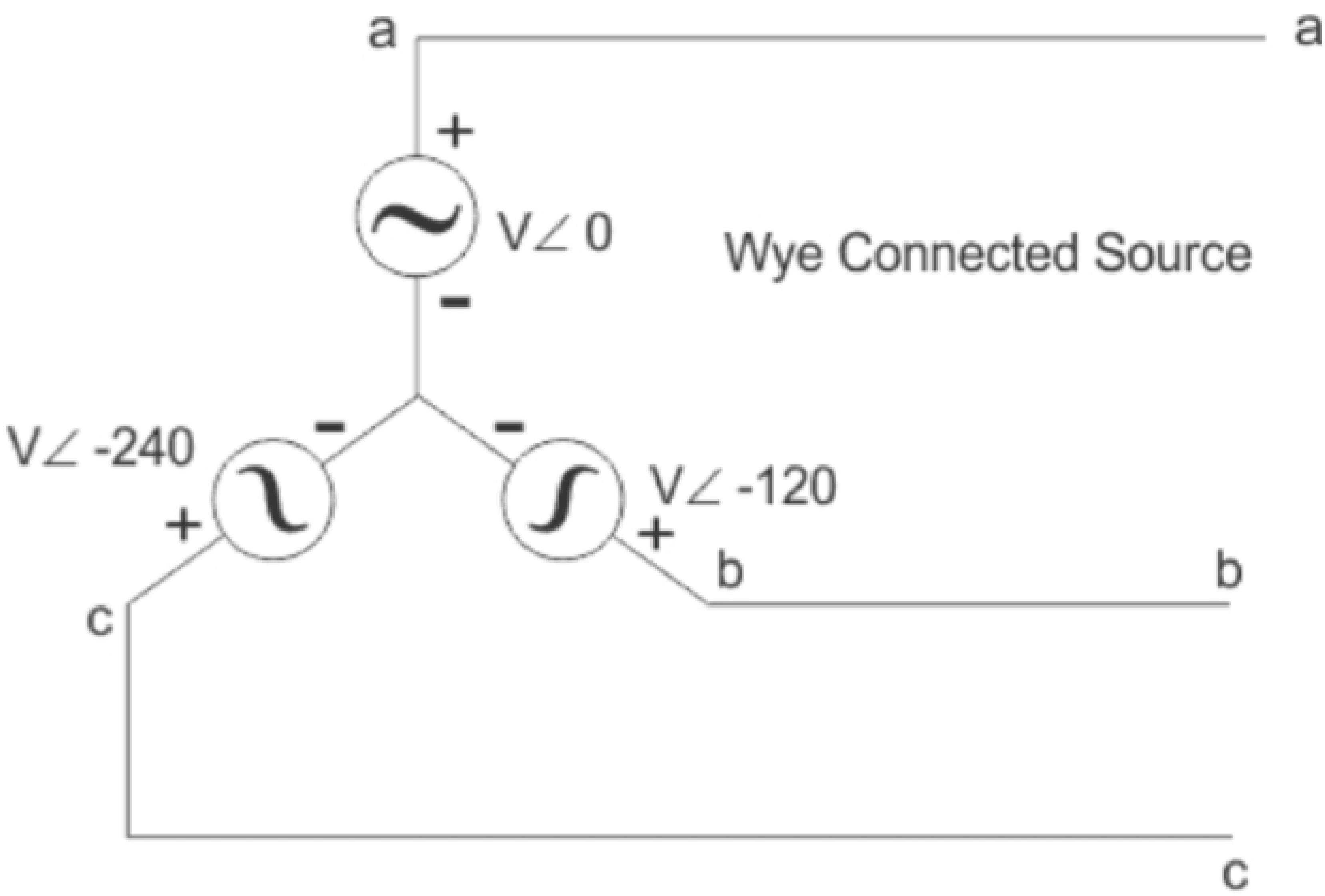
The star connection is shown below-



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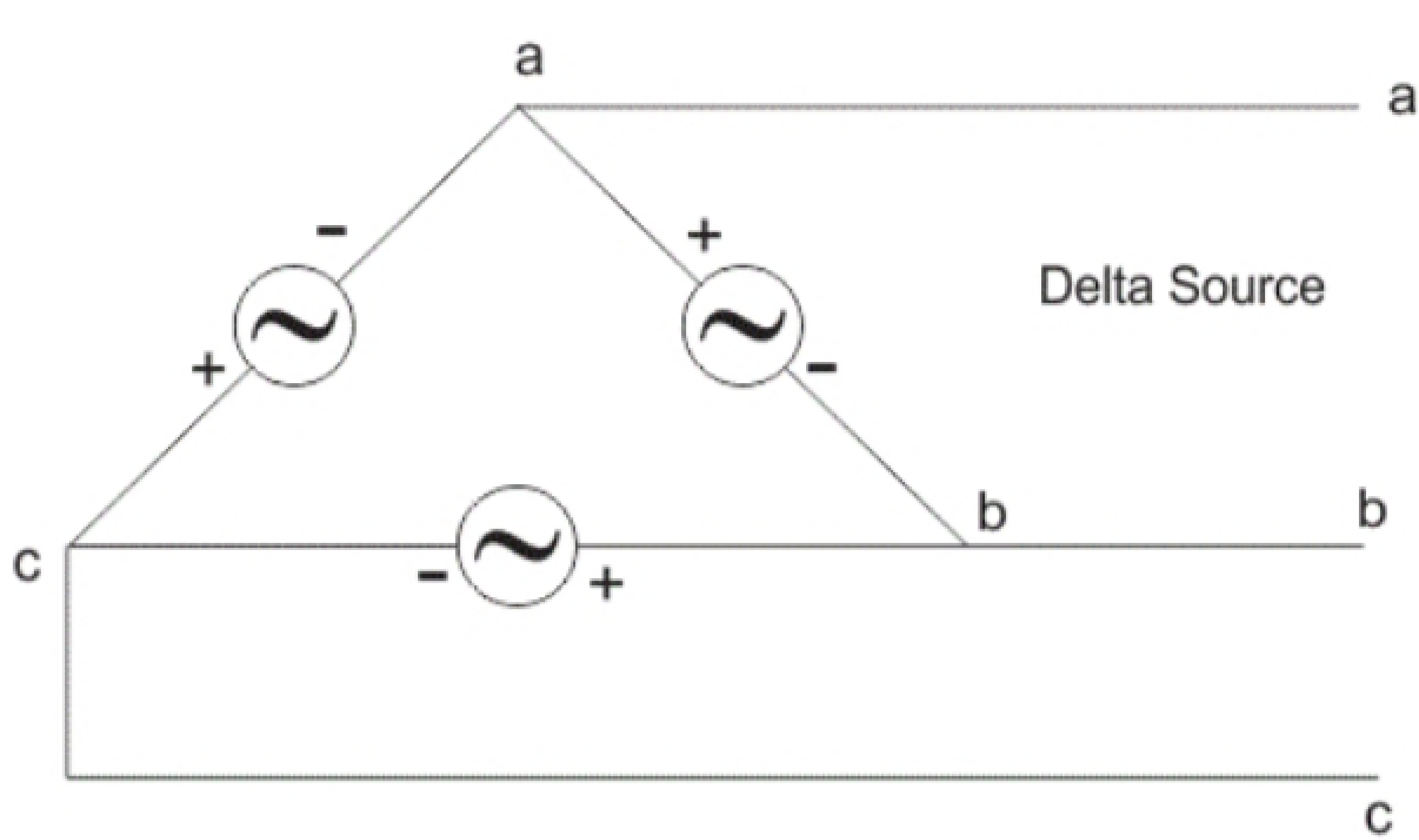
$$E_{Line} = \sqrt{3}E_{phase} \text{ and } I_{Line} = I_{Phase}$$

