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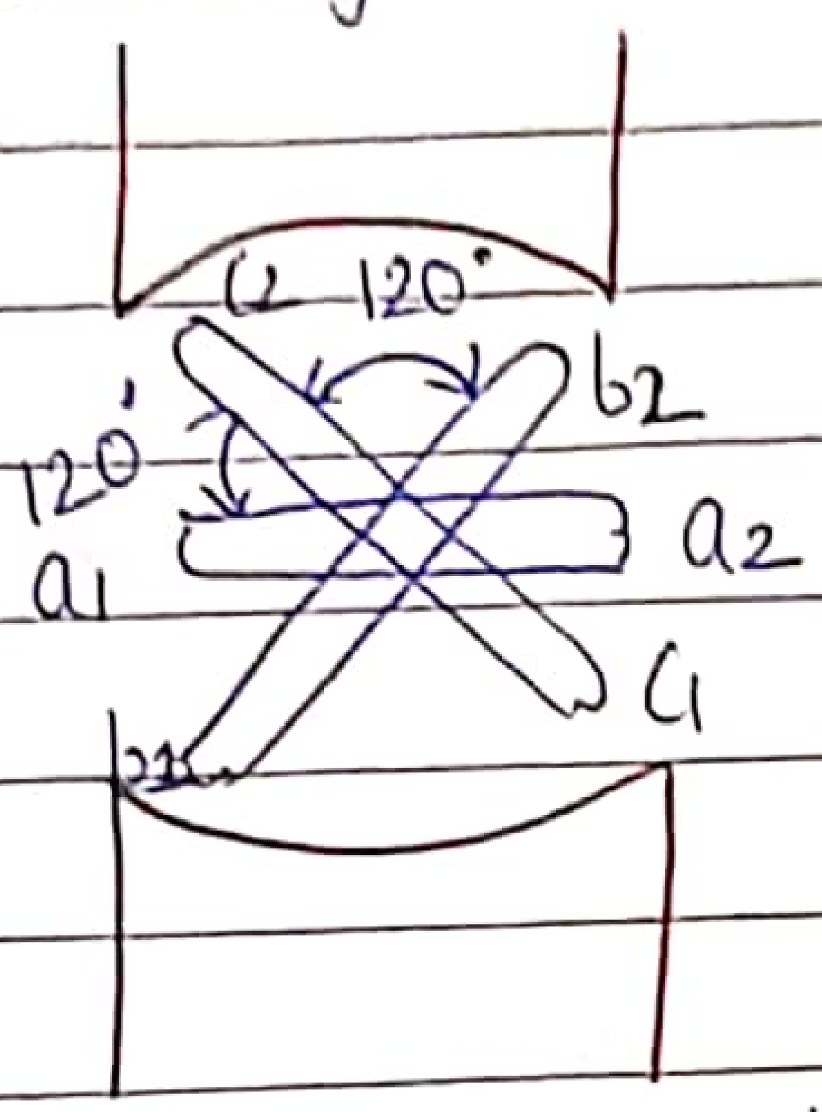
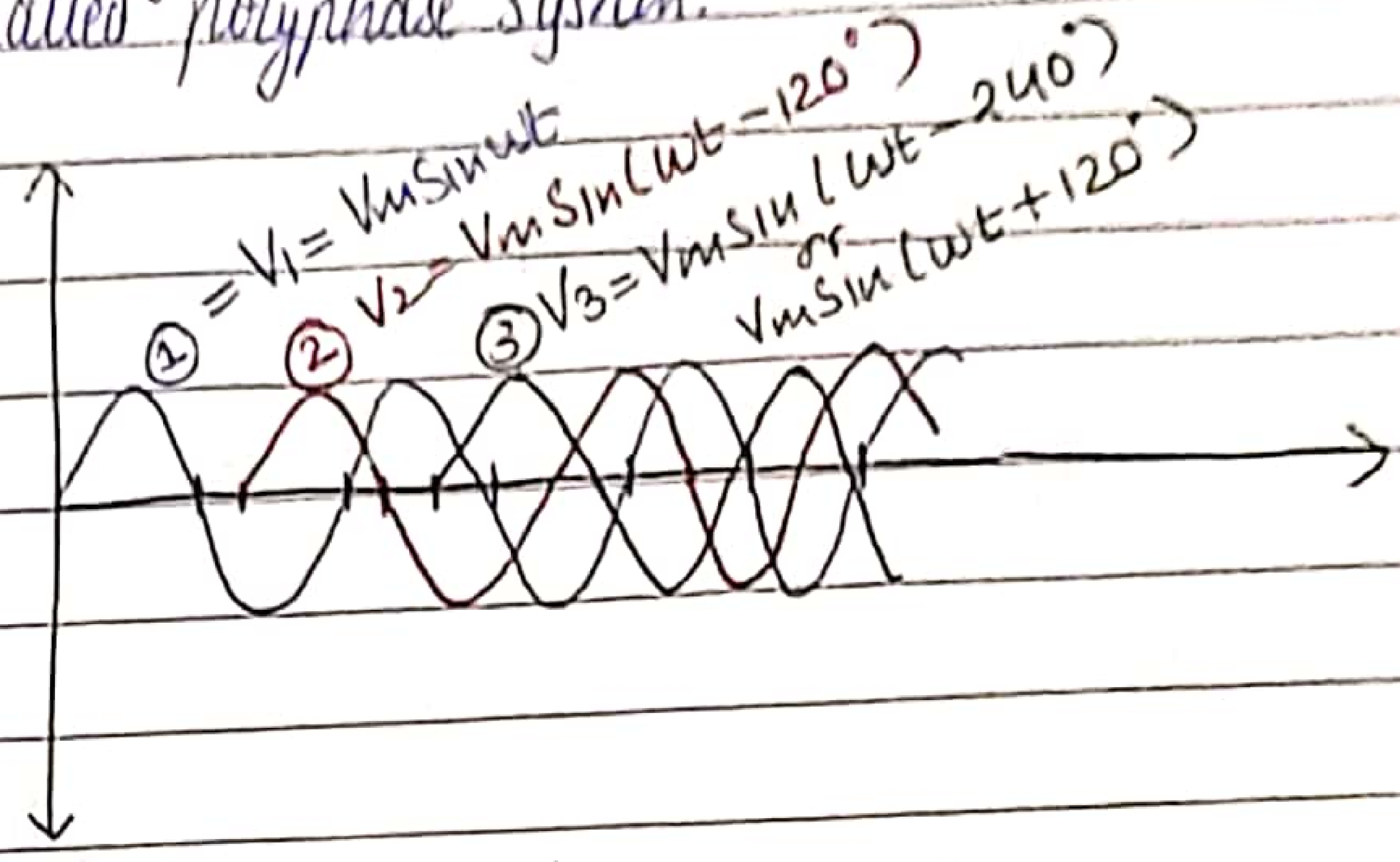
TOPIC :- 3 Phase AC Circuit

⇒ Polyphase :- More than one phase
↳ An A.C System having a group of (two or more than two) coils with equal voltages of same frequency arranged to have equal phase difference between adjacent emfs is called polyphase system.





⇒ Advantages of 3-Phase System over 1 Phase System :-

1) Constant power :- In polyphase powers delivered is const when the loads are balanced while in single phase it is pulsating.

2) Higher rating :- The rating of 3 phase is 1.5 times 1 phase system of same ~~st~~ size.

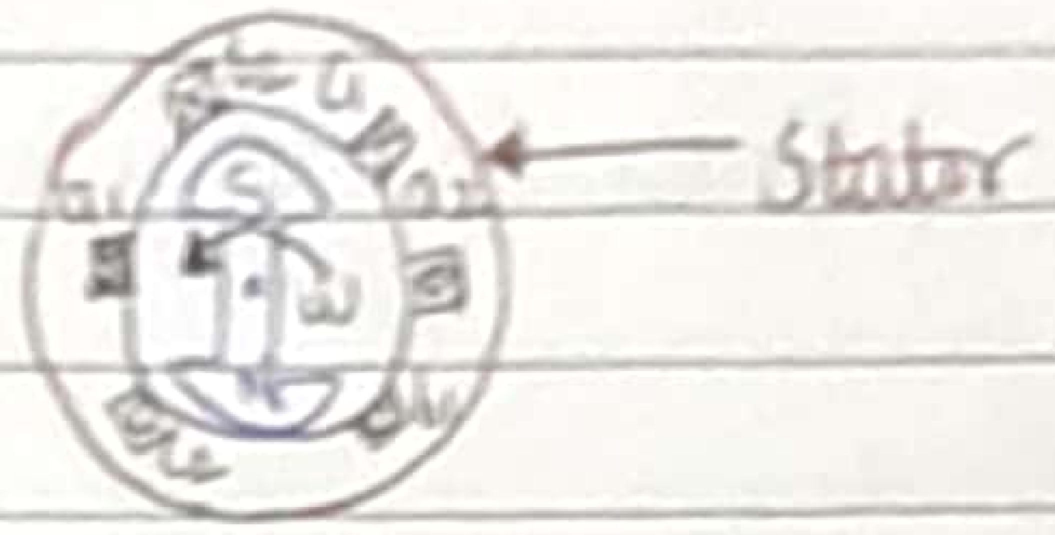
3) Power transmission economics :- 3 phase system requires 75% of the weight of conducting material required by single phase.

