Chapter 3

Measurement of Power and Energy

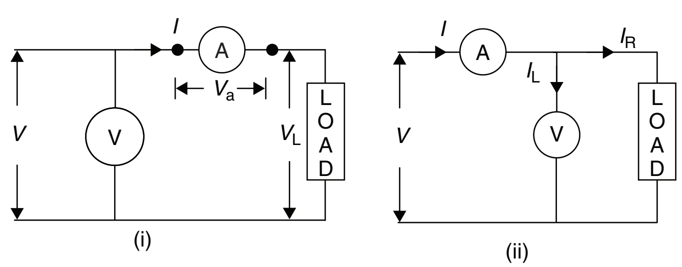
LEARNING OBJECTIVES

After reading this chapter, you will be able to understand:

- Measurement of power
- Measurement of power in AC circuits
- Deflecting torque
- Dynamometer type wattmeter
- Deflecting torque
- Measurement of power in three-phase circuits
- Braking torque
- Ficticious or phantom loading
- Shunt magnet
- Braking magnet

Measurement of Power

Measurement of Power in DC Circuits



- The power taken by a load from a DC supply is given by the product of readings of an ammeter and voltmeter when connected in a circuit.

$$\text{Power} = V \times I \text{ W}$$

Figure (i): When ammeter is connected between voltmeter and load.

- Voltmeter indicates the voltage drop across the load and also V_a (or) voltage drop across the ammeter.
- If R_a is the resistance of the ammeter

$$V_a = I_a R_a.$$

- Power consumed by the load $= V_L I$

$$= (V - V_a)I = VI - V_a I$$

$$= VI - I^2 R_a$$

$$= \text{(Power indicated by the instruments)} - \text{(Power loss in ammeter)}$$

Power indicated by instruments = (Power consumed by load) + (Power loss in ammeter)

Figure (ii): Power Consumed by load $= VI_L$

$$= V(I - I_V)$$

$$= V\left(I - \frac{V}{R_v}\right)$$

$$= VI - \frac{V^2}{R_v}$$

Power indicated by instruments = (Power consumed in load) + (Power loss in voltmeter)

In case I and II power indicated by the instruments = power consumed by the load plus power consumed by instrument nearer to load terminal.

- In order to obtain true power, corrections must be applied for power loss in instruments.

Measurement of Power in AC Circuits

The power in AC circuit is given by

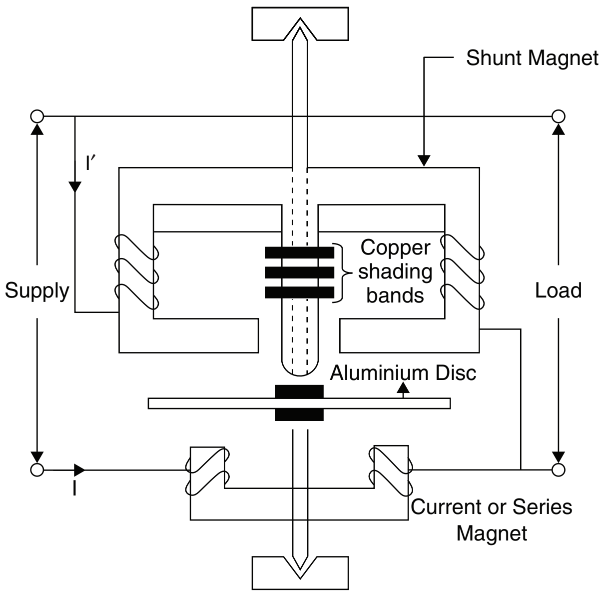
$$P = VI\cos\phi$$

V = Voltage across the load
I = Current through the load
$\cos\phi$ = Power factor of the load

- Voltmeter–ammeter method is not applicable in AC circuits because of involvement of power factor.
- There are two types of wattmeters.

Induction Type Wattmeter

- This type of wattmeter is used to measure AC power only.



Principle

- The principle of operation is same as that of induction ammeter and voltmeter.
- The only area where it differs is that two separate coils in place of one coil with phase-split arrangement.

Construction

- It consist of two laminated electromagnets.
- One electromagnet is called the shunt magnet is connected across the supply and carries current proportional to applied voltage. The coil of this magnet is highly inductive so that the current in it lags behind supply voltage lags behind by 90°.
- The other electromagnet is called series magnet and is connected in series with supply and carries load current. The coil of this magnet is highly non inductive so that the angle of lag or lead is determined wholly by the load.
- A thin aluminium disc mounted on the spindle is placed in between two magnets so that it cuts the fluxes in both the magnets.
- The controlling torque is provided by spiral springs.
- Damping is usually electromagnetic and is usually done by a permanent magnet embracing the aluminium disc.
- Two or more copper rings, called the shading rings are provided on the central limb of the shunt magnet. By adjusting their position the shunt magnet flux can be made to lag behind supply voltage exact by 90°.

Working

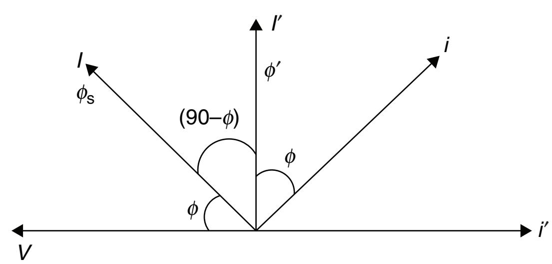
- When wattmeter is connected in the circuit, the shunt magnet carries current proportional to supply voltage and the series magnet carries the load current.
- The two fluxes produced by the magnets induce eddy currents in the aluminium disc. The interaction between fluxes and eddy currents produce the deflecting torque on the disc, causing the pointer connected to the moving system to move over the scale.

Deflecting Torque

Let V = Applied voltage
I = Load current carried by series magnet
I' = Current carried by shunt magnet
$\cos\phi$ = Lagging p.f. of the load

- Current I' in the shunt magnet lags applied voltage V by 90° and so does the flux ϕ' produced by it.
- The current I in the series magnet is the load current and hence lags behind the applied voltage by ϕ. The flux ϕ_s produced by this current is in phase with it.
- The two currents I' and I and the corresponding fluxes ϕ' and ϕ_s are $(90 - \phi°)$ apart.
- The flux ϕ' induces eddy currents i' in the aluminium disc which lags behind ϕ' by 90°.

Similarly ϕ_s induces eddy current i, which lags ϕ_s by 90°.



