CHAPTER – 7

ELECTRICAL EQUIPMENTS

7.1 Wattmeter

A wattmeter is essentially an inherent combination of an ammeter and a voltmeter and, therefore, consists of two coils known as *current coil* and *pressure coil*. The operating torque in wattmeter is produced due to interaction of fluxes on account of currents in current and pressure coils. The current coil is inserted in series with the line carrying current to be measured and the pressure coil in series with a high non-inductive resistance R as shown in Figure 7.1.

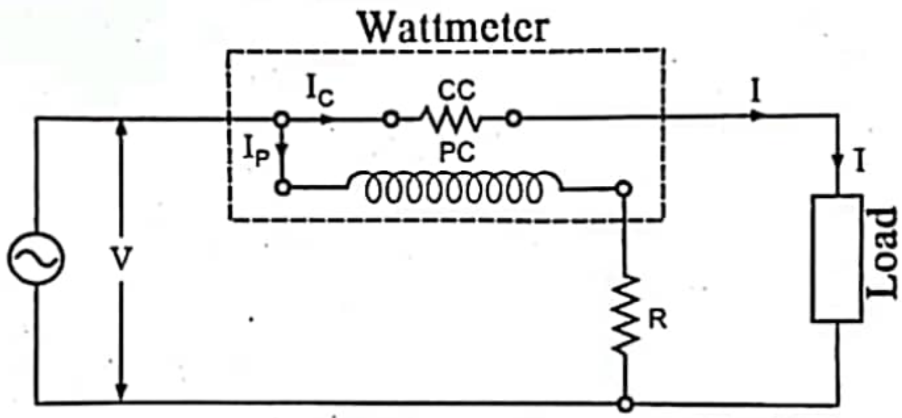

Figure 7.1 Wattmeter connections.

The wattmeter gives reading which is proportional to current flowing through its current coil, potential difference across potential coil, and cosine of the phase angle between voltage and current. The wattmeter indicates the power lost either in current coil or pressure coil in addition to load power. Normally, the power lost in current coil or in pressure coil is very small as compared with that measured and, therefore, can be neglected.

There are four types of wattmeter:

i. Dynamometer type wattmeter
ii. Induction type wattmeter
iii. Electrostatic type wattmeter
iv. Thermal type wattmeter

Dynamometer Type Wattmeter

It is used for the measurement of ac as well as dc power. It consists of the following parts:

i. **Fixed coil (current coil)**

Fixed coils are two identical circular coil of many turns through which a fraction of circuit current passes. These are divided into two equal parts so as to provide uniform magnetic field between them.

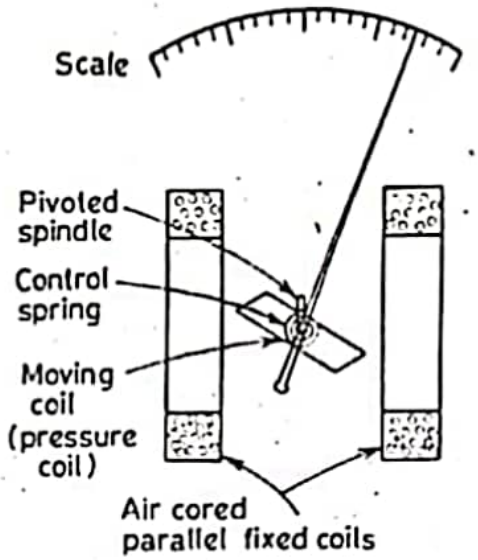

Figure 7.2 Constructional diagram of dynamometer-type wattmeter

ii. **Moving coil (pressure coil/potential coil)**

It is a circular coil of fine wire wound on a light frame mounted on a spindle and pivoted between bearings.

iii. **Control spring**

The moveable coil is controlled by two spiral springs.

iv. **Pointer**

Pointer is attached to the spindle which moves over a calibrated scale.

Working principle:

For dc measurement

When a dc voltage V is applied, let's suppose that the total current drawn by the load is I; I_1 and I_2 are the currents through current coil and potential coil respectively.

