2. Measurement of Power & Energy

→ DC power $p = VI = I^2R = \frac{V^2}{R}$

→ AC power $1\text{-}\phi = VI\cos\phi$

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

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

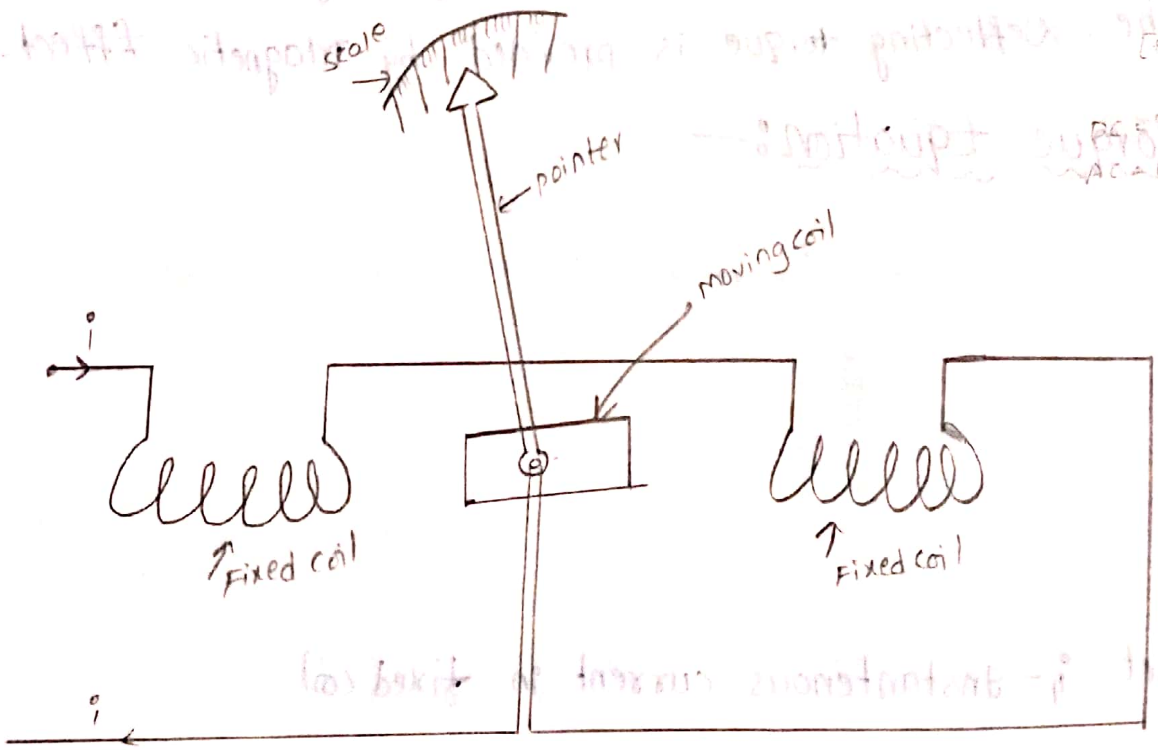
To measure power, voltmeter and Ammeter method is also used. But it has losses. To overcome this, wattmeter is used.

It shows additional value i.e meter reading = Power + meter loss

⊛⊛ Electro Dynamo meter type wattmeter

Both AC & DC

① ~~PMMC~~



Fixed coil: current coil

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→ It consists of fixed coil, moving coil, moving system, controlling system and Damping system.

→ The fixed coil consists of thin wire, if it is an voltmeter. It consists thick wire, if it is an Ammeter and wattmeter.

→ The moving coil is light Aluminum which is suspended to freely rotate about its axis.

→ The moving system consists of moving coil, spindle, pointer.

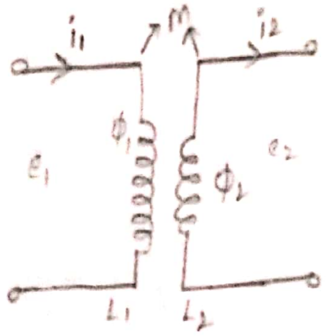
→ When the moving coil rotates, attached spindle rotates, attached pointer deflects on the scale.

→ The controlling torque is provided by spring control method.

→ The Damping torque is provided by Eddy current Damping.

→ The Deflecting torque is provided by Magnetic Effect.

Torque Equation:-



Let i_1 = Instantenous current in fixed coil

i_2 = Instantenous current in Moving coil

L_1 = Self Inductance of fixed coil

L_2 = self Inductance of moving coil

M = Mutual inductance between two Coils.

→ Flux linkages in coil 1

$$\phi_1 = L_1 i_1 + M i_2 \longrightarrow (1)$$

→ Flux linkages in coil 2

$$\phi_2 = L_2 i_2 + M i_1 \longrightarrow (2)$$

From Faraday's second law,

$$e_1 = \frac{d\phi_1}{dt} \longrightarrow (3)$$

$$e_2 = \frac{d\phi_2}{dt} \longrightarrow (4)$$

To calculate mechanical work done, EI = stored energy + MW

Electrical energy input $= e_1 i_1 dt + e_2 i_2 dt$

[∵ from (3), (4)]

$$= i_1 d\phi_1 + i_2 d\phi_2$$

from (1) & (2)

$$= i_1 d\left[L_1 i_1 + M i_2\right] + i_2 d\left[L_2 i_2 + M i_1\right]$$

$$= i_1 L_1 di_1 + i_1^2 dL_1 + i_1 M di_2 + i_1 i_2 dM + i_2 L_2 di_2 + i_2^2 dL_2 + i_2 M di_1 + i_1 i_2 dM \longrightarrow (5)$$

Energy stored in coil is $= \frac{1}{2} L I^2$ - (generally)

Here, " " " " $= \frac{1}{2} L_1 i_1^2 + \frac{1}{2} L_2 i_2^2 + i_1 i_2 M \longrightarrow (6)$

→ change in stored Energy $= d\left[\frac{1}{2} L_1 i_1^2 + \frac{1}{2} L_2 i_2^2 + i_1 i_2 M\right]$

$$= i_1 L_1 di_1 + \frac{1}{2} i_1^2 dL_1 + i_2 L_2 di_2 + \frac{1}{2} i_2^2 dL_2 + i_1 i_2 dM + i_1 M di_2 + i_2 M di_1 \longrightarrow (7)$$

→ As per law of conservation principle,

Energy input = change in stored Energy + Mechanical work done.

Mechanical work done = Energy input − change is stored energy

At instant bcoz of AC

$$T_i\, d\theta = i_1 \cancel{L_1 di_1} + i_1^2 dL_1 + i_1 \cancel{M di_2} + i_1 \cancel{i_2} dM + i_2 \cancel{L_2} di_2 + i_2^2 dL_2 + i_2 \cancel{M} di_1 + i_1 i_2 dM$$

$$- \left[i_1 \cancel{L_1 di_1} + \frac{1}{2} i_1^2 dL_1 + i_2 \cancel{L_2} di_2 + \frac{1}{2} i_2^2 dL_2 + \cancel{i_1 i_2} dM + i_1 \cancel{M} di_2 + i_2 \cancel{M} di_1 \right]$$

$\left(1 - \frac{1}{2} = \frac{1}{2}\right)$

$$T_i\, d\theta = \frac{1}{2} i_1^2 dL_1 + \frac{1}{2} i_2^2 dL_2 + i_1 i_2 dM$$

$$= \frac{1}{2}\left[i_1^2 dL_1 + i_2^2 dL_2 \right] + i_1 i_2 dM$$

$$T_i = \frac{1}{2} i_1^2 \frac{dL_1}{d\theta} + \frac{1}{2} i_2^2 \frac{dL_2}{d\theta} + i_1 i_2 \frac{dM}{d\theta}$$

If the self inductances of both the coils are constant

$$\therefore \boxed{T_i = i_1 i_2 \frac{dM}{d\theta}}$$

instantenous

(i) For DC operation:- → everything is constant ∴ $T_i = T_d$

$$T_d = I_1 I_2 \frac{dM}{d\theta}$$

→ Spring control, $T_c = K \cdot \theta$

equilibrium

$$K\theta = I_1 I_2 \frac{dM}{d\theta}$$

$$\boxed{\theta = \frac{I_1 I_2}{K} \frac{dM}{d\theta}}$$

(ii) For AC operation:-

$$T_d = \frac{1}{T}\int_0^T T_i\,dt$$

$$T_d = \frac{1}{T}\int_0^T i_1 i_2 \frac{dM}{d\theta}\,.dt$$

Here, $i_1 = I_{m_1}\sin(\omega t)$; $i_2 = I_{m_2}\sin(\omega t - \phi)$

$$T_d = \frac{dM}{d\theta}\ \frac{1}{T}\ I_{m_1} I_{m_2}\int_0^T \sin(\omega t)\sin(\omega t-\phi)\ d\omega t$$

$$T_d = -\frac{dM}{d\theta}\ \frac{1}{T}\ I_{m_1} I_{m_2}\ \frac{1}{2}\int_0^T -2\sin(\omega t)\sin(\omega t-\phi)\ d\omega t$$

$$\boxed{-2\sin A\sin B = \cos(A+B) - \cos(A-B)}$$

Then we get $\cos\phi$

$$T_d = \frac{I_{m_1} I_{m_2}}{2}\cos\phi\ \frac{dM}{d\theta}$$

Let $I_1 = \frac{I_{m_1}}{\sqrt{2}}$; $I_2 = \frac{I_{m_2}}{\sqrt{2}}$. Therefore above equation becomes

$$T_d = I_1 I_2 \cos\phi \frac{dM}{d\theta}$$

→ spring control $T_c = K\theta$

$$\therefore\ T_d = T_c$$

$$I_1 I_2 \cos\phi \frac{dM}{d\theta} = K\theta$$

$$\boxed{\therefore\ \theta = \frac{I_1 I_2}{K}\cos\phi\frac{dM}{d\theta}}$$

Advantages:-

→ It consumes less power.

→ Light in weight

→ It measures power in both AC as well as DC.

→ It is free from Hysterisis error

→ Accuracy is high

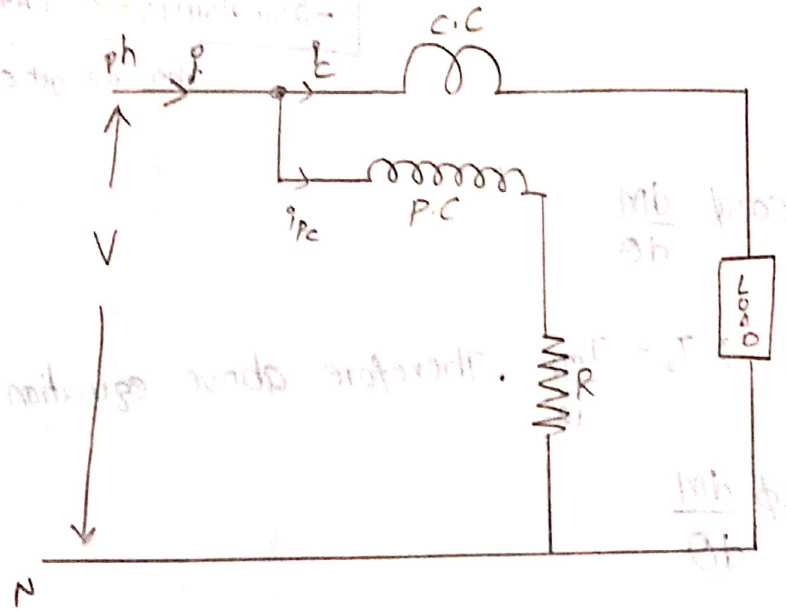
Disadvantages:-

→ cost is high

→ It can not be withstand for severe loading

→ scale is non-uniform.

1-ϕ Electrodynamometer type Wattmeter :-



i_c = current in current coil

i_{pc} = current in pressure coil

R = pressure coil Resistance

$v = V_m \sin\omega t = \sqrt{2}\, V \sin\omega t$

$\rightarrow i_{pc} = \frac{v}{R_p}$ $\left[\because V_{rms} = V = \frac{V_m}{\sqrt{2}}\right]$

$[v = V_m \sin\omega t]$

Parallel value the same

$= \frac{\sqrt{2} V}{R_p} \sin\omega t \longrightarrow (1)$ $[\because R_p = R + r_{pc}]$

$\rightarrow i_c = \sqrt{2}\, I_c \sin(\omega t - \phi) \longrightarrow (2)$ (series to load)

from the previous discussions, we have instantenous torque

as $\boxed{T_i = i_1 i_2 \frac{dM}{d\theta}}$ (i_1: curr, i_2: pressure coil)

$T_i = \sqrt{2} \frac{V}{R_p} \sin\omega t \; \sqrt{2}\, I_c \sin(\omega t - \phi) \frac{dM}{d\theta}$

$T_i = \sqrt{2}\, I_{pc} \sin\omega t \; \sqrt{2}\, I_c \sin(\omega t - \phi) \frac{dM}{d\theta}$

We can write $[\because 2\sin A \sin B = \cos(A-B) - \cos(A+B)]$

$T_d = \frac{1}{T}\int_0^T T_i \, dt$

from previous derivation that term becomes $\cos\phi$

$T_d = I_{pc} I_c \cos\phi \frac{dM}{d\theta}$

$I_{pc} = \frac{V}{R_p}$

$T_d = I_c \cdot \frac{V}{R_p} \cos\phi \frac{dM}{d\theta} \longrightarrow (1)$

$\rightarrow$ controlling torque, $T_c = K\theta$

$K\theta = I_c V \cos\phi \cdot \frac{1}{R_p} \frac{dM}{d\theta}$

$\therefore \theta \propto I_c V \cos\phi$ $\left[\because K_1 = \frac{1}{K} \frac{1}{R_p} \frac{dM}{d\theta}\right]$

$\boxed{\theta \propto P}$

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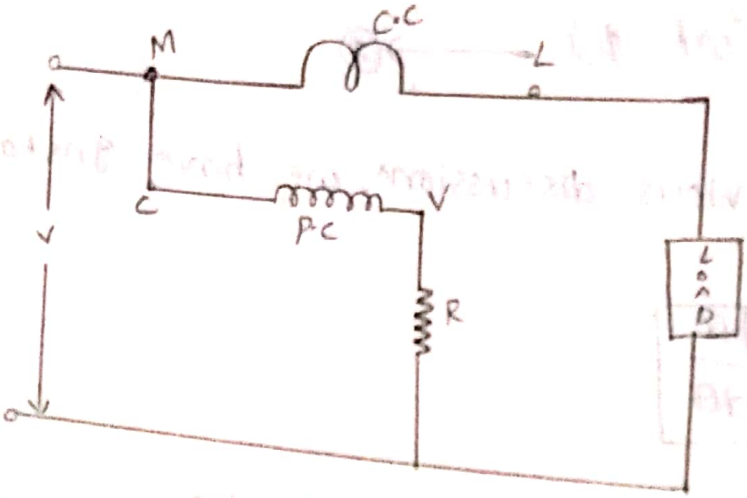
Note:- The deflection of wattmeter is directly proportional to the power measured by it.

Wattmeter Symbol:-



where, M = main
L = load
C = common
V = voltage

$\boxed{M}$ *

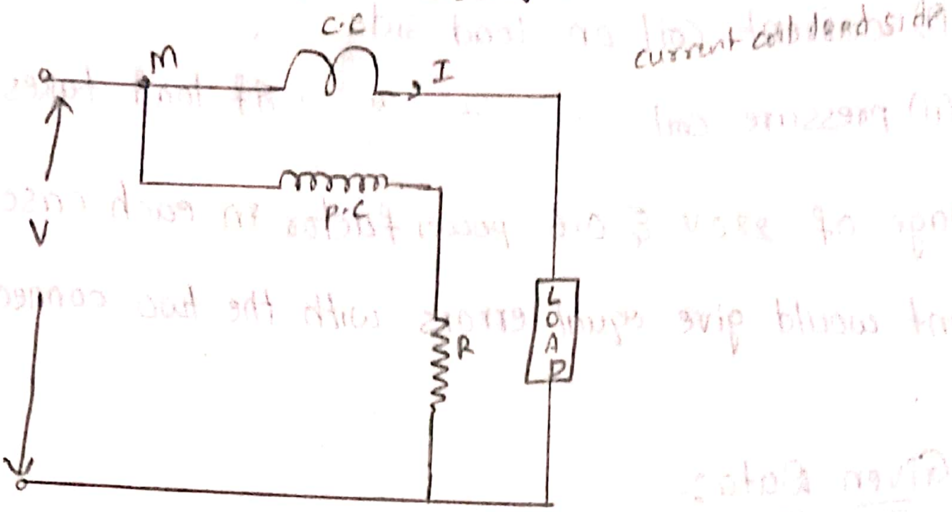
Errors in wattmeter:-

The following are the sources of errors

1. Error due to method of connection
2. Error due to pressure coil capacitance
3. Error due to pressure coil inductance
4. Eddy current errors

① Error due to method of connection:

(i) pressure coil is connected supply side:

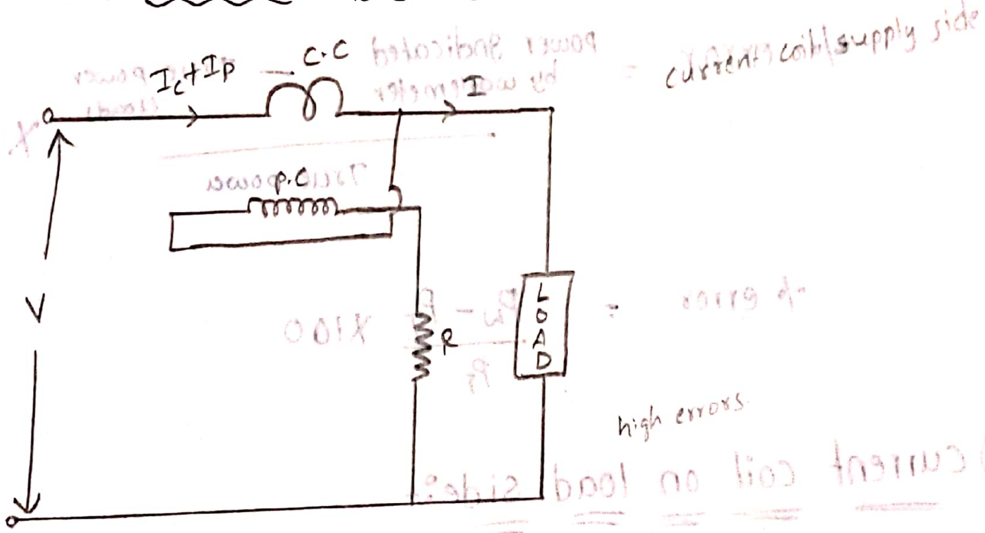


→ This method is used in small currents.