Mean deflecting torque

$$T_d \propto \phi' \phi_s \sin(90 - \phi)$$

$$[\phi' \propto V \text{ and } \phi_s \propto I]$$

$$T_d \propto VI \cos\phi$$

$$T_d \propto \text{AC power}$$

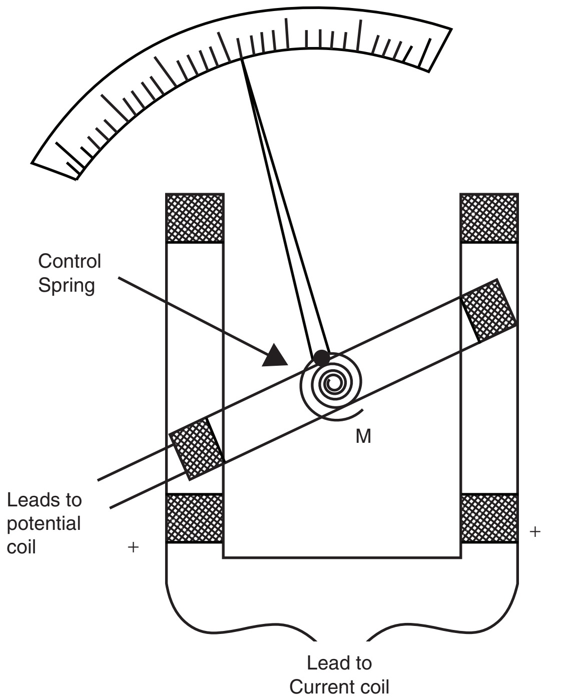
Since control is by springs $T_c \propto T_c$

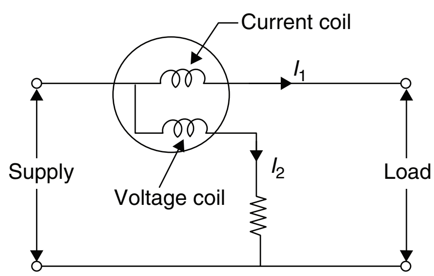
$$\theta \propto \text{Power}$$

Such instruments have uniform scale.

Dynamometer Type Wattmeter

- It is the most commonly employed for measurement of power in AC and DC.





Principle

It is based on the principle that mechanical force exists between two current carrying conductors.

Construction

- It essentially consists of two coils namely fixed coil and moving coil.
- Fixed coils are split into two equal parts which are placed close together and parallel to each other.
- The moving coil is pivoted between the two fixed coils and is placed on the spindle to which the pointer is attached.
- Fixed coils carry circuit current and are connected in series with the load. It is therefore called the current coil.
- The moving coil is connected across the load and carries current proportional to voltage. It is therefore called potential coil.
- To limit the current through the potential coil a high resistance is connected in series to it.
- Controlling torque is provided by the springs which also serve the additional purpose of leading current into and out of the moving coil.
- Damping is achieved by air friction.

Working

- Due to current in fixed and moving coils, mechanical force exist between them hence the moving coil moves the pointer over the scale. The pointer comes to rest at a position where deflecting torque is equal to controlling torque.
- Reversing the current reverses the field due to fixed coil as well as the current in the moving coil so that the direction of the deflection torque remains unchanged. Therefore such instruments can be used for the measurement of AC as well as DC power.

Deflecting Torque

Operation on DC

Let V be the voltage across the load and; be the current through the load. Current through fixed coil $I_f \propto I$; current through moving coil $I_m \propto V$. Deflecting Torque T_d is due to I_m and I_f

$$T_d \propto I_m I_f$$

$$\propto VI$$

$$T_d \propto \text{Power}$$

Operation on AC

Let e be the instantaneous voltage across load, i be the instantaneous current through load in an AC circuit

If the load has a power factor of $\cos\phi$ (lagging)

$$e = E_m \sin\omega t$$

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

Current through fixed coil $I_f \propto$ i

Current through moving coil $I_m \propto e$

Due to large inertia of the moving system, the deflection will be proportional to the average torque.

Mean deflecting torque $T_d \propto$ Average of $I_m I_f \propto$ Average of $e\ i$

$$T_d \propto \text{Average of } E_m \sin\omega t$$

$$I_m \sin(\omega t - \phi) \propto EI\cos\phi$$

$$T_d \propto \text{Power}$$

Scale

$$T_d \propto \text{power and } T_c \propto \theta \text{ (spring controlled)}$$

$$\theta \propto \text{power}$$

Hence such instruments have uniform scale.

Errors

Potential Coil Inductance

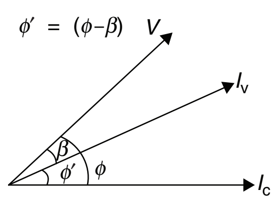
In an idealized wattmeter, potential coil is assumed to be purely resistive. In practice the potential coil has inductance also, due to which the current through the coil lags the voltage by an angle β and is not in phase with it.

$$\beta = \tan^{-1}\left(\frac{\omega L}{R_p}\right) = \tan^{-1}\left(\frac{\omega L}{r_p + R}\right)$$

where r_p = Resistance of potential coil
R = Resistance in series with potential coil

- For a lagging power factor, the angle between I_c and I_v is less than ϕ.

$$\phi' = (\phi - \beta)$$



Actual wattmeter reading $\propto VI\cos(\phi - \beta)\cos\beta$
But true power = $VI\cos\phi$

$$\text{Correction factor} = \frac{\text{True power}}{\text{Actual wattmeter reading}}$$

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

$$\text{For leading p.f.} = \frac{\cos\phi}{\cos\beta\ \cos(\phi + \beta)}$$

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

Compensation for error can be provided by connecting a capacitor across a portion of the external resistance R.

Potential Coil Capacitance

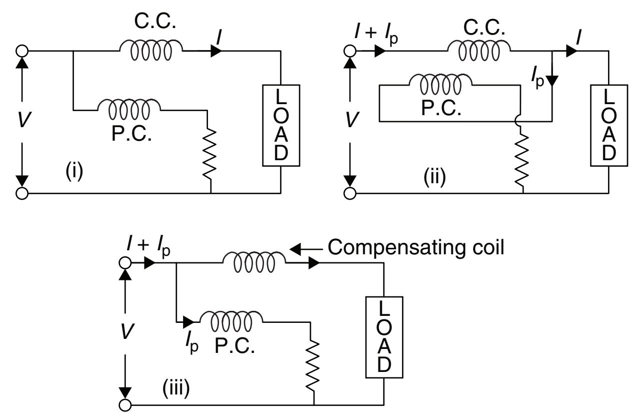
- The potential coil may have capacitance in addition to inductance due to in turn capacitance of the series resistance.
- The effect of capacitance opposite to that may be produced by inductance the wattmeter reads high on lagging power factor.