Delta Connection

In **delta connection**, there is three wires alone and no neutral terminal is taken. Normally delta connection is preferred for short distance due to the problem of unbalanced current in the circuit. The figure is shown below for delta connection. In the load station, ground can be used as neutral path if required.



In delta connection, the line voltage is the same as that of phase voltage. And the line current is √3 times of phase current. It is shown as expression below,

$$E_{Line} = E_{phase} \; and \; I_{Line} = \sqrt{3} I_{Phase}$$

In a three-phase circuit, star and delta connection can be arranged in four different ways:

1. Star-Star connection
2. Star-Delta connection
3. Delta-Star connection
4. Delta-Delta connection

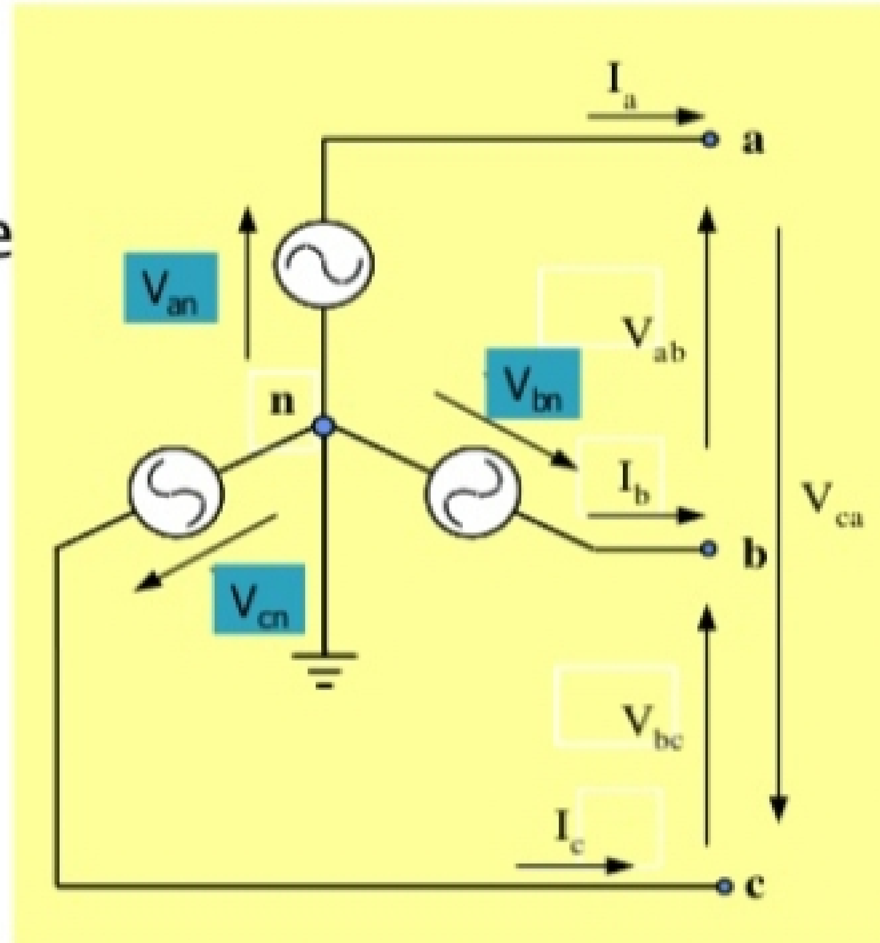
But the power is independent of the circuit arrangement of the three phase system. The net power in the circuit will be same in both star and delta connection. The power in three phase circuit can be calculated from the equation below,

$$P_{Total} = 3 \times E_{phase} \times I_{phase} \times PF$$

Since, there is three phases, so the multiple of 3 is made in the normal power equation and the PF is power factor. Power factor is a very important factor in three phase system and some times due to certain error, it is corrected by using capacitors.

PHASE VOLTAGES, V_ϕ

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



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.

