EET203 : MEASUREMENTS AND INSTRUMENTATION
MODULE II

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SYLLABUS

Module II

Measurement of power: Dynamometer type wattmeter – Construction and working - 3-phase power measurement-Low Power factor watt meters.

Measurement of energy: Induction type watt-hour meters- Single phase energy meter – construction and working, two element three phase energy meters,

Digital Energy meters -Time of Day(TOD) and Smart metering (description only). Current transformers and potential transformers – principle of working -ratio and phase angle errors.

Extension of range using instrument transformers, Hall effect multipliers

Measurement of Power in DC & AC circuits

- Power may be defined as the rate at which energy is transferred or made available.
- In DC circuits Power, $P = V\,I$
- In AC circuits, $P = V\,I\cos\phi$
- An electrical instrument used to measure electric power in watts of any circuit is called Wattmeter.
- A wattmeter can be considered as a combination of an ammeter and a voltmeter.
- It consists of two coils, a current coil and a voltage/pressure coil.
- The current coil is connected in series and the voltage/pressure coil is connected in parallel.

- Three types of wattmeter's are:

i. Dynamometer Wattmeter

ii. Induction Wattmeter

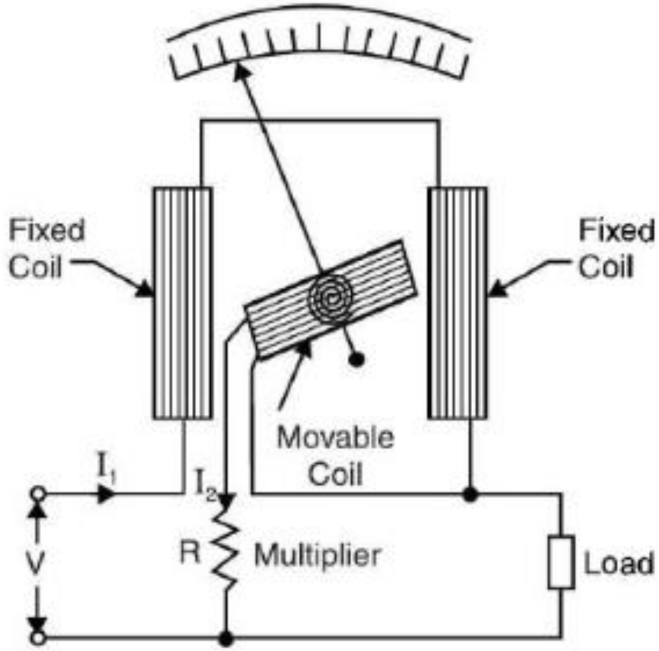
iii. Electrostatic Wattmeter

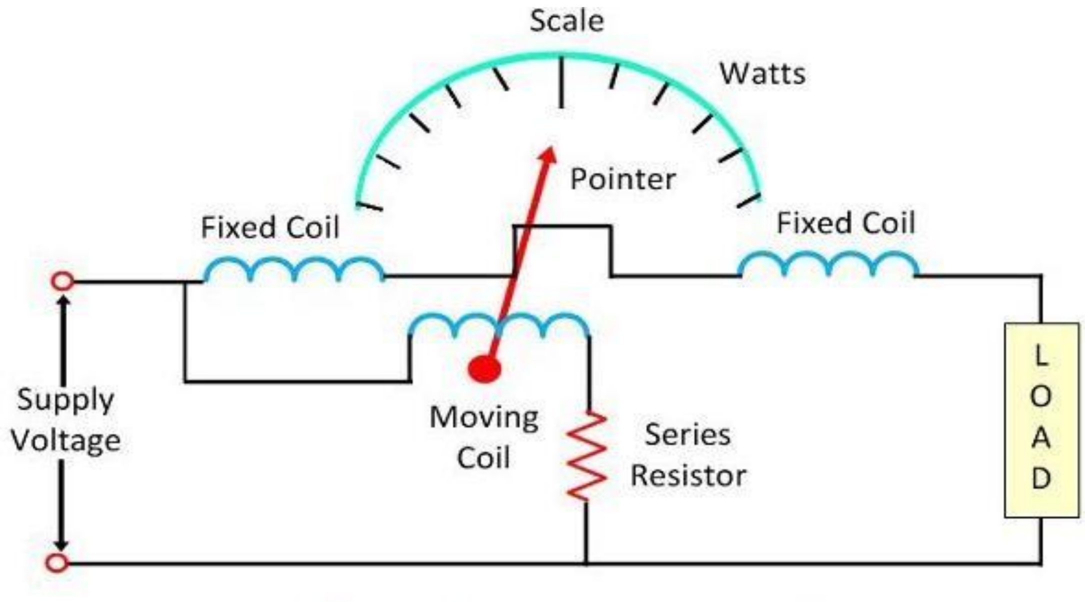
- Dynamometer and induction type wattmeter's are most used.

Dynamometer Type Wattmeter

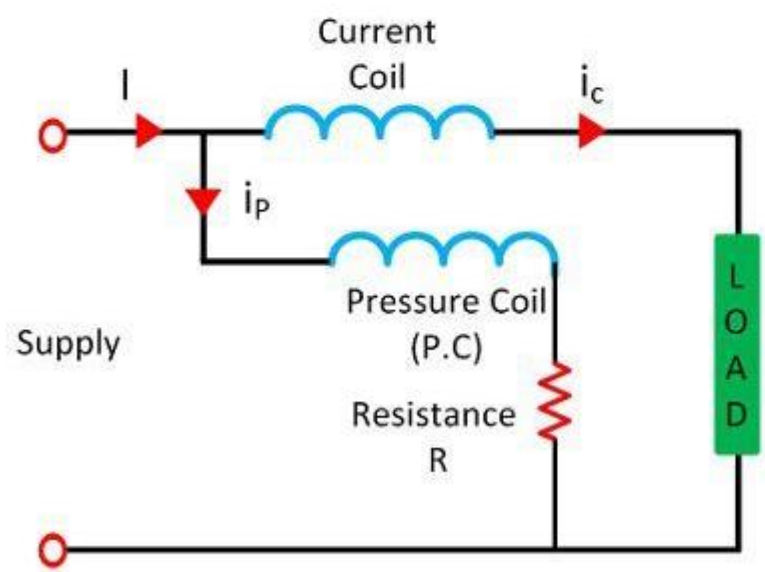
- A dynamometer type wattmeter is used for the measurement of both ac and dc power.
- The working of the Electrodynamometer Wattmeter depends on the theory that the current carrying conductor placed in a magnetic field experiences a mechanical force.
- This mechanical force deflects the pointer which is mounted on the calibrated scale

Construction of Electrodynamometer Wattmeter





Electrodynameter Wattmeter



- A dynamometer type wattmeter primarily consists of two coils called fixed coil and moving coil.
- For making the construction easy the fixed coil divide into two parts, the two fixed coils are air-cored to avoid hysteresis effects when used on AC.
- The fixed coil is connected in series with the load and carries the circuit current. It is, therefore, called the current coil.
- Since current coils carry full load current, so these are made up of thick wire.
- The moving coil is pivoted between the two fixed coils and is placed on the spindle to which the pointer is attached. The moving coil is connected across the load and carries current proportional to the voltage. It is therefore called potential coil.
- Generally, a high resistance is connected in series with the moving coil to limit the current through it.

- Control – The control system provides the controlling torque to the instrument. The gravity control and the spring control are the two types of control system. Out of two, the Electrodynamometer Wattmeter uses spring control system.
- Damping – Air friction damping is employed in such instruments.

Working of Dynamometer Type Wattmeter

- When the wattmeter is connected in the circuit to measure power, the current coil carries the load current and potential coil carries current proportional to the load voltage.
- Due to currents in the coils, mechanical force exists between them. The result is that movable coil moves the pointer over the scale.
- The deflection of the pointer is directly proportional to the power flows through it.

- The pointer comes to rest at a position where deflecting torque is equal to the controlling torque.
- Reversal of current reverses currents in both the fixed coils and the movable coil so that the direction of deflecting torque remains unchanged.
- Hence, such instruments can be used for the measurement of d.c. as well as a.c. power.

Advantages of Dynamometer Type Wattmeter

- It can be used both on AC and DC circuits.
- It has a uniform scale.
- We can obtain a high degree of accuracy through careful design.
- Low power Consumption
- Free from hysteresis errors.

Disadvantages of Dynamometer Type Wattmeter

- At low power factors, the inductance of the potential coil causes serious errors.
- The reading of the instrument may be affected by stray fields acting on the moving coil. To prevent it, magnetic shielding is provided by enclosing the instrument in an iron case.
- They are more expensive than other type of instruments.
- It introduces increased frictional losses.
- Low torque to weight ratio.
- These instruments are sensitive to overload and mechanical impacts.

Errors in Dynamometer Type Wattmeter

The following are the errors in the Electrodynamometer Wattmeter

1. Pressure Coil Inductance

The pressure coil of the Electrodynamometer has some inductance. Because of the inductance, the current of the pressure coils lags behind the voltage. Thus, the power factor of the wattmeter becomes lagging, and the meter reads high reading. The high non-inductive resistance connected in series with the coil swamps the phasing effect of the potential coil inductance.

2. Pressure Coil Capacitance

The pressure coil has capacitances along with the inductance. This capacitance increases the power factor of the instrument. Hence causes the error in the reading. The inductance in pressure coil circuit will always more than capacitance, hence the error caused by capacitance will be nullified due to inductance.

3. Error due to Mutual Inductance Effect

The mutual inductance between the pressure and current coil produces an error.

4. Eddy Current Error

The eddy current induces in the coil creates its own magnetic field. This field affects the main current flows through the coil. Thus, the error occurs in the reading. This error can be minimized by avoiding solid metal parts as much as possible and by using stranded conductors for high current applications.

5. Stray Magnetic Field

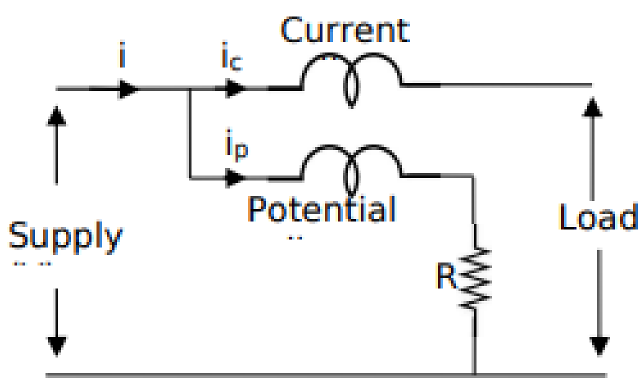
The dynamometer type wattmeter has a relatively weak operating field; therefore, stray fields affect the reading of this instrument considerably and cause serious errors. Hence, this type of instrument must be shielded against stray magnetic fields by using iron cases or providing thin iron shields over the working parts.

6. Temperature Error.

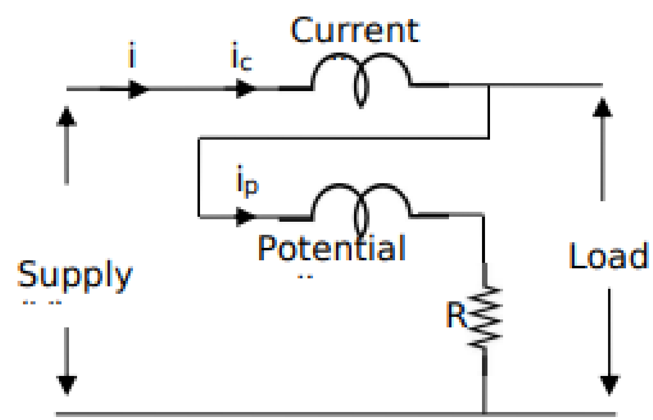
The change in temperature will change in resistance of pressure coil and stiffness of springs which provide controlling torque. The use of material of having negligible temperature coefficient of resistance will reduce change in resistance.