Mutual Inductance of Coils

Errors are caused due to mutual inductance of current and potential coils of the wattmeter.

- These errors are low at lower frequencies but they increase and become important as frequency is increased.
- The effect of mutual inductance is to increase the phase angle for the connection at which potential coil is connected on the load side and to decrease the phase angle when the current coil is connected on load side. Change in phase angle is $\tan^{-1}\dfrac{\omega M}{R_p}$.

Errors Because of Connections



Case (i)

- The potential coil is connected on the supply side and the voltage across it is equal to the sum of voltages across current coil and the load.
- The wattmeter measures power consumed by the load and power loss in current coil.

Case (ii)

- The current coil is on supply side and it carries the load current plus the potential coil current.
- The wattmeter reads power loss in potential coil plus the power consumed by the load.
- The above connection holds good only if power loss in the instrument is low and can be used if load currents are large.
- The power taken by potential coil is constant if the voltage is constant and becomes a smaller percentage of total power as a larger amount of power is measured.
- In cases where load current is large and power factor is small.

Case (ii) results in larger error since total power measured is small.

- In such cases, case (iii) can be used where a compensating coil is used to compensate the error caused by power loss in P.C.

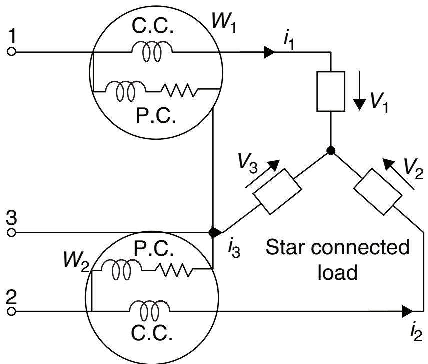
Case (iii)

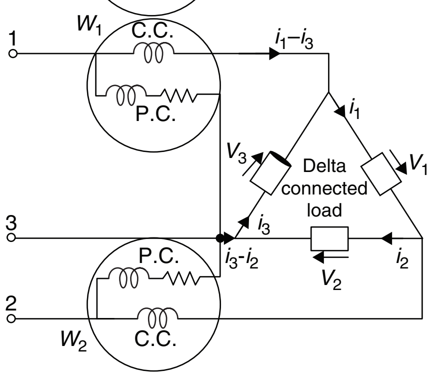
- Compensating coil connected in series with the potential coil and is identical and coincident with current coil.
- It opposes the field of C.C., the C.C. carries a current of $I + I_p$ and P.C carries a current of I_p. The resultant field is due to I only. Hence, the error is neutralized.

Eddy Current Errors

- Eddy currents are induced within the solid metal parts and within the thickness of the conductors by alternating magnetic field of the C.C.
- These currents produce a field of their own and alter the magnitude and phase of the C.C. field.

Measurement of Power in Three-phase Circuits





- Two-wattmeter method is most commonly used method to measure power in 3ϕ circuits.
- The C.C. of two wattmeters are inserted in any two lines and potential coil is connected from its own current coil to the line without a C.C.
- The power supplied is sum of the two wattmeter readings.

For both connections,

Power consumed by the load

$$P = W_1 + W_2$$

$$W_1 = VI\cos(30° - \phi)$$

$$W_2 = VI\cos(30 + \phi)$$

Load power factor ϕ

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

Case 1: For Purely Resistive Load

- Both wattmeter readings are equal

$$W_1 = W_2 \; \tan\phi = 0° \; \cos\phi = 1$$

Case 2: For Purely Reactive Load

- Both wattmeter readings are equal and opposite

$$W_1 = -W_2 \; \tan\phi = \infty \; \cos\phi = 0$$

Case 3: For Lagging Power Factor

- Only one wattmeter reads

$$W_1 = 0 \; \tan\phi = \sqrt{3} \; \cos\phi = 0.5$$

$$\phi = 60° \text{ lagging}$$

Case 4: For Leading Power Factor

- When p.f. leads by ϕ

$$W_1 = VI\cos(30 + \phi)$$

$$W_1 = VI\cos(30 - \phi)$$

i.e. readings of two wattmeter are interchanged.

Case 5: When $60 < \phi < 90°$ and $0 < \cos\phi < 0.5$

- W_1 is +ve and W_2 is –ve. As one wattmeter cannot indicate –ve reading pressure coil has to be reversed.

$$W_T = W_2 - W_1$$

Solved Examples

Example 1: Calculate the power factor of a balanced 3-ϕ inductive load, if the readings of two wattmeters (W_1 and W_2) to measure power were 6 and 4, respectively,

(A) 0.94 (B) 0.85 (C) 0.90 (D) 0.5

Solution: (A)

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

$$= \sqrt{3}\left[\frac{6-4}{6+4}\right] = \frac{\sqrt{3}}{5}$$

$$\cos\phi = \frac{5}{\sqrt{28}} = 0.94 \text{ lag.}$$

Example 2: One single-phase wattmeter having a meter constant of 300 operates on 230 V, 6 A. if it makes 1800 revolutions in 6 hours the p.f. of the load will be

(A) 0.87 (B) 0.67 (C) 0.47 (D) 0.27

Solution: (D)

Energy consumed = $230 \times 6 \times 6$ = 8280 Wh

= 8.28 kWh

Meter constant = 800 rev/kWh

$$\text{kWh} = \frac{1800}{800} = 2.25$$

$$\text{Power factor} = \frac{2.25}{8.28} = 0.27.$$

Example 3: The resistance of two coils of a wattmeter are 10 mΩ and 1 kΩ, respectively, and both being non inductive. The voltage across load is 20 V and load current is 10 A. The error in the reading when voltage coil is connected in one of the two ways would be

(A) 0.1% too high (B) 0.2% too high
(C) 0.15% too high (D) zero

Solution: (B)

$$r_{cc} = 10\ \text{m}\Omega = 0.01\ \Omega,\ r_{vc} = 1000\ \Omega$$

Two possible power losses are

1. $I_c^2 r_{cc} = 10^2 \times 0.01 = 1\ \text{W}$
2. $\dfrac{V^2}{r_{vc}} = \dfrac{20^2}{1000} = 0.4\ \text{W}$

Two percentage errors are

1. $\dfrac{1}{200} \times 100 = 0.5\%$
2. $\dfrac{0.4}{200} \times 100 = 0.2\%$.