The magnetic field produces a current coil is proportional to current I_1 as I_2 is negligible compared to I_1. The pressure coil is connected across supply through a fixed resistor R. So, current in the pressure coil I_2 is proportional to the applied voltage. Hence, the deflection torque of the coil is given by

$T_d \propto \phi_1 \phi_2$

or, $T_d \propto IV$

$\therefore T_d \propto$ power

Hence, the deflection torque is directly proportional to the power consumed by the load in dc circuit.

For ac measurement

Let the voltage $v = V_m \sin\omega t$ is applied to the inductive load. Then, the current supplied by the source is given by

$i = I_m \sin(\omega t - \theta)$ where $\cos\theta$ is power factor.

The average deflecting torque is given by

$$T_{avg} \propto \frac{1}{2\pi}\int_0^{2\pi} v\, i\, d(\omega t)$$

$$\text{or, } T_{avg} \propto \frac{1}{2\pi}\int_0^{2\pi} V_m I_m \sin\omega t \sin(\omega t - \theta)\, d(\omega t)$$

$$\text{or, } T_{avg} \propto \frac{V_m I_m}{4\pi}\int_0^{2\pi} [\cos(\omega t - \omega t + \theta) - \cos(\omega t + \omega t - \theta)\, d(\omega t)$$

$$\text{or, } T_{avg} \propto \frac{V_m I_m}{4\pi}\int_0^{2\pi} [\cos\theta - \cos(2\omega t - \theta)\, d(\omega t)$$

$$\text{or, } T_{avg} \propto \frac{V_m I_m}{2}\cos\theta$$

$$\text{or, } T_{avg} \propto \frac{V_m\ I_m}{\sqrt{2}\sqrt{2}}\cos\theta$$

or, $T_{avg} \propto V_{rms}\, I_{rms} \cos\theta$

$\therefore T_{avg} \propto$ power

Thus, the average deflection torque is directly proportional to the power consumed by ac load.

7.2 Energy Meter

Energy meter (also known as *watt-hour meter*) is an integrating instrument used to measure the quantity of electric energy supplied to a circuit in given time.

Energy meters are generally of three types:

i. Electrolytic meters

ii. Motor meters

iii. Clock meters

Induction-Type Single-Phase Energy Meter

Induction-type single-phase energy meter is used for the measurement of single-phase AC. It consists of the following components:

- **Two laminated electromagnets**

  One is excited by the load current, and is called the *series magnet* (or the *current coil*) while the other is excited by the current proportional to voltage, and is called the *shunt magnet*. The shunt magnet is in parallel with the load. The alternating flux produced by the series magnet is directly proportional to the current and is in phase with it; while the flux produced by the shunt magnet lags behind the voltage by 90°.

- **A thin aluminium disc**

  It is mounted between the two magnets so that it cuts the leakage fluxes of both the magnets when current flows in the two magnets.

- **Lag adjuster**

  In this instrument, it is absolutely essential that the shunt coil flux lags behind the voltage exactly by 90°. This is accomplished by making the shunt coil as inductive as possible, and by adjustment of copper ring (called lag adjuster) fitted on the central limits of the shunt magnet.

- **Control spring**

  The instrument is spring controlled. The springs are fixed to the spindle of the rotating aluminium disc having a pointer. The scale is uniformly even and extends over 360°.