7. Error due to the wattmeter connection

For the measurement of power, the wattmeter can be connected in two different ways, shown in Fig:



(a)

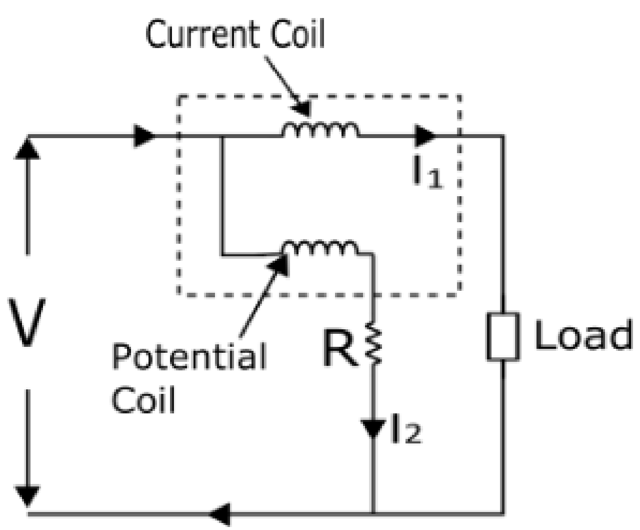


(b)

- In the wattmeter connection shown in Fig.(a), the potential coil is connected in parallel to the supply. So, the voltage across the pressure coil will be more than the voltage across the load. So, the wattmeter reading will be,
- Reading of the wattmeter = Power consumed by the load + Power loss in the current coil
- In the wattmeter connection shown in Fig.(b), the potential coil is connected in parallel to the load. So, the current through the current coil will be more than the load current. So, the wattmeter reading will be
- Reading of the wattmeter = Power consumed by the load + Power loss in the pressure coil.
- If the load current is small and the voltage drop in the current coil is small, then the wattmeter connection shown in Fig. (a) is preferred. If the load current is large and the pressure coil current is small compared to the load current, then the wattmeter connection shown in Fig. (b) is preferred.

Torque Equation of Dynamometer Type Wattmeter

- When electrodynamometer wattmeter is connected in the circuit to measure the electric power. The current coil carries the load current, and the potential coil carries a current proportional to the load voltage.
- The deflecting torque of electrodynamometer wattmeter is proportional to the load power in DC as well as AC circuit.



Let,

V = Input Voltage/Voltage across the parallel combination

I_1 = Current Passing through the current coil

I_2 = Current passing through the potential coil

R = Moving Coil resistance

DC circuit

- When the wattmeter is connected in DC circuit for power measurement, the power taken by the load is VI_1.

$$Deflecting\,Torque(\tau_d) \propto l_1 l_2$$

- Since the current I_2 is proportional to load voltage V. Thus,

$$Deflecting\,Torque(\tau_d) \propto l_1 V \propto \;Load\;Power$$

AC Circuit

- When the wattmeter is connected in an AC circuit to measure the load power. Consider at any instant, current through the load is i and voltage across the load is v and the power factor of the load is supposed to be $\cos\varphi$ lagging.

$$v = V_m\, sin\theta$$

$$i = I_m sin(\theta - \varphi)$$

- Instantaneous deflecting torque $\propto vi$
- Due to inertia of moving system, the pointer cannot follow the rapid changes in the instantaneous power. Hence the wattmeter indicates the average power.

$$\therefore\ Average\ Deflecting\ torque(\tau_d) \propto\ Average\ of\ vi\ over\ one\ cycle$$

$$\tau_d \propto \frac{1}{2\pi}\int_0^{2\pi} V_m I_m \sin\theta \sin(\theta-\varphi)d\theta \propto \frac{V_m I_m}{2}\cos\varphi \propto VI\cos\varphi$$

- Where, V and I are RMS values $\tau_d \propto VI\cos\varphi \propto\ Load\ Power$
- Since the controlling torque in the wattmeter is provided by spring. Thus, $\tau_c \propto \theta$
- Under steady state condition, $\tau_d = \tau_c$
- Therefore, $\theta \propto\ Load\ Power$
- Hence the electrodynamometer wattmeter has uniform scale.

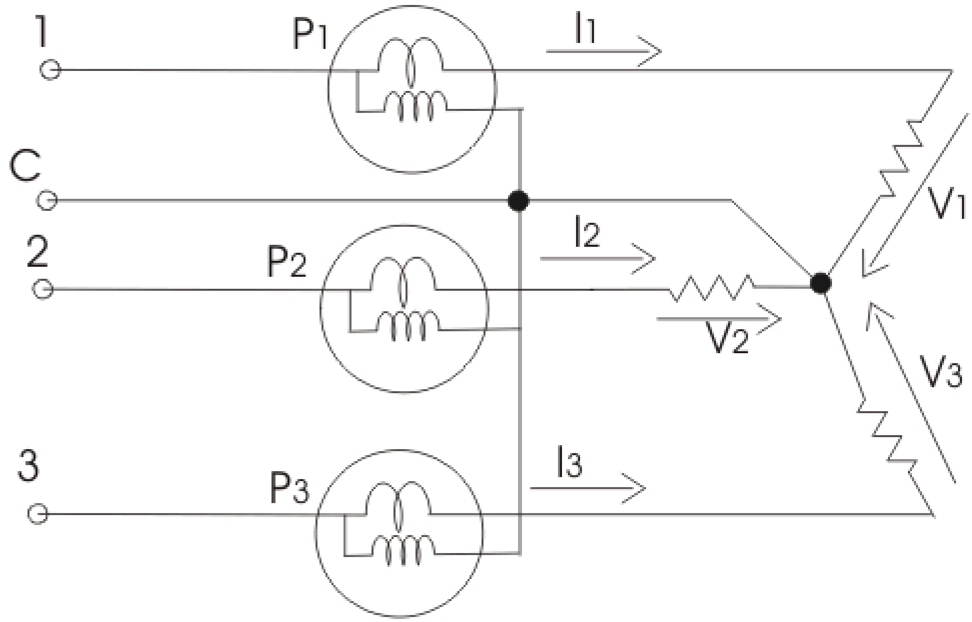
3-phase power measurement

- Measurement of power in 3 phase AC circuits can be done by any of the three methods which depends on whether the system is balanced or not.

1. Three Wattmeter Method
2. Two Wattmeter Method
3. One Wattmeter Method

Three Wattmeter Method

- This method is employed for measurement of power in 3 phase, 4 wire (star connected loads) as well as 3 phase, 3 wire circuits (delta connected loads) where each phase is connected with a wattmeter. It is specifically designed to measure power in both balanced and unbalanced circuits.



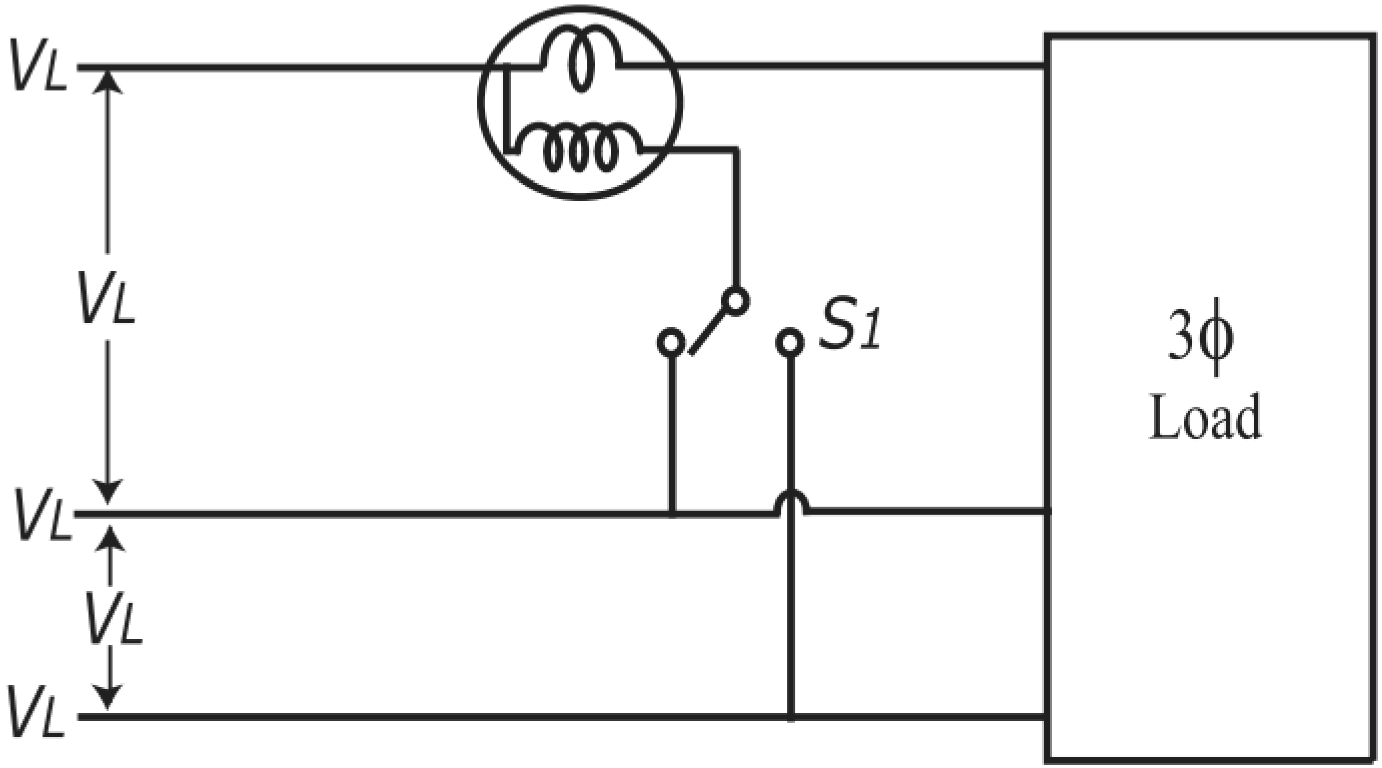
- The current coil of each wattmeter carries the current of one phase only and the pressure coil measures the phase voltage of the phase and Hence, each wattmeter measures the power in a single phase. The total power of the load is given by the algebraic sum of the readings of the three watt meters.