Example 4: In electrodynamometer type wattmeters, laminated conductors (or) stranded wires are used as current coils (which are designed to carry heavy currents) because it minimizes
(A) Hysteresis losses
(B) Eddy current losses
(C) Iron losses
(D) All of the above

Solution: (B).

Example 5: If an electrodynamometer type wattmeter was used for power measurement with very large value of load current them
(A) The pressure coil should be connected to the supply side.
(B) The current coil should be connected to the supply side.
(C) The pressure coil should be connected to the load side.
(D) The current coil should be connected to the load side.

Solution: (C)

Example 6: A two-wattmeter method employed in the measurement of power flowing in a three-phase three-wire balanced load system. Wattmeters W_1 reads 3500 W and W_2 reads −700 W. If the circuit is operating at 440 V, 50 Hz and if the entire power measured was to be appeared on W_1, the value of capacitance which must be introduced into each phase should be?
(A) 0.41 mF (B) 4.1 mF
(C) 40 μF (D) 0.41 μF

Solution: (A)

$$W_1 = 3500\ \text{W}$$
$$W_2 = -700\ \text{W}$$

Total power

$$P = W_1 + W_2$$
$$= 3500 + (-700)$$
$$= 2800\ \text{W}$$

$$\tan\phi = \sqrt{3}\left(\frac{W_1 - W_2}{W_1 + W_2}\right) = \sqrt{3} \times (1.5)$$

$$\phi = \tan^{-1}(2.6) \cong 69°$$

$$\cos\phi = 0.358$$

Power consumed by each phase $= \dfrac{2800}{3} = 933.33$ W

$$V_{ph} = \frac{440}{\sqrt{3}} = 254\ \text{V}$$

$$I_{ph} = \frac{933.33}{254 \times 0.358} = 10.26\ \text{A}$$

$$Z_{ph} = \frac{V_{ph}}{I_{ph}} = 24.76\ \Omega$$

$$R_{ph} = Z_{ph}\cos\phi = 8.86\ \Omega$$

$$X_{ph} = \sqrt{Z_{ph}^{\ 2} - R_{ph}^{\ 2}} = 23.12\ \Omega$$

In order that one wattmeter reads zero (i.e. $W_2 = 0$) p.f. = $\cos\phi = 0.5$

$$\tan\phi = 1.73$$

$$\tan\phi = \frac{X}{R}$$

$$\Rightarrow \quad X = R\tan\phi$$

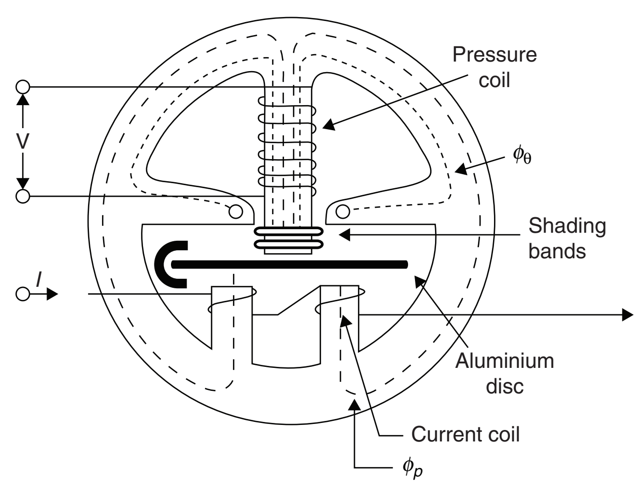
$$X_{ph} = 8.86 \times 1.73$$
$$= 15.33\ \Omega$$

Capacitive reactance required

$$= 23.12 - 15.33 = 7.79\ \Omega$$

$$C = \frac{1}{2\pi \times 50 \times 7.79} = 4.086 \times 10^{-4}$$
$$= 0.41\ \text{mF}.$$

MEASUREMENT OF ENERGY



Induction type single-phase energy meter is extensively used to measure energy supplied to a single-phase circuit.

Energymeter is an integrating instrument which works on the principle of induction. It consists of

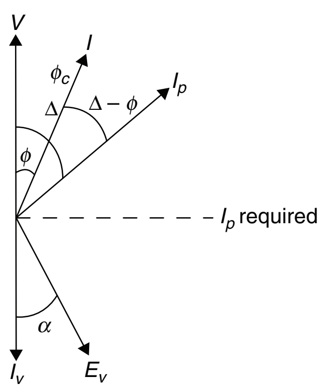
1. Driving mechanism
2. Rotating mechanism
3. Braking mechanism
4. Recording or Registering mechanism

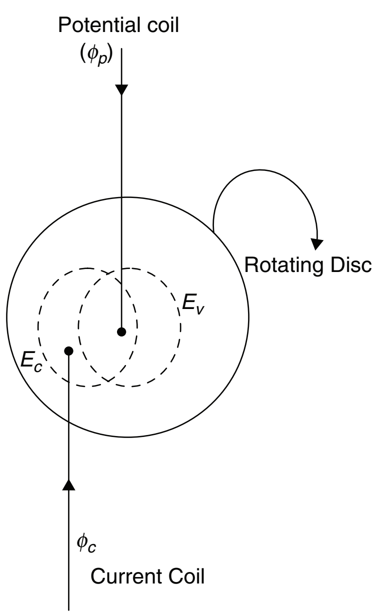
Driving Torque

Torque, $T_d \alpha I_1 I_2 \cos\Phi \dfrac{dM}{d\theta}$

Torque due to pressure coil current and current coil flux

$$T_d \alpha I \cos[(10 + \alpha) + (\Delta - \Phi)].$$



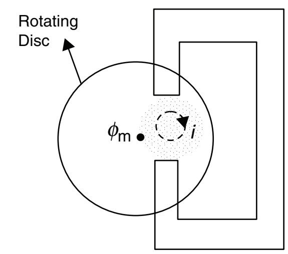


Approximate equation, $T_d \propto VI \sin(\Delta - \Phi)$

If $\Delta = 90°$, $T_d \propto VI \cos\Phi \propto$ power.

$$\text{Error} = VI\,[\sin(\Delta - \Phi) - \cos\Phi]$$

Braking Torque



Braking torque, $T_B \, \alpha \, (N\phi_M)\, Id$

where N = Speed of the rotating disc

Φ_m = Magnetic flux of paramount magnet

d = Distance between centre of rotating disc and permanent magnet

$$T_B \, \alpha \, N$$

At equilibrium $T_d = T_B$

$$\int VI \cos\phi dt = \int N dt$$

$$\text{Energy} = \int N dt$$

Braking magnet is used to produce the braking torque, which keeps the disc rotation constant speed depending on the load.