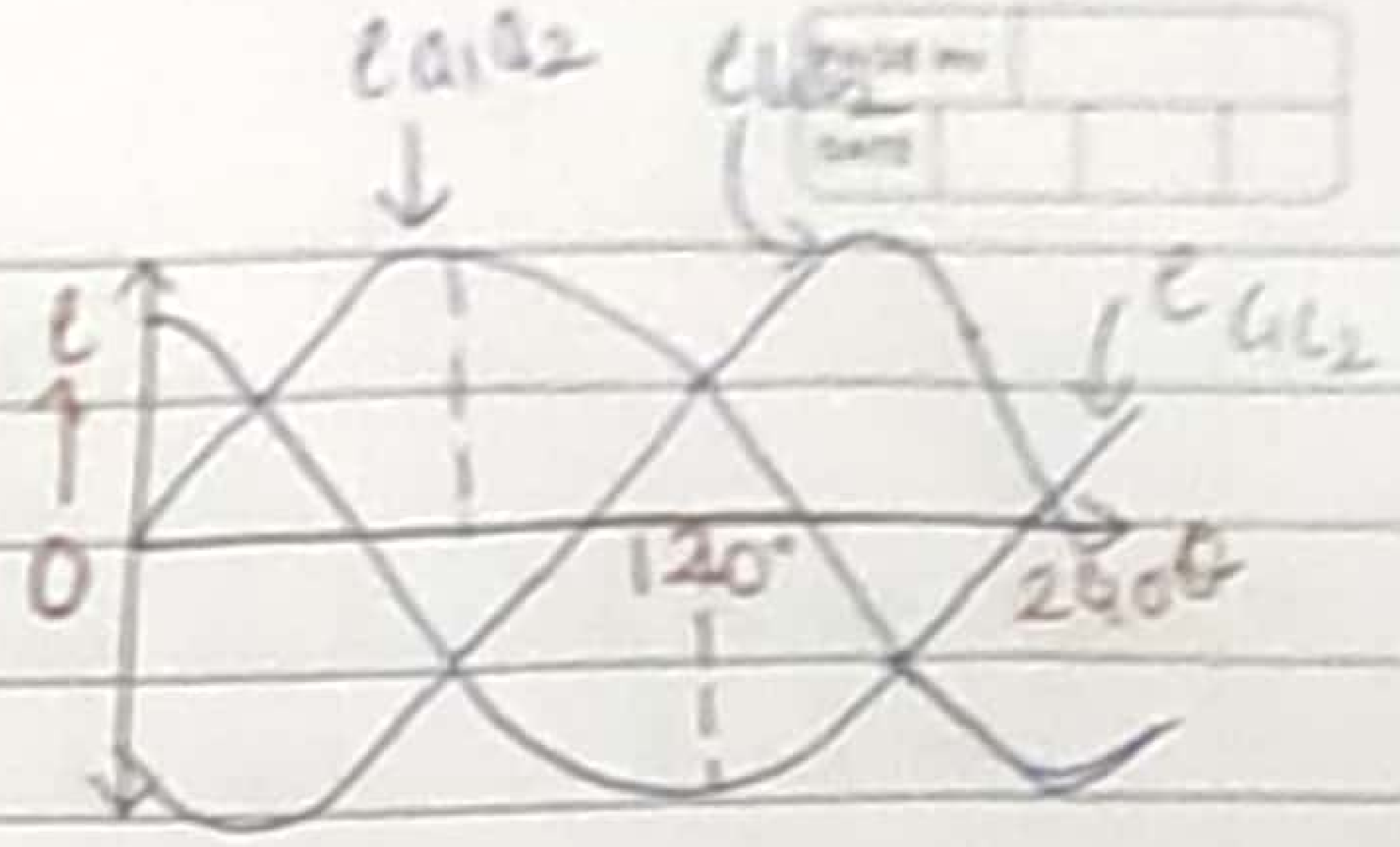
4) Self starting :- 3 phase induction motor are self starting while 1 phase has no starting torque without using auxilliary means

5) Higher Power factor, Efficiency

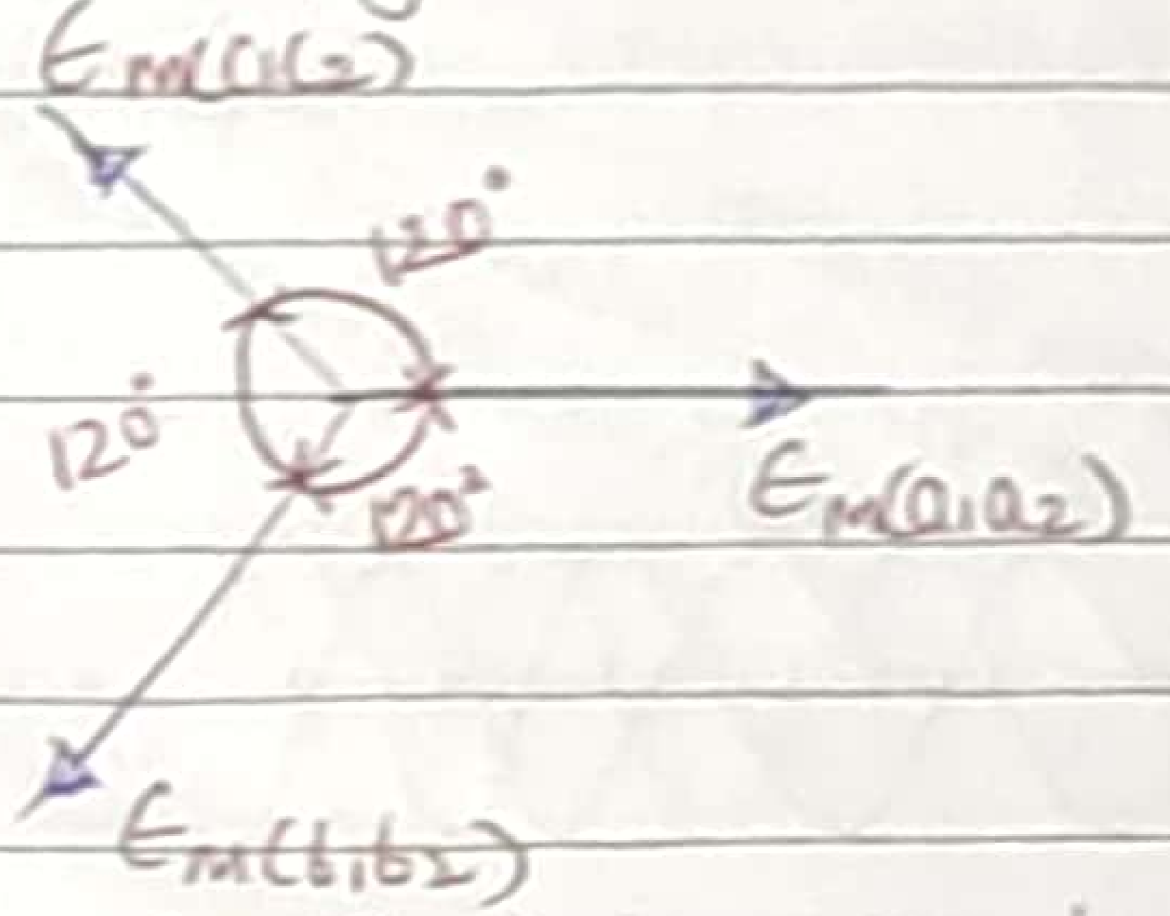
⇒ Generation of 3-Phase EMFs :-

In a 3 phase system, there are 3 equal voltages of the same frequency having a phase difference of 120°. These voltages can be produced by a 3 phase AC generator having 3 identical windings (or phases) displaced 120° apart & when these are rotated or when the windings are stationary and magnetic field is rotated an emf is induced in each winding or phase. The emf are of same magnetic and frequency but are displaced from one another by 120 electrical degrees





→ Phasor diagram :-



$e_{a_1a_2} = E_m \sin \omega t$

$e_{b_1b_2} = E_m \sin(\omega t - 2\pi/3)$

$= E_m \sin(\omega t - 120°)$

$e_{c_1c_2} = E_m \sin(\omega t - 4\pi/3)$

$= E_m \sin(\omega t - 240°)$

→ Naming :- The 3 phases may be named by no. (1, 2, 3), by letters (a, b and c) by colours (Red, yellow, blue i.e RYB) ↳ used in India

⇒ Phase Sequence :-

The order in which the voltages (or emfs) in the three phase attain their maximum positive value is called phase sequence.