BALANCED 3ϕ VOLTAGES

- Balanced three phase voltages:
  1) same magnitude
  2) 120° phase shift

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

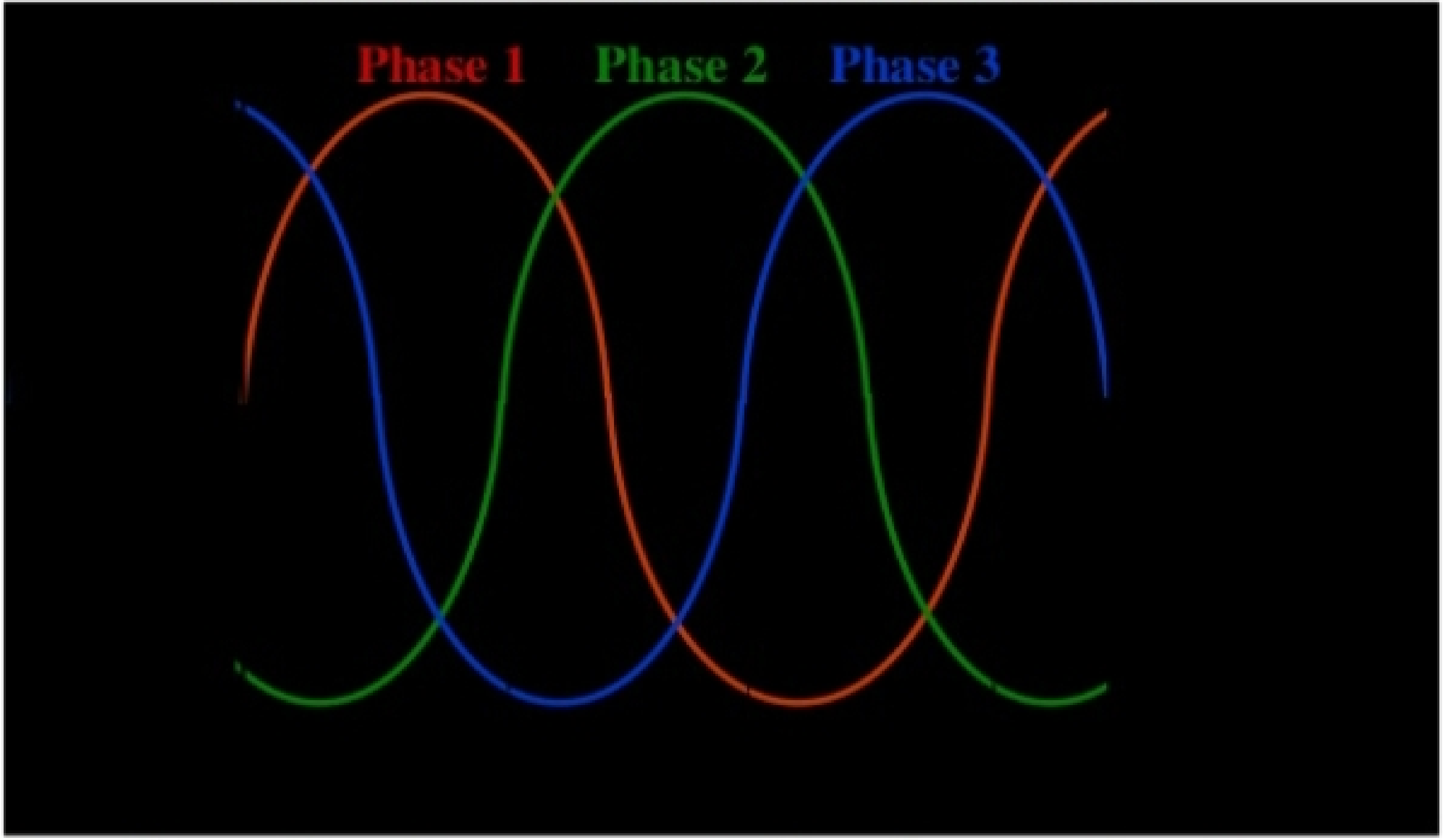
BALANCED 3ϕ CURRENTS

•Balanced three phas currents:

1) same magnitude
2) 120° phase shift

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

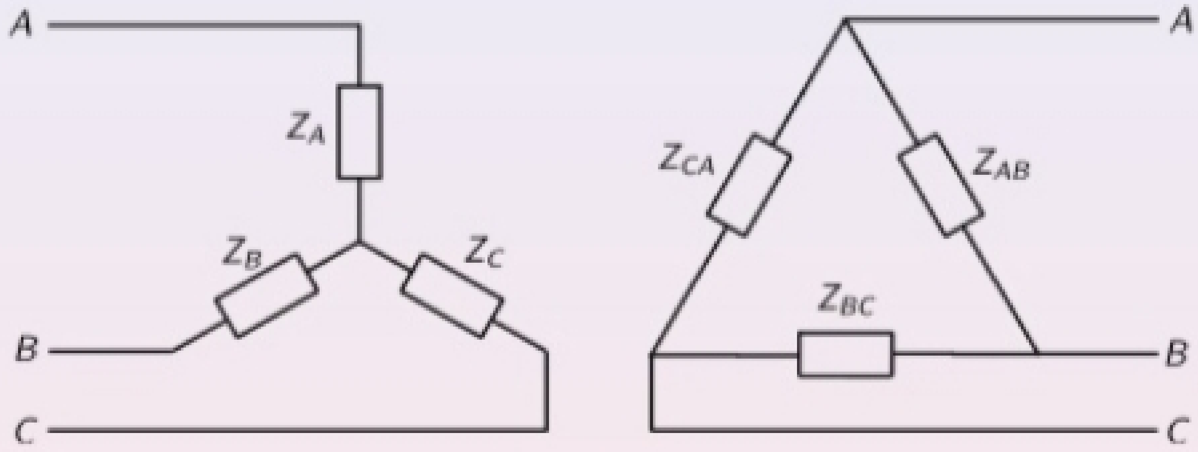
THREE-PHASE WAVEFORM



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

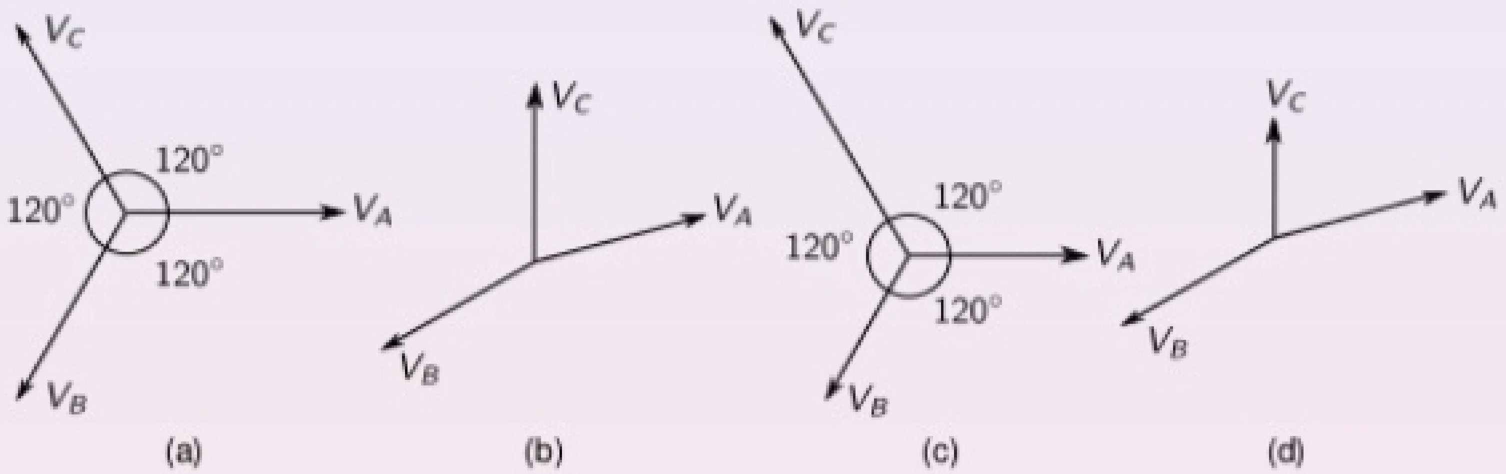
Phase 3 lags phase 1 by 240°. Phase 1 leads phase 3 by 240°.

Meaning of Balanced/Unbalanced Load and System



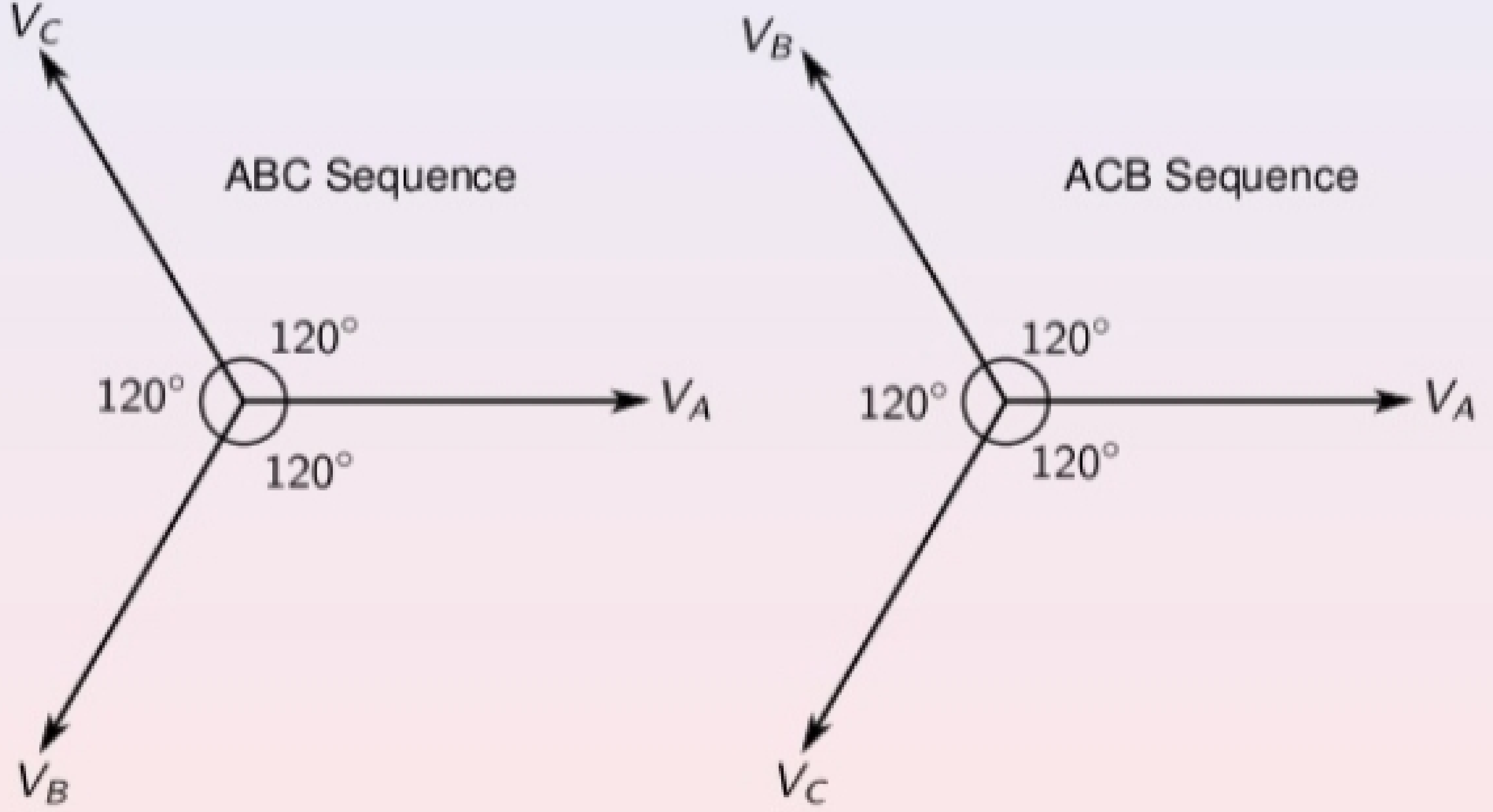
- If the three impedances, which may be Y or Δ connected are equal, then, the three-phase load is said to be balanced.
- If load and supply are both balanced, then three-phase system is said to be balanced.
- Under normal working conditions, a three-phase system can be taken to be balanced.

