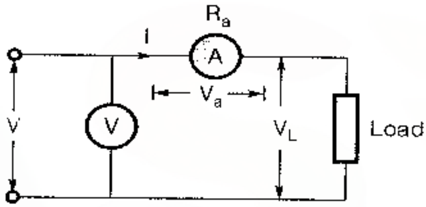
Measurement of Power and Wattmeters

6

Measurement of Power

1. D.C. Circuits

- Ammeter connected between load and voltmeter



Power consumed by load:

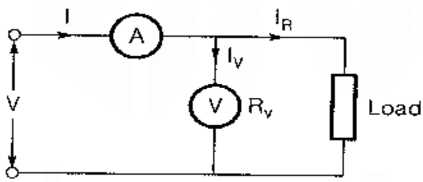
$$P = VI - I^2 R_a$$

where, V = Voltage across voltmeter

I = Current through ammeter

R_a = Resistance of ammeter

- Voltmeter connected between load and ammeter



Power consumed by load:

$$P = VI - \frac{V^2}{R_V}$$

where, V = Voltage across voltmeter

I = Current through ammeter

R_V = Resistance of voltmeter

2. A.C. Circuits

- Instantaneous power

$$p = vi = V_m I_m \sin\omega t \cdot \sin(\omega t - \phi)$$

where, $v = V_m \sin\omega t$

$i = I_m \sin(\omega t - \phi)$

- Average power

$$P = VI\cos\phi = \frac{V_m I_m}{2}\cos\phi$$

where, V, I = Rms values of voltage and current

$\cos\phi$ = Power factor of the load

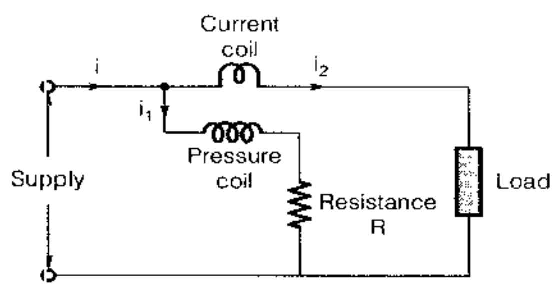
- Let $v = V_o + \sum_{n=1}^{m} V_n \sin(n\omega t + \theta_n)$ and $i = I_o + \sum_{n=1}^{m} I_n \sin(n\omega t + \phi_n)$

then $$P_{avg.} = V_o I_o + \frac{1}{2}\sum_{n=1}^{m} V_n I_n \cos[\theta_n - \phi_n]$$

Remember:

Wattmeter reads average active power.

electrodynamometer wattmeter



- Instantaneous torque

$$T_i = i_1 i_2 \left(\frac{dM}{d\theta}\right)$$

where i_1, i_2 = instantaneous value of current in pressure and current coils

- Deflecting torque

$$T_d = \frac{VI}{R_p}\cos\phi \cdot \frac{dM}{d\theta}$$

where, R_p = resistance of pressure coil circuit

- Controlling torque

$$T_c = K\theta$$

where K = spring constant

θ = final steady deflection

- Deflection

$$\theta = \left(K_1 \frac{dM}{d\theta}\right)P$$

where, P = power being measured = VI $\cos\phi$

$$K_1 = \frac{1}{R_p K}$$

Note:

Scale is linear in terms of power as $\theta \propto P$.

Errors in Electrodynamometer Wattmeters

Correction Factor (K)

The correction factor is a factor by which the actual wattmeter reading is multiplied to get the true power.

- For lagging power factor

$$K = \frac{\cos\phi}{\cos\beta\cos(\phi - \beta)}$$

- For leading power factor

$$K = \frac{\cos\phi}{\cos\beta\cos(\phi + \beta)}$$

where, ϕ = Angle between current in the current coil and voltage of pressure coil

β = Angle between current and voltage of pressure coil

$$\boxed{\text{True power} = \text{Correction factor} \times \text{actual wattmeter reading}}$$

- For β very small

$$\boxed{\text{Actual wattmeter reading} = \text{true power } (1 + \tan\phi \tan\beta)}$$

$$\boxed{\text{Error} = \tan\phi \tan\beta \times \text{true power} = VI \sin\phi \tan\beta}$$