In the above article, The RYB (or YBR or BRY) is considered as positive phase sequence, whereas RBY (or BYR or YRB) is considered as negative phase sequence

NOTE :-

Phase sequence is essential for following applications :-

i) The direction of rotation of 3 phase induction motor depends on the phase sequence of 3 phase supply. To reverse the direction of rotation, the phase sequence of the supply given to the motor has to be changed

ii) The parallel operation of 3 phase alternators and transformers is only possible if phase sequence is known.

⇒ Double subscript Notation :-

An alternating quantity is generally represented by a double ~~subsb~~ subscript notation. This conveys the following info.

i) The subscript of the symbol for voltage or current indicates the portion of circuit where quantity is located

ii) The ~~order~~ order of the subscript indicates the positive direction of the quantity in which it acts.

⇒ Interconnection of Three Phases :-

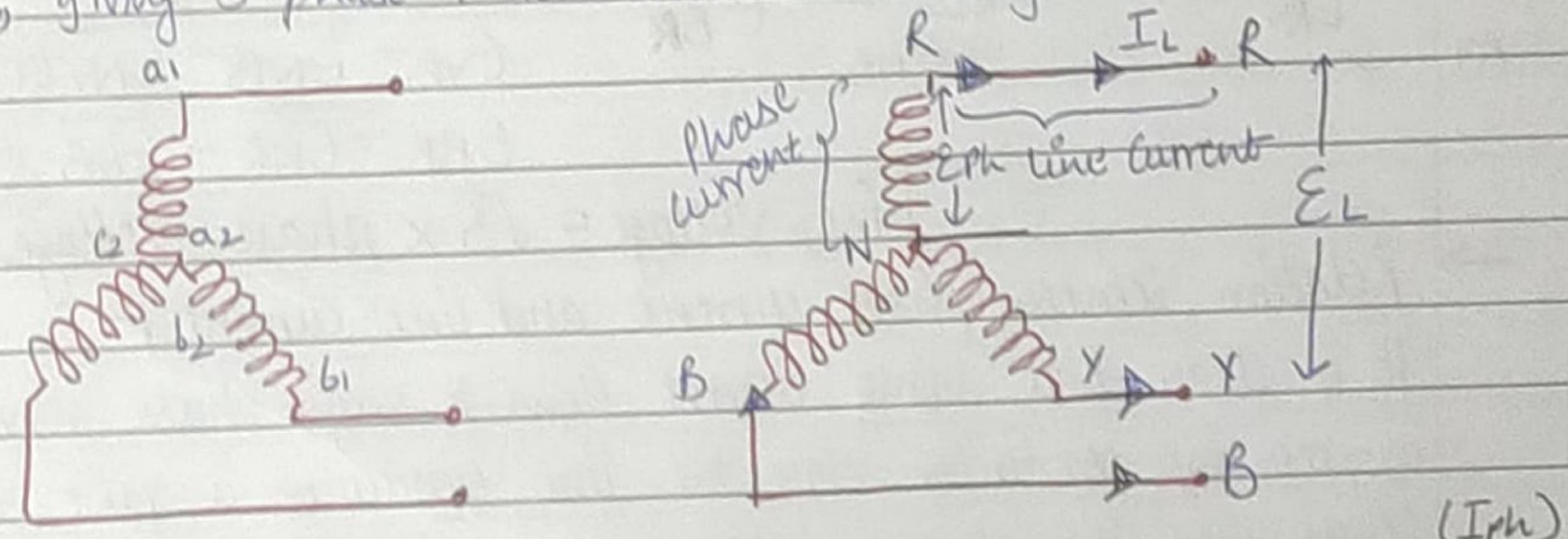
In a 3 phase AC generator, there a 3 windings. Each winding has 2 terminals (start and finish). If a separate load is connected across each phase then each phase supplies as independent load through a pair of loads indeed making the whole system complicated and expensive.

In order to reduce the number of line conductors, the three phase windings of the AC generator are suitably interconnected.

⇒ Star of Wye (Y) Connection :-

In star or Wye (Y) Connections, the similar ends (either start or finish) of the 3 windings are connected to a common point called start or neutral point.

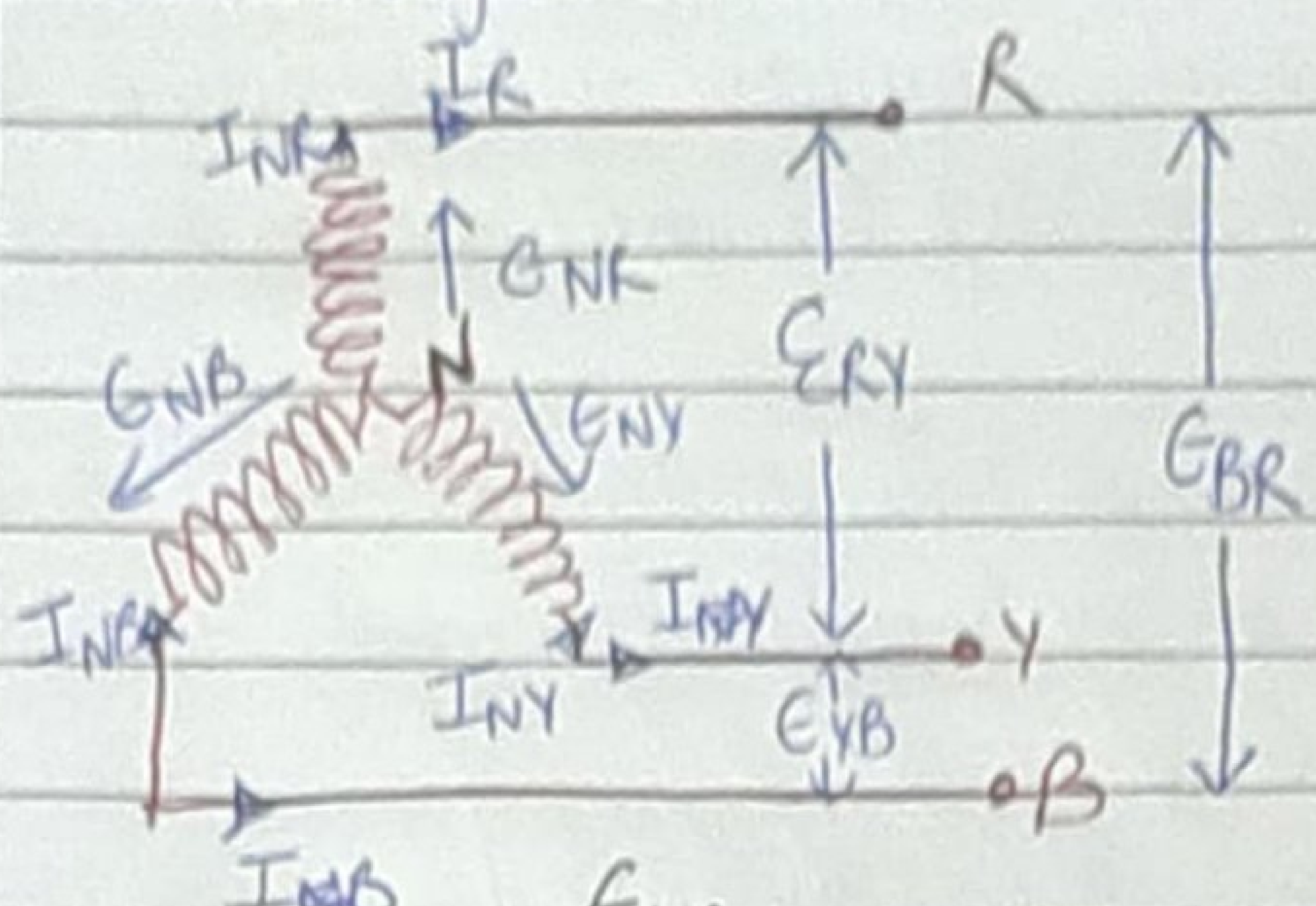
Ordinarily only 3 wires are carried to the external circuit giving 3 phase, 3 wire star connected system. However sometimes a fourth wire is carried from the star point to the external circuit called neutral wire, giving 3 phase 4 wire star connected system.



The current flowing through each phase is called phase current (I_{ph}) and current flowing through each line conductor is called ~~line curre~~ Line current (I_L). Similarly voltage across each phase is called phase voltage (E_{ph}) and voltage across 2 conductors is called line voltage (~~V_L~~ E_L)

→ Relation between phase voltage and line voltage:-

Since the system is balanced the three voltages E_{NR}, E_{NY} and E_{NB} are equal in magnitude but displaced from one another by 120° electrical degrees.