Speed adjustment: To decrease the speed, permanent magnet is kept far away from the disc.

$$T_B \, \alpha \, N \, \phi_m \, d$$

$$A \, \alpha \, \frac{T_B}{d\phi_m}$$

$$N \, \alpha \, \frac{1}{d}$$

Formula in Energy Meter

Energy = Power × Time = $VI \cos\Phi \times t$.

$$\text{Energy} = \frac{VI\cos\phi}{1000} \times \frac{t}{3600} \quad \text{kWhr}$$

where t in terms of seconds and 1 kWhr = 1 unit

$$\text{Energymeter constant, } K = \frac{\text{No. of revoultions}}{\text{kWhr}}$$

% Creeping error

$$= \frac{\text{No. of revoultions due to creeping}}{\text{Revolutions due to load}} \times 100.$$

% Energy meter error

$$= \frac{\text{Energy recorded} - \text{True energy consumed}}{\text{True energy consumed}} \times 100.$$

Errors and Compensation in Energy Meter

1. Phase lag/Quadrature/Inductive compensation/Lag coil. For measurement of true energy by the energy meter the potential coil should be highly inductive. But in practice the presence coil current lagging its voltage by 'Δ', which is less than 90°. To improve this, a lag coil is connected below the potential coil. Otherwise, shaded bands are similar to the lag coil. which are made of copper. By adjusting the position of shading bands its flux is adjusted so that resultant flux is kept at 90° with respect to voltage.
2. Light load or friction compensation: A shading loop is kept between central limb of the shunt magnet and the rotating disc which compensates light load and friction produced in the bearings.
3. Creeping: If the friction is over compensated by keeping the shading loop very nearer to the potential coil then the energy meter records the energy without any load, due to potential coil is energized, is called creeping.

   To avoid or reducing the effect of creeping two holes are kept in the opposite sides of the rotating discs.
4. Overvoltage compensation: The saturable shunt magnets are kept between the side limb and central limb of the shunt magnet. For normal voltages an air gap between the saturable shunt magnet and the side limbs produces maximum reluctance but under high voltages the reluctance breaks so the flux being diverted and hence meter will be protected.
5. Overcurrent Compensation: Under heavy load currents, the magnetic flux diverts through a saturable series magnet kept between the side limbs of series magnet hence meter will be protected.
6. Temperature Compensation: A permanent magnet made up of MUTEMP will be less affected by the surrounding temperature that is the reason braking magnet is made up of MU TEMP.

Fictitious or Phantom Loading

It is used to reduce the energy loss due to actual loading so that the energy meter can be tested at the desired load conditions at nominal supply voltage. A variable resistance is connected in series with the low voltage supply of current coil. By varying this, current through the current coil can be adjusted which is equivalent to the load current. This called fictitious loading.

Operating Principle

- The operation of the instrument depends on the passage of alternating current through suitably located coils. Producing a rotating magnetic field which interacts with a metallic disc suspended near to the coils and cause the disc to rotate.
- Current coil carries line current and produces field in phase with the line current.
- Pressure coil is made highly inductive so that the current through it lags behind supply voltage by 90°.
- A phase difference of 90° exists between the fluxes produced by the two coils.
- This sets up rotating field which interacts with the disc to cause it to rotate.

Construction

Series Magnet

- It consists of a number of U-shaped laminations assembled together to form a core. A thick wire of few turns is wound on both legs of U-shaped core.
- The wound coil is known as current coil and is connected in series with the load so that it carries load current.
- The series magnet is placed underside the aluminium disc and produces magnetic field proportional to and in phase with the current.

Shunt Magnet

- It consists of number of M-shaped laminations assembled together to form a core.
- A fine wire of large turns is wound on the control limb of this magnet. The wound coil is known as pressure coil and is connected across the load so that it carries current proportional to supply voltage. Shunt magnet is placed above aluminium disc.
- In order to obtain deflecting torque current in the pressure coil must lag behind supply voltage by 90°. This is obtained by placing a copper ring (compensating loop) over the control limb of the shunt magnet.
- This copper acts as short circuited transformer secondary. As its resistance the current circulating in the ring will lag nearly by 90° behind the supply voltage.

Braking Magnet

- The speed of aluminium is controlled to required value by the C-shaped permanent braking magnet. The magnet is mounted so that the disc revolves in the air gap between the polar extremities.
- As the disc rotates, currents are induced in the disc because it cuts the flux, produced by the braking magnet.
- The direction of current in disc is such that it opposes the rotation of the disc. Since the induced currents in the disc are proportional to the speed of the disc, braking torque is proportional to disc speed $T_B \propto N$.

Recording Mechanism

The number of revolutions of the disc is a measure of electrical energy passing through the meter and is recorded on dials which are geared to shaft.

Working

When energy meter is connected in the circuit to measure electrical energy the current coil carries the load current and pressure coil carries current proportional to supply voltage.

- The current coil produces eddy currents in the disc which react with the field due to the pressure coil. Thus a driving force is created which causes the disc to rotate.
- The braking magnet provides the braking torque on the disc. By altering the position of this magnet desired speed can be obtained.
- The spindle is geared to the recording mechanism so that electrical energy consumed in the circuit is directly registered in kWh.