→ power indicated by wattmeter = power consumed by load + $I^2 R_c$ (small errors)

$$PIW = PCL + I^2 R_c$$

(ii) pressure coil connected load side:-



→ This method of connection is used in large currents.

→ power indicated by wattmeter = power consumed by load + $\frac{V^2}{R_p}$

$$PIW = PCL + \frac{V^2}{R_p}$$

A wattmeter has a current coil of 0.03Ω resistance & pressure coil of 6000Ω resistance. Calculate % error

(i) current coil on load side

(ii) pressure coil " " " . If load takes 20 Amp at a voltage of 220V & 0.6 power factor in each case. What load current would give equal errors with the two connections.

Sol: Given Data:-

current coil Resistance = $R_c = 0.03\Omega$

pressure " " = $R_P = 6000\Omega$

Load current = $I_L = 20A$

Voltage = 220V

power factor = 0.6

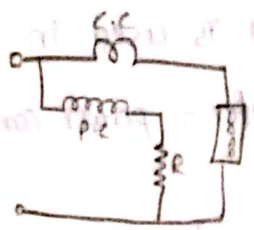
Formula:-

$$\% \text{ error} = \frac{\text{power indicated by wattmeter} - \text{True power (load)}}{\text{True power}} \times 100$$

$$\% \text{ error} = \frac{P_W - P_T}{P_T} \times 100$$

(i) Current coil on load side:-

PC on supply side



$P_{IW} = \underbrace{PCL}_{P_T} + I^2 R_c$

$P_T = VI\cos\phi$

$= 220 \times 20 \times 0.6 = 2640$ watts

$I^2 R_c = (20)^2 \times 0.03 = 12W$

$\therefore P_W = 12 + 2640$

$$\boxed{P_W = 2652 \text{ watts}}$$

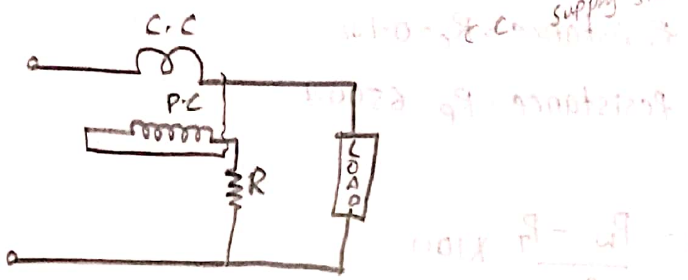
$$\% \text{ Error} = \frac{2652 - 2640}{2640} \times 100$$

8.066

PIW 2648.066

$= 0.4545\%$

(ii) pressure coil on load side:



$$PIW = \underbrace{PCL}_{\substack{P_T \\ \text{from } b4}} + \frac{V^2}{R_P}$$

$= 2640 + 8.066$

$$\boxed{\underset{P_W}{PIW} = 2648.066 \text{ watts}}$$

$$\% \text{ Error} = \frac{2648.066 - 2640}{2640} \times 100$$

$= 0.3055\%$

→ If the errors are same $\left[P_T + I^2 R_c = P_T + \frac{V^2}{R_P}\right]$

$$\therefore \cancel{P_T} + I^2 R_c = \cancel{P_T} + \frac{V^2}{R_P}$$

$$I^2 = \frac{V^2}{R_P R_C} = \frac{(220)^2}{(0.03)(6000)}$$

$$\boxed{I = 16.39 \text{ A}}$$

A wattmeter has a current coil of 0.1 Ω resistance and a pressure coil of 6500 Ω resistance. calculate percentage errors due to the method of connection (i) current coil is on load side

(ii) current coil is on supply side

(i) 12 Amps at 250V with unity power factor

(ii) 12 Amps at 250 V & 0.4 power factor

Sol Given Data:-

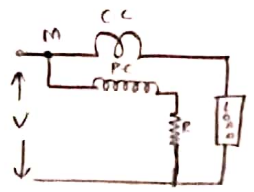
current coil Resistance $= R_c = 0.1\Omega$

pressure coil Resistance $= R_p = 6500\Omega$

Find:-

$$\%\ \text{error} = \frac{P_W - P_T}{P_T} \times 100$$

(i) current coil on load side:-



$$PIN = PCL + I^2 R_c$$

$$P_W = P_T + I^2 R_c$$

i)
$\cos\phi = 1 \longrightarrow P_T = VI\cos\phi$

$$P_T = 250 \times 12 \times 1 = 3000 \text{ watts}$$

$$I^2 R_c = (12)^2 \times 0.1 = 14.4 \text{ watts}$$

$$\boxed{\therefore P_W = 3014.4 \text{ watts}}$$

$$\%\ \text{error} = \frac{P_W - P_T}{P_T} \times 100$$

$$= \frac{3014.4 - 3000}{3000} \times 100$$

$$= 0.48\%$$

(ii) $\cos\phi = 0.4$

$P_T = VI\cos\phi$

$= 250 \times 12 \times 0.4$

$= 1200$ watts

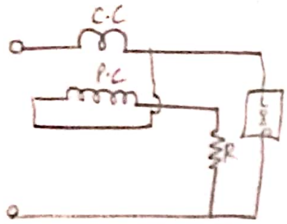
$$\boxed{\therefore \; P_W = 1214.4 \text{ watts}}$$

$\% \text{ error} = \dfrac{P_W - P_T}{P_T} \times 100$

$= \dfrac{1214.4 - 1200}{1200} \times 100$

$= 1.2\,\%$

(ii) current coil on supply side:



$PIW = PCL + \dfrac{V^2}{R_P}$

$P_W = P_T + \dfrac{V^2}{R_P}$

(1) $\cos\phi = 1$

$P_T = 3000$ watts

$\dfrac{V^2}{R_P} = \dfrac{(250)^2}{6500} = 9.615$ watts

$$\boxed{\therefore \; P_W = 3009.615 \text{ watts}}$$

$\% \text{ error} = \dfrac{3009.615 - 3000}{3000} \times 100$

$= 0.3205\,\%$

(ii) $\cos\phi = 0.4$

$P_T = 1200$ watts

$P_W = 1200 + 9.615 = 1209.615$ watts

$\% \text{ error} = \dfrac{1209.615 - 1200}{1200} \times 100$

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Error due to pressure coil capacitance:-

when the pressure coil is connected across the lines, the capacitance is formed which increase reactance value. Hence, wattmeter shows error reading.

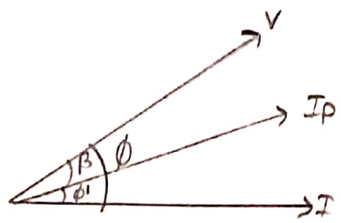
→ X_L is generally high.
→ on "C" forming, X_c decreases
To maintain zero error, X_L is ↑ which is practically impossible.

when $\boxed{X_L = X_C}$ then error is equal to zero.

→ To decrease the capacitive reactance value, increase inductive reactance.

Error due to pressure coil Inductance:-

capacitance is connected parallel to balance / make zero error.



$$\phi = \phi' + \beta$$

$$\boxed{\phi' = \phi - \beta}$$

→ Actual wattmeter reading $= \dfrac{I_1 I_2}{K} \cos\phi \dfrac{dM}{d\theta}$

$I_1 = I$; $I_2 = \dfrac{V_P}{Z_P}$; $\phi \Rightarrow \phi'$

→ Actual wattmeter reading $= \dfrac{I V_P}{Z_P K} \cos\phi' \dfrac{dM}{d\theta}$

$$= \frac{I V_P}{\boxed{Z_P} K} \cos(\phi - \beta) \frac{dM}{d\theta}$$

$$Z = \frac{R}{\cos\beta}$$

$$= \frac{I V_P}{\frac{R_P}{\cos\beta} K} \cos(\phi - \beta) \frac{dM}{d\theta} \longrightarrow (1)$$

$\rightarrow$ True power $= \frac{I_1 I_2}{K} \cos\phi \frac{dM}{d\theta}$

$I_1 = I, \quad I_2 = \frac{V_P}{R_P}$

True power $= \frac{V_P I}{R_P K} \cos\phi \frac{dM}{d\theta} \longrightarrow (2)$

$\rightarrow \frac{\text{True power}}{AWR} = \frac{\frac{V_P I}{R_P K} \cos\phi \cdot \frac{dM}{d\theta}}{\frac{I V_P}{R_P K} \cos\beta \cdot \cos(\phi-\beta) \frac{dM}{d\theta}}$

True power $= \frac{\cos\phi}{\cos\beta \cdot \cos(\phi-\beta)} * AWR$

where $\frac{\cos\phi}{\cos\beta \cdot \cos(\phi-\beta)}$ is called correction factor

$\cos(\phi-\beta)$

$= \frac{\cos\phi}{\cos\beta [\cos\phi \cos\beta + \sin\phi \sin\beta]}$

$= \frac{\cancel{\cos\phi}}{\cos^2\beta \cancel{\cos\phi} [1 + \tan\phi \tan\beta]}$

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

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

$\tan^2\beta << 1.$

$\therefore \frac{TP}{AWR} = \frac{1}{1 + \tan\phi \tan\beta}$

from here,

$AWR = [1 + \tan\phi \tan\beta]$ True power

→ Error = AWR − TP

Error = $\left[1+\tan\phi\tan\beta\right] \times T_P - T_P$

$= \cancel{T_P} + \tan\phi\tan\beta\, T_P - \cancel{T_P}$

Error = $(\tan\phi\tan\beta)$ True power

[∵ True power = $VI\cos\phi$

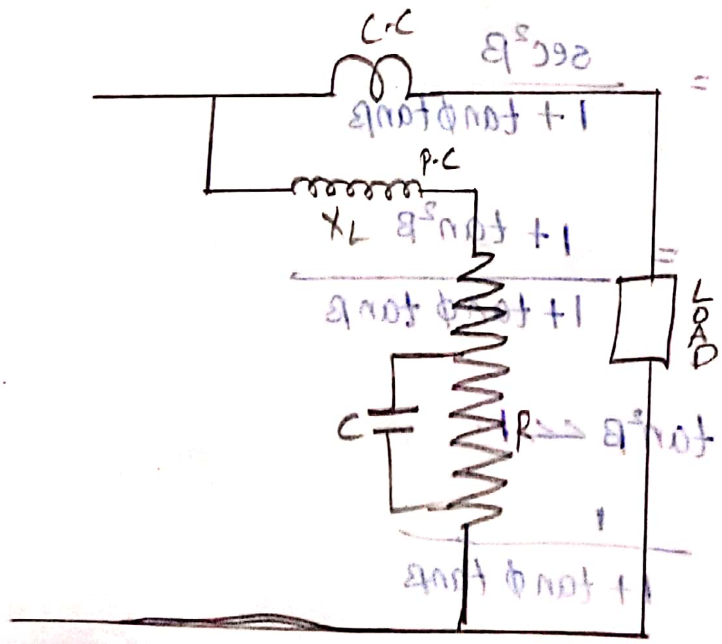
Error = $VI\sin\phi\tan\beta$]

→ % Error = $\dfrac{AWR - TP}{TP} \times 100 \Rightarrow \dfrac{\text{Error}}{TP} \times 100$

$= \dfrac{(\tan\phi\tan\beta)\cancel{TP}}{\cancel{TP}} \times 100$

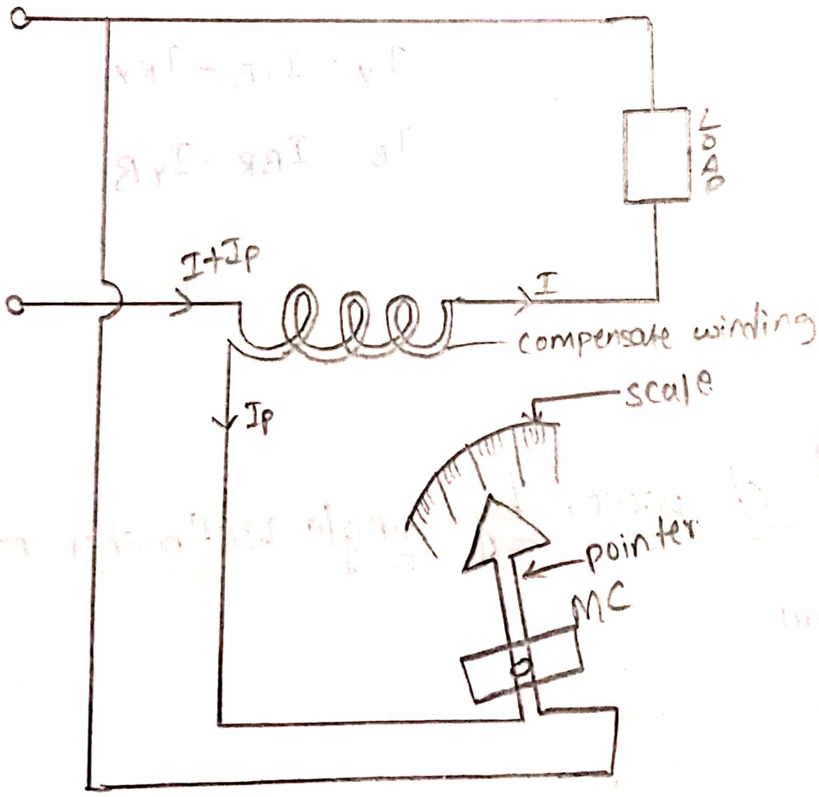
$$\boxed{\%\ \text{Error} = \tan\phi\tan\beta \times 100}$$

To compensate the error due to pressure coil inductance, connect a ~~parallel~~ capacitor across the resistance in pressure coil.



LPF ~~Ro~~Wattmeter [Lower power factor]:- used at No load

Under no load condition, load current is very small to get the accurate reading connect a compensating winding opposite to the pressure coil. Hence from the total current $(I+I_p)$, the pressure coil current is cancelled out (I_p). So, current ("I") flows through the load.



Measurement of 3ϕ power:

$P = 3 V_{ph} I_{ph} \cos\phi$ (or) $\sqrt{3} V_L I_L \cos\phi$

$\rightarrow 3\phi$, λ; Δ, Balanced, unBalanced

λ

$V_L = \sqrt{3} V_{ph}$

$I_L = I_{ph}$

$V_R, V_Y, V_B = V_{ph}$

$V_{RY}, V_{YB}, V_{BR} = V_L$

$V_{RY} = V_R - V_Y$

$V_{YB} = V_Y - V_B$

$V_{BR} = V_B - V_R$

Δ

$I_L = \sqrt{3} I_{ph}$

$V_L = V_{ph}$

$I_{RY}, I_{YB}, I_{BR} = I_{ph}$

$I_R, I_Y, I_B = I_L$

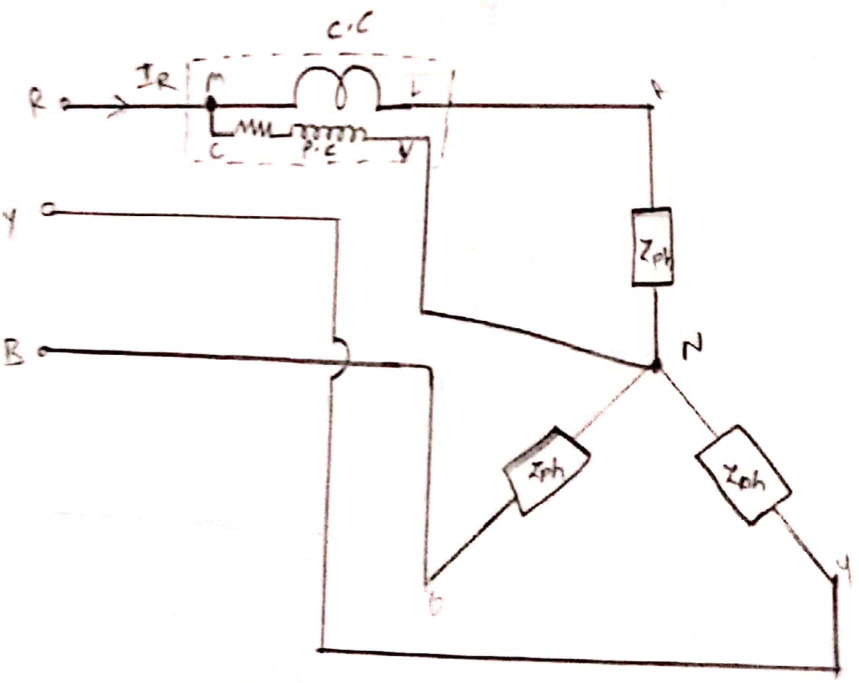
$I_R = I_{RY} - I_{BR}$

$I_Y = I_{YB} - I_{RY}$

$I_B = I_{BR} - I_{YB}$

Measurement of power by single wattmeter method:-

i) star connection:

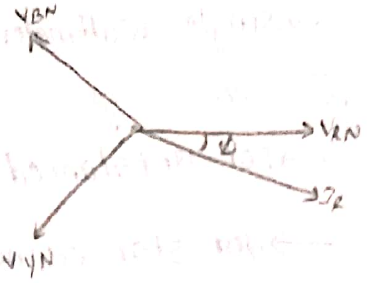


$\rightarrow I_c = I_R, \; V_{PC} = V_{RN}, \; \cos\phi \; [V_{RN} \wedge I_R]$

$\rightarrow$ Total power $P = V_{PC} I_c \cos\phi$

$= V_{RN} I_R \cos(V_{RN} \wedge I_R)$

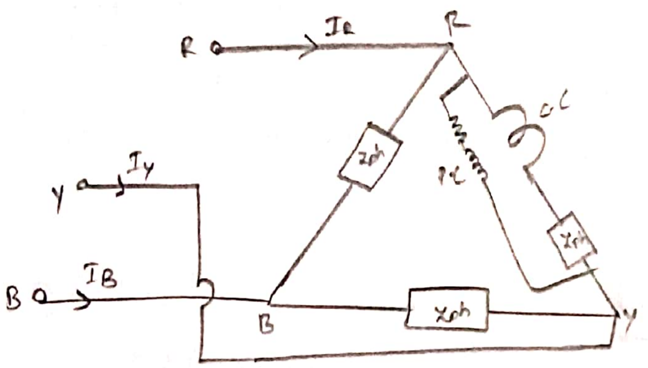
$$\boxed{P = V_{ph} I_{ph} \cos\phi}$$



$\rightarrow$ For Balanced system, Total power $= P = 3W_1 = 3W_2 = 3W_3$

$\rightarrow$ For unbalanced system, Total power $= P \Rightarrow 3W_1 \neq 3W_2 \neq 3W_3$.