Meaning of Balanced and Unbalanced Supply



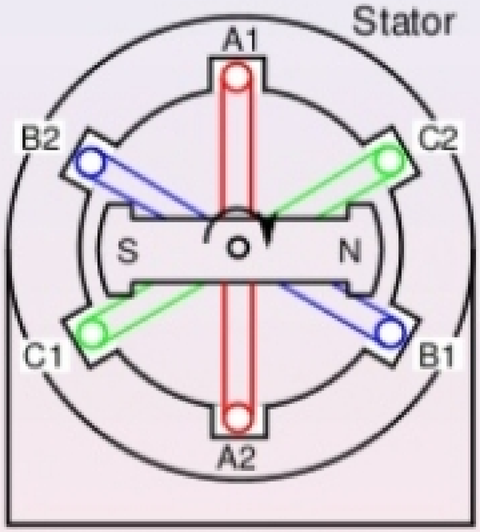
- If $|V_A| = |V_B| = |V_C| = |V_{ph}|$ and if the phase difference between V_A and V_B, V_B and V_C, V_C and V_A is equal to 120° as shown in (a) then, the supply is said to be balanced or symmetrical.
- Phasor diagrams (b), (c), and (d) represent unbalanced

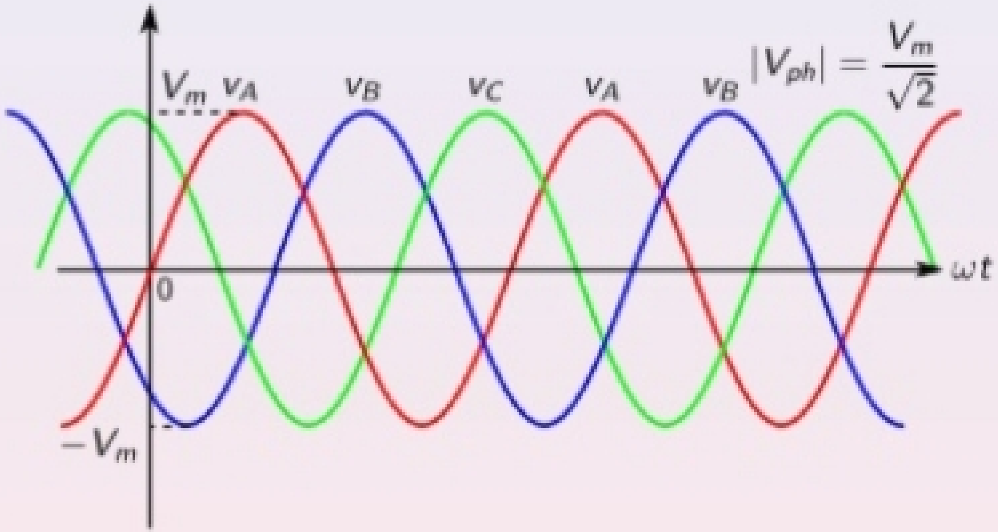
Meaning of Phase Sequence



Phase sequence can be changed by reversing the direction of rotation of rotor of the alternator.