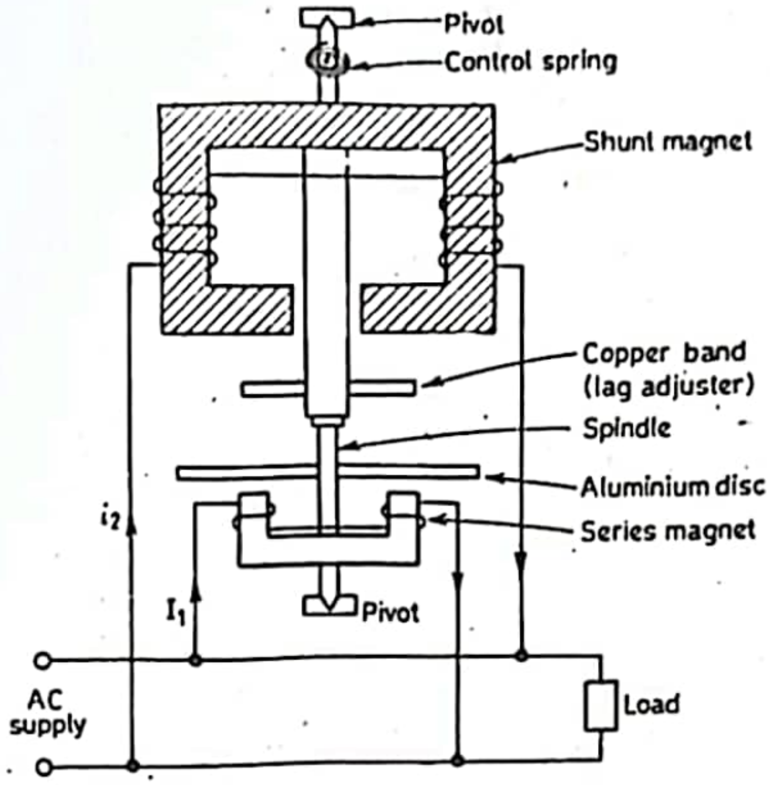

Figure 7.3 Induction-type single-phase energy meter.

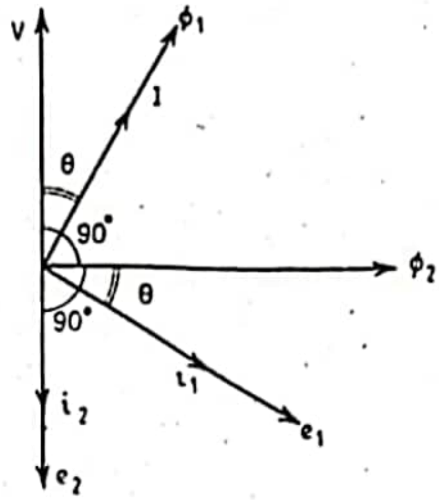

Figure 7.4 Vector diagram of the induction-type single-phase energy meter.

Operation:

The shunt magnet produces flux Φ_2 which after correct adjustment by the copper bands lags behind the applied voltage exactly by 90°. The series magnet produces flux Φ_1 which is in phase with the current I. The fluxes Φ_2 and Φ_1 induce emfs e_2 and e_1 respectively in the disc which lags behind the respective fluxes by 90°

as shown in Figure 7.4. The eddy-currents i_2 and i_1 set up by these induced emfs is in phase with the respective emfs (as shown by considering the inductance of the eddy-currents path to be negligible).

The aluminium disc is thus acted upon by two torques which are oppositely directed– one due to interaction of i_1 and Φ_2, and the other due to interaction of i_2 and Φ_1. From the vector diagram, it can be seen that the angle between Φ_2 and i_1 is θ, and the angle between Φ_1 and i_2 is $(180°–\theta)$.

$$\therefore\ T_1 = k_1\, \Phi_2\, i_1 \cos\theta,\ T_2 = k_2\, \Phi_1\, i_2 \cos(180° - \theta)$$

Average torque acting on the disc is

$$T = k_1\, \Phi_2\, i_1 \cos\theta - k_2\, \Phi_1\, i_2 \cos(180° - \theta)$$

$$= k_1\, \Phi_2\, i_1 \cos\theta + k_2\, \Phi_1\, i_2 \cos\theta$$

But $i_2 \propto V$, $\Phi_2 \propto V$, $i_1 \propto I$, and $\Phi_1 \propto I$

Therefore, $T \propto VI \cos\theta \propto$ power

i.e., the average torque acting on the aluminium disc is proportional to the power consumed by the circuit.

7.4 Power Factor Meter

Power factor meter is a device which measures the power factor of an electric circuit.

There are two types of power factor meters in common use:

i. Dynamometer type

ii. Moving iron type

Dynamometer Type Single Phase Power Factor Meter

It consists of two fixed coils CC connected in series carrying the load current (or a definite fraction of it) and two identical coils P_1 and P_2 of fine wire wound, pivoted on the same spindle and fixed at right angle to each other forming the pressure circuit and constituting the moving system. The pressure coil P_1 is connected across the supply through a non-inductive resistance R and pressure coil P_2 is connected across the supply through a highly inductive choke coil of inductance L. The values of non-inductive resistance R and inductance L are selected in such a way that for the normal frequency, the currents in the two pressure coils P_1 and P_2 are same. The pressure coils P_1 and P_2 move together and carry a pointer, which indicates the power factor of the circuit directly on the scale.