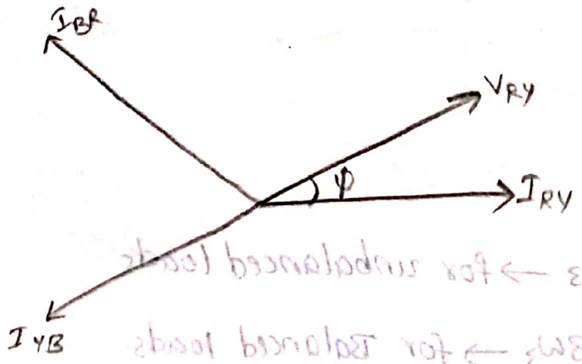
(ii) Delta connection :-



$I_c = I_{RY} = I_{ph}$; $V_{RY} = V_L = V_{ph}$; $\cos\phi = \cos(V_{RY} \wedge I_{RY})$

$P = V_{PC} I_c \cos\phi$

$P = V_{ph} I_{ph} \cos(V_{RY} \wedge I_{RY})$



$\rightarrow$ For Balanced, $P = 3W_1 \, (or) \, 3W_2 \, (or) \, 3W_3$

$\rightarrow$ un " , $P = 3W_1 \neq 3W_2 \neq 3W_3$

Advantages:

→ single wattmeter is enough to measure 3ϕ power.

Disadvantage:

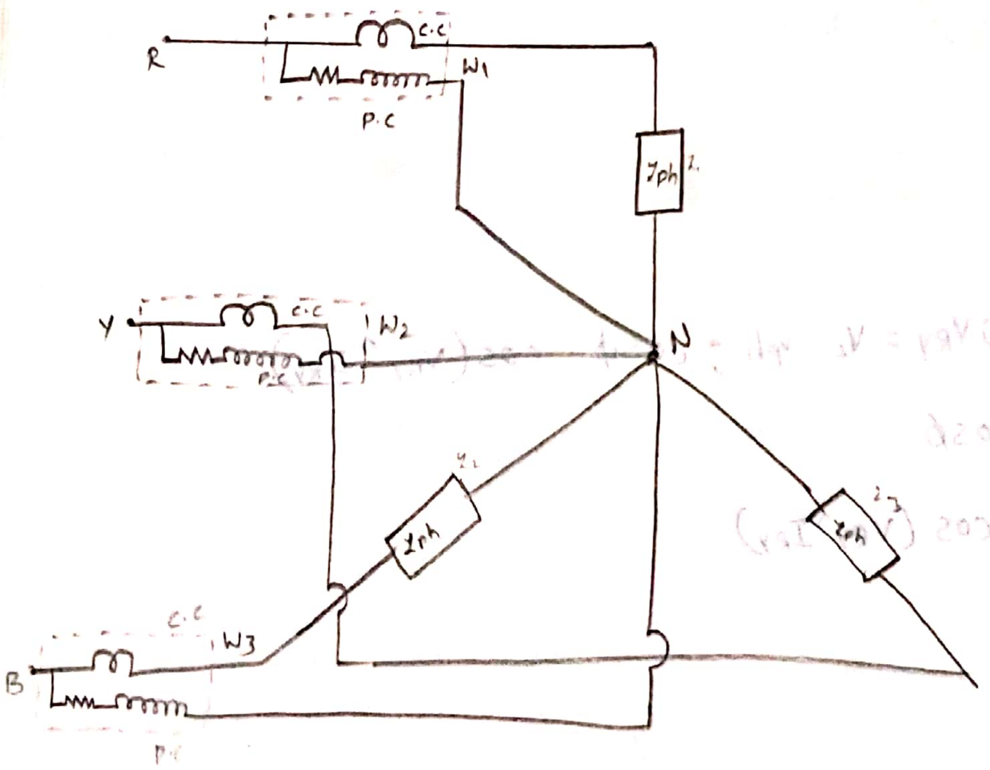
→ For unbalanced load, it is not possible to measure 3ϕ power

→ For star connection, Neutral point must be available.

→ For Delta connection, open the closed Delta to insert current coil & pressure coil, which is practically not possible.

II 3-Wattmeter method:-

(i) star connection

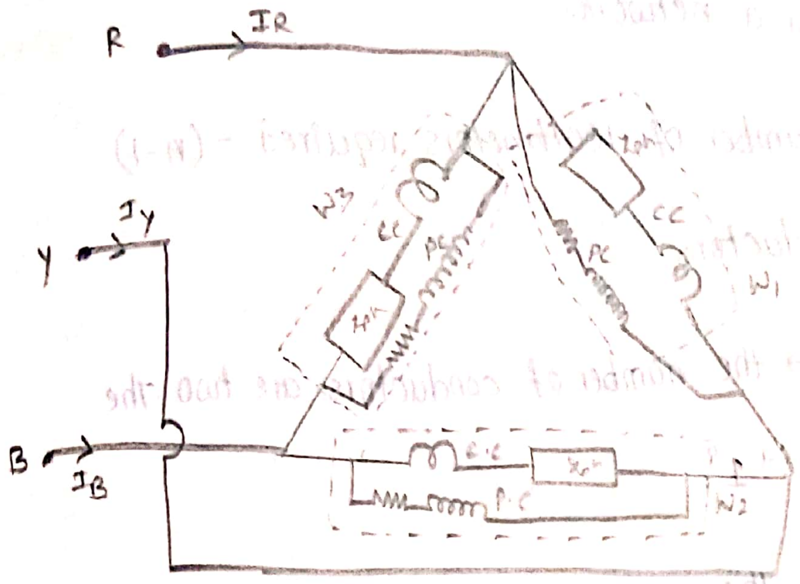


→ Total power

$P = W_1 + W_2 + W_3$ → for unbalanced loads

$P = 3W_1 = 3W_2 = 3W_3$ → for Balanced loads.

(ii) Delta connection:-



→ Total power

$P = W_1 + W_2 + W_3$ → unbalanced loads

$P = 3W_1 = 3W_2 = 3W_3$ → Balanced loads

Advantages:

→ This method is used to measure power in 3ϕ unbalanced loads.

Disadvantages:

→ It requires 3 wattmeters

→ In star connection, Neutral must be available.

→ In Delta connection, closed Delta must be open to insert current coil & pressure coil which is practically not possible.

23/12/19

Blondel's Theorem:-

→ It is used to calculate the number of wattmeters required for a network.

→ The number of wattmeters required $= (n-1)$

where, n = No. of conductors.

eg:- For 1ϕ, 2 wires (Ph, N) → the number of conductors are two. The wattmeter required is "1".

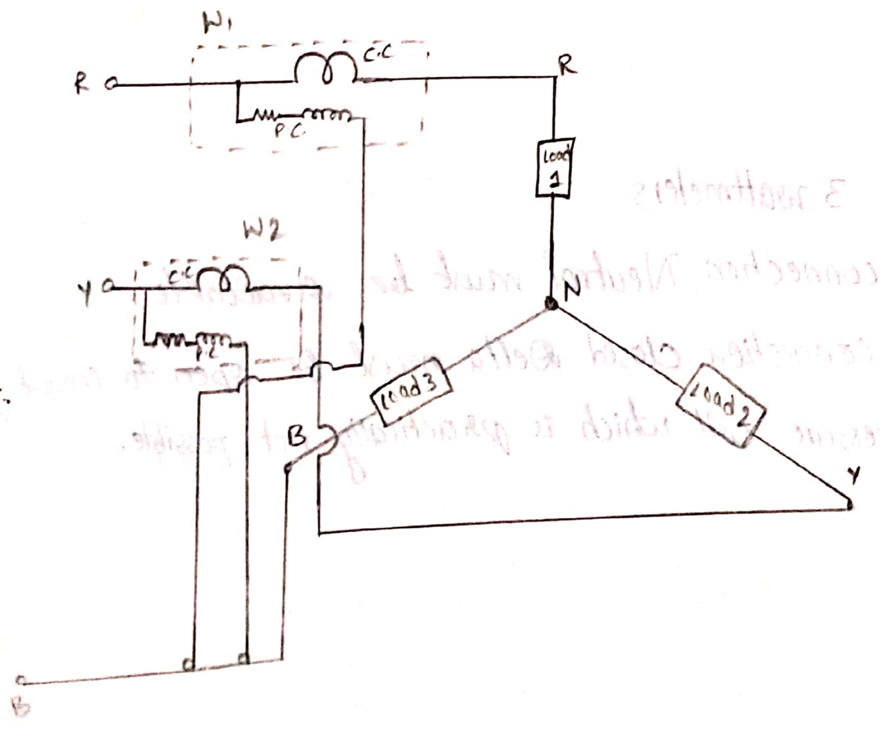
→ For 3ϕ, 3wire, the number of conductors are three, the wattmeters required are "2".

→ For 3ϕ, 4 wire system, the number of conductors are four, the wattmeters required are "3".

8M — All star (B, Unb), Delta (B).

Two Wattmeter Method:-

i) For unbalanced load star connection:-



→ v_r, v_y, v_b are the instantenous voltages (avg)

→ i_r, i_y, i_b are the instantenous current.

$W_{instantenous} = i_c V_{pc} = i_c V_{pc}$

→ For $W_1 = i_r V_{rb}$ → ① ; $W_2 = i_y V_{yb}$

WKT $V_{rb} = V_r - V_b$ & $V_{yb} = V_y - V_b$

$\therefore W_1 = i_r(V_r - V_b)$; $W_2 = i_y(V_y - V_b)$

Total power $= W_1 + W_2$

$= i_r(V_r - V_b) + i_y(V_y - V_b)$

$= i_r V_r - i_r V_b + i_y V_y - i_y V_b$

$= P_R + P_y - V_b(i_r + i_y)$ $\quad [\because i_r + i_y + i_b = 0$, $\therefore i_r + i_y = -i_b]$

$= P_R + P_Y - V_b(-i_b)$

$\boxed{W_1 + W_2 = P_R + P_Y + P_B}$. ∴ By using two wattmeters, 3ϕ power is calculated.

ii) For Balanced load star connection:-

same diagram.

→ $W = i_c V_{pc} \cos(i_c \wedge V_{pc})$

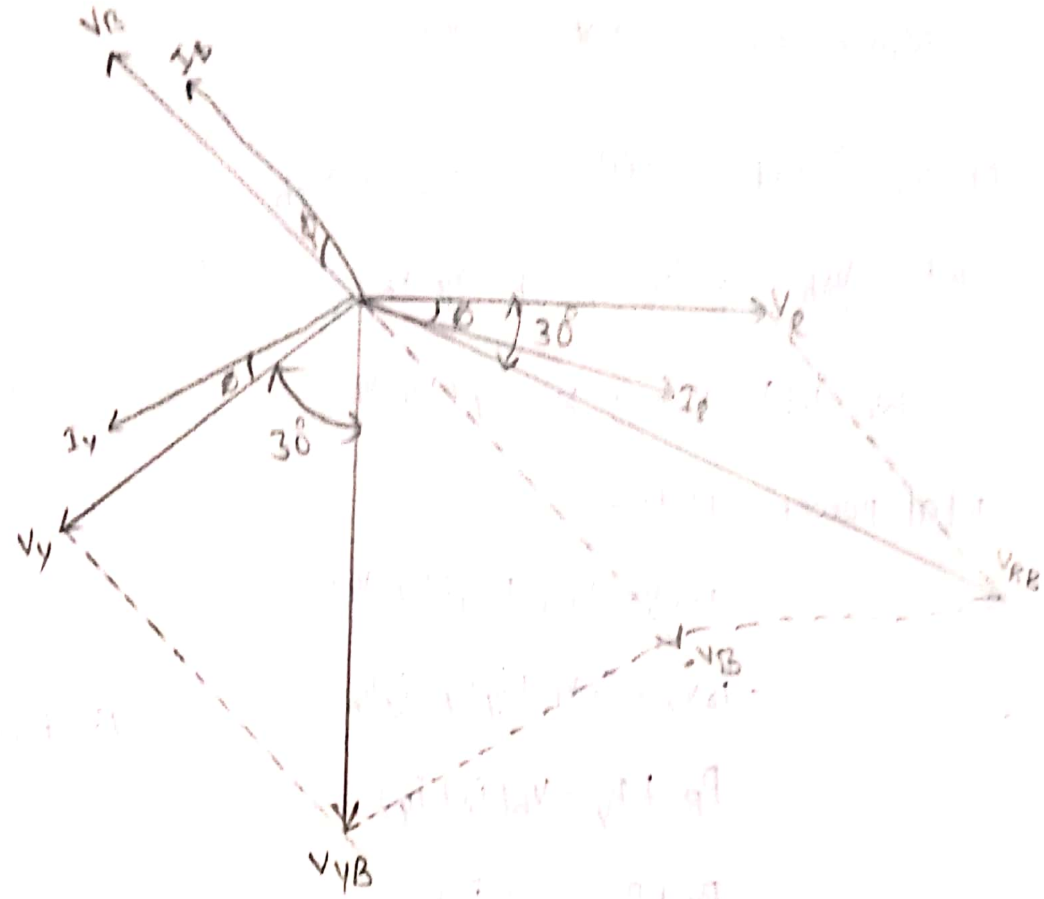
→ $W_1 = \dot{I}_R V_{RB} \cos(I_R \wedge V_{RB})$

→ $W_2 = I_Y V_{YB} \cos(I_Y \wedge V_{YB})$

$I_R = I_Y = I_L = I_{ph}$; $V_{RB} = V_{YB} = V_L$

→ $V_{RB} = V_R - V_B$ & $V_{YB} = V_Y - V_B$

Phasor Diagram



$\rightarrow W_1 = I_L V_L \cos(30-\phi) \longrightarrow (1)$

$W_2 = I_L V_L \cos(30+\phi) \longrightarrow (2)$

$\rightarrow$ Total power $= W_1 + W_2$

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

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

$\cos(A+B) + \cos(A-B) = 2\cos A \cos B$

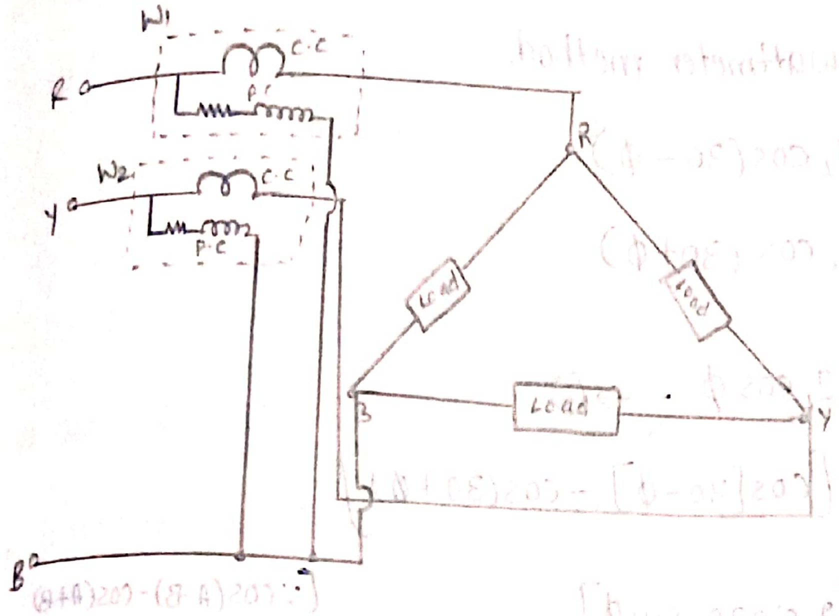
$= I_L V_L [2 \cos 30^\circ \cos\phi]$

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

$$\boxed{\text{Total power } (W_1+W_2) = \sqrt{3}\, V_L I_L \cos\phi}$$

II Delta connection:– Balanced

$V_L = V_{ph}$

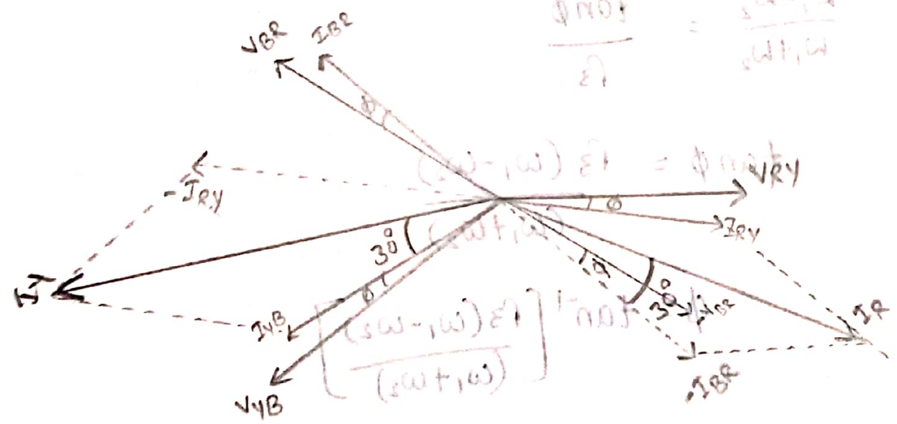


$\rightarrow$ $W_1 = I_R V_{RB} \cos(I_R \wedge V_{RB})$; $W_2 = I_Y V_{YB} \cos(I_Y \wedge V_{YB})$