$$P = P_1 + P_2 + P_3 = V_1 I_1 + V_2 I_2 + V_3 I_3$$

One Wattmeter Method of Measurement of Power

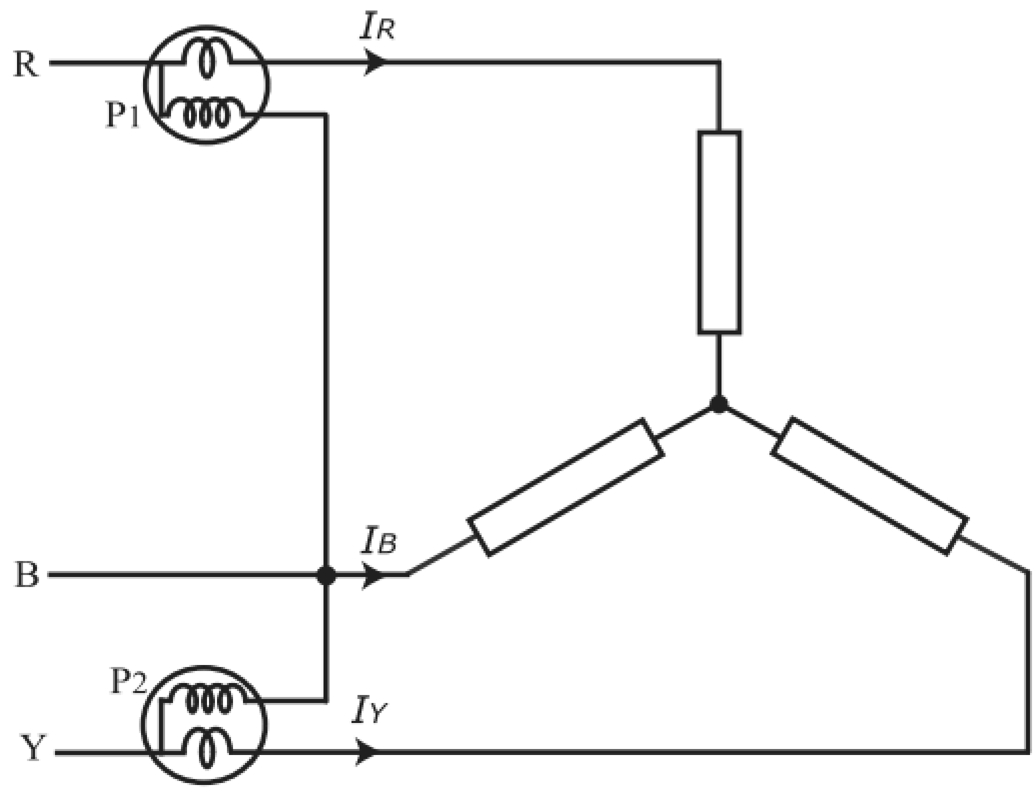
- It is a modified version of two wattmeter method. In this circuit there is a selector switch, with which we can change the connection of the pressure coil to two phases alternatively.
- With the switch in the two different positions, two separate readings P_1 and P_2 can be taken. Then the total active power is equal to $P_1 + P_2$.
- One wattmeter method is used for the measurement of 3 phase power in balanced loads (star and delta connected) only.
- The current coil is connected in any line and the pressure coil is connected alternately between this and the other two lines as shown in the figure.
- The two readings so obtained, for a balanced load, correspond to those obtained by normal two wattmeter method.

Connection Diagram – One Wattmeter Method

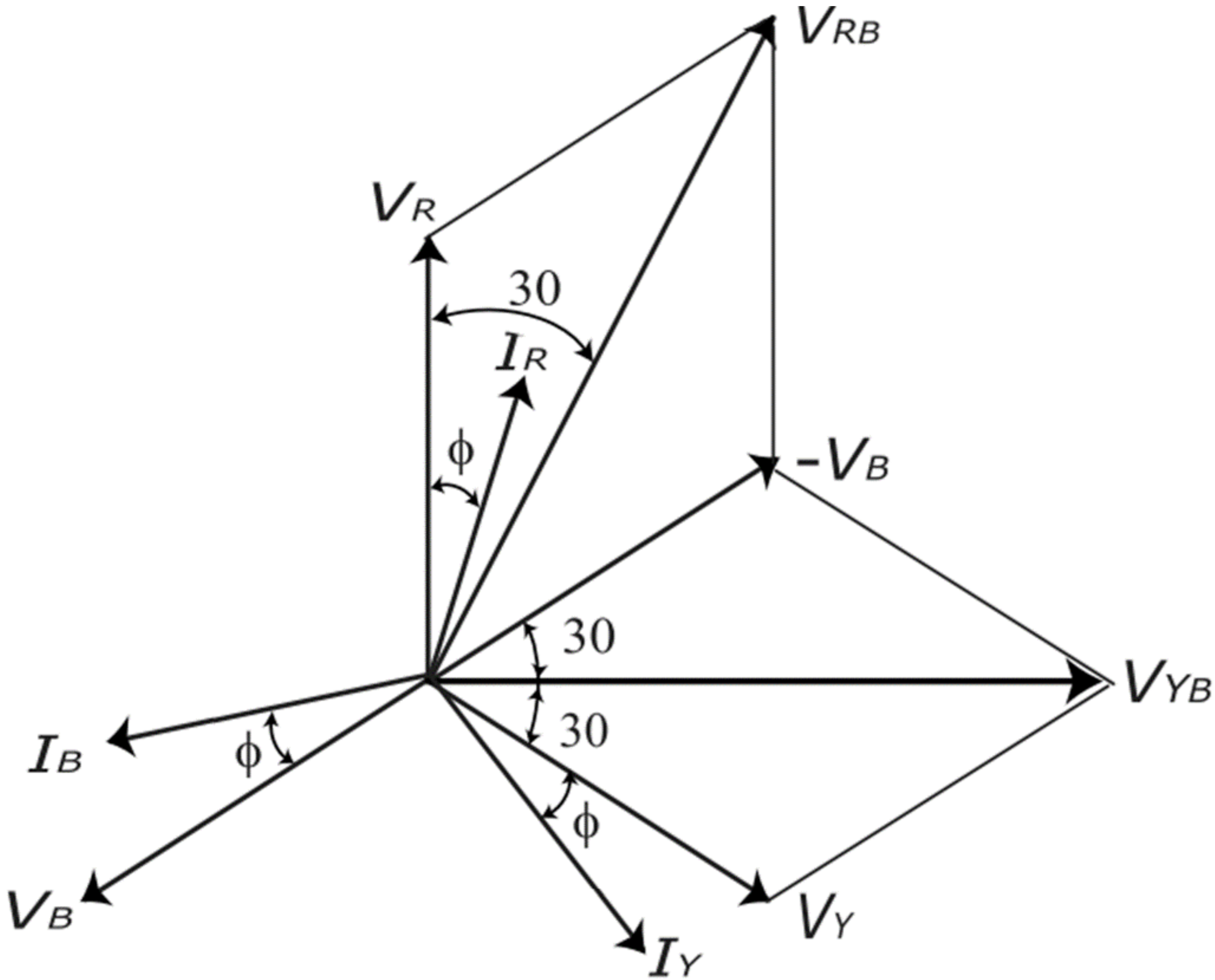


Two Wattmeter Method

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



Phasor Diagram – Two Wattmeter Method



$$P_1 = V_{RB} I_R \cos(30 - \phi) = V_L I_L \cos(30 - \phi)$$

(Because, V_{RB} = Line voltage V_L and I_R = Line current I_L)

Similarly, reading in wattmeter P_2 is

$$P_2 = V_{YB} I_Y \cos(30 + \phi) = V_L I_L \cos(30 + \phi)$$

$$\begin{aligned}
P_1 + P_2 &= V_L I_L (\cos(30 - \phi) + \cos(30 + \phi)) \\
&= V_L I_L (\cos 30 \cos \phi + \sin 30 \sin \phi \\
&\qquad + \cos 30 \cos \phi - \sin 30 \sin \phi) \\
&= V_L I_L \left(\frac{\sqrt{3}}{2} \cos \phi + \frac{\sqrt{3}}{2} \cos \phi \right) \\
&= \sqrt{3} V_L I_L \cos \phi
\end{aligned}$$

In two wattmeter method,

$$\text{Active power, } P = P_1 + P_2$$

Now,

$$\begin{aligned}
P_1 - P_2 &= V_L I_L(\cos(30-\phi) - \cos(30+\phi)) \\
&= V_L I_L(\cos 30 \cos\phi + \sin 30 \sin\phi \\
&\qquad\qquad - \cos 30 \cos\phi + \sin 30 \sin\phi) \\
&= V_L I_L\left(\frac{1}{2}\sin\phi + \frac{1}{2}\sin\phi\right) \\
&= V_L I_L \sin\phi
\end{aligned}$$

$$\begin{aligned}
\text{We have, } P_1 + P_2 &= \sqrt{3} V_L I_L \cos\phi \\
\therefore \frac{P_1 - P_2}{P_1 + P_2} &= \frac{V_L I_L \sin\phi}{\sqrt{3} V_L I_L \cos\phi} \\
&= \frac{1}{\sqrt{3}} \tan\phi \\
\therefore \tan\phi &= \sqrt{3}\frac{P_1 - P_2}{P_1 + P_2} \\
\text{Phase angle, } \phi &= \tan^{-1}\sqrt{3}\frac{P_1 - P_2}{P_1 + P_2}
\end{aligned}$$

Example 1

The power input to a 400 volts 3-phase load is measured by two wattmeters which indicates 300 W and 100 W respectively. Determine the power input and the power factor.

Solution

$$\begin{aligned}
\text{Power input,}\ \ P &= P_1 + P_2 = 300 + 100 = 400\ \text{W} \\
\text{Phase angle,}\ \ \phi &= \tan^{-1}\sqrt{3}\frac{P_1 - P_2}{P_1 + P_2} \\
&= \tan^{-1}\sqrt{3}\frac{300 - 100}{300 + 100} = 40.9 \\
\text{Power factor} \quad &= \cos\phi = \cos 40.9^\circ = 0.756
\end{aligned}$$

Example 2

For the circuit shown in Figure 7.6 W_1 and W_2 read -1000 W and 2000 W respectively when connected to a 400 V supply. The load is balanced. Find the line current and power factor. State whether the load is inductive or capacitive.

Solution

$$\text{Total power, } P = P_1 + P_2 = -1000 + 2000 = 1000 \text{ W}$$

$$\text{Phase angle, } \phi = \tan^{-1}\sqrt{3}\frac{P_1 - P_2}{P_1 + P_2}$$

$$= \tan^{-1}\sqrt{3}\frac{-1000 - 2000}{-1000 + 2000} = -79.1^\circ$$

$$\text{Power factor } = \cos\phi = \cos(-79.1) = 0.189$$

$$\text{We have, } P = \sqrt{3}V_L I_L \cos\phi$$

$$\text{Line current, } I_L = \frac{P}{\sqrt{3}V_L\cos\phi} = \frac{1000}{\sqrt{3}\times 400\times 0.189} = 7.637 \text{ A}$$

Since the phase angle ϕ is obtained as negative, the load is capacitive.

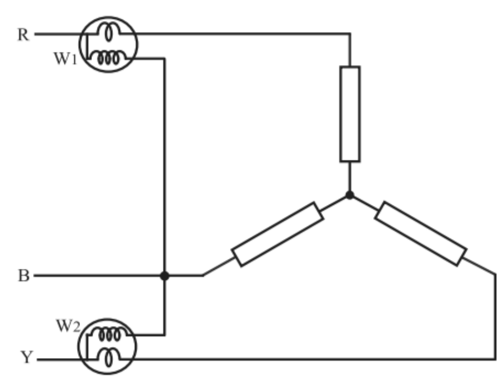


Figure 7.6: Phasor diagram for two wattmeter method

Variation of wattmeter reading with power factor

Power factor $= 1$

$$
\begin{aligned}
\text{Here,}\quad \phi &= 0^\circ \\
P_1 &= V_L I_L \cos(30-\phi) \\
&= V_L I_L \cos 30 = \frac{\sqrt{3}}{2} V_L I_L \\
P_2 &= V_L I_L \cos(30+\phi) \\
&= V_L I_L \cos 30 = \frac{\sqrt{3}}{2} V_L I_L
\end{aligned}
$$

When power factor $= 1$, the two wattmeters will show the same reading; both positive.