Generation of Three-phase Supply



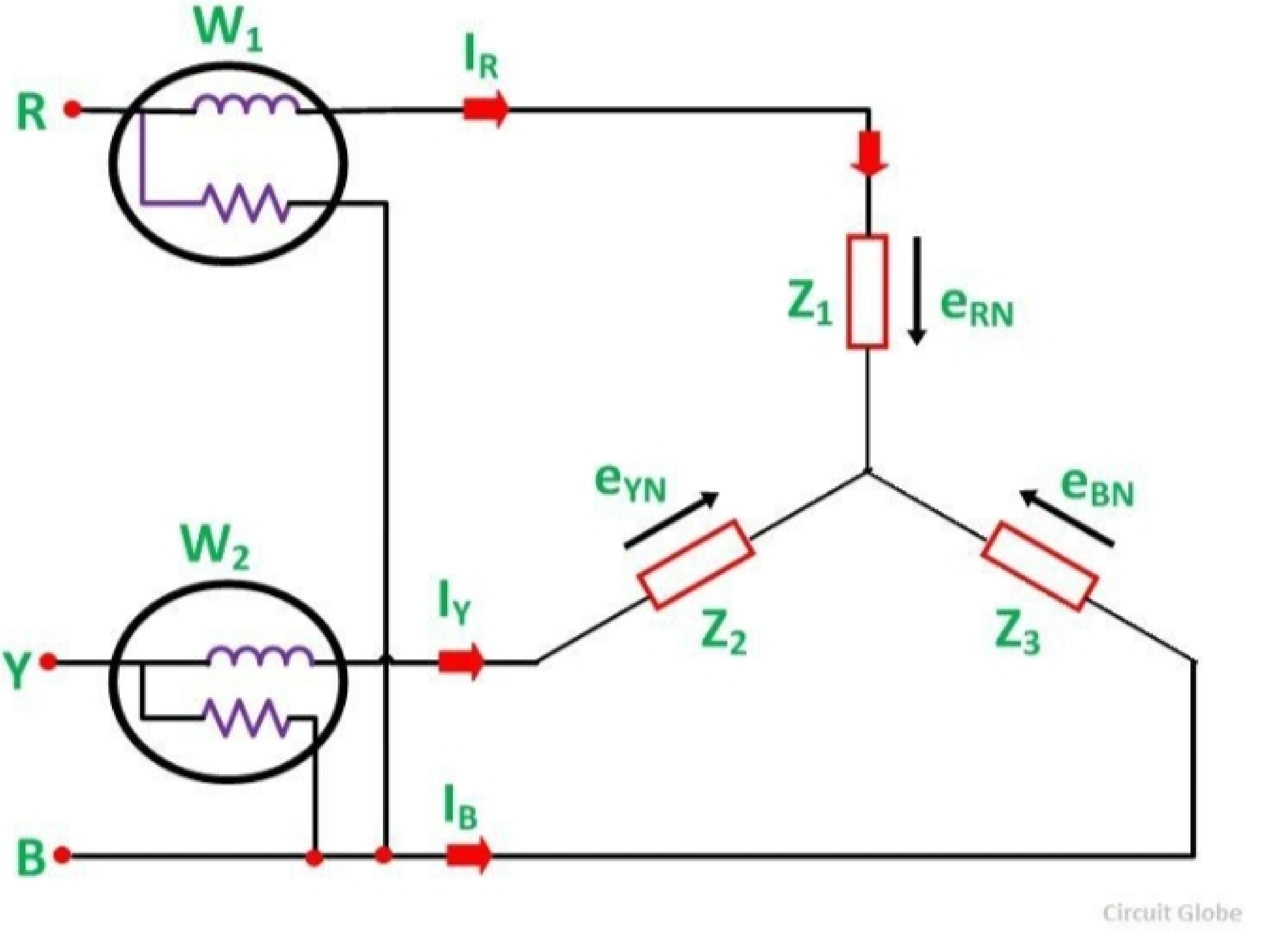


$$v_A = V_m \sin \omega t \implies V_A = |V_{ph}|\angle 0^\circ$$
$$v_B = V_m \sin(\omega t - 120^\circ) \implies V_B = |V_{ph}|\angle -120^\circ$$
$$v_C = V_m \sin(\omega t - 240^\circ) \implies V_B = |V_{ph}|\angle -240^\circ$$

Two Wattmeter Method of Power Measurement

Two Wattmeter Method can be employed to measure the power in a 3 phase, three-wire star or delta connected the balanced or unbalanced load.

In two wattmeter method, the current coils of the wattmeter are connected with any two lines, say R and Y and the potential coil of each wattmeter is joined on the same line, the third line i.e. B as shown below in figure (A):



The total instantaneous power absorbed by the three loads Z_1, Z_2 and Z_3, is equal to the sum of the powers measured by the two wattmeters, W_1 and W_2.

Measurement of Power by Two Wattmeter Method in Star Connection

Considering the above figure (A) in which Two Wattmeter W_1 and W_2 are connected, the instantaneous current through the current coil of Wattmeter, W_1 is given by the equation shown below:

$$W_1 = i_R$$

The instantaneous potential difference across the potential coil of Wattmeter, W_1 is given as:

$$W_1 = e_{RN} - e_{BN}$$

Instantaneous power measured by the Wattmeter, W_1 is

$$W_1 = i_R \left(e_{RN} - e_{BN}\right) \quad \ldots\ldots\ldots (1)$$

The instantaneous current through the current coil of Wattmeter, W_2 is given by the equation:

$$W_2 = i_Y$$

The instantaneous potential difference across the potential coil of Wattmeter, W_2 is given as:

$$W_2 = e_{YN} - e_{BN}$$

Instantaneous power measured by the Wattmeter, W_2 is:

$$W_2 = i_Y \left(e_{YN} - e_{BN}\right) \quad \ldots\ldots\ldots (2)$$

Therefore, the total power measured by the two wattmeters W_1 and W_2 will be obtained by adding the equation (1) and (2).

Therefore, the total power measured by the two wattmeters W_1 and W_2 will be obtained by adding the equation (1) and (2).

$$W_1 + W_2 = i_R (e_{RN} - e_{BN}) + i_Y (e_{YN} - e_{BN})$$

$$W_1 + W_2 = i_R e_{RN} + i_Y e_{YN} - e_{BN} (i_R + i_Y) \quad \text{or}$$

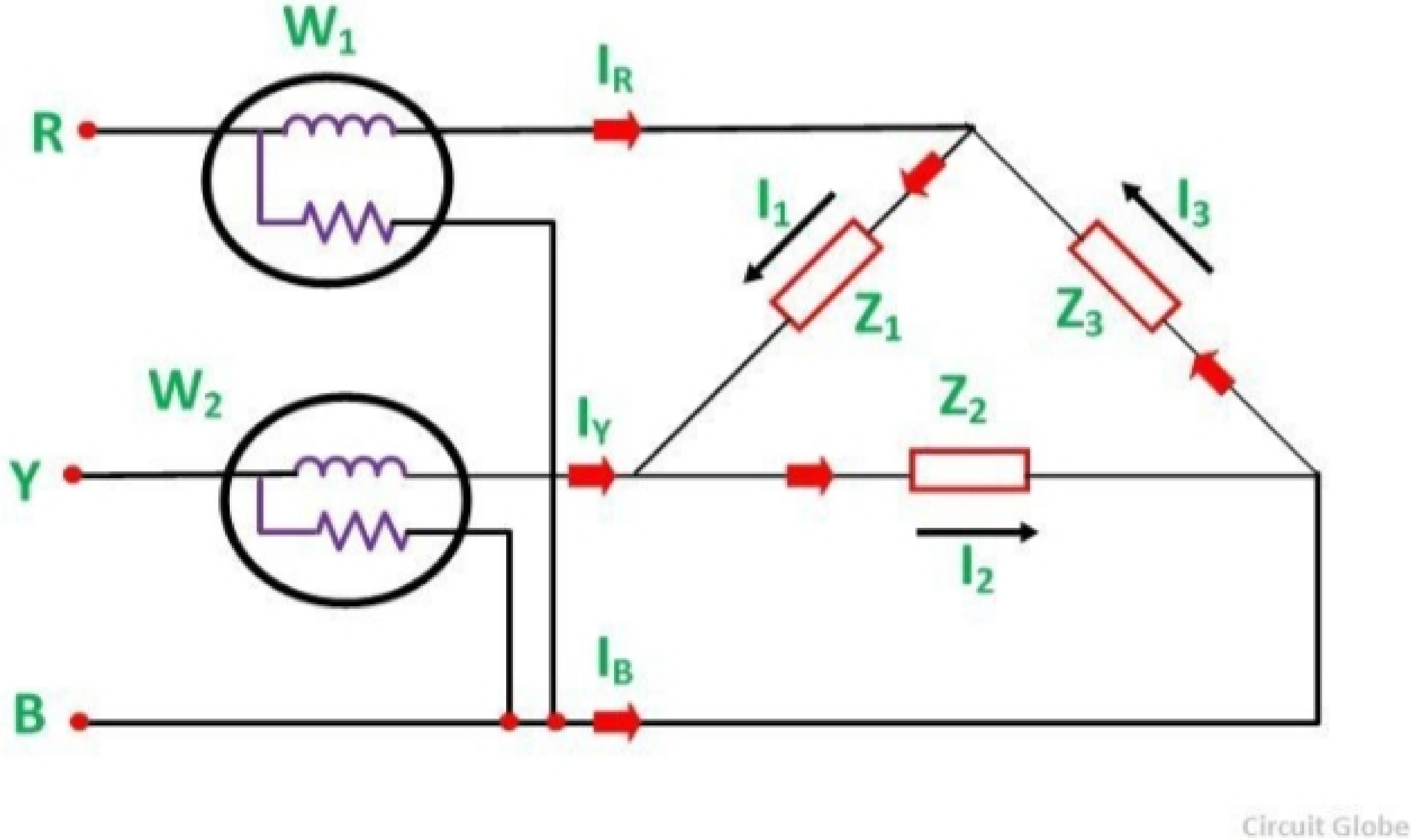
$$W_1 + W_2 = i_R e_{RN} + i_Y e_{YN} + i_B e_{BN} \qquad (\text{i.e. } i_R + i_Y + i_B = 0)$$