$\rightarrow$ $V_{RB} = V_{YB} = V_L = V_{ph}$; $I_R = I_Y = I_L$

$I_R = I_{RY} - I_{BR}$

$I_Y = I_{YB} - I_{RY}$



$W_1 = V_L I_L \cos(30-\phi) \longrightarrow (1)$

$W_2 = V_L I_L \cos(30+\phi) \longrightarrow (2)$

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

$= V_L I_L \; 2 \cdot \cos 30 \cos\phi$

$$\boxed{\text{Total power } (W_1+W_2) = \sqrt{3} V_L I_L \cos\phi}$$

Power factor calculation:—

→ From two wattmeter method,

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

for balanced, U.B
λ, Δ

$$\rightarrow W_1 + W_2 = \sqrt{3} V_L I_L \cos\phi \longrightarrow (1)$$

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

$$= V_L I_L \left[2 \sin 30 \cdot \sin\phi\right]$$

$[\because \cos(A-B) - \cos(A+B) = 2 \sin A \sin B]$

$$W_1 - W_2 = V_L I_L \sin\phi \longrightarrow (2)$$

Take $\frac{(2)}{(1)} = \frac{W_1 - W_2}{W_1 + W_2} = \frac{\cancel{V_L I_L} \sin\phi}{\sqrt{3} \cancel{V_L I_L} \cos\phi}$

$$\frac{W_1 - W_2}{W_1 + W_2} = \frac{\tan\phi}{\sqrt{3}}$$

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

$$\phi = \tan^{-1}\left[\frac{\sqrt{3}(W_1 - W_2)}{(W_1 + W_2)}\right]$$

$\therefore$ power factor $= \cos\phi$

$$= \cos\left[\tan^{-1}\left[\frac{\sqrt{3}(W_1 - W_2)}{(W_1 + W_2)}\right]\right]$$

→ For Balanced (or) unbalanced, star (or) Delta, Lagging power factors :

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

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

→ For Balanced (or) Unbalanced, star (or) Delta connection, Leading power factors

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

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

→ For Balanced (or) Unbalanced, star (or) Delta connection, Unity power factor

$$\cos\phi = 1$$

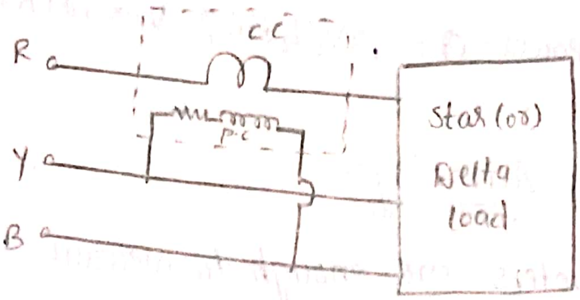
$$\phi = 0^\circ$$

$$W_1 = W_2 = V_L I_L \cos 30^\circ$$

$$= \frac{\sqrt{3}}{2} V_L I_L$$

Range of power factor	Range of ϕ	W_1 sign	W_2 sign	Remarks
$\cos\phi = 0$	$\phi = 90^\circ$	+ve	-ve	$\lvert W_1\rvert = \lvert W_2\rvert$
$0 < \cos\phi < 0.5$	$\phi = 60^\circ$	+ve	0	
$\cos\phi = 1$	$\phi = 0^\circ$	+ve	+ve	$W_1 = W_2$

Measurement of Reactive power:-



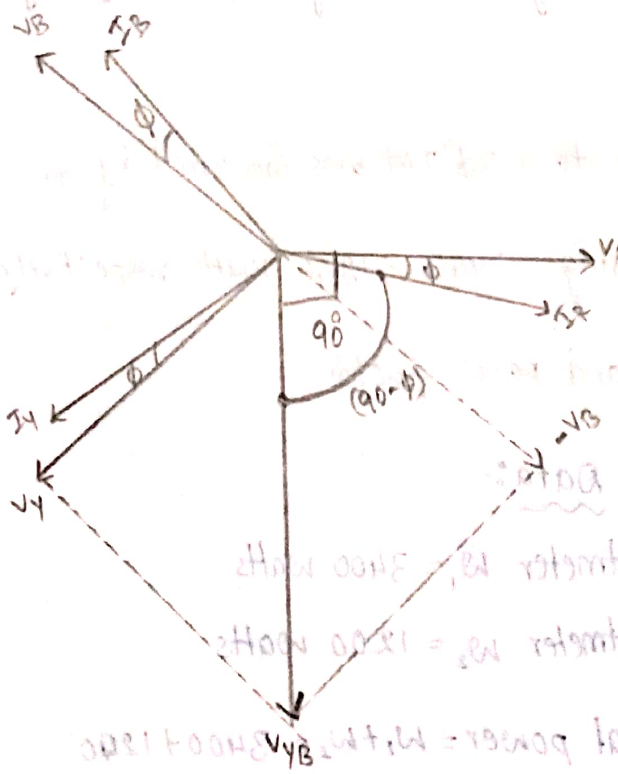
$W = I_C V_{PC} \cos(I_C \wedge V_{PC})$

$I_C = I_R, \quad V_{PC} = V_{YB}$

$V_{YB} = V_Y - V_B$

$W = I_R V_{YB} \cos(90-\phi)$ → phase diagram

$$\boxed{\therefore W = V_L I_L \sin\phi}$$



→ For 3φ, 3 wire

Reactive power

$$\boxed{W = \sqrt{3} V_L I_L \sin\phi}$$

→ Apparent power = $S = \sqrt{3} V_L I_L$ VA (or) KVA

→ Active power: $P = \sqrt{3} V_L I_L \cos\phi$ watts (or) Kwatts

→ Reactive power = $Q = \sqrt{3} V_L I_L \sin\phi$ VAR (or) KVAR

- Two wattmeter Advantages:

→ Two wattmeters are enough to measure 3ϕ power

→ There is no need for Neutral connection in star.

→ There is no need for opening of closed Delta.

→ This method is used for measurement of Active, Reactive Powers & power factor

Disadvantage:-

→ This is not suitable for 3ϕ, 4 wire system.

→ While taking the readings of W_1 & W_2 signs must be obser (change M, L)

24/12/19

The power to a 3ϕ IM was measured by two wattmeter method with the readings 3400 & 1200 watts respectively. calculate the total power and power factor.

Sol: Given Data:-

Wattmeter W_1 = 3400 watts

Wattmeter W_2 = 1200 watts

→ Total power = $W_1 + W_2$ = 3400 + 1200

= 4600 watts.

(ii) power factor = $\cos\phi$

$$\cos\left[\tan^{-1}\left(\frac{\sqrt{3}(\omega_1-\omega_2)}{\omega_1+\omega_2}\right)\right]$$

$$= \cos\left[\tan^{-1}\left[\frac{\sqrt{3}(3400-1200)}{4600}\right]\right]$$

$= 0.75$ (lagging) power factor.

The power to a 3ϕ IM was measured by two wattmeter method & readings are 3500 & 1500 watts respectively. calculate T.P & P.f

Sol:

$W_1 = 3500$ watts

$W_2 = 1500$ watts

(i) $T.P = W_1 + W_2 = 5000$ watts

(ii) $\cos\phi = \cos\left[\tan^{-1}\left(\frac{\sqrt{3}(\omega_1-\omega_2)}{\omega_1+\omega_2}\right)\right]$

$= 0.821$ lag

Two wattmeters are connected to measure the input to a balanced 3ϕ circuit indicates 2000 watts & 500 watts respectively. Find power factor of the circuit.

(i) when both readings are +ve

(ii) One of the meter shows negative.

Sol: Given Data,

Balanced, 3ϕ

$W_1 = 2000$

$W_2 = 500$

(i) $\cos\phi = \cos\left[\tan^{-1}\left(\frac{\sqrt{3}(\omega_1-\omega_2)}{\omega_1+\omega_2}\right)\right] = \cos\left[\tan^{-1}\left(\frac{\sqrt{3}(2000-500)}{2000+500}\right)\right] = 0.69$ lagging

$W_1 = 2000$
$W_2 = -500$

(ii) $\cos\phi = 0.327$ lag

In a particular test, 2 wattmeter readings are 4KW & 1KW calculate power & power factor

(i) If both meters read direct

(ii) one meter is reversed.

Sol: Given,

$W_1 = 4000\,W = 4KW$
$W_2 = 1000\,W = 1KW$

(i) $W_1 = 4KW$; $W_2 = 1KW$

Total power $= W_1 + W_2 = 4+1 = 5KW$

$$\cos\phi = \cos\left[\tan^{-1}\left(\frac{\sqrt{3}(W_1 - W_2)}{W_1 + W_2}\right)\right]$$

$$= \cos\left[\tan^{-1}\left(\frac{\sqrt{3}(4-1)}{4+1}\right)\right]$$

$$= 0.693 \text{ lag}$$

(ii) $W_1 = 4KW$; $W_2 = -1KW$

$$\cos\phi = \cos\left[\tan^{-1}\left(\frac{\sqrt{3}(4-(-1))}{4-1}\right)\right]$$

$$= 0.327 \text{ lag}$$

Total power $= W_1 + W_2$
$= 4-1$
$= 3KW.$

A 3ϕ 10 KVA load has a power factor of 0.342. The power is measured by 2 wattmeter method. Find the reading of each wattmeter (i) when p.f is leading
(ii) when p.f is lagging.

Sol: Given Data,

$S = 10\ KVA \Rightarrow \sqrt{3} V_L I_L$

$\cos\phi = 0.342$

$\rightarrow \sqrt{3} V_L I_L = 10\ KVA$

$V_L I_L = \frac{10 \times 10^3}{\sqrt{3}} = 5773.50\ VA$

(i) P.f is leading.

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

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

$\phi = \cos^{-1}(-0.342)$

$= \cancel{-70.00^\circ}$

$\phi = 109.99^\circ$

$\therefore W_1 = 5773.50 \cos(30+\cancel{70}\ 109.99)$

$= \cancel{4422.75}$ watts 1002.55 watts

$\therefore W_2 = 5773.50 \cos(30-(\cancel{-70}\ 109.99))$

$= +\cancel{1002.55}$ watts.
4422.75

(ii) P.f lagging:

$\phi = \cos^{-1}(0.342)$
$= 70.00$

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

$= 5773.50 \cos(30-70)$

$= 4422.75$ watts

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

$= 5773.50 \cos(30+70)$

$= -1002.55$ watts

A 3ϕ 400V, load has p.f of 0.6 lagging. The two wattmeter reads a total i/p power of 20 KW. Find reading of each wattmeter.

Sol: Given Data,

3ϕ, $V_L = 400$

$\cos\phi = 0.6$ (lag)

$\phi = \cos^{-1}(0.6)$

$\phi = 53.13$

Total i/p power $= W_1 + W_2$

$\sqrt{3} V_L I_L \cos\phi = 20 KW$

$$I_L = \frac{20 \times 10^3}{400 \times \sqrt{3} \times 0.6}$$

$I_L = 48.11$ Amp

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

$= 400 \times 48.11 \cos(30 - 53.13)$

$= 17.697$ KW

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

$= 400 \times 48.11 \cos(30 + 53.13)$

$= 2.30$ KW

26/12/19

A 500 V, 20 Amps dynamometer instrument is used as a wattmeter. Its current coil has 0.1Ω resistance & pressure coil has $25K\Omega$ resistance with 0.1 H Inductance. The meter has calibrated on DC supply. What is the error in the instrument. If it is used to measure the power in circuit with supply voltage of 500V, load current of 24Amps at 0.2 power factor. Assume that the pressure coil is connected across the load.

use below formula

Sol: Given Data,

Actual wattmeter reading = $[1+\tan\phi\tan\beta] \times$ True power

$\cos\phi = 0.2$

$\phi = \cos^{-1}(0.2) = 78.46°$

$\rightarrow \tan\phi = 4.89°$

$\tan\beta = \left[\frac{X_p}{R_p}\right]$

$X_p = 2\pi f L$
$= 2\pi \times 50 \times 0.1 = 31.41\Omega$

$\beta = \tan^{-1}\left[\frac{X_p}{R_p}\right]$

$\beta = \tan^{-1}\left[\frac{31.41}{25000}\right]$

$\boxed{\beta = 1.23\times10^{-3}}$

$\rightarrow$ True power = $VI\cos\phi = 500\times24\times0.2 = 400$ watts

$\rightarrow$ Actual wattmeter reading = $(1+4.89\times\tan(1.23\times10^{-3}))\times400$

$= 2414.54$ watts

$$\% \text{ Error} = \frac{AW - TP}{TP} \times 100$$

$$= 0.6058\%$$

Two wattmeters are connected to measure power in a 3ϕ network. The two wattmeter readings are 200W, 1000W respectively & If another wattmeter is connected such that its current coil is in one phase & potential coil is across other two phase terminals. What will it read. Also estimate Reactive power of N/w.

Two ~~wattmeters are~~

Sol: Given Data,

Wattmeter W_1 = 200W

Wattmeter W_2 = 1000W

$$\rightarrow \cos\phi = \cos\left[\tan^{-1}\left(\frac{\sqrt{3}(W_1 - W_2)}{W_1 + W_2}\right)\right]$$

$$\boxed{\cos\phi = 0.654}$$

49.15

sin (49.15)

$$\phi = \tan^{-1}\left[\frac{\sqrt{3}(\omega_1 - \omega_2)}{\omega_1 + \omega_2}\right]$$

$$= \tan^{-1}\left[\frac{\sqrt{3}(200 - 1000)}{1200}\right]$$

$$\boxed{\phi = -49.106^\circ}$$

$\sin\phi = -0.755$

$\therefore Q = V_L I_L \sin\phi$

$= 1058.24 \times -0.755$

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

$V_L I_L = \dfrac{200}{\cos(30 + 49.106)} = 1058.24$

$Q = -798.97$ VAR

Total $= \sqrt{3} \times Q = -1385.41$ VAR

The Inductive reactance of the pressure coil of dynamometer wattmeter is 8% of its resistance at normal frequency, and capacitance is negligble. Calculate % error & correction factor due to reactance

$\dfrac{\cos\phi}{\cos\beta \cos(\phi - \beta)}$

(i) 0.6 pf leading

(ii) 0.8 pf leading

Sol: Given Data,

$X_p = 0.08 R_p$

correction factor $= \dfrac{\cos\phi}{\cos B \cos(\phi - B)}$

?

$\cos\phi = 0.6$

$\phi = \cos^{-1}(0.6)$

$\phi = 126.86$

$\cos\phi = 0.8$

$\phi = \cos^{-1}(-0.8)$

$= 143.13$

$\beta = \tan^{-1}\left[\frac{X_P}{R_P}\right] = \tan^{-1}\left[\frac{0.08 R_P}{R_P}\right]$

$= 4.57^\circ$

(i) 0.6 pf lead:

$\phi = \cos^{-1}(0.6) = 53.13^\circ$

$$\text{correction factor} = \frac{\cos(53.13^\circ)}{\cos(4.57^\circ)\cos(53.13^\circ - 4.57^\circ)}$$

$= 0.9094$

$\rightarrow$ % Error $= \tan\phi \tan\beta \times 100$

$= 10.65\%$

(ii) 0.8 pf leading:

$\phi = 36.86$

$$\text{correction factor} = \frac{\cos(36.86)}{\cos(4.57^\circ)\cos(36.86 - 4.57^\circ)}$$

$= 0.9493$

$\rightarrow$ % Error $= \tan\phi \tan\beta \times 100$

$= 5.99\%$

$W_1 + W_2 = 30\,kW$

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

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

A 3ϕ 500V motor load, as pf of 0.4. Two wattmeters connected to measure the i/p. They show the i/p is 30KW. Find the reading of each instrument. $\cos^{-1}(0.4) = 66.42$

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

$I_L = \frac{30 \times 10^3}{\sqrt{3} \times 500 \times 0.4}$

$I_L = 86.602\,A$

Sol: $V_L = 500\,V$

$\cos\phi = 0.4$

i/p power $= 30\,kW$

$W_1 + W_2 = 30\,kW$

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

$= 500 \times 86.602 \times \cos(30-66.42)$

$= 34.843\,KW$

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

$= 500 \times 86.602 \times 0.8046 = -4.841\,KW$

A certain circuit takes 10A at 200V & power absorbed is 1000 W If c.c of wattmeter has a resistance of 0.15Ω & its pressure coil has resistance of 5000 Ω & Inductance of 0.3 H. Find

(i) Error due to resistance for each of two possible methods

(ii) The Error due to Inductance with frequency 50 Hz.