Power factor $= 0.5$

$$
\begin{aligned}
\text{Here,}\quad \phi &= 60^\circ \\
P_1 &= V_L I_L \cos(30-\phi) \\
&= V_L I_L \cos(30-60) = V_L I_L \cos(-30) = \frac{\sqrt{3}}{2} V_L I_L
\end{aligned}
$$

$$P_2 = V_L I_L \cos(30 + \phi)$$
$$= V_L I_L \cos(30 + 60) = V_L I_L \cos 90 = 0$$

When power factor $= 0.5$, one wattmeter will read zero and the other will read a positive value.

Power factor $= 0$

Here, $\phi = 90°$

$$P_1 = V_L I_L \cos(30 - \phi)$$
$$= V_L I_L \cos(30 - 90) = V_L I_L \cos(-60) = \frac{1}{2} V_L I_L$$
$$P_2 = V_L I_L \cos(30 + \phi)$$
$$= V_L I_L \cos(30 + 90) = V_L I_L \cos 120 = -\frac{1}{2} V_L I_L$$

When power factor = 0, the readings of the two wattmeters will be of the same magnitude but with opposite sign.

Low Power Factor Watt meters

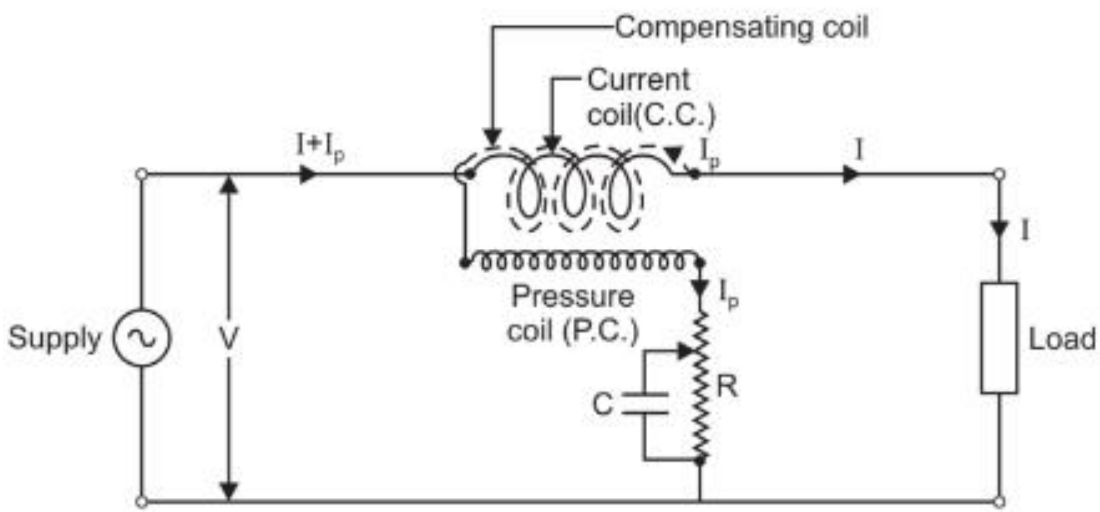
- To measure power in low power factor circuits, ordinary dynamometer wattmeter is not suitable because of the following reasons.

1. Even when the current coils and pressure coils are fully excited, the deflecting torque on the moving system is small.
2. Large error is introduced due to inductance of the pressure coil at lower power factor.

- The special features incorporated in an electrodynamometer type wattmeter to make it suitable for the measurement of power in low power factor circuits are as follows

1. Increasing the pressure coil current by decreasing the resistance of the pressure coil. This high pressure coil increases the operating torque of the meter. The pressure coil current in a low power factor wattmeter may be as high as 10 times the value of the current used in ordinary wattmeter's.

2. A compensating coil is connected in series with the potential coil and so placed that it produces field in the opposite direction to that of current coil as shown in figure.



3. By compensating for the inductance of the pressure coil : Connecting a capacitor across a part of series resistance in the pressure coil circuit in order to compensate the inductance of pressure coil. This will avoid the error caused by the inductance.

Measurement of Energy

- The meter which is used for measuring the energy utilizes by the electric load is known as the energy meter.

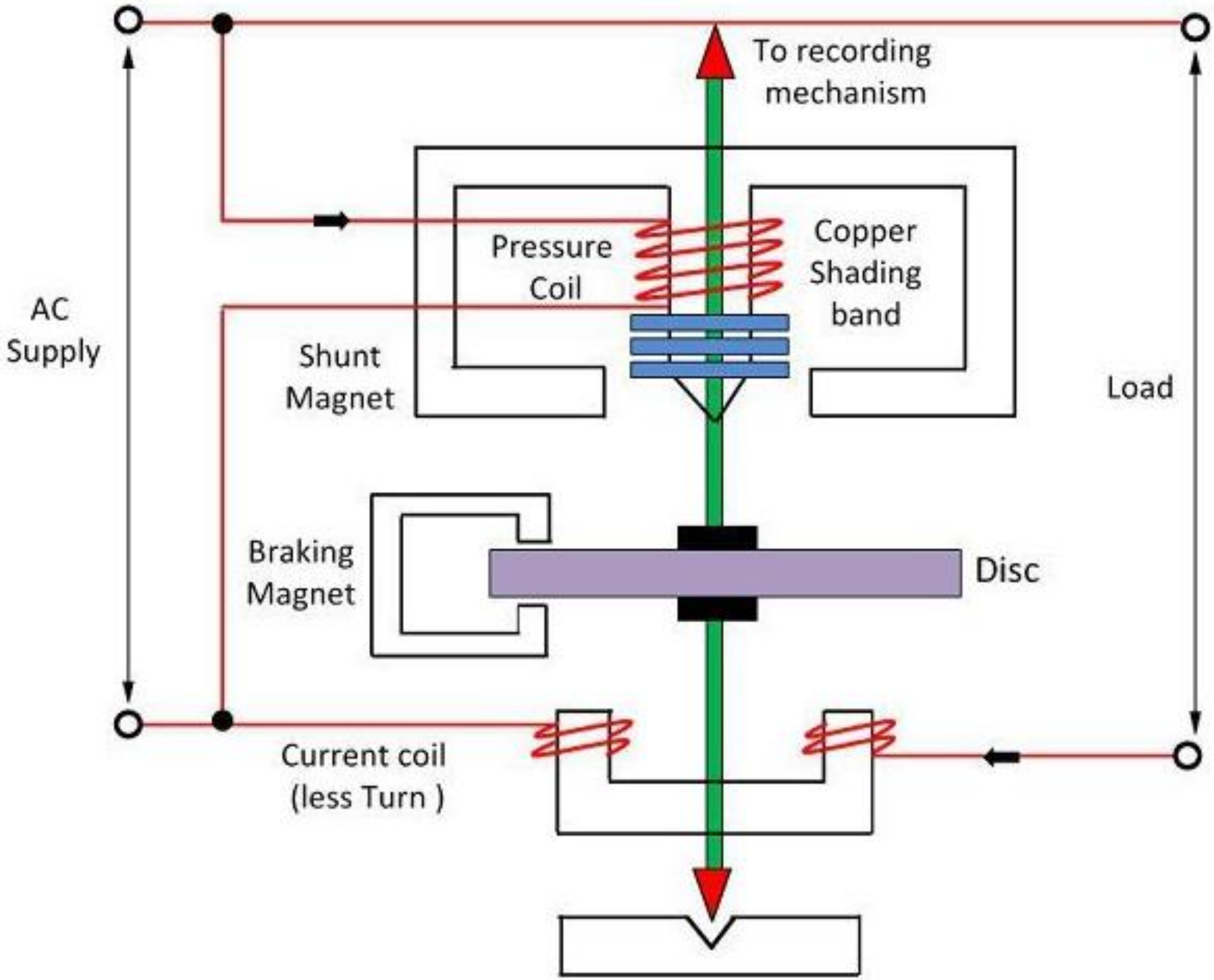
Single - Phase Energy Meter(Induction type)

- Single-phase induction type energy meters (or watthour meters) are extensively used for the measurement of electrical energy in ac circuits.

Construction of Energy Meter

The energy meter has four main parts. They are

a) Driving System
b) Moving System
c) Braking System
d) Registering System


To recording mechanism
Pressure Coil
Copper Shading band
AC Supply
Shunt Magnet
Load
Braking Magnet
Disc
Current coil (less Turn)

1. Driving System

- The driving system of the meter consists of two electromagnets. The core of these electromagnets is made up of silicon steel laminations.
- The coil of one of the electromagnets is excited by the load current. This coil is called the current coil.
- The coil of the second electromagnet is connected across the supply and therefore, carries a current proportional to the supply voltage. This coil is called the pressure coil. Consequently, the two electromagnets are known as series and shunt magnets respectively.
- Copper shading bands are provided on the central limb. The position of these bands are adjustable. The function of these bands is to bring the flux produced by the shunt magnet exactly in quadrature with the applied voltage.

2. Moving System

- The moving system is the aluminum disc mounted on the shaft of the alloy. The disc is placed in the air gap of the two electromagnets. The interaction of the flux and the disc induces the deflecting torque.
- When the devices consume power, the aluminum disc starts rotating, and after some number of rotations, the disc displays the unit used by the load. The number of rotations of the disc is counted at particular interval of time. The disc measured the energy consumption in kilowatt hours.

3. Braking system

- The permanent magnet is used for reducing the rotation of the aluminum disc.

- The aluminum disc moves in the field of this magnet and thus provides a braking torque. This braking torque opposes the movement of the disc, thus reduces their speed. The permanent magnet is adjustable due to which the braking torque is also adjusted by shifting the magnet to the other radial position.

4. Registering (Counting Mechanism)

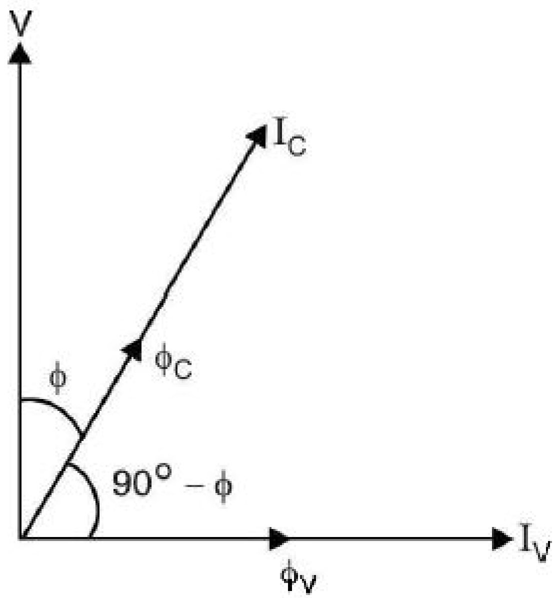
- The main function of the registering or counting mechanism is to record the number of rotations of the aluminum disc. Their rotation is directly proportional to the energy consumed by the loads in the kilowatt hour. The rotation of the disc is transmitted to the pointers of the different dial for recording the different readings. The reading in kWh is obtained by multiply the number of rotations of the disc with the meter constant.