$E_{NR} = E_{NY} = E_{NB} = E_{ph}$ (in magnitude)

$\overline{E_{NR}} + \overline{E_{RY}} - \overline{E_{NY}} = 0$

(Tracing loop NRYN)

$\overline{E_{RY}} = \overline{E_{NY}} - \overline{E_{NR}}$

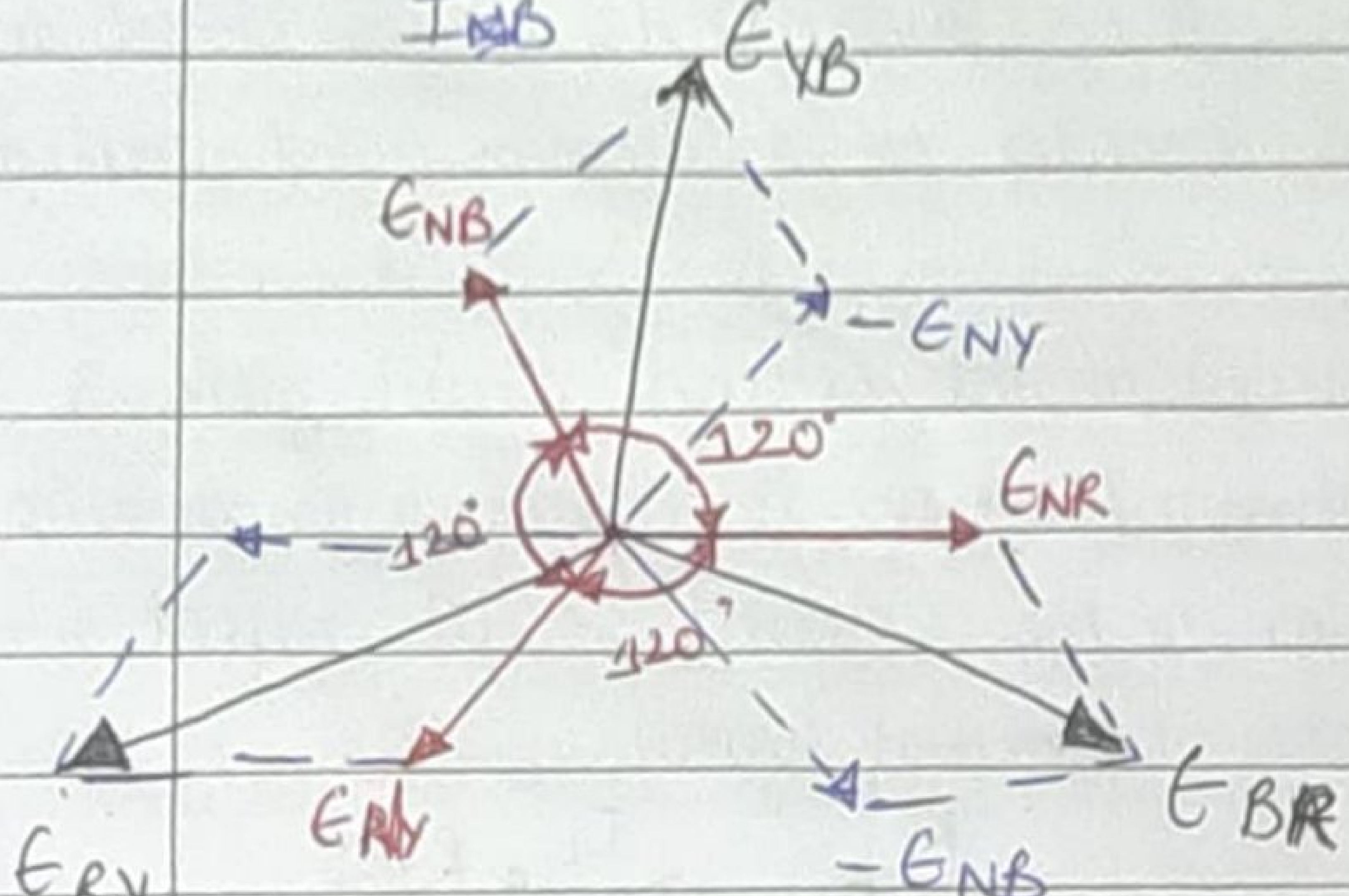
To find the vector sum of E_{NY} and $-E_{NR}$ reverse the vector E_{NR} and add vectorially with E_{NY}

$E_{RY} = \sqrt{E_{NY}^2 + E_{NR}^2 + 2E_{NY}E_{NR}\cos 60°}$

$E_L = \sqrt{E_{ph}^2 + E_{ph}^2 + 2E_{ph}E_{ph} \times 1/2}$

$E_L = \sqrt{3E_{ph}^2}$

$= \sqrt{3}\,E_{ph}$



Similarly

$\overline{E_{YB}} = \overline{E_{NB}} - \overline{E_{NY}}$ or $E_L = \sqrt{3}\,E_{ph}$

$E_{BR} = \overline{E_{NR}} - \overline{E_{NB}}$ or $E_L = \sqrt{3}\,E_{ph}$

Line voltage = $\sqrt{3}$ x phase voltage.

→ Relation between phase current and line current :-

It is clear that same current flows through phase winding as well as the line conductor since the line conductor is just connected in series with the phase winding.

$I_R = I_{NR}$; $I_y = I_{Ny}$ and $I_B = I_{NB}$ whereas $I_{NR} = I_{NY} = I_{NB} = I_{ph}$ and $I_R = I_y = I_B = I_L$ (line current)

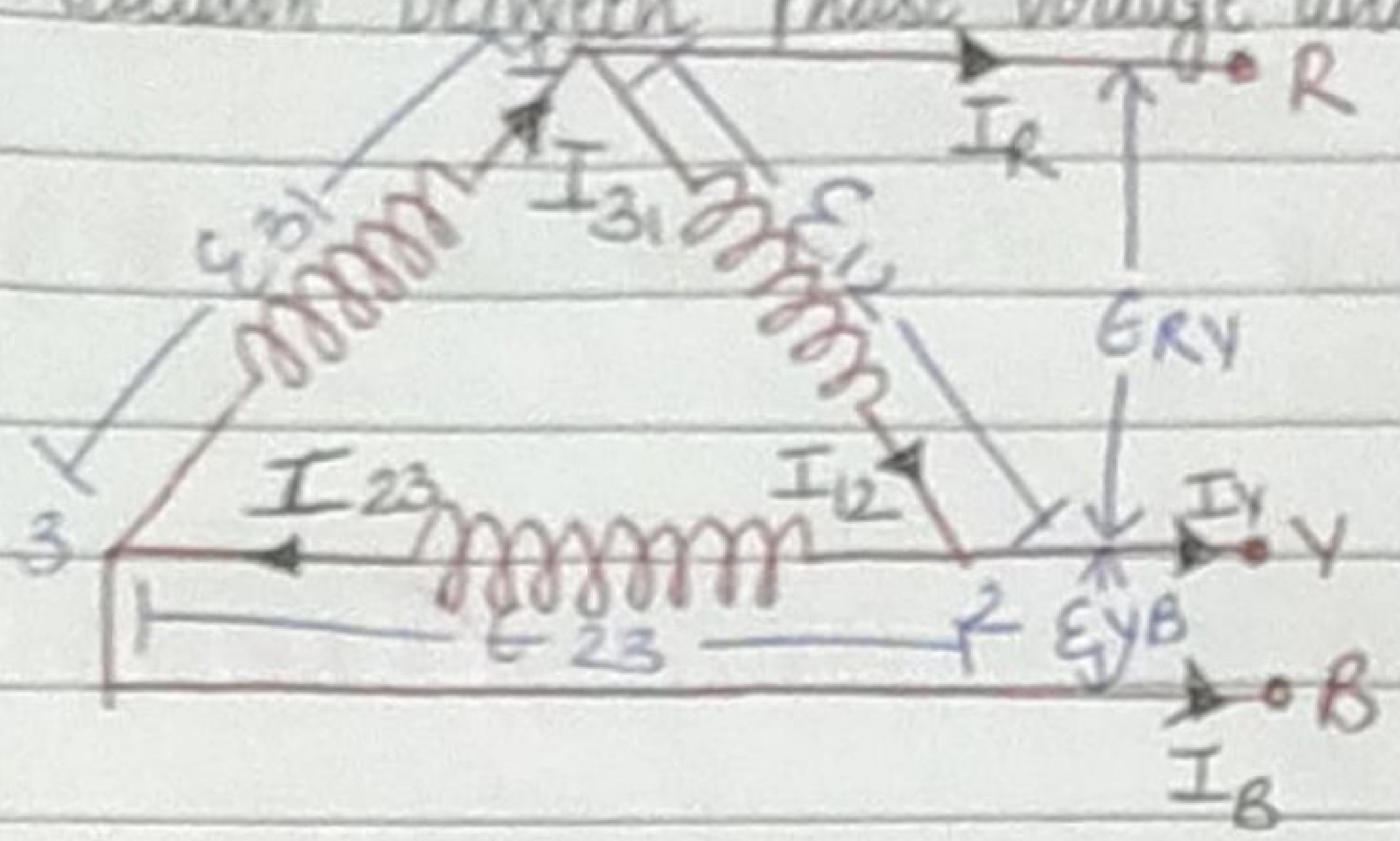
Line current = Phase current

⇒ Mesh or Delta (Δ) Connection :-

In delta the finish terminal of one winding is connected to start terminal of the other junction and so on which gives a close circuit