Example 7: A single-phase energy meter is operating on 380, 50 Hz supply with a load of 15 A for two hours at u.p.f. The meter makes 1260 revolutions in that period. The meter constant is

(A) 695 rev/kWh (B) 1/111 rev/kWh
(C) 0.15 rev/kWh (D) 111 rev/kWh

Solution: (D)

$$\text{Energy consumed} = \frac{380\times15\times1\times2}{1000}$$

$$= 11.4 \text{ kWh}$$

Revolutions = 1260

$$\text{Meter constant} = \frac{1260}{11.4}$$

$$= 110.53$$

$$= 111 \text{ rev/kWh.}$$

Example 8: A 220 V, 6 A single-phase energy meter at u.p.f., half load, rated voltage makes 120 revolutions in 4 min. Calculate the error at half load (meter constant = 2400 revs/kWh)

(A) 13.04% slow (B) 12% fast
(C) 13.04% fast (D) 12% slow

Solution: (D)

$$\text{Energy consumed} = \frac{120}{2400} = 0.05 \text{ kWh}$$

Actual energy consumed

$$= \frac{220\times\left(\frac{6}{2}\right)\times1\times\left(\frac{4}{60}\right)}{1000}$$

$$= 0.044$$

Error = 0.05 – 0.044 = 0.006 kWh

$$\text{Hence meter is fast by } \frac{0.006}{0.05}\times100 = 12\%$$

Example 9: One single-phase wattmeter operating on 230 V and 10 A for 5 h makes 1380 revolutions. Meter constant is 150 power factor of the load will be

(A) 0.8 (B) 1
(C) 0.7 (D) 0.6

Solution: (A)

$$\text{Energy consumed} = \frac{1380}{150} = 9.2 \text{ kWh}$$

Actual energy consumed = 230 × 10 × 5

$$= 11.5 \text{ kW}$$

$$\cos\phi = \frac{9.2}{11.5} = 0.8.$$

Example 10: The direction of rotation of a household single-phase induction type wattmeter can be reversed by

(A) Reversing the supply terminals without opening the meter connection.
(B) Reversing the load terminals without opening the meter connection.
(C) Reversing either the supply or load terminals after opening the meter connections.
(D) Reversing both supply and load terminals after opening the meter connections.

Solution: (C).

Example 11: If a household induction energy meter is running slower it can be made to run faster by

(A) Light load adjustment.
(B) Making the position of the braking magnet come closer to the centre of the rotating disc.
(C) Making the position of the braking magnet to move away from the centre of the rotating disc.
(D) Lag adjustment.

Solution: (B).

Example 12: Which among the following options is true? Creeping in a single-phase induction type energymeter may be due to

(1) Overcompensation of friction
(2) Vibration
(3) Overvoltage

(A) 1 and 2 only
(B) 2 and 3 only
(C) 1 and 3 only
(D) 1, 2 and 3

Solution: (D).

Important Definitions

1. **Creep:** Continuous rotation of the meter even when there is no current flowing through the current coil and only pressure coil is energized due to over compensation of friction over voltage and vibration. It can be prevented by drilling two holes on diametrically opposite side of the disc.
2. Phantom loading for testing of energy meter is used to test meters having a large current rating for which loads may not be available.

3. Braking torque provided by a permanent magnet $T_B \propto$
   - Square of flux of the permanent magnet
   - Speed of the meter
   - Distance of permanent magnet from the centre of the revolving disc
4. In order to obtain true value of energy shunt magnet flux should lag behind applied voltage by 90°.
5. Maximum torque is produced when phase angle between two fluxes is 90°.
6. Shading bands are actuated to provide a constant torque irrespective of load and also compensates static friction.
7. Induction type energy meter can be slowed down by light load adjustment and is usually done at 1% of full-load current.

Exercises

Practice Problems I

Q No 1–4 consists of two statements one is assertion (A) and the other is Reason (R). Examine these two statements and select the answer using code given below

(A) Both A and R are individually correct and R is correct explanation of A
(B) Both A and R are individually correct and R is not the correct explanation of A
(C) A is true but R is false
(D) A is false but R is true

1. A: General purpose dynamometer type wattmeter cannot indicate the correct value of power at low p.f.
R: The pressure of self-inductance in the pressure coil circuit introduces an error in the indicated valve which increases with decrease in p.f. of the load.

2. A: Power factor meters commonly used are of dynamometer type.
R: Dynamometer type p.f. meter is more accurate than moving iron one.

3. A: A good energy meter should be provided with a low load fraction compensation loop arrangement.
R: The frictional force at bearings causes small errors at light loads.

4. A: For an energymeter, careful design and treatment of braking magnet during its manufacture are essential in order to ensure constancy of brake magnet strength during the use of meter.
R: Steady rotational speed of energymeter disc is directly proportional to flux of the brake magnet.

5. Creep error is associated with which one of the following meters:
(A) Moving iron meter
(B) Energymeter
(C) Electrodynamometer
(D) Wattmeter

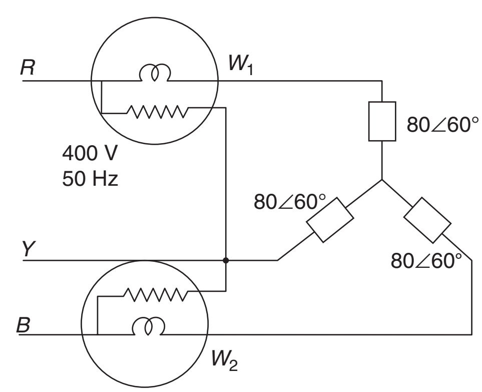
6. Holes drilled on diametrically opposite sides of the disc of an induction type energy meter to
(A) Avoid creep on no load
(B) Balance the disc
(C) Dissipate the energy due to eddy currents
(D) Increase the deflecting torque

7. In a 3-phase power measurements the reading of one of the wattmeters is zero when the power factor of the load is
(A) 0.866 (B) 0.707
(C) 0.5 (D) 0

8. Two wattmeters connected in a 3-ϕ circuit to measure power shows reading of 600 W and 300 W. The p.f. of the circuit is
(A) 0.5 (B) 0.707
(C) 0.866 (D) 1

9. A 230 V, 10 A single-phase energy meter makes 90 revs in 3 min at half full load, rated voltage and p.f. If the meter constant is 1800 rev/kWh then its error will be
(A) 13.04% slow
(B) 13.04% fast
(C) 15% slow
(D) 15% fast

10. Two wattmeters W_1 and W_2 are used to measure the power in a 3-ϕ star-connected circuit as shown below. If the phase sequence is RYB then wattmeter would read.



(A) 1732 W, 1268 W (B) 1500 W, 1500 W
(C) 0 W, 3000 W (D) 1250 W, 1750 W

Common Data for Questions 11 and 12:
A wattmeter is rated at 5 A and 12 V. The current coil has a resistance of 0.02 Ω and reactance of 0.04 Ω. The potential coil circuit may be assumed to be purely resistive having a resistance of 6230 Ω.

The load is 5 A at a p.f. of 0.15 lagging. The voltage across the load is 12 V.