Sol: $X_p = 2\pi \times 50 \times 0.3 = 94.24\,\Omega$; $R_p = 5000\,\Omega$; $R_c = 0.1\,\Omega$

$T.P = 1000\,W$

Pressure coil at source

(i) $AW = P.R.L + I^2 R_c$

$= 1000 + (100 \times 0.15)$

$= 1010$

$\%\ Error = \frac{AW - TP}{TP} \times 100$

$= \frac{1015 - 1000}{1000} \times 100$

$= 1.5\%$

Pressure coil at load

(2) $AW = P.R.L + \frac{V^2}{R_p}$

$= 1000 + \frac{40000}{5000}$

$= 1008$ watts

$\%\ Error = \frac{1008 - 1000}{1000} \times 100$

$= 0.8\%$

(ii) $AW = [1 + \underset{1.732}{\tan\phi}\ \underset{0.0134}{\tan\beta}]TP$

$\tan\beta = \frac{94.24}{5000}$

$\boxed{\beta = 1.077^\circ}$

$\%\ Error = \frac{AW - TP}{TP} \times 100$

$= \frac{[1 + \tan\phi \tan\beta]T.P - T.P}{TP} \times 100$

$= \tan\phi \times \tan\beta \times 100$

$P = V_L I_L \cos\phi$

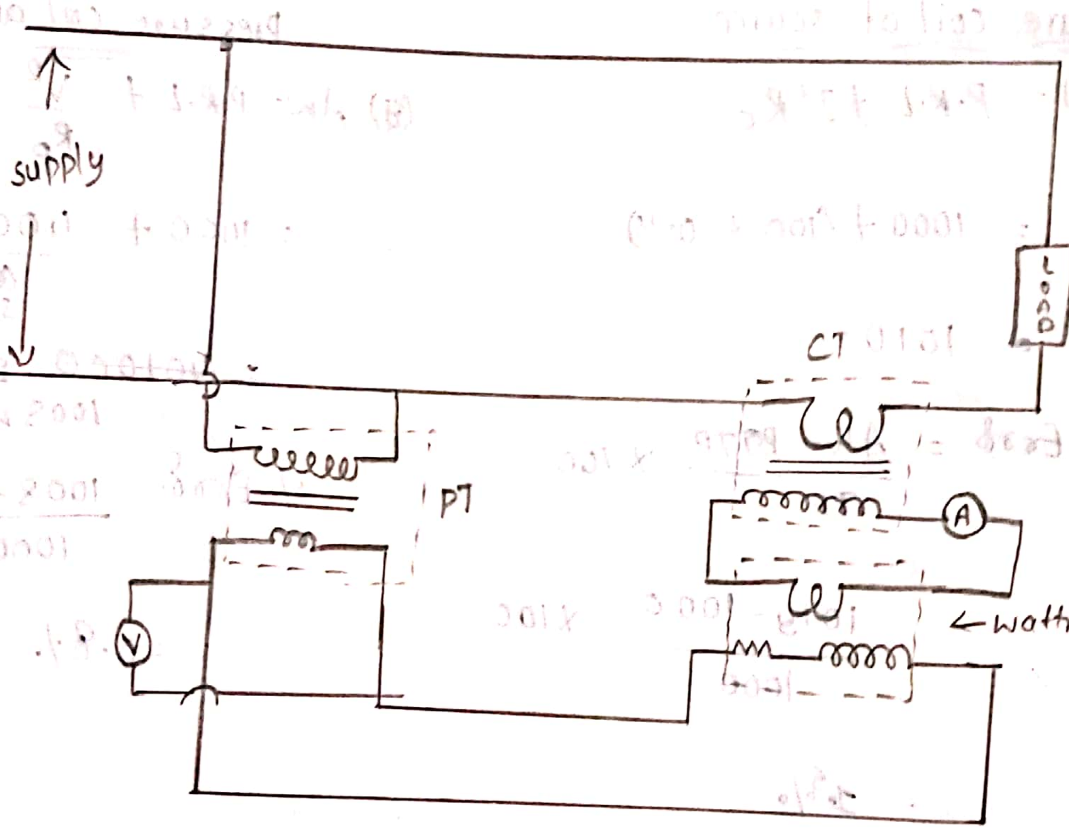
$1000 = 200 \times 10 \cos\phi$

$\boxed{\phi = 60^\circ}$

Extension of Range of wattmeter by using Instrument Transformers.

To measure power in high voltage ckt's, it is not possible to measure with the help of ordinary wattmeters.

To measure the power in high voltage ckt's, Extension of range with instrument transformers are used.



True power = K × RCF of CT × RCF of PT × nominal ratio of CT × nominal ratio of PT × wattmeter reading.

27/12/17

Two wattmeter method is used to measure power in a 3ϕ balanced load. Find the power factor, the two readings are equal and have the same sign $\cos\phi = 1$

(ii) The two readings are equal and have opposite sign. $\cos\phi = 0$, $\phi = 90^\circ$

(iii) The readings of one wattmeter is zero. $\cos\phi = 0 < \cos\phi < 0.5$, $\phi = 60^\circ$

(iv) The reading of one wattmeter is half of the other wattmeter.

Sol: (iv) $\cos\phi = \cos\left[\tan^{-1}\left[\frac{\sqrt{3}(\omega_1-\omega_2)}{\omega_1+\omega_2}\right]\right]$ (iii) $\cos\phi = 0.5^\circ$

$$= \cos\left[\tan^{-1}\left[\sqrt{3}\left(\frac{\omega_1-\frac{\omega_1}{2}}{\omega_1+\frac{\omega_1}{2}}\right)\right]\right]$$

$$= \cos\left[\tan^{-1}\left[\sqrt{3}\,\frac{\omega_1}{3\omega_1}\right]\right]$$

$\cos\phi = 0.866^\circ$

Find the power and power factor of the Balanced circuit in which of the wattmeter readings are 5KW and 0.5KW, later after the reversal of current coil terminal of the wattmeter.

Sol: $W_1 = 5KW$; $W_2 = 0.5KW$

Total $W_1+W_2 = 5+0.5 = 5.5\,KW$

Reversal,

$W_1 = 5KW$; $W_2 = -0.5KW$

$W_1+W_2 = 5-0.5 = 4.5\,KW$

power

$$\cos\phi = \cos\left[\tan^{-1}\left(\frac{\sqrt{3}(\omega_1-\omega_2)}{\omega_1+\omega_2}\right)\right]$$

$$= \cos\left[\tan^{-1}\left(\frac{\sqrt{3}(5-0.5)}{5.5}\right)\right]$$

$\cos\phi = 0.576^\circ$

8M

A 10 KW 3ϕ IM having full load effeciency of 85% is connected to a 400 volts supply. The motor when running on full load draws a current of 20 Amp from the supply. If two wattmeter are connected measure the total power input to the motor. Deter-mine the reading of each wattmeter. Also find out total reactive power in terms of wattmeter readings.

Sol: Given Data:-

output = 10 KW

η = 85% = 0.85

V_L = 400 V

I = 20 Amp

$\rightarrow \eta = \frac{o/p\ power}{i/p\ power} \times 100$ i/p power = $\sqrt{3} V_L I_L \cos\phi$

$0.85 = \frac{10\times10^3}{i/p\ power} \cancel{\times 100}$

$i/p\ power = \frac{10\times10^3}{0.85} \cancel{\times 100}$

= 11764.7 watts

= 11.764 KW

i/p power = $W_T + W_2$

$\boxed{W_T = i/p\ Power = \sqrt{3}\, V_L I_L \cos\phi}$

$\cos\phi = \frac{11.764}{\sqrt{3}\times 400\times 20} = \frac{11764.7}{\sqrt{3}\times 8000} = 0.849$

$\cos\phi = 0.849^\circ$ (logg)

$\phi = 31.89^\circ$

$\sin(31.89) = 0.528$

$\rightarrow W_1 = V_L I_L \cos(30-\phi) = 400 \times 20 \times \cos(30-31.89) = 7995.6\ W$

$= 7.995\ KW$

$W_2 = V_L I_L \cos(30+\phi) = 400 \times 20 \times \cos(30+31.89) = 3.769\ KW$

Total Reactive power interms of wattmeter readings

$\rightarrow Q = \sqrt{3} V_L I_L \sin\phi$

$= \sqrt{3} \times 400 \times 20 \times 0.528$

$Q = 7316.18$ ~~watts~~ VAR

$Q = 7.316$ KVAR

A 3ϕ 440V, 50Hz IM takes line current of 30 Amp and delivers 10KW o/p power under full load. Assuming its effeciency is 90% calculate (i) power factor of motor

(ii) Readings on two wattmeters

(iii) Total Reactive power.

Sol: Given, $V_L = 440$; $I_L = 30A$;

o/p power = 10KW

$\eta = 90\% = 0.9$

$\eta = \dfrac{o/p}{i/p}$

$i/p = \dfrac{10\ KW}{0.9}$

i/p power = 11.11 KW

i/p power $= \sqrt{3} V_L I_L \cos\phi$

$\cos\phi = \dfrac{11111.11}{\sqrt{3} \times 440 \times 30}$

$\cos\phi = 0.485$

$\phi = 60.92^\circ$

$I_L = 30A$

$o/p = 10 \times 10^3$

$\eta = 0.9$

$i/p = \dfrac{10 \times 10^3}{0.9}$

$i/p = 11.11\ KW$

$11.111 = \sqrt{3} V_L I_L \cos\phi$

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

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

$Q = \sqrt{3} V_L I_L \sin\phi$

$\rightarrow W_1 = V_L I_L \cos(30-\phi) = 440 \times 30 \times \cos(30-60.92) = 11.324\,kW$

$\rightarrow W_2 = V_L I_L \cos(30+\phi) = 440 \times 30 \times \cos(30+60.92) = -0.211\,kW$

$\rightarrow$ Total Reactive Power $= \sqrt{3} V_L I_L \sin\phi$

$= \sqrt{3} \times 440 \times 30 \times \sin(60.92)$

$= 19.980\ KVAR$

Power input to a 3ϕ, 415 V, 50 Hz IM is measured using two wattmeters. one wattmeter reads 7.5 kW. while other 2.5 kW After reversing the connections of pressure coil. calculate

(i) Total power

(ii) power factor

(iii) Line current. Also Identify which wattmeter reading 2.5 kW if it is given that the two wattmeters was connected in lines R & Y.

Sol: Given Data,

$V_L = 415V$

$W_1 = 7.5\ KW$; $W_2 = 2.5\ KW$

Total power $= W_1 + W_2 = 10\ KW$

Reversals:-

$W_1 = 7.5\ KW$; $W_2 = -2.5\ KW$

(i) Total power $= W_1 + W_2 = 5\ KW$

(ii) $\cos\phi = \cos\left[\tan^{-1}\left(\dfrac{\sqrt{3}(W_1 - W_2)}{(W_1 + W_2)}\right)\right]$

$= \cos\left[\tan^{-1}\left(\dfrac{\sqrt{3}(7.5+2.5)}{7.5-2.5}\right)\right]$

$\boxed{\phi = 73.91}$

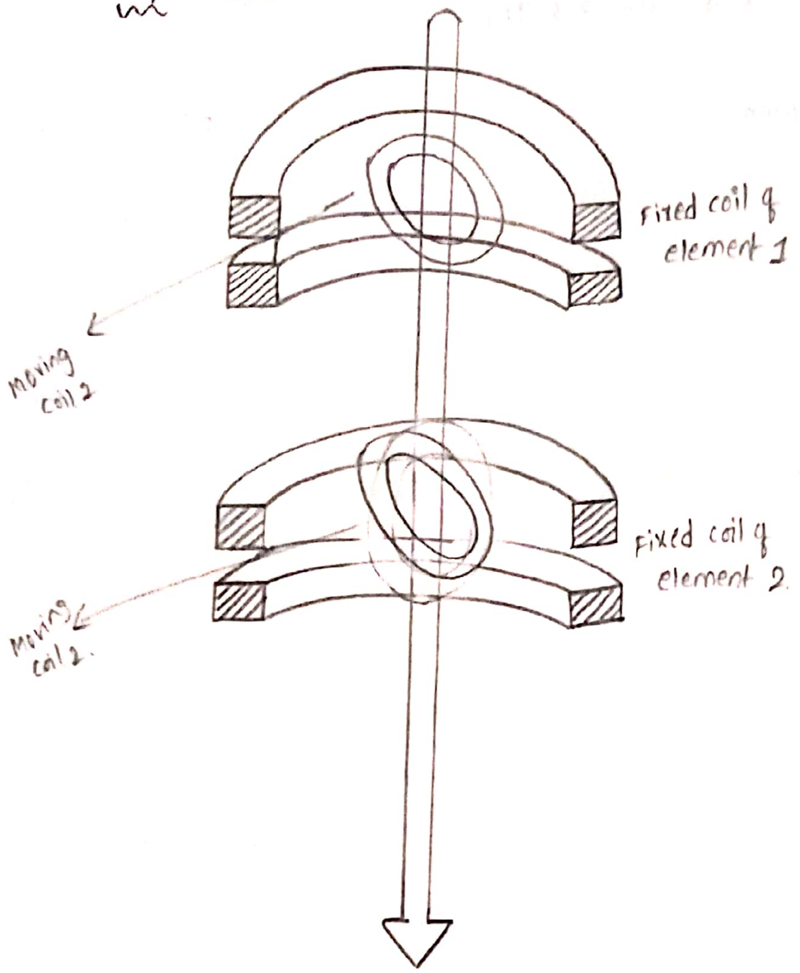
$\cos\phi = 0.277$ (lagging)

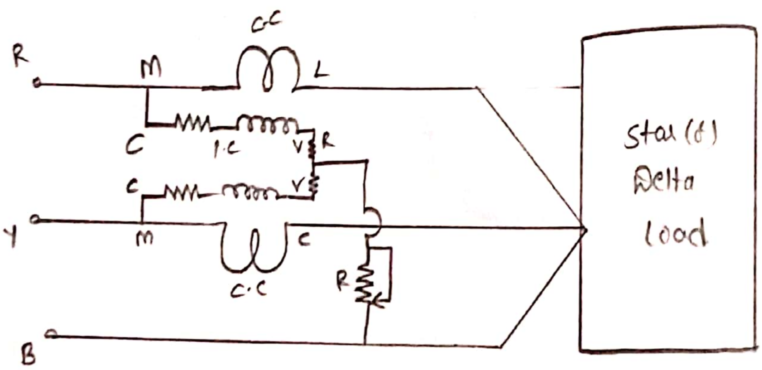
(iii) $W_1 = V_L I_L \cos(30 - \phi)$

$$7.5 \times 1000 = 415 \times I_L \times \cos(30 - 73.91)$$

$$I_L = 25.085 \text{ Amp}$$

3φ Electro Dynamometer type wattmeter





$T_{d_1} \propto \omega_1$; $T_{d_2} \propto \omega_2$

→ Total torque is $T_d \propto (\omega_1 + \omega_2)$

It consists of a two set of fixed coils and moving coils. These two are constructed on same spindle. The resultant torque is obtained by the interaction of two fixed coils and moving coil fluxes. Hence the resultant torque is $T_{d_1} \propto W_1$; $T_{d_2} \propto W_2$

Total torque is $T_d \propto (W_1 + W_2)$

→ The variable resistor is connected in between the two pressure coils to avoid the Mutual Inductance effect.

→ this meter gives the direct reading of 3ϕ power.

→ The main Disadvantage is cost of Instrument is high.

Measurement of Energy :-

→ The Energy is measured by an Instrument

"Energy Meter".