~~To obtain delta connections a2 is connected ω~~

→ Relation between Phase voltage and line voltage :-



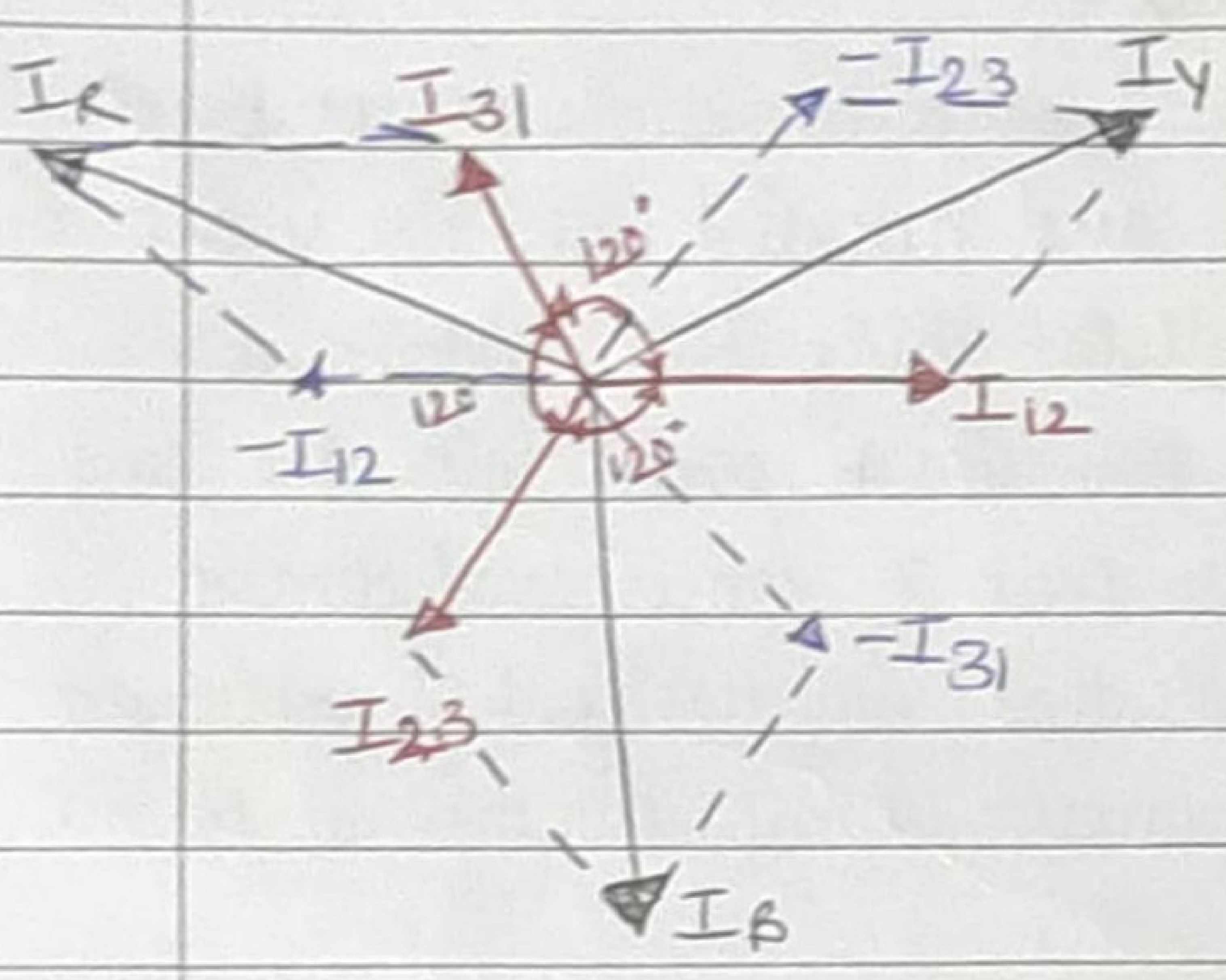
It is clear that voltage across terminals 1 and 2 is the same across terminals R and Y

$\therefore E_{12} = E_{RY}$; Similarly $E_{23} = E_{YB}$ and $E_{31} = E_{BR}$

Where $E_{12} = E_{23} = E_{31} = E_{ph}$ (phase voltage) and $E_{RY} = E_{YB} = E_{BR} = E_L$ (line voltage)

Line voltage = Phase Voltage

→ Relation between Line current and phase current



Since the system is balanced, $\therefore$, the three phase currents I_{12}, I_{23} and I_{31} are equal in magnitude but displaced by 120° electrical degrees.

$I_{12} = I_{23} = I_{31} = I_{ph}$ (in magnitude)

Applying Kirchoff's first law at junction 1 :-

$\overline{I_{31}} = \overline{I_R} + \overline{I_{12}}$

or $\overline{I_R} = \overline{I_{31}} - \overline{I_{12}}$

$I_R = \sqrt{I_{31}^2 + I_{12}^2 + 2 I_{31} I_{12} \cos 60}$

$I_L = \sqrt{I_{ph}^2 + I_{ph}^2 + 2 I_{ph} I_{ph} \frac{1}{2}}$

$I_L = \sqrt{3 I_{ph}^2} = \sqrt{3}\, I_{ph}$ (in magnitude)

Similar for $\overline{I_Y}$, $\overline{I_B}$

Line Current = $\sqrt{3}$ Phase Current

⇒ Power in 3 phase circuits :-

Power in single phase system or circuit is given by the relation

$P = VI\cos\phi$, V = voltage of single phase i.e V_{ph}

I = current of single phase i.e I_{ph}

$\cos\phi$ = power factor of the circuit

I 3 phase circuits (balanced load), the power is sum of 3 phase

$$P = 3V_{ph}I_{ph}\cos\phi$$

In Star Connection :-

$$P = 3\frac{V_L}{\sqrt{3}}I_L\cos\phi = \sqrt{3}V_LI_L\cos\phi \text{ (KW or W)}$$