11. The power lost in pressure coil is
(A) 0.01 W (B) 0.1 W
(C) 0.2 W (D) 0.023 W

12. The power indicated by wattmeter and error, respectively, are
(A) 9.023 W, 0.25 (B) 9.023 W, 2.5
(C) 9 W, 0.25 (D) 8.5 W, 0.25 W

13. A single-phase energymeter is operating on 200 V, 50 Hz supply with a load of 15 A at u.p.f. for 2 h. The meter makes 960 revolutions during this period. The meter constant is
(A) 0.16 rev/kWh
(B) 1/160 rev/kWh
(C) 256 rev/kWh
(D) 160 rev/kWh

14. The pressure coil of a wattmeter is connected across *R* phase and neutral of a 3-ϕ balanced system having phase sequence RYB. The current coil is connected in the *R* phase. The wattmeter measures a power of 6000 W. If the power of the circuit is 0.707 lag, and the wattmeter pressure coil is reconnected across *Y* and *B*, the power measured by the meter would be
(A) −273 W (B) 1273 W
(C) 1039 W (D) 1800 W

15. Two-wattmeter method is used to measure power in a 3-ϕ circuit operated at 400 V and p.f. of 0.35. The power measured by them s 10 kW. The individual readings of meters are
(A) 12.73 kW, −2.73 kW (B) 3 kW, 2 kW
(C) 13.26 kW, −3.26 kW (D) 11.28 kW, −1.28 kW

Practice Problems 2

1. Two wattmeters, W_1 and W_2, are used to measure power in a 3-ϕ circuit having a phase sequence of RYB. The current coil of W_1 is connected in *R* and that of W_2 is connected in *B*. If reading of W_2 is zero, the power factor of the circuit is
(A) 0.5 lead (B) 0.5 lag
(C) Zero lead (D) Zero lag

2. Holes are drilled on the opposite sides of the disc of an induction type energy meter to
(A) Avoid creep on no load
(B) Balance the disk
(C) Dissipate the energy due to eddy currents
(D) Increase the deflecting torque

3. A dynamometer type power factor meter has
(A) One current coil and one voltage coil
(B) One current coil and two voltage coils
(C) One voltage coil and two current coils
(D) Two current coils and two voltage coils

4. A 10 mA ammeter has a resistance of 50 Ω. It has to be converted to a 1 A ammeter. The value of shunt resistance is
(A) 5 Ω (B) 0.05 Ω
(C) 0.5 Ω (D) 50 Ω

5. High AC voltages are measured with
(A) Potential transformer with voltmeters
(B) Current transformers with voltmeters
(C) Inductive voltmeter
(D) Magnetic voltmeter

6. To measure a voltage above 100 kV, the type of measuring arrangement used is
(A) Potential transformer with voltmeter
(B) Capacitive potential transformer
(C) Current transformer with voltmeter
(D) All of these

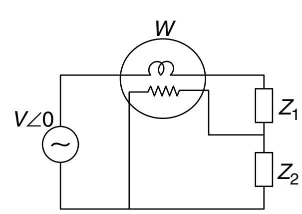
7. An electrodynamometer type instrument finds its major use as
(A) Indicator type of instrument only
(B) Standard instrument only
(C) Transfer instrument only
(D) Both as standard and transfer instrument

8. A current transformer has a rating of 200/5 A. The magnetizing and loss component of exciting current are 2 A and 1 A, respectively, and secondary has a burden of pure resistance. The transformation ratio at rated current is
(A) 40 (B) 40.1
(C) 40.2 (D) 41

9. An electrodynamometer type wattmeter is used to measure power in a circuit where the load current is small. Then,
(A) Voltage coil is connected on load side
(B) Current coil is connected on load side
(C) Does not matter whether current coil or voltage coil is connected on load side.
(D) None of these

10. Highly erroneous results are obtained if power factor of a non-sinusoidal wave form is measured by electrodynamometer type power factor meters. This is true of
(A) Single-phase meter only
(B) Three-phase meter only
(C) Both single- and three-phase meters
(D) None of these

11. A wattmeter is connected as shown in the figure



The wattmeter reads
(A) Zero
(B) Power consumed by Z_1
(C) Power consumed by Z_2
(D) Total power connected by Z_1 and Z_2

12. The error produced due to the inductance in the voltage coil of an electrodynamometer type wattmeter
(A) Increases as power factor decreases
(B) Decreases as power factor decreases
(C) Constant irrespective of the power factor of the circuit
(D) No relation between p.f. and inductance of voltage coil

13. The burden of a CT is expressed in
(A) Power rating of the resistor
(B) VA rating
(C) Current rating of secondary winding
(D) Current and voltage rating of secondary

14. The core flux in the current transformer under this operating condition is
(A) 56 μWb (B) 112 mWb
(C) 112 μWb (D) 56 mWb

Question no. 15 consists of two statements: one is Assertion (A) and the other is Reason (R). You have to examine these two statements and select the answer using the code given below.
(A) Both A and R are individually correct and R is the correct explanation of A.
(B) Both A and R are individually correct, but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

15. A: General purpose dynamometer type wattmeter cannot indicate the correct value of power at low power factors.
R: The pressure of self-inductance in the pressure coil circuit introduces an error in the indicated value which increases with decrease in power factor of the load.

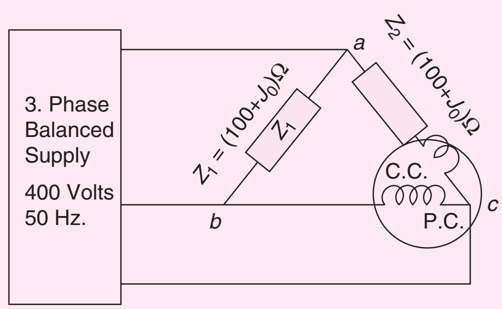
Previous Years' Questions

1. Two wattmeters, which are connected to measure the total power on a three-phase system supplying a balanced load, read 10.5 kW and –2.5 kW, respectively. The total power and the power factor, respectively, are **[2005]**
(A) 13.0 kW, 0.334
(B) 13.0 kW, 0.684
(C) 8.0 kW, 0.52
(D) 8.0 kW, 0.334

2. An energymeter connected to an immersion heater (resistive) operating on an AC 230 V, 50 Hz, AC single-phase source reads 2.3 units (kWh) in 1 hour. The heater is removed from the supply and now connected to a 400 V peak-to-peak square-wave source of 150 Hz. The power in kW dissipated by the heater will be **[2006]**
(A) 3.478 (B) 1.739
(C) 1.540 (D) 0.870