$$W_1 + W_2 = P$$

Where, P – the total power absorbed in the three loads at any instant.

Measurement of Power by Two Wattmeter Method in Delta Connection

Considering the delta connected circuit shown in the figure below:



The instantaneous current through the coil of the wattmeter, W_1 is given by the equation:

$$W_1 = i_R = i_1 - i_3$$

$$W_1 + W_2 = e_{RB}(i_1 - i_3) + e_{YB}(i_2 - i_1)$$

$$W_1 + W_2 = i_1 e_{RB} + i_1 e_{YB} - i_3 e_{RB} - i_1 e_{YB}$$

$$W_1 + W_2 = i_2 e_{YB} + i_3 e_{BR} - i_1(e_{YB} + e_{BR}) \qquad (\text{i.e.} -e_{RB} = e_{RB})$$

$$W_1 + W_2 = i_1 e_{RY} + i_2 e_{YB} + i_3 e_{BR} \quad (\text{i.e } e_{RY} + e_{YB} + e_{BR} = 0)$$

$$W_1 + W_2 = P$$

Where P is the total power absorbed in the three loads at any instant.

The power measured by the Two Wattmeter at any instant is the instantaneous power absorbed by the three loads connected in three phases. In fact, this power is the average power drawn by the load since the Wattmeter reads the average power because of the inertia of their moving system.

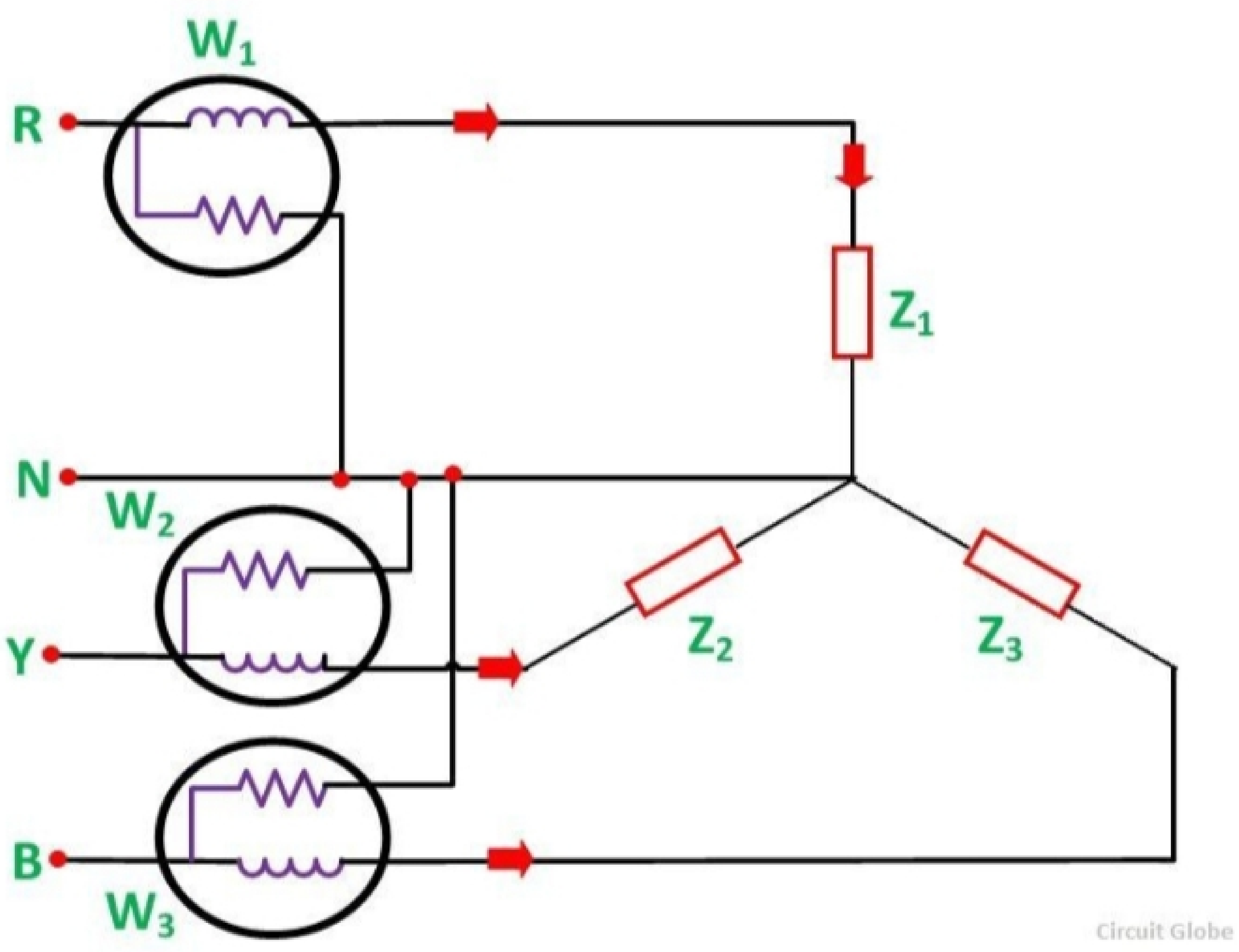
Measurement of Three Phase Power: Three Wattmeter Method