In delta Connection :-

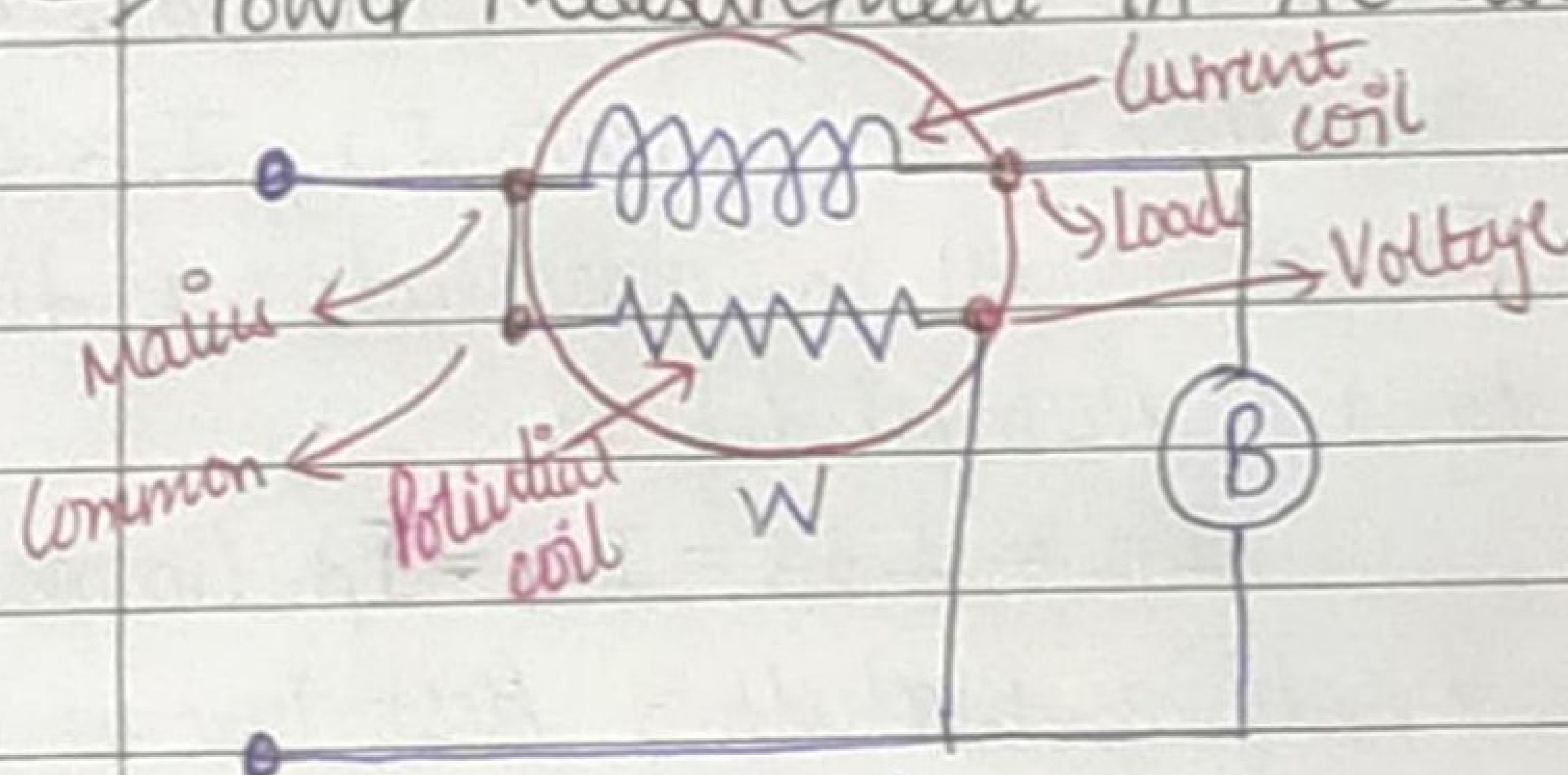
$$P = 3V_L\frac{I_L}{\sqrt{3}}\cos\phi = \sqrt{3}V_LI_L\cos\phi \text{ (KW or W)}$$

hence total power irrespective of connections ~~is~~ is same.

Apparent Power, $P_a = \sqrt{3}V_LI_L$ (KVA or VA) (volt-ampere)

Reactive Power $P_r = \sqrt{3}V_LI_L\sin\phi$ (KVAR or VAR) (volt-ampere-reactive)

⇒ Power Measurement in AC Circuit :-



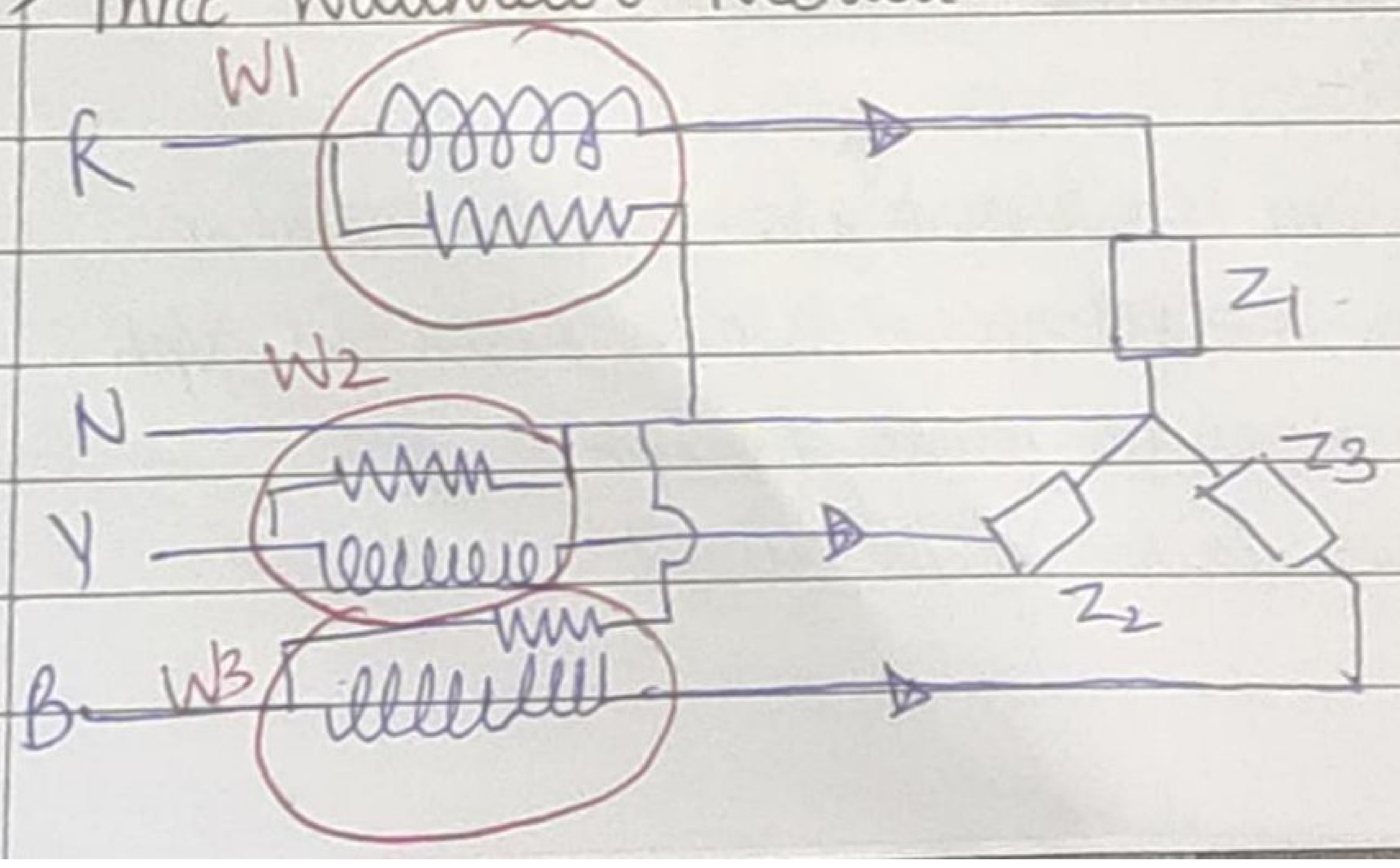
Wattmeter

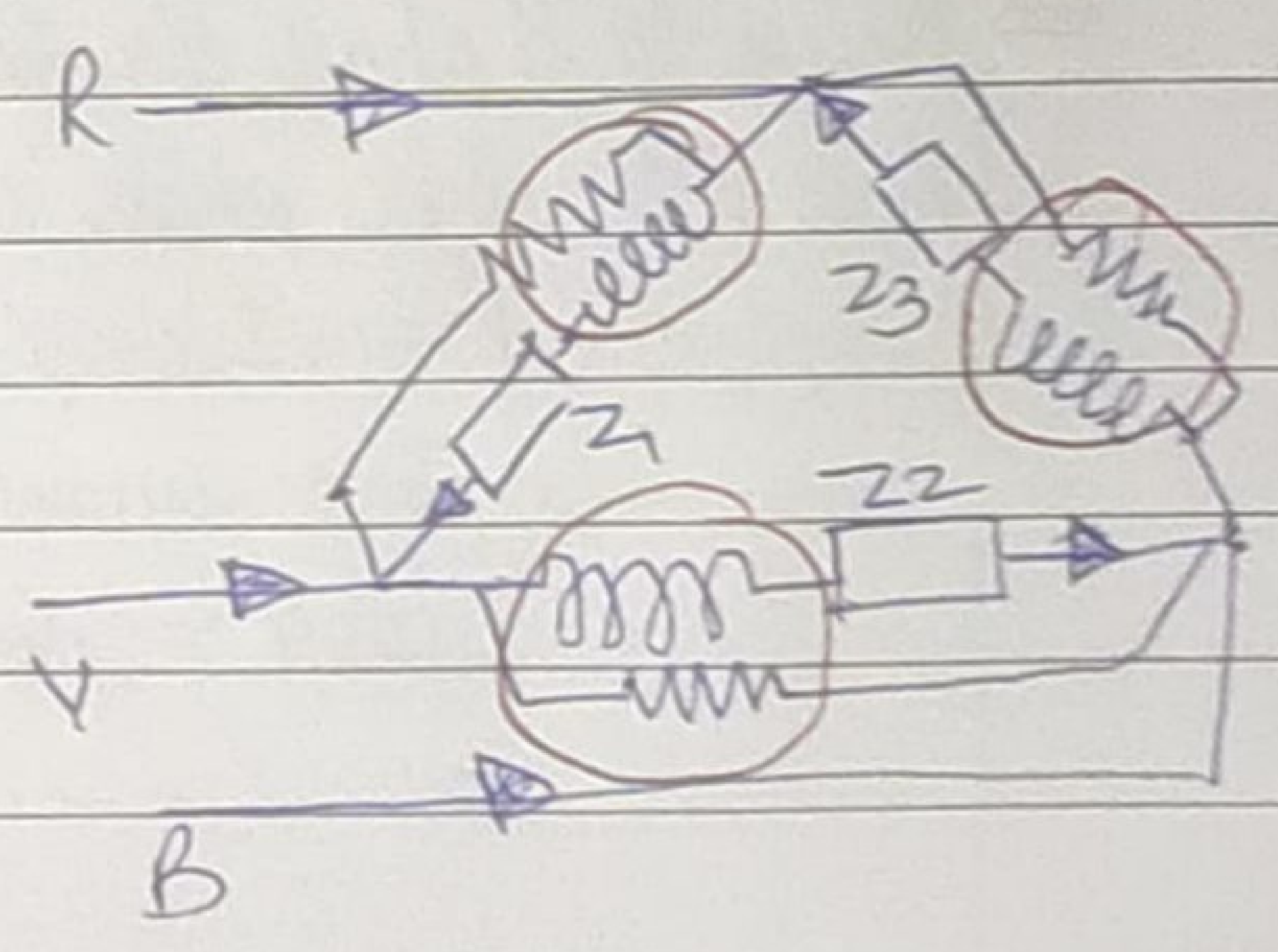
Consists of 2 coils → current coil and potential coil. The current coil having low resistance is connected in series with the load so that it carries load current. The potential coil having high resistance is connected across the load and carries current proportional to the potential difference.