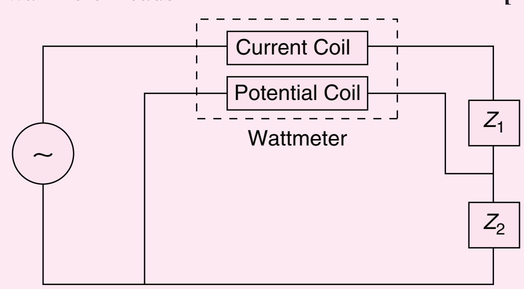
3. The pressure coil of a dynamometer type wattmeter is **[2009]**
(A) Highly inductive (B) Highly resistive
(C) Purely resistive (D) Purely inductive

4. The figure shows a three-phase delta-connected load supplied from a 400 V, 50 Hz, 3-phase balanced source. The pressure coil (PC) and current coil (CC) of a wattmeter are connected to the load as shown, with the coil polarities suitably selected to ensure a positive deflection. The wattmeter reading will be **[2009]**



(A) 0 (B) 1600 W
(C) 800 W (D) 400 W

5. A wattmeter is connected as shown in the figure. The wattmeter reads **[2010]**



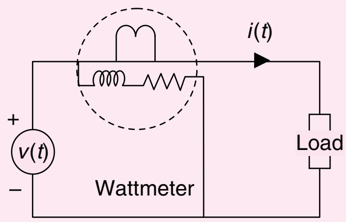
(A) Zero always
(B) Total power consumed by Z_1 and Z_2
(C) Power consumed by Z_1
(D) Power consumed by Z_2

6. The active power drawn by converter is **[2011]**
(A) 181 W (B) 500 W
(C) 707 W (D) 887 W

7. The input power factor of the converter is **[2011]**
(A) 0.31 (B) 0.44
(C) 0.5 (D) 0.71

8. A two-phase load draws the following phase currents: $i_1(t) = I_m \sin(\omega t - \phi_1)$, $i_2(t) = I_m \cos(\omega t - \phi_2)$. These currents are balanced if ϕ_1 is equal to **[2012]**
(A) $-\phi_2$ (B) ϕ_2
(C) $(\pi/2 - \phi_2)$ (D) $(\pi/2 + \phi_2)$

9. For the circuit shown in the figure, the voltage and current expressions are $v(t) = E_1 \sin(\omega t) + E_3 \sin(3\omega t)$ and $i(t) = I_1 \sin(\omega t - \varphi_1) + I_3 \sin(3\omega t - \phi_3) + I_5 \sin(5\omega t)$. The average power measured by the wattmeter is **[2012]**



(A) $\frac{1}{2} E_1 I_1 \cos\phi_1$

(B) $\frac{1}{2}[E_1 I_1 \cos\phi_1 + E_1 I_3 \cos\phi_3 + E_1 I_5]$

(C) $\frac{1}{2}[E_1 I_1 \cos\phi_1 + E_3 I_3 \cos\phi_3]$

(D) $\frac{1}{2}[E_1 I_1 \cos\phi_1 + E_1 I_1 \cos\phi_1]$

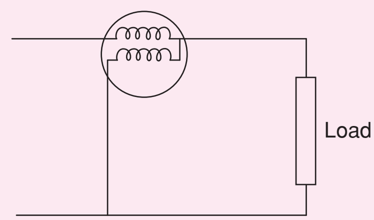
10. Power consumed by a balanced three-phase, 3-wire load is measured by the two-wattmeter method. The first wattmeter reads twice that of the second. Then the load impedance angle in radians is **[2014]**
(A) $\pi/12$ (B) $\pi/8$
(C) $\pi/6$ (D) $\pi/3$

11. An incandescent lamp is marked 40 W, 240 V. If resistance at room temperature (26°C) is 120 Ω, and temperature coefficient of resistance is 4.5×10^{-3}/°C, then its 'ON' state filament temperature in °C is approximately ________. **[2014]**

12. While measuring power of a three-phase balanced load by the two-wattmeter method, the readings are 100 W and 250 W. The power factor of the load is ________. **[2014]**

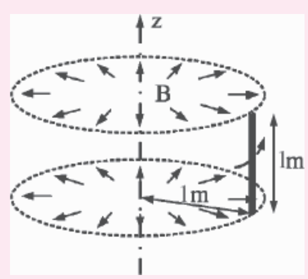
13. A 3-phase balanced load which has a power factor of 0.707 is connected to a balanced supply. The power consumed by the load is 5 kW. The power is measured by the two-wattmeter method. The readings of the two wattmeters are **[2015]**
(A) 3.94 kW and 1.06 kW
(B) 2.50 kW and 2.50 kW
(C) 5.00 kW and 0.00 kW
(D) 2.96 kW and 2.04 kW

14. The coils of a wattmeter have resistances 0.01 Ω and 1000 Ω; their inductances may be neglected. The wattmeter is connected as shown in the figure, to measure the power consumed by a load, which draws 25 A at power factor 0.8. The voltage across the load terminals is 30 V. The percentage error on the wattmeter reading is ______. **[2015]**



15. An energy meter, having meter constant of 1200 revolutions/kWh, makes 20 revolutions in 30 seconds for a constant load. The load, in kW, is ________. **[2016]**

16. A rotating conductor of 1m length is placed in a radially outward (about the z - axis) magnetic flux density (B) of 1 Tesla as shown in figure below. Conductor is parallel to and at 1m distance from the z - axis. The speed of the conductor in r.p.m. required to induce a voltage of 1 V across it, should be ________. **[2016]**



Answer Keys

Exercises

Practice Problems 1

1. A	**2.** D	**3.** C	**4.** C	**5.** B	**6.** A	**7.** C	**8.** C	**9.** C	**10.** C
11. D	**12.** A	**13.** D	**14.** C	**15.** A					

Practice Problems 2

1. A	**2.** A	**3.** B	**4.** C	**5.** A	**6.** B	**7.** D	**8.** C	**9.** B	**10.** A
11. C	**12.** D	**13.** B	**14.** C	**15.** A					

Previous Years' Questions

1. D	**2.** B	**3.** B	**4.** C	**5.** D	**6.** B	**7.** B	**8.** D	**9.** C	**10.** C
11. 2470	**12.** 0.8029		**13.** A	**14.** 0.14 to 0.16		**15.** 2	**16.** 9.54		