Power measurement in an AC circuit is measured with the help of a Wattmeter. A wattmeter is an instrument which consists of two coils called **Current coil** and **Potential coil.**

Three-Wattmeter Method of Three-Phase Power Measurement

Three Wattmeter method is employed to measure power in a 3 phase, 4 wire system. However, this method can also be employed in a 3 phase, 3 wire delta connected load, where power consumed by each load is required to be determined separately.

The connections for star connected loads for measuring power by three wattmeter method is shown below:



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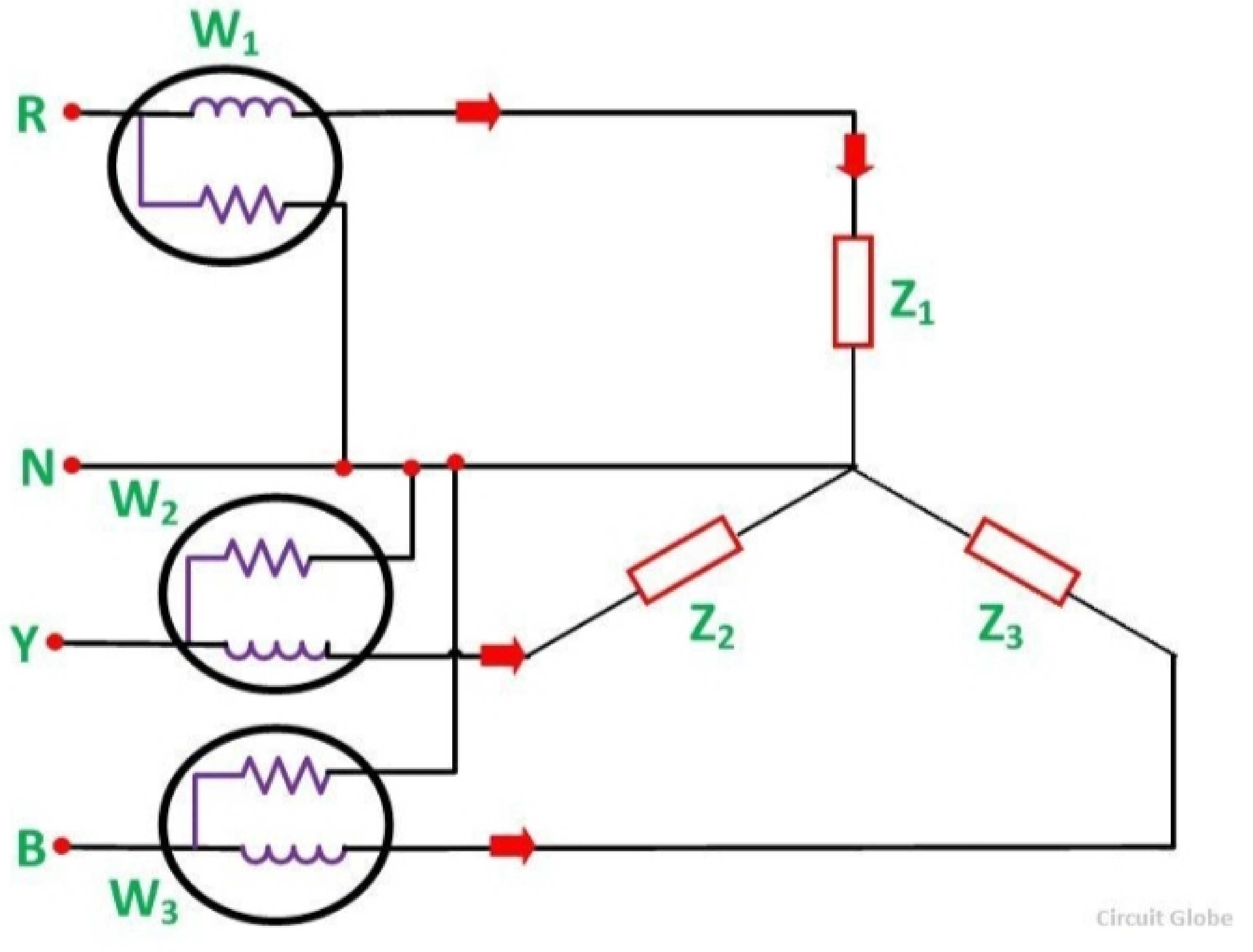

The pressure coil of all the three wattmeters namely W_1, W_2 and W_3 are connected to a common terminal known as the **neutral point**. The product of the phase current and line voltage represents phase power and is recorded by an individual wattmeter.

The total power in a three wattmeter method of power measurement is given by the algebraic sum of the readings of three wattmeters. i.e.

$$\text{Total power } P = W_1 + W_2 + W_3$$

Where,

$W_1 = V_1 I_1$

$W_2 = V_2 I_2$

$W_3 = V_3 I_3$

Except for 3 phase, 4 wire unbalanced load, 3 phase power can be measured by using only Two Wattmeter Method.