→ The Energy $(E) = \int_0^t P\,dt$

→ Energy (E) = power × Time

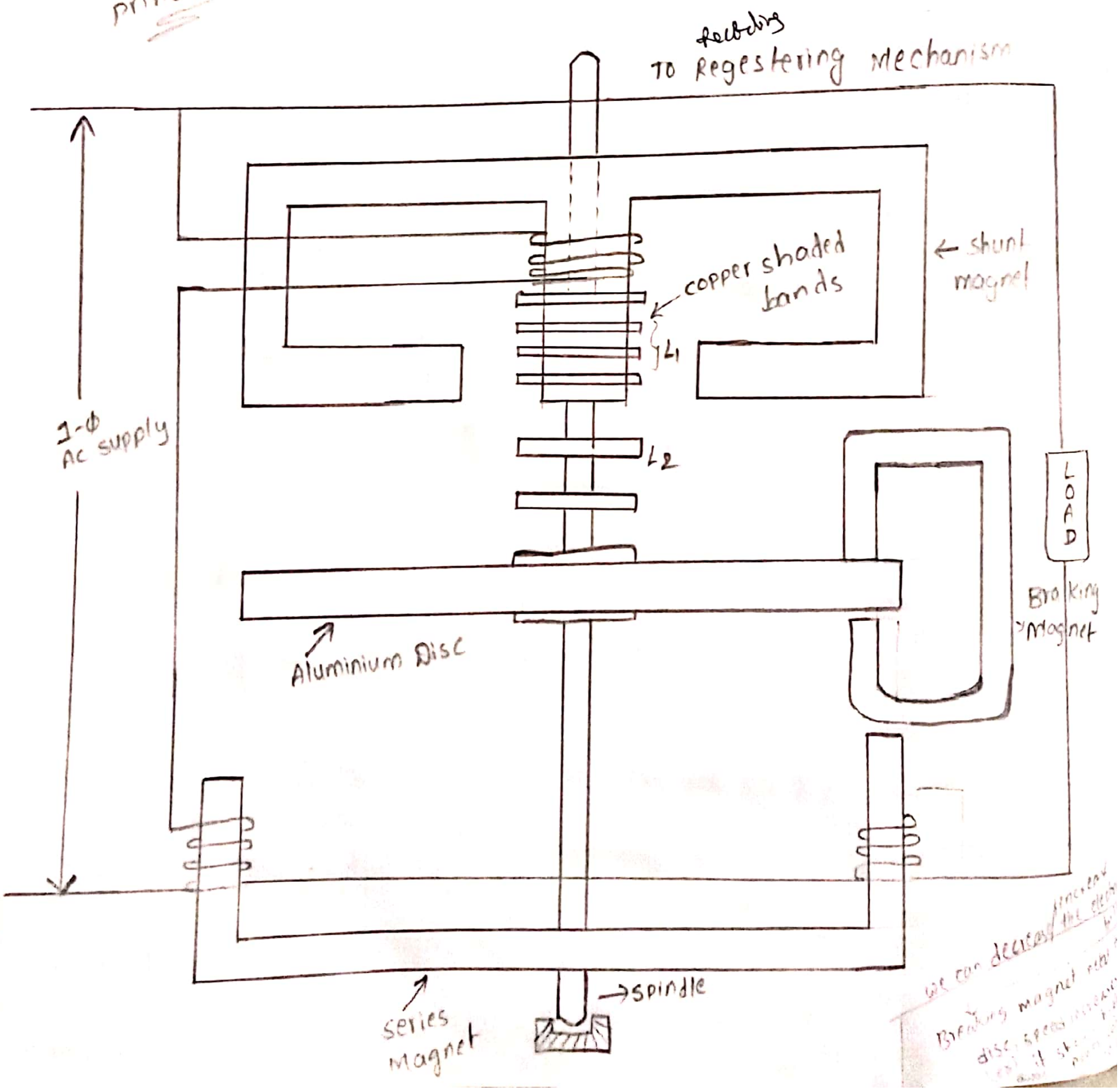
→ Energy is measured by a Induction type

Energy Meter

Induction Type Energy Meter:-

(2)

principle: Electromagnetic Induction Principle



It consists of mainly 4 parts.

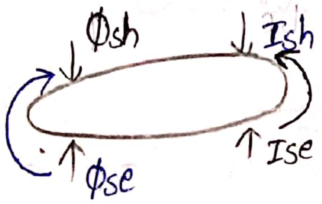
1. Driving system
2. Braking system
3. Moving system
4. Regestering system

Driving system:- It consists two electromagnet. shunt magnet & series magnet. These two are designed with silicon steel laminations. The shunt magnet central limb consists copper shading bands L_1 & L_2.

The shunt magnet is across the load & series magnet is connected in series with load. In between two magnets, light Aluminium disc is placed.

When Alternating supply is given to the two magnets it produces ϕ_{sh}, ϕ_{se}. An alternating flux links with stationary disc, an emf is induced in the disc.

Disc is closed path; currents produces. These currents are Eddy currents. The interaction of magnetic flux, Eddy currents, the disc rotates.



moves opposite to high flux

force

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To reduce ~~adju~~ friction losses, light load Adjustment is provided

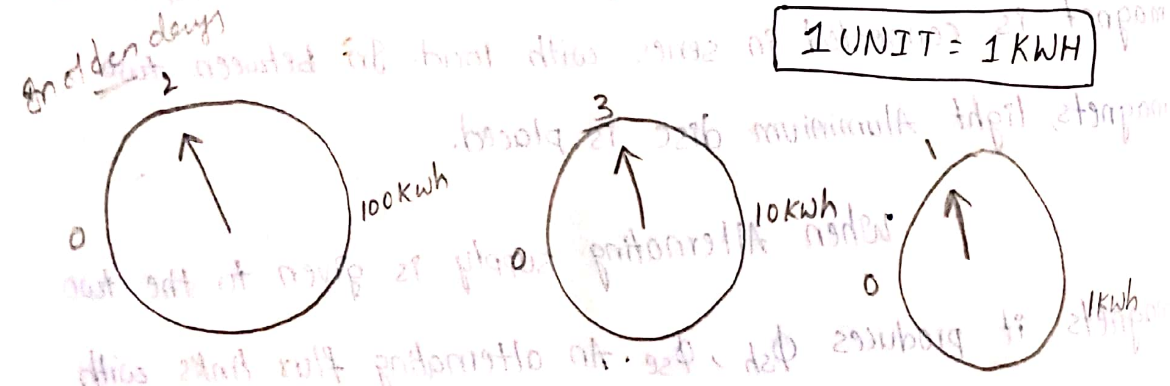
Braking system: It consists of Braking magnet to adjust the speed of a disc.

Moving system:- It consists of light Aluminium disc which is attached to the spindle.

With the help of "gearing Mechanism" the number of units consumed are registered.

Regestering system:- It consists of a gearing mechanism, which is connected to the spindle to indicate number of units consumed.

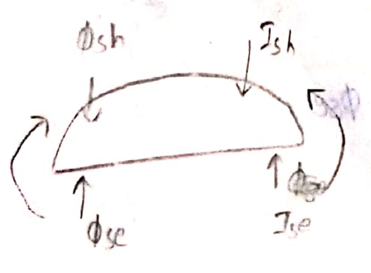
$\boxed{1\ \text{UNIT} = 1\ \text{KWH}}$



Total units consumed $= (2\times100) + (3\times10) + (1\times1)$

$= 231$ KWh

Torque Equation:-



$\phi_{sh} \propto I_{sh} \simeq \phi_p \propto I_p$

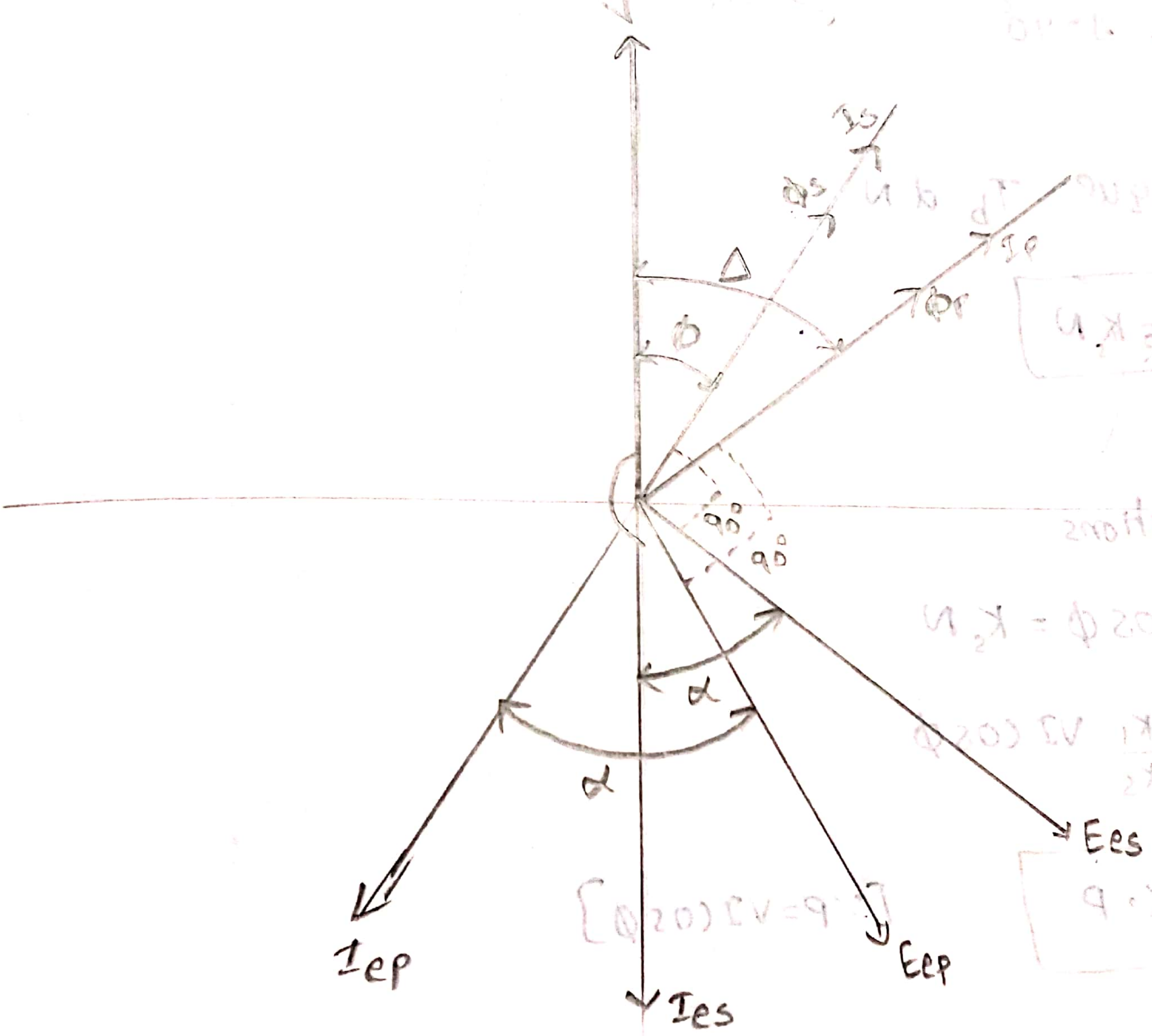
E_{ep}, I_{ep}

$E_{ep} \propto I_{ep}$

$\phi_s \propto I_s \propto \phi_s$

E_{es}, I_{es}

$E_{es} \propto I_{es}$


V
Is
φs
Ip
φp
Δ
φ
90°
90°
90°
α
α
Ees
Eep
Iep
Ies

→ Deflecting Torque

$$T_{d_1} \propto \phi_p \cdot I_{es} \cos(\phi_p \wedge I_{es}) \quad ; \quad T_{d_2} \propto \phi_s \cdot I_{ep} \cos(\phi_s \wedge I_{ep})$$

→ Resultant Torque: $T_d \propto T_{d_1} - T_{d_2}$

$\phi_p \propto I_p \propto V$; $I_{es} \propto \phi_s \propto I$; $\phi_s \propto I$; $I_{ep} \propto \phi_p \propto V$

$$\therefore \quad T_d \propto VI\left[\cos(\alpha+\phi) - \cos(180-\phi+\alpha)\right]$$

$$T_d \propto VI\left[\cos\alpha\cos\phi - \sin\alpha\sin\phi - \cos(180-\phi)\cos\alpha + \sin(180-\phi)\sin\alpha\right]$$

$\cos(180-\phi) = -\cos\phi$

$\sin(180-\phi) = \sin\phi$

$$\therefore \quad T_d \propto 2VI\cos\phi\cos\alpha$$

$$\boxed{T_d = KVI\cos\phi} \qquad [\because K = 2\cos\alpha]$$

If Delta "Δ" is considered as 90°,

$T_d \propto VI\sin(\Delta - \phi)$ $\quad [\because \sin(90-\theta) = \cos\theta]$

where, $\Delta = 90^\circ$

→ Breaking Torque $T_b \propto N$

$$\boxed{T_b = K_s N}$$

→ No. of revolutions

$K_1 VI\cos\phi = K_s N$

$N = \frac{K_1}{K_s} VI\cos\phi$

$$\boxed{N = K \cdot P}$$ $[\because P = VI\cos\phi]$

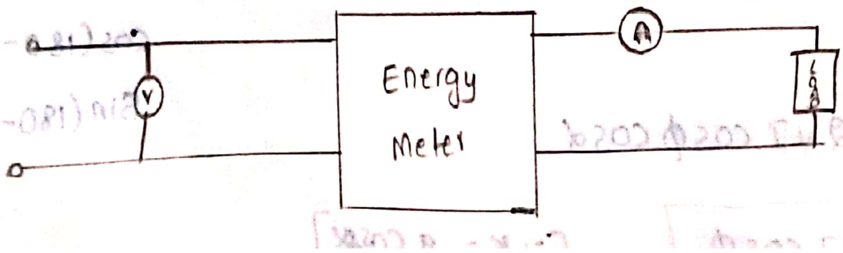
→ Total no. of revolutions $N = K\int_0^t P\,dt$

$$\boxed{N = K \cdot E}$$

→ Meter constant $K = \frac{N}{E} = \frac{\text{No. of Revolutions}}{\text{Energy in KWh}}$

Testing of Energy Meter :- (or) calibration of Energy meter

To calculate the percentage error, testing is essential. If the error is negative, disc is rotating slowly. If the error is positive, then disc rotates fastly.



Sl NO	V	I	$E_t = VI\cos\phi \times t$	t	N	% Error = $\frac{E_r - E_t}{E_t} \times 100$

percentage Error (% Error) = $\frac{E_r - E_t}{E_t} \times 100$

where,

E_t = True Energy = $VI\cos\phi \times t$

E_r = Recorded Energy

$\boxed{K = \frac{N}{E}}$

problems: (1)

An Energy Meter is designed to make 100 revolutions of the disc. For 1 unit of Energy, calculate the no. of revolutions made by it, when connected to a load carrying 20A at 230V at 0.8 power factor for an hour. If it actually makes 360 revolutions. Find percentage Error.

Sol: Given Data,

current = 20 A

voltage = 230 V

$\cos\phi$ = 0.8

Time = 1 hr = 3600 sec

Meter constant = 100 rev/KWh

$K = \frac{N}{E} = \frac{100}{1}$

$\rightarrow E_t = VI\cos\phi \times t$

$= \frac{230 \times 20 \times 0.8 \times 3600}{3600 \times 1000}$ → W-sec int KWh

KWh

$\frac{230 \times 20 \times 0.8 \times 1}{1000}$ KWhr

$$\boxed{E_t = 3.68 \text{ KWh}}$$

$\rightarrow$ Recorded Energy $= E_r = \frac{N}{K} = \frac{360}{100} = 3.6$ KWh

$$\therefore \% \text{ Error} = \frac{E_r - E_t}{E_t} \times 100$$

$$= \frac{3.6 - 3.68}{3.68} \times 100$$

$$= -2.174\%$$

Here Error negative, so disc rotates slowly.

The meter constant of a 230 volts, 10A, watt-hour meter (or Energy meter) is 1800 revolutions / KWh. The meter is tested at half load and rated voltage and unity power factor. The meter is found to make 80 revolutions in 138 seconds. Determine the meter error at half load.

full load = rated load = 10A
half load = $\frac{10}{2} = 5A$.

$\frac{E_r - E_t}{E_t} \times 100$

$E_t = VI\cos\phi \times t$

$230 \times 5 \times 1 \times 138 / 3600$

$r = \frac{N}{K} = 1800$

$E_r = \frac{N}{K} = 80$

Sol: Given Data,

$K = 1800$ rev/KWh

$V = 230$ V

full load $\rightarrow$ $I = 10$ A

half load $\rightarrow$ $I = 5$ A

$\cos\phi = 1$

$N = 80$

$t = 138$ seconds.

$$\% \text{ Error} = \frac{E_r - E_t}{E_t} \times 100$$

$E_t = VI\cos\phi \times t$

$= 230 \times 5 \times 1 \times 138 = 158700$ W-S $= 0.044$ KWh

$= 0.04408$ KWh

$\rightarrow E_r = \frac{N}{K} = \frac{80}{1800}$

$= 0.0444 \text{ Kwh}$

~~$E_r = 0.04408 \text{ Kwh}$~~

$\% \text{ Error} = \frac{E_r - E_t}{E_t} \times 100$

$= 0.7259 \%$

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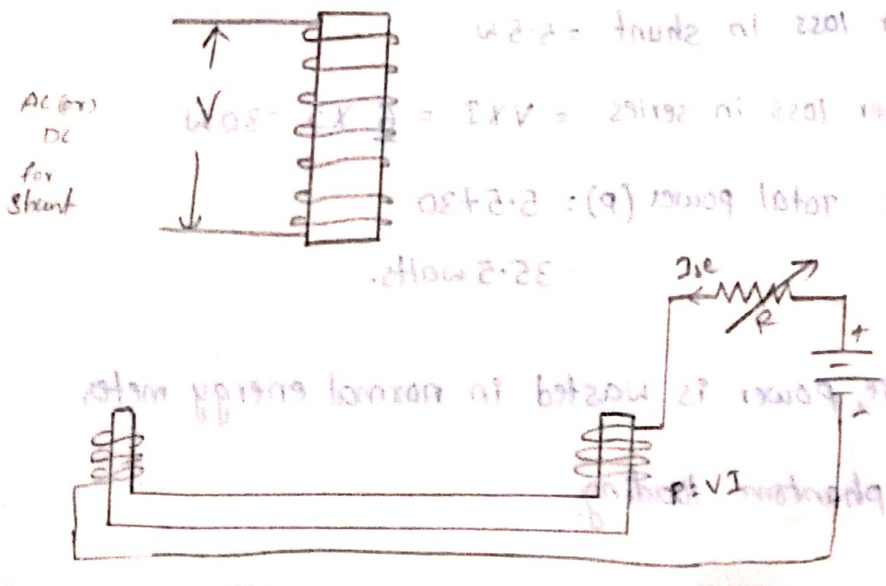
phantom Loading:—

→ To avoid wastage of power while testing an energy meter, phantom loading is used. It is also called "Ficticious load" (Imaginary load)

→ In this type of testing, shunt magnet is connected across the supply terminals (AC supply)

→ The series magnet is connected in series with DC supply.