Working of the Energy Meter

- The energy meter has the aluminum disc whose rotation determines the power consumption of the load. The disc is placed between the air gap of the series and shunt electromagnet. The shunt magnet has the pressure coil, and the series magnet has the current coil.
- The pressure coil creates the magnetic field because of the supply voltage, and the current coil produces it because of the current.
- The field induces by the voltage coil is lagging by 90^{o} on the magnetic field of the current coil (due to copper shading bands) because of which eddy current induced in the disc.
- The interaction of the eddy current and the magnetic field causes torque, which exerts a force on the disc. Thus, the disc starts rotating.

- The force on the disc is proportional to the current and voltage of the coil. The permanent magnet controls their rotation. The permanent magnet opposes the movement of the disc and equalizes it on the power consumption. The counting mechanism counts the rotation of the disc. The counting mechanism is so arranged that the meter indicates kWh directly.

Theory of induction type energy meter – Phasor Diagram



$$\theta = 90^\circ - \phi$$

$$\therefore \text{ Mean deflecting torque, } T_d \propto \phi_V \phi_C \sin\theta \quad \ldots$$

$$\propto VI \sin(90^\circ - \phi)$$

$$\propto VI \sin(90^\circ - \phi)$$

$$[\because \phi_V \propto V \text{ and } \phi_C \propto I]$$

$$\propto VI \cos\phi$$

$$\propto \text{a.c. power}$$

- The braking torque is due to the eddy currents induced in the aluminum disc. Since the magnitude of eddy currents is proportional to the disc speed, the braking torque will also be proportional to the disc speed n i.e.,

Braking torque, $T_B \, \alpha \, n$

For steady speed of rotation, $Td = T_B$

$$Power \, \alpha \, n$$

Multiplying both sides by t, the time for which power is supplied

$Power \times t \, \alpha \, n \times t$ or Energy α N

where $N \, (= nt)$ is the total number of revolutions in time t.

The counting mechanism is so arranged that the meter indicates kilo watt hours (kWh) directly and not the revolutions.

- **Meter Constant** – We have seen above that

$$N \propto \text{Energy}$$
$$N = K \times \text{Energy}$$

Where K is a constant called meter constant.

$$\therefore \text{Meter Constant, } K = \frac{N}{\text{Energy}} = \frac{\text{No.of revolutions}}{\text{kWh}}$$

- The energy meter constant is always written on the name plates of the energy meter installed in homes, commercial and industrial establishments.

Advantages of Induction Type Energy Meter

1. They can be used over a long period of time with very little maintenance.
2. It is an inexpensive energy meter and almost used universally for ac measurements.

3. High torque to weight ratio.
4. Can be used for the measurement of energy over a wide range of loads.

Disadvantages of Induction Type Energy Meter

1. If there are no proper adjustments in the meter, large errors are introduced in readings.
2. The principle of induction can be only in ac, hence these meters are limited to ac measurements only.

Errors in Energy Meters

Some of the common errors in energy meters are

1) Phase error
2) Speed error
3) Frictional error

4) Creeping
5) Temperature error
6) Frequency variations
7) Voltage variations

1. **Phase error -** The meter will read correctly only if the shunt magnet flux lags behind the supply voltage by exactly 90^0. Since the shunt magnet coil has some resistance and is not completely reactive, the shunt magnet flux does not lag the supply voltage by exactly 90^0. The result is that the meter will not read correctly at all power factors. The flux in the shunt magnet can be made to lag behind the supply voltage by exactly 90^0 by adjusting the position of the shading coil placed round the lower part of the central limb of the shunt magnet.

2. **Speed error -** Due to the incorrect position of the brake magnet, the braking torque is not correctly developed. The speed can be adjusted to the correct value by varying the position of the braking magnet towards the centre of the disc or away from the centre.
3. **Frictional error -** Frictional forces at the rotor bearings and in the registering mechanism give rise to an unwanted braking torque on the disc rotor.
4. **Creeping -** A slow but continuous rotation of the energy meter disc even when there is no current flowing through the current coil but only potential coil is energized is called creeping. This error may be caused due to excessive supply voltage, vibrations, stray magnetic fields etc. In order to prevent this creeping, two diametrically opposite holes are drilled in the disc.

This causes sufficient distortion of the field. The result is that the disc tends to remain stationary when one of the holes comes under one of the poles of the shunt magnet

5. **Temperature error -** Since energy meters are frequently required to operate in outdoor installations and are subject to extreme temperatures, the effects of temperatures and their compensation are very important. So great care is exercised in the design of the meter to eliminate the errors due to temperature variations.
6. **Frequency variations -** The meter is designed to give minimum error at a particular frequency generally 50Hz. If the supply frequency changes, the reactance of the coils also changes, resulting in a small error.

Three Phase Energy Meter (Two element energy meter)

- The meter which is used for measuring the power of three phase supply is known as the three phase energy meter.
- The three-phase meter is constructed by connecting the two single phase meter through the shaft. The total energy is the sum of the reading of both the elements.

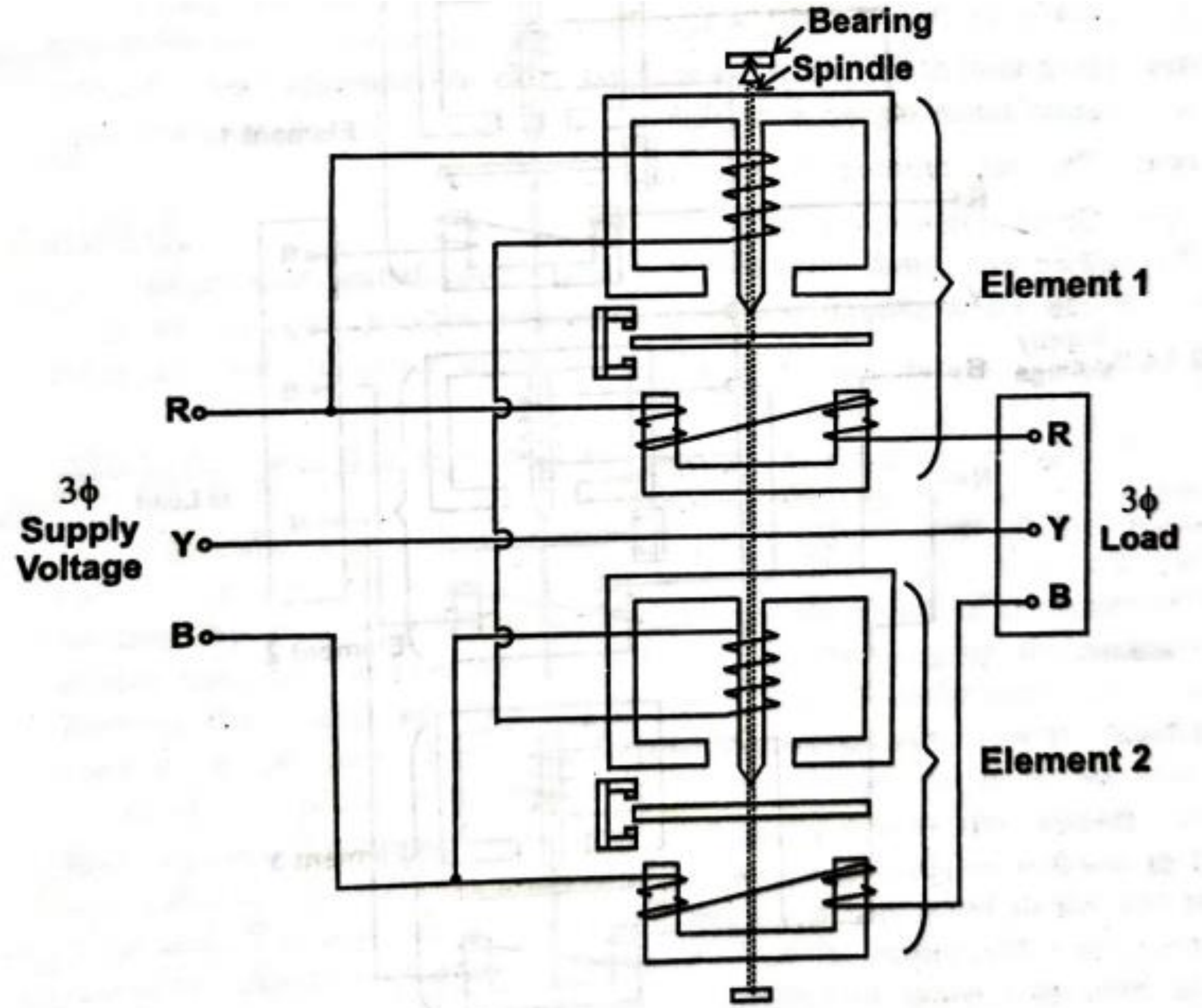
Working Principle of Three Phase Energy Meter

- The torque of both the elements is added mechanically, and the total rotation of the shaft is proportional to the three-phase energy consumption.

Construction of Three Phase Energy Meter

- The three phase energy meter has two discs mounted on the common shaft. Both the disc has its braking magnet, copper ring, shading band and the compensator for getting the correct reading.

- The two elements are used for measuring the three-phase power.



- A three wire three phase induction energy meter has the following main components.

1. **Shunt Magnet –** A three phase meter has two sets of shunt electromagnet. The connections for the winding of voltage coils are connected in parallel to the supply voltage. The coils carry the current proportional to the shunt voltage between two phases of supply line. The voltage coil winding is so arranged that during no load conditions the torque developed by the both shunt magnets is opposite in nature.
2. Series Magnet – A three phase meter has two sets of series electromagnet. The connections for the winding of current coils are connected in series to each of phase supply to the load. It carries the current equal to the current flowing through the load.

- The necessary driving torque is obtained due to the interaction between the shunt and series magnetic fields on the disc in each element.

3. Rotor Discs – Meter has two numbers of light weight Aluminum alloy disc mounted on a common spindle. The torque developed by each disc is added up and as a result, the total torque is proportional to the three-phase power consumed by the load. The spindle also carries a pinion which mesh with gear train mechanism which connects the disc to the registering mechanism and display.
4. Braking Magnet – Each rotating disc is provided with its individual braking magnet. It is a horseshoe type of permanent. Magnet placed at radial position of the rotor disc. It is required to control the speed of rotation of the rotor disc and also bring the disc to an idle state when the power to the load is disconnected.