According to Blondel (Blondel's Theorem) :-

When power is supplied by K-wire ac system the number of wattmeter required to measure power is one less than the no. of wires i.e (K-1), regardless the load is balanced or not.

⇒ Three Wattmeter Method :-





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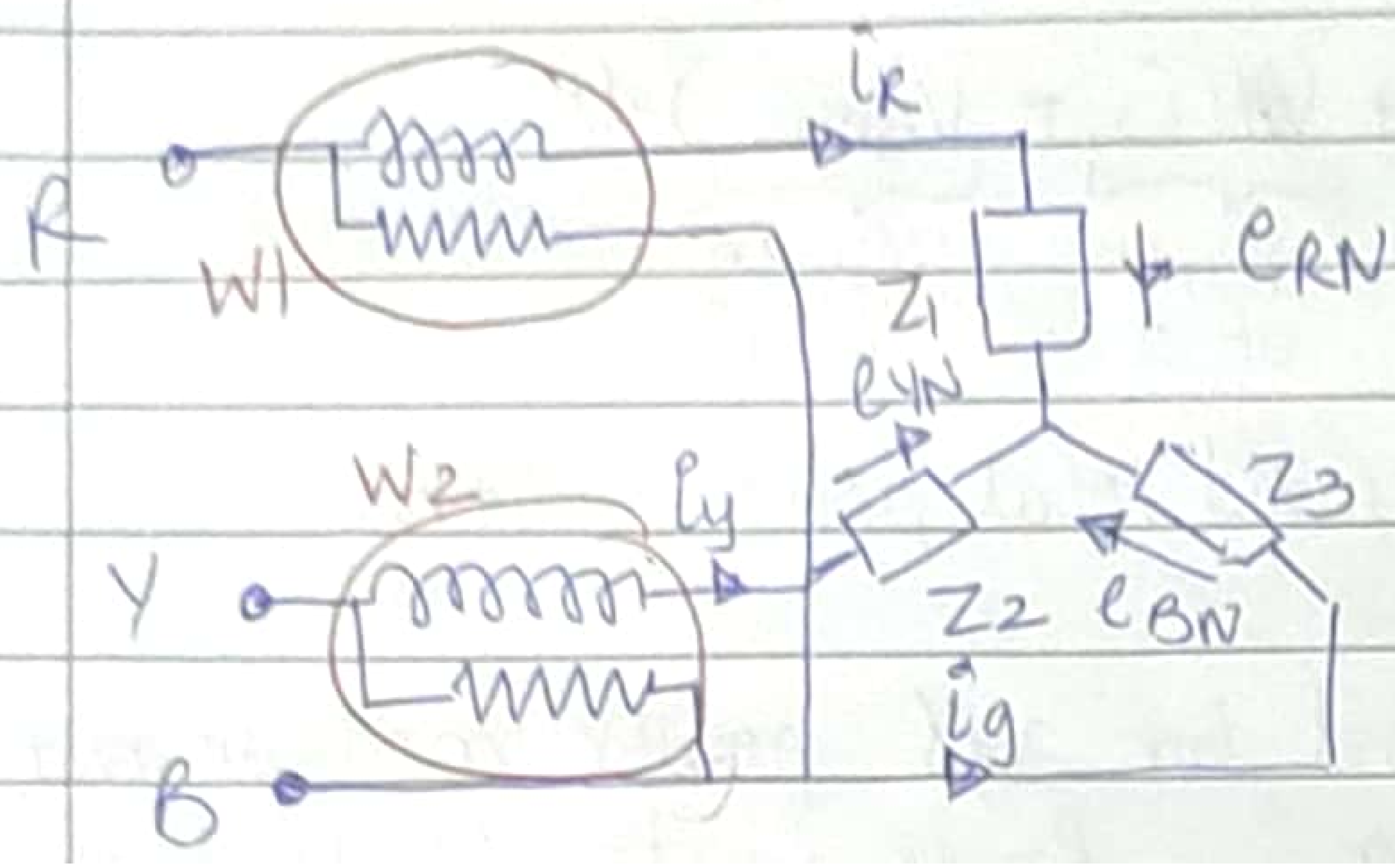
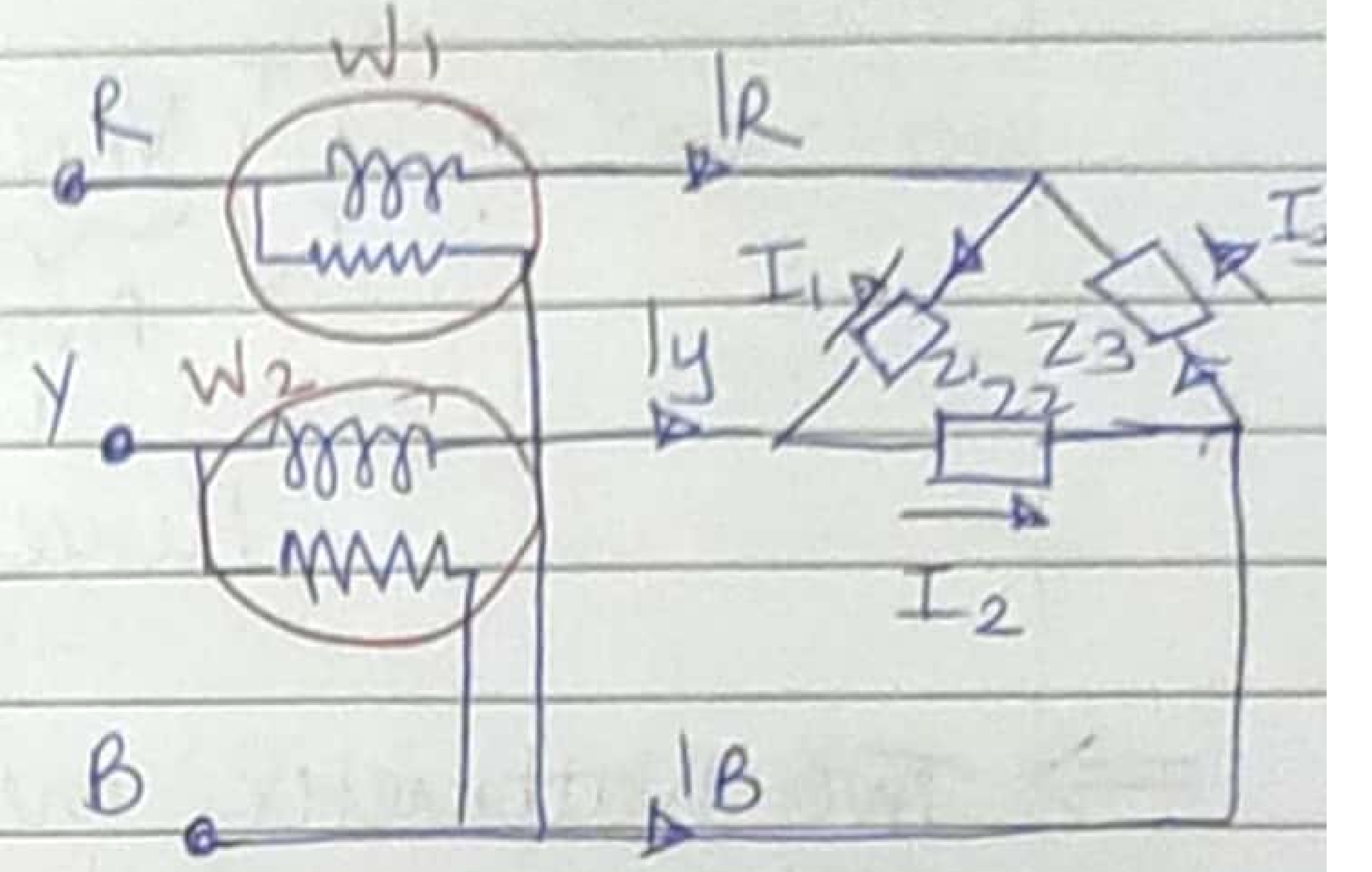
The total power is given by the algebraic sum of the readings of 3 wattmeters i.e.,