→ For shunt magnet apply rated voltage, for series magnet apply rated current.



→ power loss in shunt magnet $P_{sh} = \frac{V^2}{R_P}$

→ power loss in series magnet $P_{se} = V \times I$

→ Total power $(P) = P_{sh} + P_{se}$

A 220V, 5A, DC Energy meter is tested at its marked ranges. The resistance of pressure coil ckt is 8800Ω and current coil is 0.1Ω. calculate the power consumed when testing the meter with phantom loading with current coil ckt excited by 6V battery.

AC = $VI\cos\phi \times t$
DC = $VI \times t$

Sol: Given Data:-

Supply = 220

power loss in shunt $P_{sh} = \frac{V^2}{R_P} = \frac{(220)^2}{8800} = 5.5\,W$

power loss in series magnet $P_{se} = VI = 6$

$= 220 \times 5$ } using normal meter

$= 1100\,W$

∴ Total power $= P_{sh} + P_{se}$

$= 5.5 + 1100$

$= 1105.5$ watts

Using phantom loading:-

→ power loss in shunt $= 5.5\,W$

But → power loss in series $= V \times I = \underline{6} \times 5 = 30\,W$

∴ Total power $(P) = 5.5 + 30$

$= 35.5$ watts.

Therefore, power is wasted in normal energy meter than phantom loading.

Errors and its compensations :— [8M]

The following are the sources of errors in Energy meter.

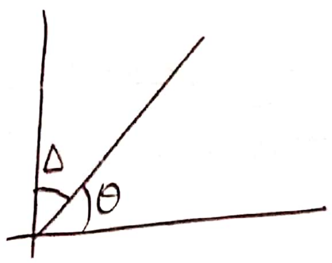
1. power factor (or) Lag Adjustment
2. Light load (or) Friction Adjustment
3. creeping Error
4. overload compensation
5. Temperature Error
6. voltage compensation
7. Mainspeed Adjustment.

1. power factor (or) Lag Adjustment:—

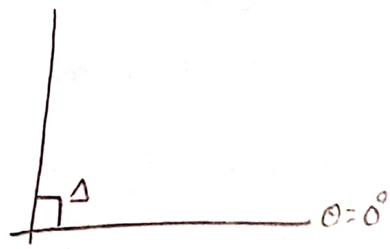
→ By Adjusting the copper shading bands of central limb of an Energy meter, the power factor is improved. α_1

→ If copper shading bands (α_1) moves upward direction Ampere turns (NI) increases, mmf also increases, power factor increases.

→ If copper shading bands moves downward, power factor decreases.



$P = VI\sin(\Delta - \theta)$



$P = VI$

2. Light Load (or) Friction Adjustment:-

During light load, some torque is lost due to friction. To compensate its lost torque, copper shaded band(L_2) is used.

☆☆☆

3. Creeping Error:—

The disc in the energy meter rotates slowly even though the current flowing in the secondary (or) load is zero (i.e series current is zero) This is because of shunt magnet. As the supply is given to shunt magnet, current flows, magnetic field produces which rotates the disc. This process is said to be creeping Error.

→ To avoid this, two small holes are placed at 180° on disc.

4. Overload Compensation:—

As the supply is given to shunt magnet, alternating current flows, which increases continuous flux, disc rotates and cuts the constant magnetic field which induces dynamical emf.

→ So, constant (or) saturable shunt magnet is placed between centre and side limbs of magnet so, the continuous flowing flux may divert.

* disc rotates, attached spindle also rotates.

The series flux kept less compared to shunt flux.

5. Temperature Error:—

As the instruments are using, heat produces, which increases temperature error. So, the proper material is used to avoid temperature Error.

6. Voltage compensation:-

→ when voltage is below required level, reactive power produced by inductance needs to offset by capacitance and when voltage is above required level, reactive power produced by capacitance needs to offset by inductance

→ shunt capacitance - capacitor banks connected in parallel.

→ series capacitance - capacitors connected in series, especially for long lines to raise voltage.

7. Mainspeed Adjustment:-

→ Mainspeed of energymeter is adjusted with the help of braking magnet.

→ If braking magnet is near, disc rotates speedly or if braking magnet is far, disc rotates slowly.

2/1/20

The meter constant of a 5A, 220 V DC Energy watt-hour meter is 3275 revolutions/KWH. Calculate the speed of disc at full load. In a test run at half load the meter takes 59.5 sec to complete 30 revolutions. Calculate the error of meter.

$N = ?$

$K = 3275$

$K = \frac{N}{E}$

$N = E_r \cdot K$

$\frac{E_r - E_t}{E_t} \times 100$

$E_r = VI\cos\phi \times t$

$= 220 \times$

Sol: 2

Given Data:

$K = 3275 \ r/kwh$

$I = 5A$; $V = 220V$

Find:- $N = K \times E_r \Rightarrow ?$

Error of meter = ?

Solution:- WKT,

$$K = \frac{N}{E_r}$$

$$\therefore N = K \times E_r$$

$$\rightarrow E_r = VI\cos\phi \times t$$

Assume $t = 1 \text{ min} = \frac{1}{60} \text{ hr}$

$$= 220 \times 5 \times \underset{\rightarrow DC}{1} \times \frac{1}{60}$$

$$E_r = \frac{18.33}{1000} \text{ wh}$$

$$\boxed{E_r = 0.018 \text{ KWh}}$$

$$\therefore N = 3275 \times 0.018$$

$$\boxed{N = 59.98 \text{ revolutions}}$$

$\rightarrow E_t = VI\cos\phi \times t$

At half load: 5/2

$= \dfrac{220 \times 5 \times 1 \times 59.5}{2 \times 1000 \times 3600}$

$= \cancel{0.01818\ Kwh}$

$= 0.00909$ Kwh.

$\rightarrow$ speed $(N) = 30$ revolution

$K = 3275$ r/Kwh

$E_r = \dfrac{N}{K} = 0.009160$ Kwh

$\therefore$ % Error $= \dfrac{E_r - E_t}{E_t} \times 100$

$= \dfrac{0.009160 - 0.00909}{0.00909} \times 100$

$\boxed{\%\ \text{Error} = 0.77\%}$

A correctly adjusted 240V induction watt-hour meter, has meter constant of 600 revolutions/Kwh. Determine the speed of disc ($N = ?$) for a current of 10Amp at a power factor of 0.8 lag. If the lag Adjustment is altered so that, the phase angle between flux & applied voltage is 86°. Calculate the error introduced at (i) unity power factor

(ii) 0.5 power factor lagging.

Sol: Given Data:

Voltage = 240V

K = 600 rev/Kwh

I = 10 Amp

$N = K \cdot E_r$

$= \dfrac{600 \times 240 \times 10 \times 0.8 \times \frac{1}{60}}{1000}$

Find:- $N = ?$

WKT, $N = K \times E_r$ $\rightarrow$ Assume 1 min

$E_r = VI\cos\phi \times t$

$= 240 \times 10 \times 0.8 \times \dfrac{1}{60} = \cancel{32}\,0.032$ Kwh

$\therefore N = 0.032 \times 600$

$$\boxed{N = 19.2 \text{ revolutions}}$$

Formula:-

$$\text{percentage error} = \frac{E_r - E_t}{E_t} \times 100$$

$$\% \text{ err} = \frac{VI\sin(\Delta - \phi) - VI\cos\phi}{VI\cos\phi} \times 100$$

$$\% \text{ err} = \frac{\sin(\Delta - \phi) - \cos\phi}{\cos\phi} \times 100$$

(i) Unity power factor

$\cos\phi = 1$

$\phi = 0^\circ$

$$\therefore \% \text{ err} = \frac{\sin(86 - 0^\circ) - \cos(0^\circ)}{\cos(0^\circ)} \times 100$$

$= 0.243\%$

(ii) pf $= 0.5$

$\cos\phi = 0.5$

$\phi = 60^\circ$

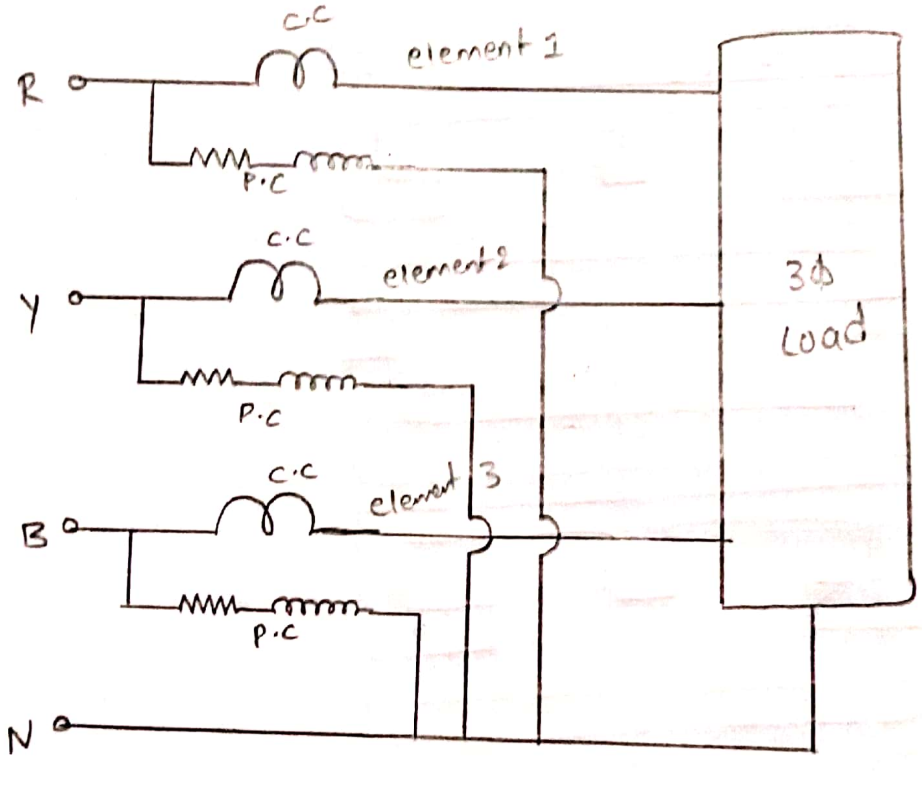
$$\therefore \% \text{ err} = \frac{\sin(86 - 60) - \cos 60}{\cos 60} \times 100$$

$= -12.326\%$

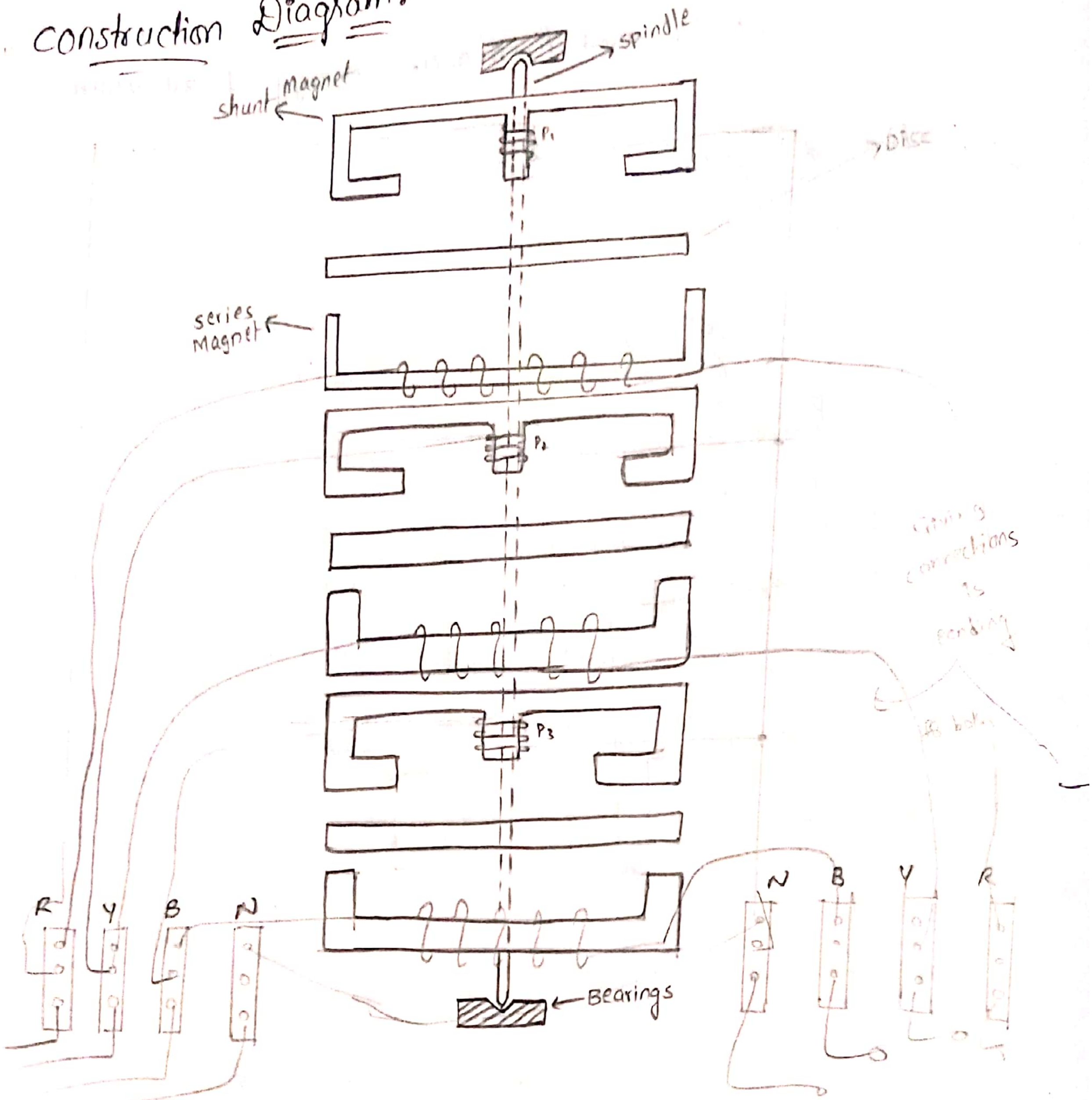
3-ϕ Element Energy Meter:- used to find Energy in 3ϕ, 4wire

It is used to measure Energy of 3ϕ, 4wire

Connection Diagram:



Construction Diagram:-



4|1|20

Two Element Energy Meter:—

→ It is used to measure the energy in 3-ϕ, "3" wire system

→ It consits of 2-elements i.e., "2" shunt magnets and two series magnets in between this two Aluminium disc is provided.

→ The net Torque produced is $T_d \propto T_{d_1} + T_{d_2}$

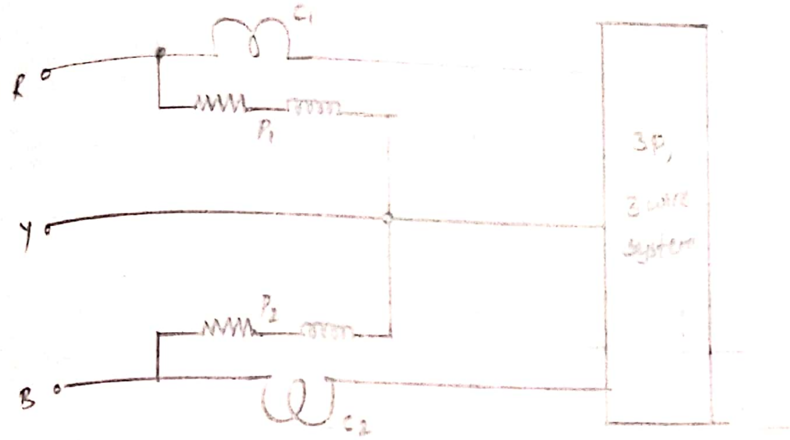
Here, T_{d_1} is due to element 1.