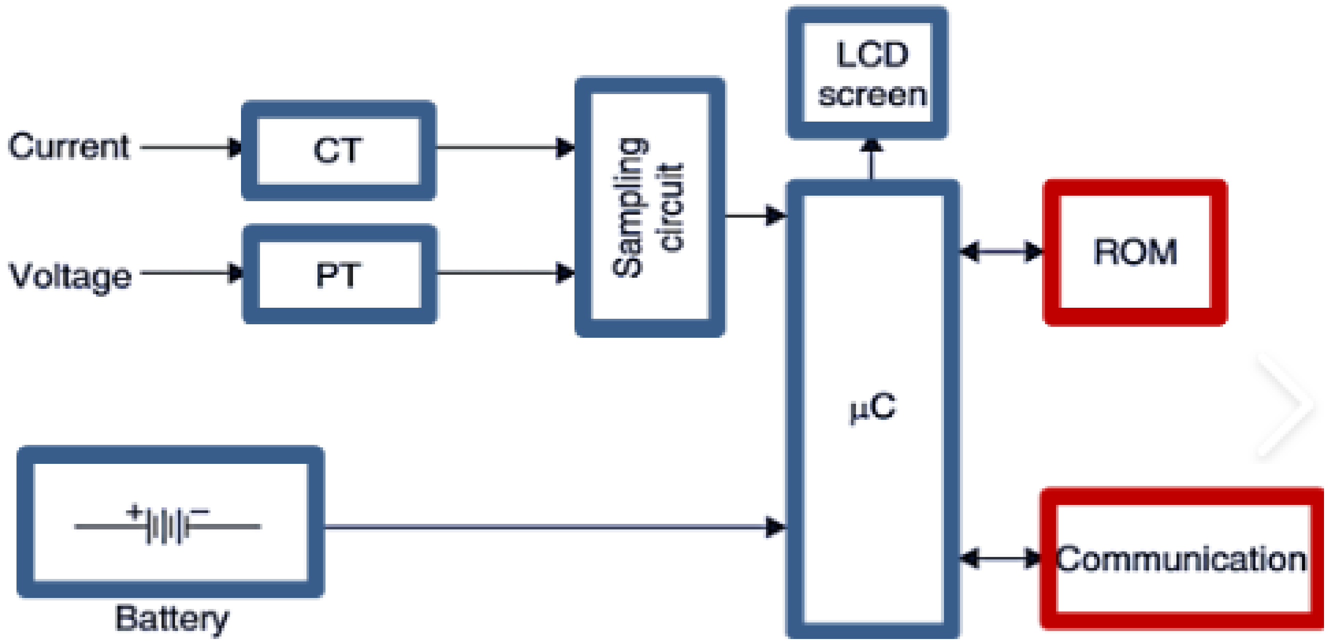
- There is a provision for adjusting the position of each brake magnet in order to vary the braking torque.

5. Cyclometer & Display Mechanism – The system is attached to the spindle of rotor disc through a pinion and gear tarin. It continuously counts or registers the number of revolutions made by the discs.

- It means it integrates the power consumed by the three-phase load over a period of time. The rotation of rotor disc is directly proportional to the three-phase energy consumed by the load.
- Disc rotation is transmitted to the pointers of different dials and cyclometer recording. After some number of rotations, the disc displays the unit used by the load by display mechanism.

Electronic Energy Meter /Digital Energy meters

- A digital energy meter, also known as an electronic energy meter measures the consumption of electrical energy in a more advanced and accurate way compared to traditional analog meters.
- It is based on Digital technology and uses no moving parts. So, the electronic energy meter is known as Static Energy meter.



- Current and Voltage Sensors : Digital energy meters have built in current and voltage sensors that measure the current and voltage of the electrical supply.
- Current sensors typically use current transformers (CTs) to measure the flow of electrical current, while voltage sensors measure the voltage between the phases.
- Analog to Digital Conversion (ADC): The measured current and voltage signals are analog in nature. To process these signals digitally, an ADC is used to convert the analog signals into digital form.
- This conversion allows the meter to work with digital data, making it more accurate and flexible.
- Signal Processing: The digital energy meter processes the digitized current and voltage signals to calculate instantaneous power.

- Instantaneous power (P) is calculated as the product of the current (I) and voltage (V) at the given moment, $P = V \times I$. This calculation is performed continuously at a high sampling rate, typically many times per second.
- Energy calculation : To determine the energy consumption over time, the meter integrates the instantaneous power values over specific time intervals, usually in watt-hours. This integration can be done using methods such as the trapezoidal rule or Simpson's rule for numerical integration.
- Display and Communication : Digital Energy Meters often come equipped with an LCD or digital display that shows real – time energy consumption. They can also have communication modules like Wi-Fi, or cellular connectivity to transmit consumption data to utility companies or for remote monitoring and control.

- Data Storage: Energy usage data, along with timestamps, can be store in memory for record – keeping and analysis purposes.
- This data can be retrieved for billing, troubleshooting, or energy management purposes.
- Tamper Detection : Digital energy meters often include tamper detection mechanisms to alert authorities if someone tries to tamper with the meter's operation. This helps to prevent energy theft and ensures accurate billing.
- In summary, the working principle of a digital energy meter involves measuring current and voltage, converting these analog signals into digital form, calculating instantaneous power, integrating power over time to determine energy consumption, and displaying or transmitting this data.

Advantages of Digital Energy Meters

1. These meters are more accurate , efficient, highly precise readings of energy consumption, and versatile compared to traditional analog meters , making them essential for modern energy management and billing systems.
2. This ensures accurate billing for consumers, eliminating discrepancies and ensuring you only pay for the energy used.
3. They offer real – time data on energy consumption, empowering both consumers and utility companies to make informed decisions.
4. Consumers can track their usage habits and identify areas for improvement , leading to more efficient energy use and potentially lower bills.
5. Digital meters possess superior environmental resilience compared to their mechanical counter parts. less susceptible to external factors like temperature and humidity fluctuations, ensuring consistent and reliable readings regardless of weather conditions.

TOD Meter

- Time Of Day (TOD) meter records the demand, time, and energy usage of electricity. TOD metering normally splits rates into an arrangement of multiple segments including on-peak, off-peak, and critical peak.
- TOD metering involves dividing the day into tariff slots with higher rates at peak load periods and lower tariff rates at off-peak load periods. This can be used to automatically control usage on the part of consumer.
- The TOD metering benefits customers by providing reduced usage rates during off-peak times, which gives customers a chance to reduce their utility bill.
- It means that cost of using 1 unit of electricity will be different in mornings, noon, evenings and nights.

- This means that using appliances during certain time of the day will be cheaper than using them during other times. This can be used to automatically control usage on the part of consumer.
- Time of Day tariff is implemented to reduce consumption of electricity during peak hours. To do this, electricity is made expensive during peak hours so that consumers use less of it. Utilities also reduce the electricity charges during off peak hours

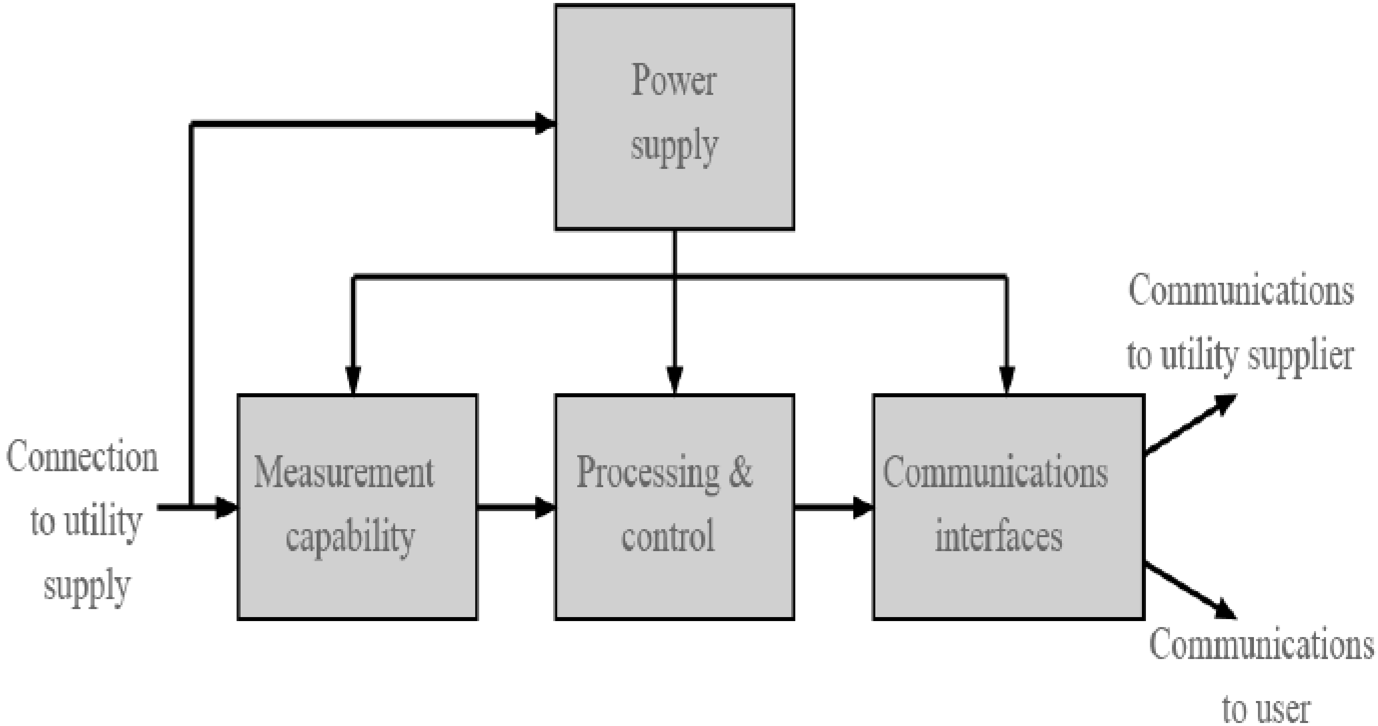
Smart Energy Meter

- Smart meter is an electronic device that records information such as consumption of electric energy, voltage levels, current, and power factor.
- It is an advanced metering technology involving intelligent methods to read, process and feedback the data to customers. It measures energy consumption, remotely switches the supply to customers and remotely controls the maximum electricity consumption.

- Smart metering system uses the advanced metering infrastructure system technology for better performance. These can communicate in both directions.
- They can transmit the data to the utilities like energy consumption, parameter values, alarms, etc. and can receive information from utilities such as automatic meter reading system, reconnected/disconnected instructions etc.
- These meters reduces the need to visit while taking or reading monthly bill. Modems are used in these smart meters to facilitate communication systems such as wireless, fiber cable, power line communications.
- Another advantage of smart metering is complete avoidance of tampering of energy meter where there is scope of using power in an illegal way.

- Tampering means doing any act which causes the meter to run slowly or not at all and is basically theft of electricity
- The block diagram of a smart metering is shown in the fig.
- It consists of 1)Measurement capability 2)Processing and control and 3)Communications interfaces

Block diagram of Smart metering



1. **Measurement capability**

- This section of the smart energy meter block diagram addresses the basic measurement of the utility that is use. It requires to be reliable and accurate. It will typically output the data in a digital format and will therefore include an analog to digital converter

2. **Processing and control**

- Any meter like this will require manipulation of the data. It needs to be formatted to send via the communications links as well as displaying on the smart meter itself

3. **Communications interfaces**

- The smart meter needs to communicate the information back to the utility supplier for billing and management of their smart grid. It also needs to provide information on a smart energy monitor or In-Home Display, IHD.

- A variety of different communications methods can be used for this including cellular communications, power-line communications, etc.