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

⇒ Two-Wattmeter method :-

In this method, the current coils of the wattmeters are connected in any two lines, say R and Y and the potential coil of each wattmeter is joining across the same line and the third line

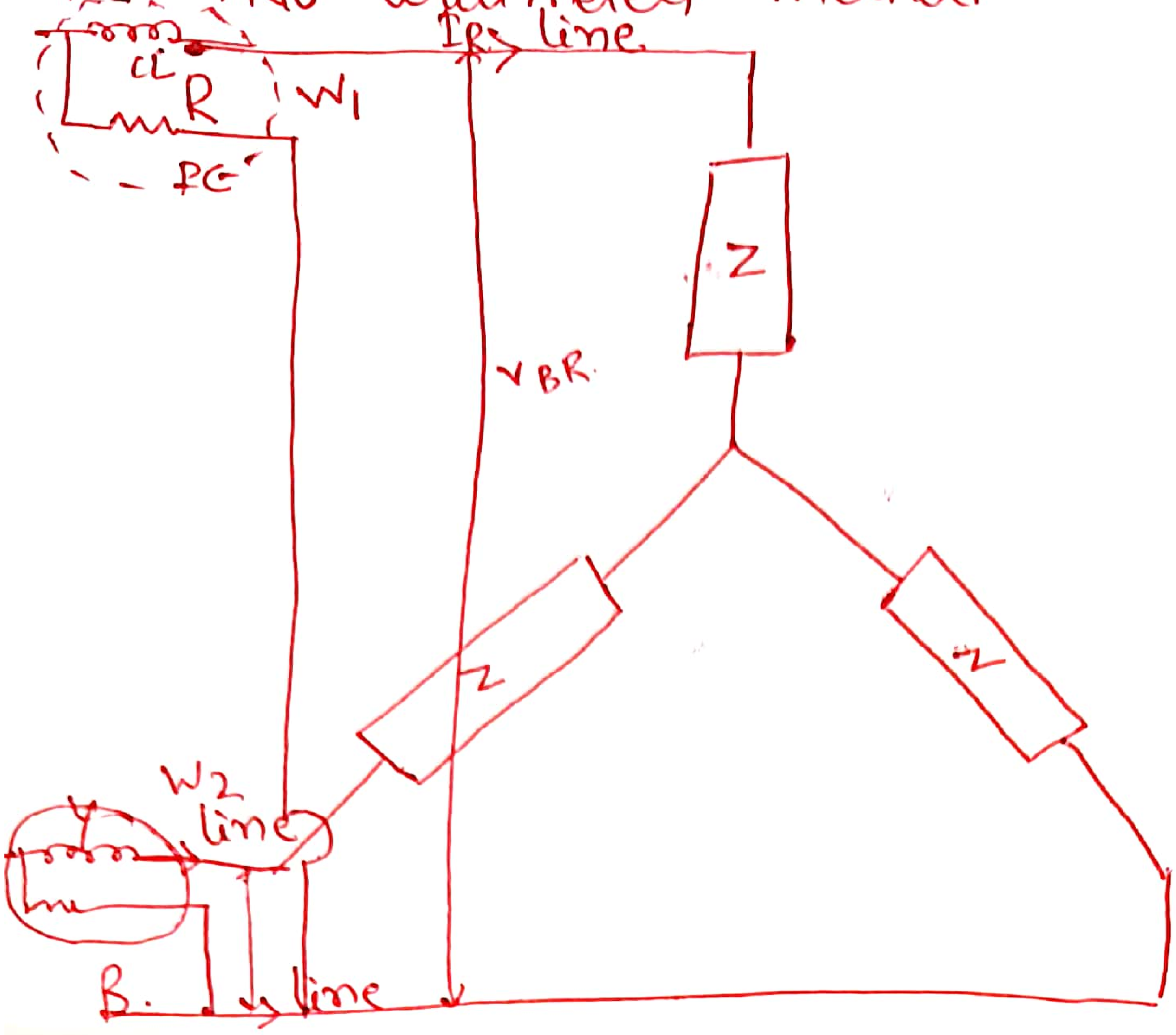




⇒ Two Wattmeter method for 3ϕ power measurment :-

→ Star connected lagging Power Factor (Inductive) load
→ Star connected leading Power Factor (Capacitive) load
→ Delta connected lagging PF (Inductive) load
→ Delta connected leading PF (Capacitive) load.

Two wattmeter method-



measures power
↓
2 coil
↓
Current Coil - Connected in series

Pressure coil / voltage coil = V
↓
Connected in Parallel. $P = VI\cos\phi$

$W_1 = V_{BR} I_R \cos(30-\phi)$ ①, $W_2 = V_{YB} I_Y \cos(30+\phi)$ ②

for Balanced system
all line Voltage are same & line Currents are same.

$I_R = I_Y = I_B = I_L$ & $V_{BR} = V_{YB} = V_{RY} = V_L$.

$W_1 = V_L I_L \cos(30-\phi)$ $W_2 = V_L I_L \cos(30+\phi)$

$\cos A \cos B + \sin A \sin B$

$W_1 + W_2 = V_L I_L[(\cos 30-\phi) + \cos(30+\phi)]$

$= V_L I_L[\cos 30 \cos\phi + \sin 30 \sin\phi + \cos 30 \cos 0 - \sin 30 \sin\phi]$

$V_L I_L[2\cos 30 \cos\phi]$

$V_L I_L[2 \times \frac{\sqrt{3}}{2}]\cos\phi$

$= \sqrt{3} V_L I_L \cos\phi$

$W_1 - W_2 = V_L I_L[2\sin 30 \sin\phi)$

$= V_L I_L[2 \times \frac{1}{2} \sin\phi]$

$= V_L I_L \sin\phi$.

$\frac{W_1 - W_2}{W_1 + W_2} = \frac{\cancel{V_L I_L} \sin\phi}{\cancel{V_L I_L} \sqrt{3} \cos\phi}$

$= \frac{1}{\sqrt{3}} \tan\phi$

$\tan\phi = \sqrt{3}\left(\frac{W_1 - W_2}{W_1 + W_2}\right)$

$\cos\phi = \frac{1}{\sec\phi}$

$= \frac{1}{\sqrt{\sec^2\phi}} = \frac{1}{\sqrt{1+\tan^2\phi}}$

②

$$= \frac{1}{\sqrt{1+3\left(\frac{W_1-W_2}{W_1+W_2}\right)^2}}$$

$$= \frac{1}{\sqrt{1+3\frac{W_1\left(1-\frac{W_2}{W_1}\right)^2}{W_1\left(1+\frac{W_2}{W_1}\right)^2}}}$$

$$= \frac{1}{\sqrt{1+3\left(\frac{1-\frac{W_2}{W_1}}{1+\frac{W_2}{W_1}}\right)^2}}$$

$\frac{W_2}{W_1} = r \longrightarrow$ ratio of wattmeter readings.

$$= \frac{1}{\sqrt{1+3\left(\frac{\cancel{r}1-r}{1+r}\right)^2}}$$

$$\cos\phi = \frac{1}{\sqrt{\frac{(1+r)^2+3(1-r)^2}{(1+r)^2}}}$$

$$\cos\phi = \frac{\cancel{\sqrt{(1+r)^2}}}{\sqrt{(1+r)^2+3(1-r)^2}}$$

$$= \frac{(1+r)}{\sqrt{1+2r+r^2+3(1-2r+r^2)}}$$

$$= \frac{(1+r)}{\sqrt{4-4r+4r^2}}$$

$\cos\phi = \frac{1+r}{2(\sqrt{\cancel{1}-r+r^2}} \longrightarrow$ Power factor.