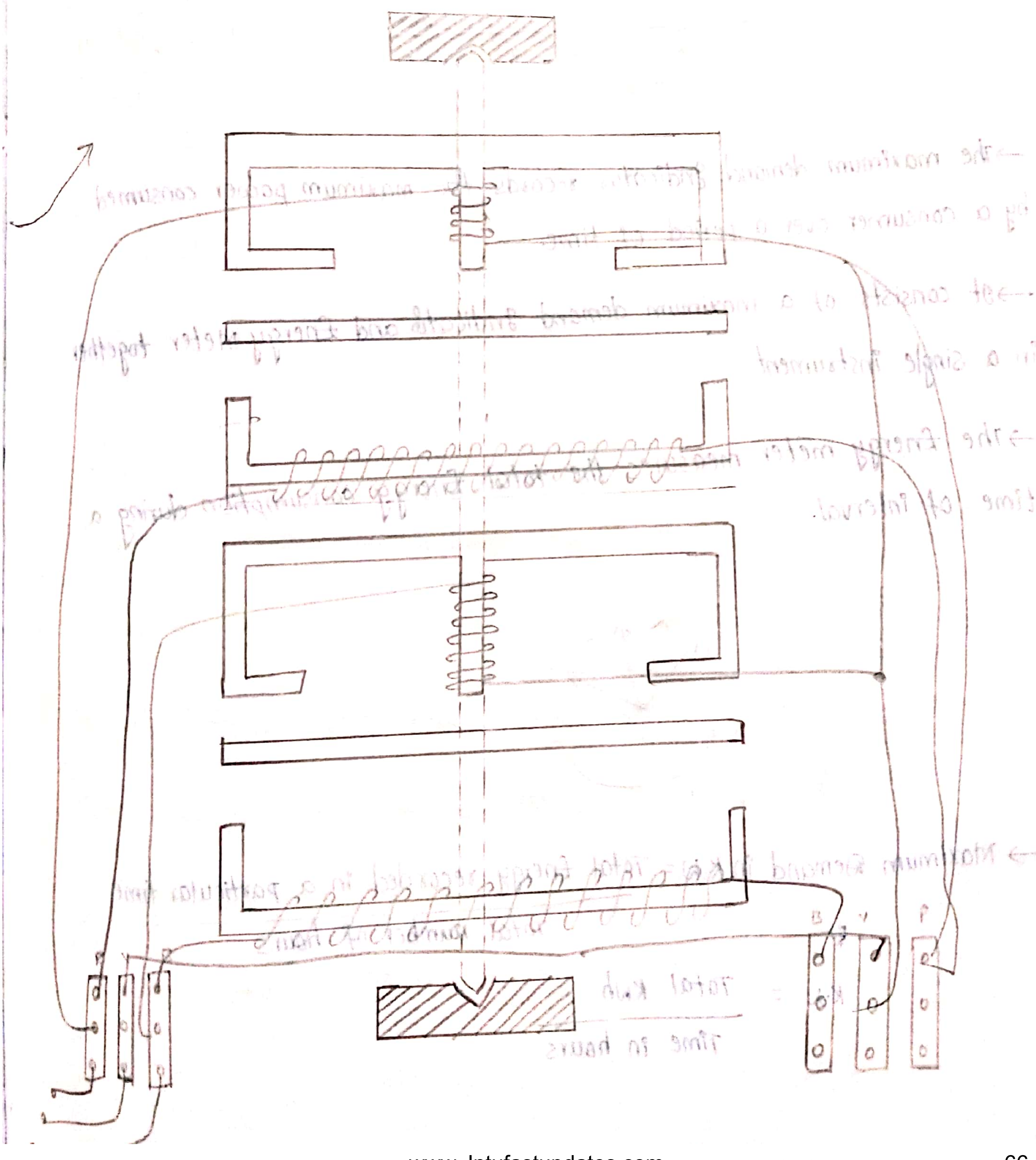
T_{d_2} is due to element 2.

→ Instead of using "3" single phase Energy meter's only one two element

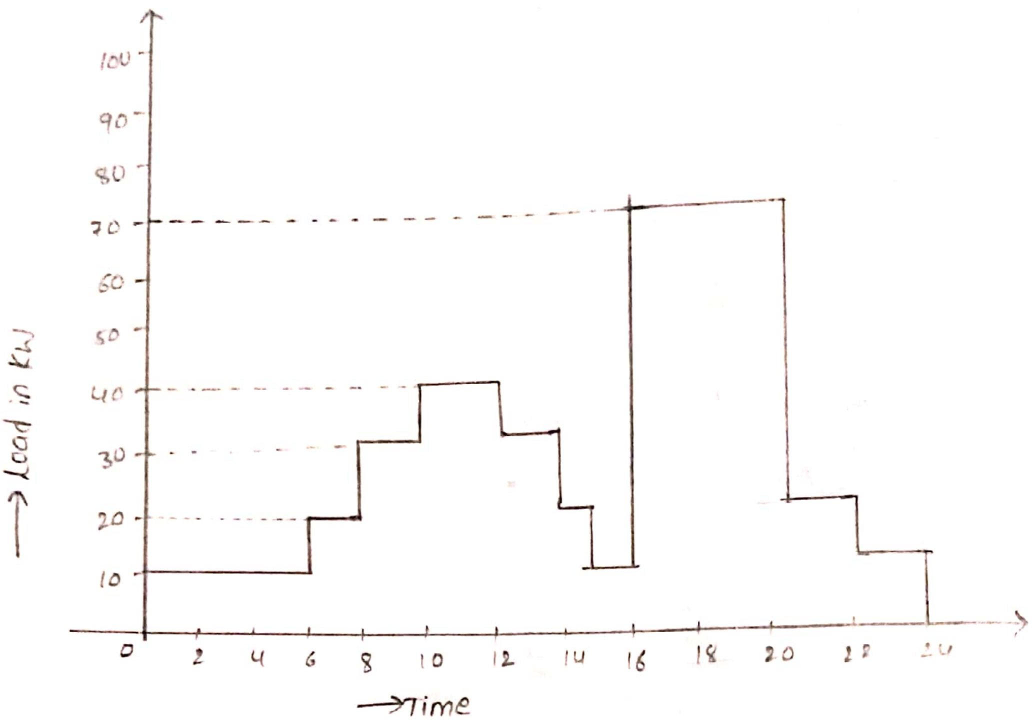
Energy meter is sufficient to measure the three phase Energy.

Connection Diagram:-





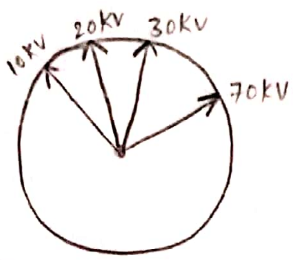
* Merz price Maximum Demand Indicator (IM)



→ The maximum demand Indicator records the maximum power consumed by a consumer over a period of time.

→ It consists of a maximum demand Indicator and Energy meter together in a single instrument.

→ The Energy meter measures the total Energy consumption during a time of interval.



→ Maximum Demand in K.W = $\dfrac{\text{Total Energy recorded in a particular time}}{\text{Total number of hours}}$

$$K.W = \frac{\text{Total KWh}}{\text{Time in hours}}$$

Trivector Meter:-

$$y \rightarrow Am \rightarrow Rm \rightarrow S$$

$Am \downarrow$ KWh, $Rm \downarrow$ KVARh

1.

$$KVAh = \sqrt{(KWh)^2 + (KVARh)^2}$$

→ It is used to measure three powers simultaneously i.e., KVA, KW & KVAR.

→ It consists of a watt hour meter and reactive power meter, summator along with complicated gearing mechanism.

→ It is operated by a 5 gearing mechanisms.

1.) watt hour meter driving alone, then the power factor is unity.

2) watt hour meter speed is slightly reduced and reactive meter speed is considerably reduced then $\phi = 22.5°$ & power factor is 0.95

3.) watt hour meter and reactive meter speeds are reduced by same factors then $\phi = 45°$ and power factor is 0.707.

4) watt hour meter speed is considerably reduced and reactive power meter speed is slightly reduced, $\phi = 67.5°$, Pf = 0.38

5) Reactive meter driving alone, $\phi = 90°$, pf is 0.

Q. A large consumer has a KVA demand and KVAh tarrif is measured by sine and cosine watt hour meters. Each equipped with a max price demand indicator. The tarrif is RS 40 per month per KVA of demand plus 30 paise per KVAh. Determine the monthly bill for 30 days based upon following readings.

Reactive meter   watt hour meter

(i) sine meter advances by 90,000

(ii) Reactive KVAR and demand indicator by 150 KVAR, cosine meter advances by 1,20,000 Kwh & demand indicator by 200 KW. What is the average monthly power factor and total cost per unit.

Sol: Given Data:

Total KVARh = 90,000

Total Kwh = 1,20,000

$\therefore$ Total KVAh = $\sqrt{(90,000)^2 + (1,20,000)^2}$

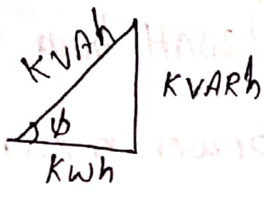
$\boxed{\text{KVAh} = 1,50,000 \text{ KVAh}}$

Trivector meter

Max maximum Demand

$\rightarrow$ power factor, $\cos\phi = \frac{Kwh}{KVAh} = \frac{1,20,000}{1,50000}$

$= 0.8$ lag.



$\rightarrow$ Maximum KW demand = 200 KW

$\rightarrow$ Maximum KVAR " = 150 KVAR.

$\therefore$ Maximum KVA = $\sqrt{(200)^2 + (150)^2}$ = 250 KVA

$\rightarrow \cos\phi = \frac{KW}{KVA} = \frac{200}{250} = 0.8$ lag

Monthly bill = $40[250] + \frac{30}{100}[1,50,000]$

$= 40[250] + 0.3[1,50,000]$

$= 55,000/-$

$\rightarrow$ cost $\underbrace{\text{per unit}}_{\text{per kwh}} = \frac{55,000}{1,20,000}$

$= 0.4583/-$

⊛ Frequency Meter:—

It is also called Resonance type frequency meter. It consits of a two coils. Coil A & coil B. These two coils are connected perpendicular to each other exactly by 90°. It consists of a inductances L_A, L_B and L. The main function of inductor "L" is to avoid harmonic content. It also consists resistances R_A & R_B. The main function of resistances are to avoid the limit the current values.

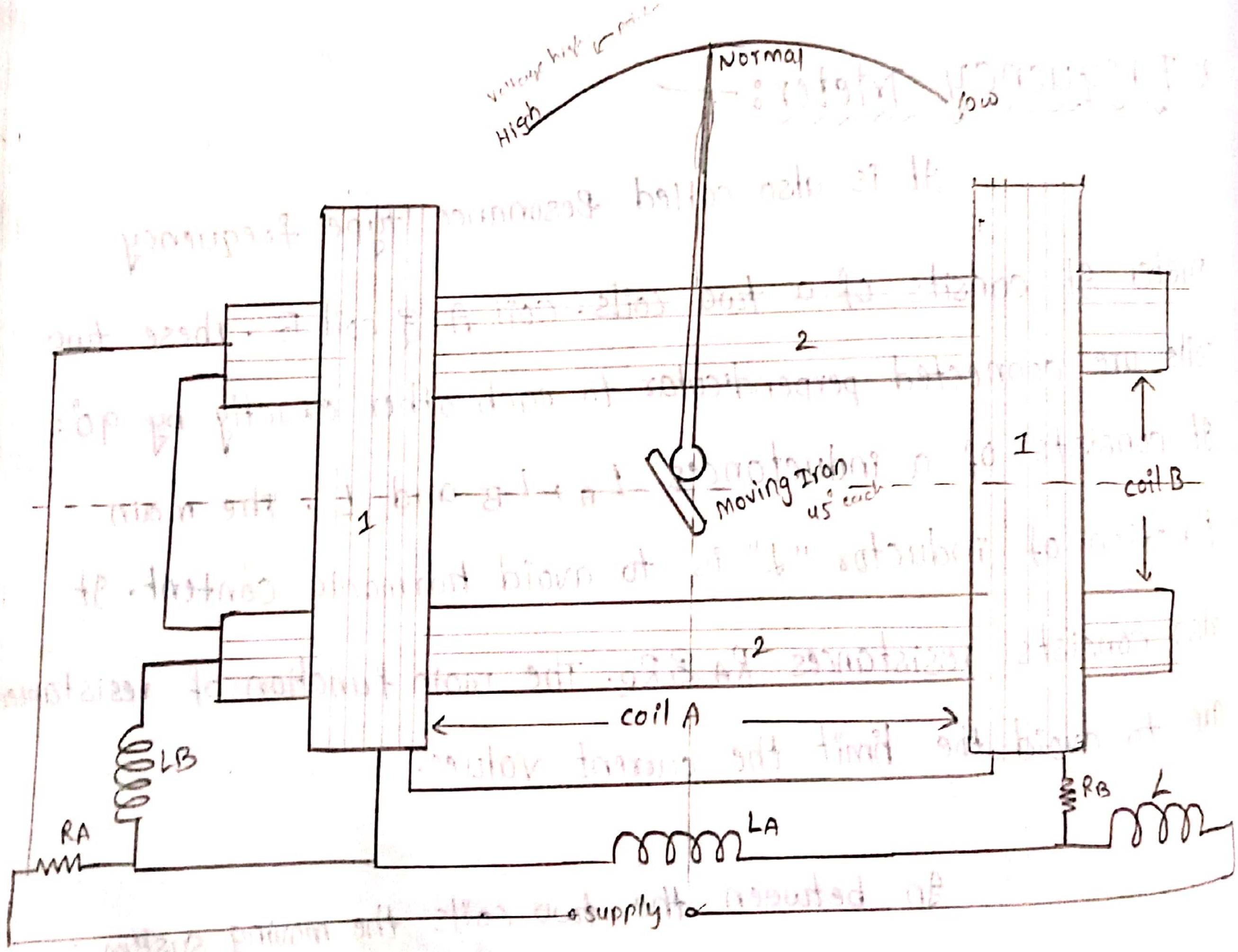
In between the two coils the moving system is arranged which consists needle supported by a moving iron.

Working:-

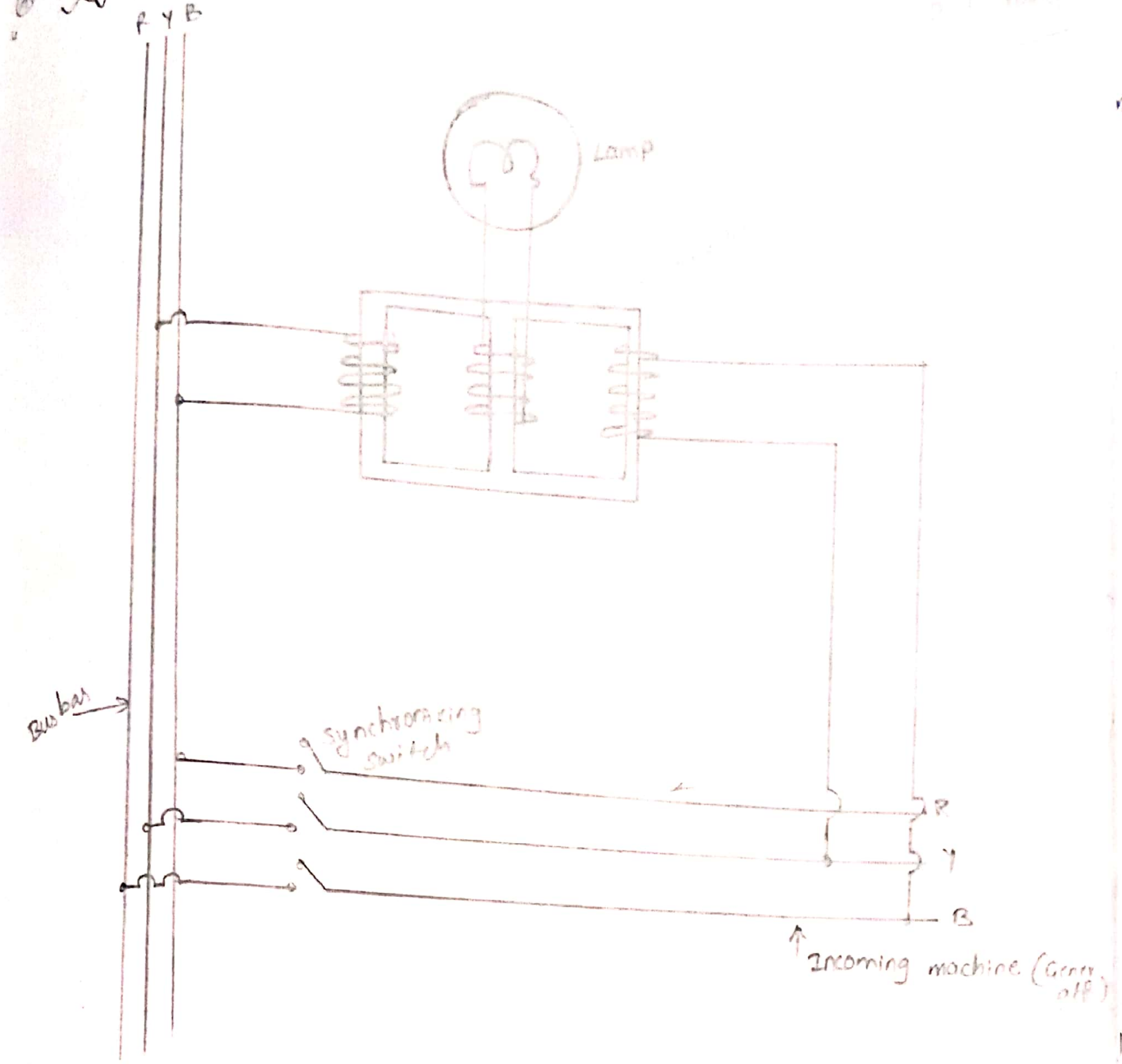
Under Normal operating condition, the interaction of fluxes due to two coils places the pointer at 45°. Hence, the pointer shows normal.

When the frequency is high, the voltage impressed on L_A & L_B is different and the pointer moves left side. It indicates high frequency.

When the frequency is less, voltage values are less in coil A. Hence, the pointer moves right side. It indicates low frequency.



synchroscope:-



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Conditions:-

→ Magnitude of voltages must be same.

→ Frequency must be same.

→ Synchronising machines and bus bar voltages must be inphase.

→ The synchroscope is used in Generating stations for the parallel operation of incoming machines to the bus bar.

→ The synchronizing switch is closed at a correct instant. i.e., when the lamp is in bright condition with less flickering.