Advantages of Smart Energy Meter

- Eliminating manual meter readings
- Monitoring the electrical system more quickly
- Providing real time data useful for balancing electrical load and reducing power outages

Disadvantages of Smart Energy Meter

- Managing and storing vast quantities of metering data
- Ensuring the security of metering data

Instrument Transformers

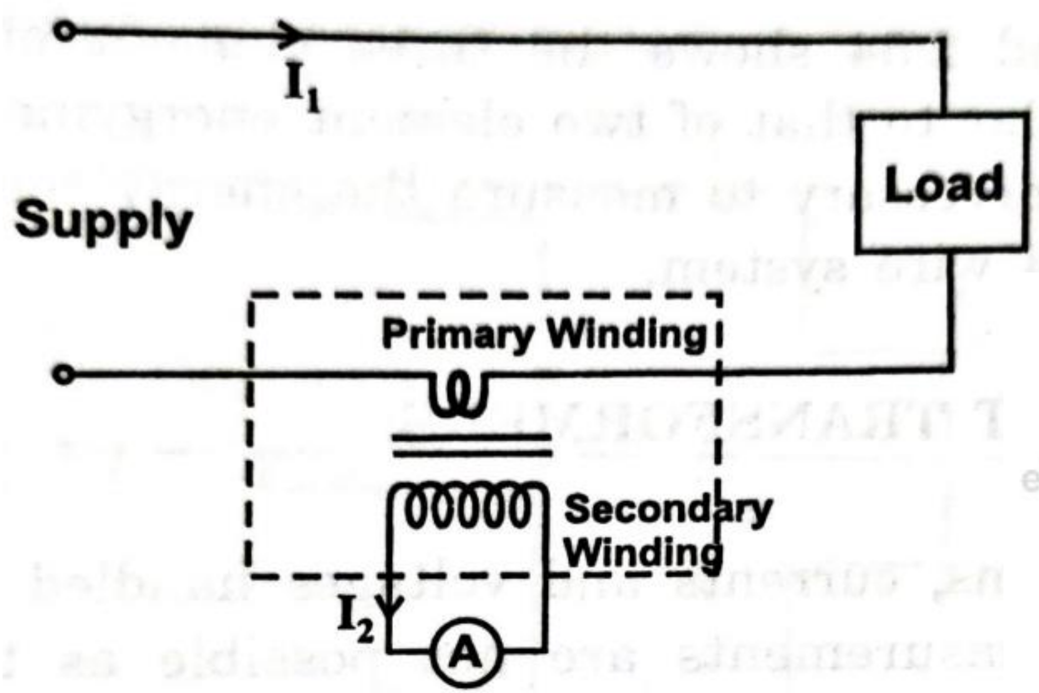
- In DC Circuits, large currents are measured using low range ammeters with suitable shunts (low resistance in parallel) and high voltages are measured using low range voltmeters with multipliers (high resistance connected in series).
- The voltage and current level of power system is very high. It is very difficult and costly to design the measuring instruments for measurement of such high level voltage and current. Generally measuring instruments are designed for 5 A and 110 V.
- Thus, the transformers used in conjunction with measuring instruments for measurement purposes are called as instrument transformers. Or in other words, To measure high alternating currents and voltages, employ specially designed transformers, called instrument transformers.

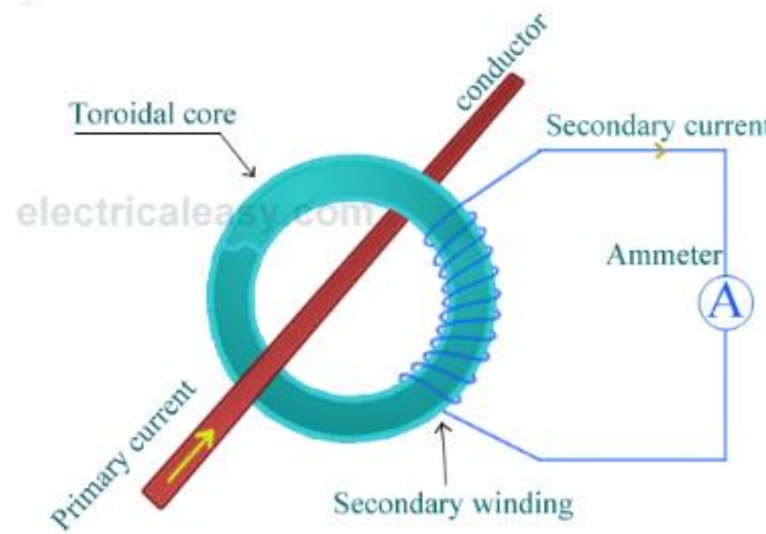
Types of Instrument Transformers

Instrument transformers are of two types

- Current Transformer (CT) & Potential Transformer (PT)

Current Transformer (CT)





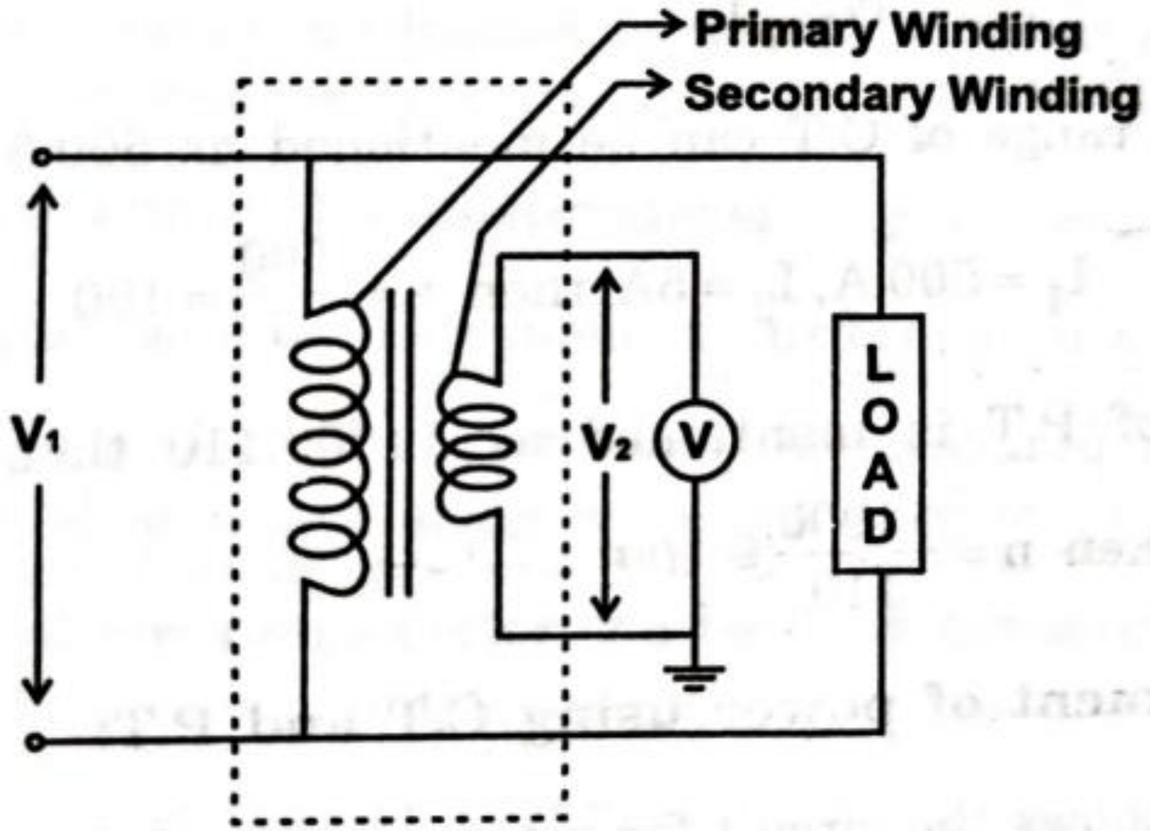
- Transformer used for the measurement of current is called a current transformer or C.T. These transformers step down the current to be measured, so that it can be measured with a normal range ammeter.
- It is a device used to decrease the current level by stepping up the voltage and keeping the energy as constant. Hence current transformers are basically step up transformers.
- Figure shows that the circuit of a current transformer in which the primary winding of the CT is connected in series with the line carrying the current to be measured and therefore the primary current is dependent on the load connected to the system whose current is to be measured.
- The secondary winding of the CT is connected to the low range ammeter.

- As the secondary voltage of CT is higher than the primary voltage, secondary winding has more number of turns compared to the primary winding. In case of CT, the secondary current is less than the primary current.
- If the turns ratio of a current transformer is known and the meter reading is known the actual highline current value can be determined.
- The main precaution to be followed in a current transformer is, the secondary winding of CT should never be open circuited while its primary winding is energized.
- Either it can be short circuited or connected in series with the low resistance coil such as coil of ammeter, current coil of wattmeter, relay coil etc.
- If the secondary winding of a CT is open circuited while the primary winding is carrying current a very high voltage in the secondary winding which can damage the transformer insulation.

Potential Transformer (PT)

- Potential transformers are also known as voltage transformers, and they are basically step-down transformers with extremely accurate turns ratio.
- The basic principle of a potential transformer is same as that of current transformer that is the primary winding is connected across the high voltage line whose voltage is to be measured and the secondary winding is connected to the low range voltmeter coil. One end of the secondary winding is always grounded for safety purposes.
- Potential transformers step down the voltage of high magnitude to a lower voltage which can be measured with standard measuring instrument. These transformers have large number of primary turns and smaller number of secondary turns.

- A potential transformer is typically expressed in primary to secondary voltage ratio. For example, a 600:120 PT would mean the voltage across secondary is 120 volts when primary voltage is 600 volts.

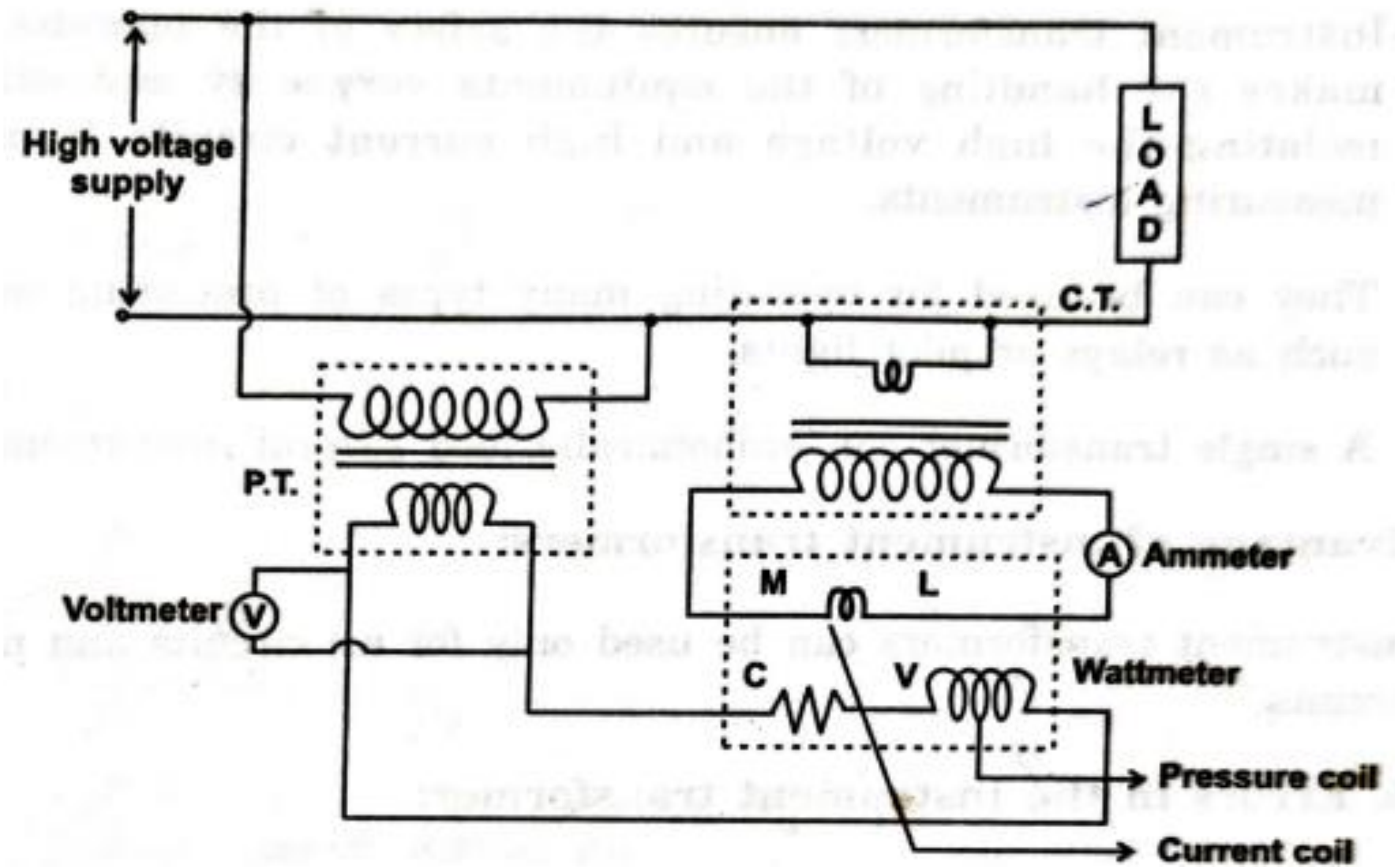


Difference between CT and PT

Sl No	Current Transformer (CT)	Potential Transformer (PT)
1	Primary winding is connected in series with the load.	Primary winding is connected in Parallel (or across) with the load.
2	Secondary is connected to Ammeter.	Secondary is connected to Voltmeter.
3	CT acts as the step-up transformer, its primary winding has less number of turns as compared to secondary.	PT acts as the step-down transformer, its primary winding has more number of turns as compared to secondary.
4	Secondary is never be open circuited.	One terminal of secondary can be earthed for Safety.
5	Primary current depends on power circuit current.	Primary current depends on secondary burden.