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

$$\boxed{\text{True power} = VI\cos\phi}$$

where, V = Voltage applied to pressure coil

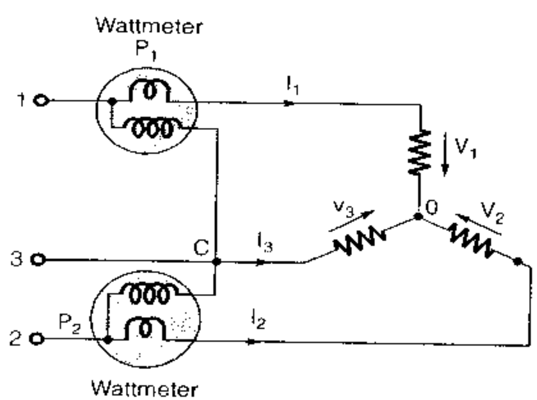
I = Current in current coil

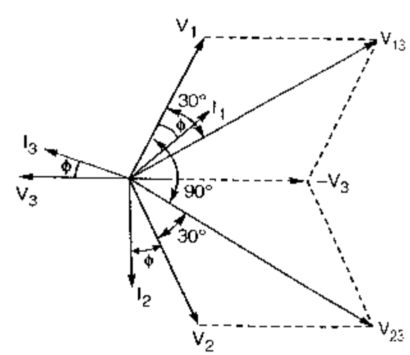
Power in Poly-Phase Systems

Blondel's Theorem

If a network is supplied through n conductors, the total power is measured by summing the reading of n wattmeters so arranged that a current element of a wattmeter is in each line and the corresponding voltage element is connected between that line and a common point, if the common point is located on one of the lines, then the power may be measured by (n – 1) wattmeters.

Two wattmeter method





- Reading of P_1 wattmeter

$$\boxed{P_1 = \sqrt{3}\,VI\cos(30° - \phi)}$$

- Reading of P_2 wattmeter

$$\boxed{P_2 = \sqrt{3}\,VI\cos(30° + \phi)}$$

- Total power consumed by load

$$\boxed{P = P_1 + P_2}$$

- Power factor

$$\boxed{\cos\phi = \cos\left[\tan^{-1}\left(\sqrt{3}\,\frac{P_1 - P_2}{P_1 + P_2}\right)\right]}$$

$$\boxed{\tan\phi = \sqrt{3}\,\frac{P_1 - P_2}{P_1 + P_2}}$$

where, V = Phase voltage

I = Phase current

φ = Angle between phase current and phase voltage

Reading of Wattmeter at Different Power Factor

S.No	ϕ	$\cos\phi$	P_1	P_2	$P = P_1 + P_2$	Comment
1.	0	1	$\frac{\sqrt{3}}{2} V_L I_L$	$\frac{\sqrt{3}}{2} V_L I_L$	$\sqrt{3} V_L I_L$	$P_1 = P_2$ (eqaul reading)
2.	30°	0.866	$V_L I_L$	$\frac{V_L I_L}{2}$	$1.5 V_L I_L$	$P_1 = 2P_2$
3.	60°	0.5	$\frac{\sqrt{3}}{2} V_L I_L$	0	$\frac{\sqrt{3}}{2} V_L I_L$	$P_2 = 0, P_2 = P$
4.	90°	0	$+\frac{V_L I_L}{2}$	$-\frac{V_L I_L}{2}$	0	$P_1 = -P_2$

Note:

When wattmeter reading comes into negative, reverse either P.C. or C.C. terminal and then take the reading of negative wattmeter.

Measurement of Energy

For the measurement of energy, we use energy meter. Energy meter is an integrating instrument which adds the energy cumulatively over a period of time.

$$\text{Energy} = \text{Power} \times \text{time}$$

$$\text{Energy} = \int_0^t P \cdot dt \quad \text{kWhr}$$

Note:

- Energy meter works on principle of induction motor.
- The meter which measure A.C. energy is called watt hour meter.
- The meter which measure D.C. energy is called amp-hour meter.

- Deflection torque

$$T_D \propto P$$

- Breaking torque

$$T_B \propto N$$

where, N = Speed of disc in rps

- At balance

$$T_d = T_B$$

$$\int P \cdot dt = K \int N \cdot dt$$

$$\text{Energy} \propto \int N \cdot dt$$

- Energy meter constant (EMC)

$$\text{EMC} = \frac{\text{Number of revolution made by disc}}{\text{Energy recorded in kWhr}}$$

$$K = \frac{N}{P \times t}$$

where, P = Power in kW

t = Time in hrs.

- $$\%\text{ Creeping Error} = \frac{\text{Revolution of disc due to creeping per hour}}{\text{Revolution of disc due to total load per hour}} \times 100$$

Remember:

Potential coil of energy meter should be highly inductive so that it measures true energy.

Compensation in Energy Meter

1. **Lag compensation :** Through lag coil or shading coil.
2. **Low load or friction adjustment :** By using shading loop.
3. **Over friction or creeping :** By providing holes or slots on rotating disc.
4. **Over load compensation :** By keeping saturable shunt magnet in series magnet or current coil.
5. **Over voltage compensation :** By keeping saturable shunt magnet in shunt magnet.
6. **Temperature compensation :** By making permanent magnet of "mutemp" material.
7. **Speed adjustment :** By adjusting position of break magnet.

Remember:

- Creeping error is always positive.
- If either potential coil or current coil is wrongly connected then the disc rotates in opposite direction.

■■■■