Measurement of power using CT and PT

- Figure shows the circuit for measurement of power in high voltage and high current circuit using wattmeter and instrument transformers.



- From the above circuit diagram it is clear that the primary winding of current transformer is connected in series with the load and the secondary is connected in series within an ammeter and the current coil of a wattmeter.
- The primary winding of PT is connected across the supply voltage and the secondary is connected across voltmeter and the pressure coil of the wattmeter.

Measurement of Energy using CT and PT

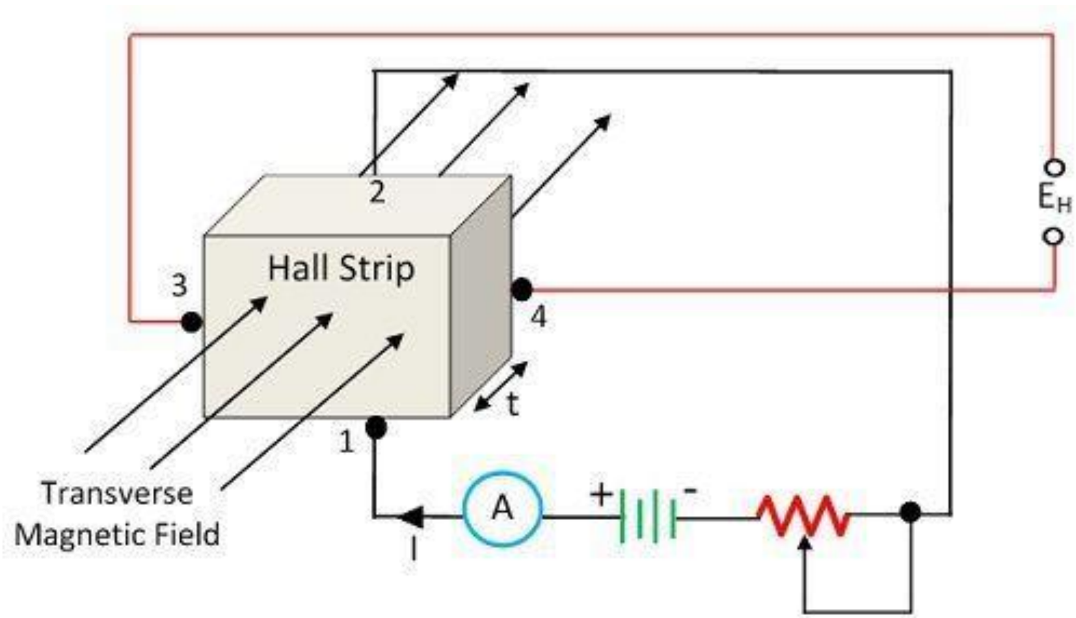
- The circuit connections of single-phase energy meter is exactly similar to the connections of the wattmeter along with current transformer and potential transformer for power measurements. The only difference is the pressure coil of wattmeter is replaced by pressure coil of energy meter and the current coil of wattmeter is replaced by current coil of energy meter.

Advantages of Instrument Transformers

1. Large voltages and currents in AC power systems can be accurately measured using low range voltmeter and ammeter along with the instrument transformer.
2. The rating of low range meter can be fixed irrespective of the value of high voltage or high current to be measured.
3. Wide range of voltage or currents can be measured using is single low range meter.
4. Instrument transformers provide electrical isolation between high voltage power circuit and measuring instruments. Which reduces the electrical insulation requirement for measuring instruments and protective circuits and also assures the safety of operators.
5. Due to low voltage and current level in measuring and protective circuit, there is low power consumption in measuring and protective circuits.

Hall Effect & Hall Effect Multipliers

- When current passes through a conductor (or semiconductor) in the presence of transverse magnetic field, a voltage is produced at the ends of the conductor. This effect is called as Hall Effect and the generated voltage is known as Hall voltage. The magnitude of the developed voltage depends on the density of flux.

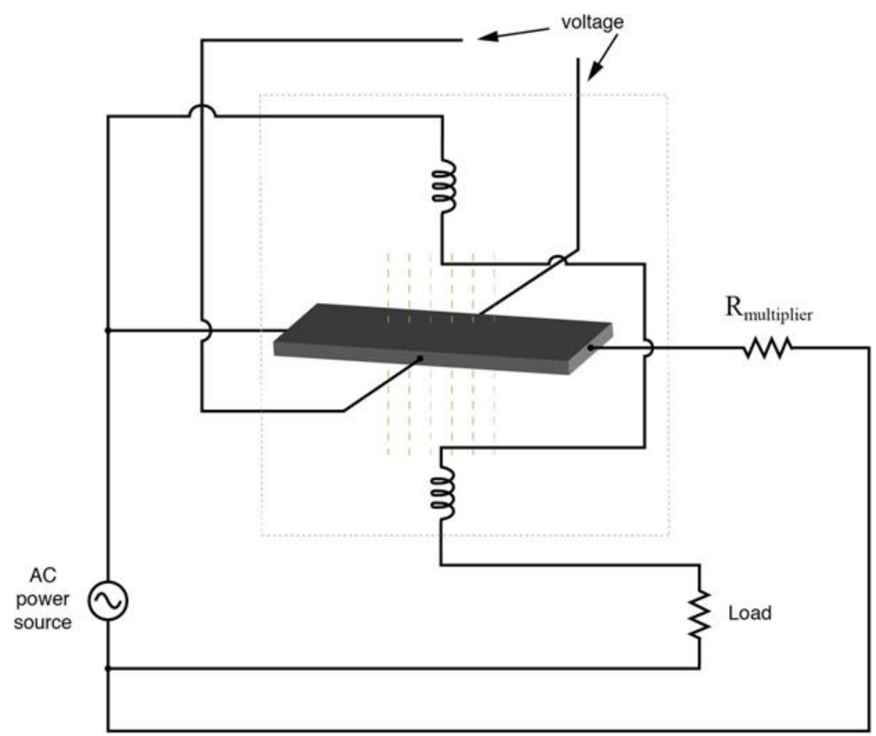


Hall Effect Element

- Consider the hall effect element shown in the figure below. The current is supplied through the lead 1 and 2 and a transverse magnetic field is applied to the strip, an output voltage develops across the output leads 3 and 4.

Hall effect multiplier

- The current is passed through the current coil which produces a magnetic field proportional to the current i.



- The field is perpendicular to the Hall effect element. A current i_p proportional to the voltage is passed through the hall effect element in a direction perpendicular to field.
- The current is limited by the multiplier resistance R_s. The output voltage of the hall effect multiplier is proportional to instantaneous power.
- Hence the voltmeter connected at the output terminals can be calibrated in terms of power. The Hall effect voltage which is representative of the power, can be processed further for control and other purposes.
- This is the major advantage of Hall effect multiplier over electrodynamometer wattmeters the output of the later being the deflection of a pointer which cannot be processed further.

Previous Year University Questions

June 2024

1. The deflection produced by an Electrodynamometer wattmeter is proportional to the power being measured. Justify with necessary equations. (3 Marks)
2. In single phase induction type Energy meter, why shunt magnet flux should be in exact quadrature with the applied voltage. How this is made possible? (3 Marks)
3. Explain the various errors in electrodynamometer type wattmeter. (8 Marks)
4. Derive the expression for transformation ratio and phase angle error of a potential transformer using its equivalent circuit and phasor diagram. (14 Marks)
5. With neat circuit show that the deflection produced by a wattmeter is proportional to the power consumed in the circuit. (6 Marks)

December 2023

1. What is a TOD meter? (3 Marks)
2. Write short note on smart metering (3 Marks)
3. Using equivalent circuit and phasor diagram, derive the expression for transformation ratio and phase angle error of a current transformer(14 Marks)
4. W1 and W2 reads -1000W and 2000W respectively when connected to 400 V supply. The load is balanced. Find the line current and power factor. State whether the load is inductive or capacitive(7 Marks)
5. Explain the measurement of three phase power using two wattmeter method? (7 Marks)

December 2022

1. List the advantages of smart energy meters over conventional energy meters. (3 Marks)
2. Explain the working principle of potential transformer with help of neat diagrams. (3 Marks)
3. With neat diagram, explain the construction and working of Dynamometer type wattmeter. (8 Marks)
4. Two wattmeters are connected to measure the power consumed by a 3-phase balanced load. One of the wattmeters read 1500 Watts and the other 700 Watts. Find power factor of the load,(i)when both the readings are positive, and (ii)when the reading of the second wattmeter is obtained after reversing its current coil connection.(6 Marks)

5. Conventional wattmeter, when used to measure power with low power factor value shows erroneous reading. Justify the statement. What are the modifications to be made to convert it into a low power factor (LPF) wattmeter?(8 Marks)
6. With neat diagram, explain the construction and working of Induction type single phase energy meter. (6 Marks)

December 2021

1. Explain the working of Hall effect multipliers. (3 Marks)
2. What is a TOD meter? (3 Marks)
3. With neat diagram explain the construction and working of an electrodynamometer wattmeter.(8 Marks)
4. Derive the expression for torque of a single-phase induction type energy meter.(6 Marks)

5. Derive the expression for ratio and phase angle error in a current transformer. (10 Marks)
6. Explain how power can be measured in a 3-phase circuit using two wattmeters with a neat circuit diagram in unbalanced load condition. (4 Marks)

December 2020

1. The deflection produced by an Electrodynamometer wattmeter is proportional to the power being measured. Justify with necessary equations.(3 Marks)
2. In single phase induction type Energy meter, why shunt magnet flux should be in exact quadrature with the applied voltage. How this is made possible?(3 Marks)
3. Derive the expression for transformation ratio and phase angle error of a potential transformer using its equivalent circuit and phasor diagram.(14 Marks)

4. Explain the various errors in electrodynamometer type wattmeter.(8 Marks)
5. With neat circuit show that the deflection produced by a wattmeter is proportional to the power consumed in the circuit.(6 Marks)