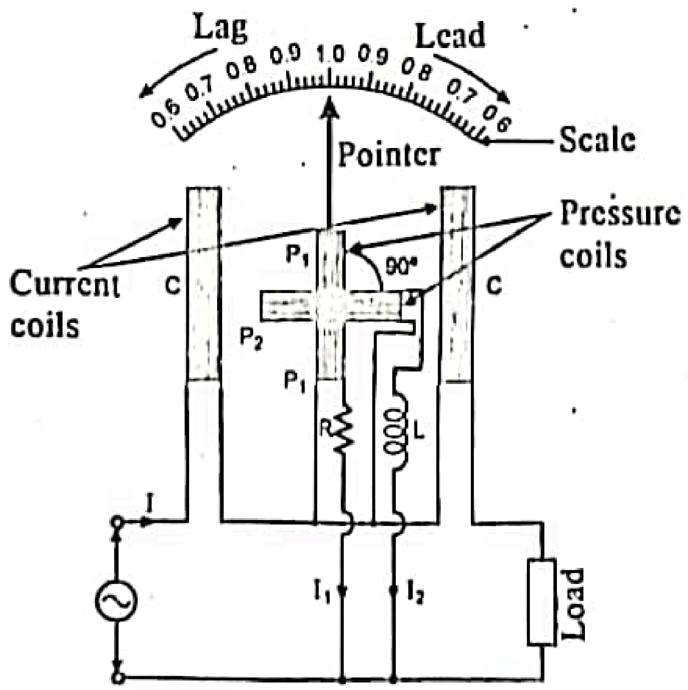

Figure 7.7 Dynamometer-type single-phase power factor meter.

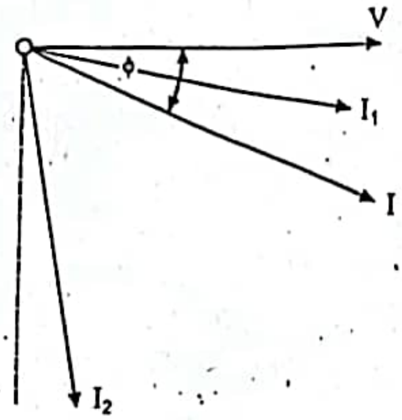

Figure 7.8 Phasor diagram.

Operation:

When the instrument is connected in the load circuit, current flows through moving coils P_1 and P_2 and fixed coils CC, the flux is set up by these coils which turns moving coils to such a position that the resultant torque experienced by these coils is zero.

If V is the supply voltage, I is the load current lagging behind the supply voltage V by an angle ϕ, and I_1 and I_2 are the currents flowing through coils P_1 and P_2 respectively, then

torque T_1 acting on coil P_1 is

$$T_1 = KVI \cos\phi \sin\theta$$

where θ is the angle between the moving part's equilibrium position and reference plane.

Similarly, torque T_2 acting on coil P_2 is

$$T_2 = KVI \cos(90° - \phi) \sin(90° + \theta)$$

In the equilibrium position,

$$T_1 = T_2$$

or, $KVI \cos\phi \sin\theta = KVI \cos(90° - \phi) \sin(90° + \theta)$

or, $\cos\phi \sin\theta = \sin\phi \cos\theta$

or, $\tan\theta = \tan\phi$

$\therefore \theta = \phi$

Hence, in equilibrium position, angular deflection of coils from reference plane is measurement of phase angle of the system.

7.6 Instrument Transformer

In power systems, currents and voltages are very large and so direct measurements are not possible as such currents and voltages are far too large for any instrument or meter of reasonable size and cost. Hence, it becomes imperative that these high voltages are stepped down with the help of transformers to values convenient for measurement. Transformers used in conjunction with instruments for measurement are called *instrument transformers*.

Instrument transformers are of two types:

i. Current (or series) transformer

ii. Potential (or parallel) transformer

i. Current transformer

Current transformer is used whenever the current of an ac circuit exceeds the safe current of the measuring instrument (e.g., ammeter, wattmeter, energy meter). It is step-up transformer having one or two turns of thick wire on primary side and large number of turns of thin wire on secondary side.

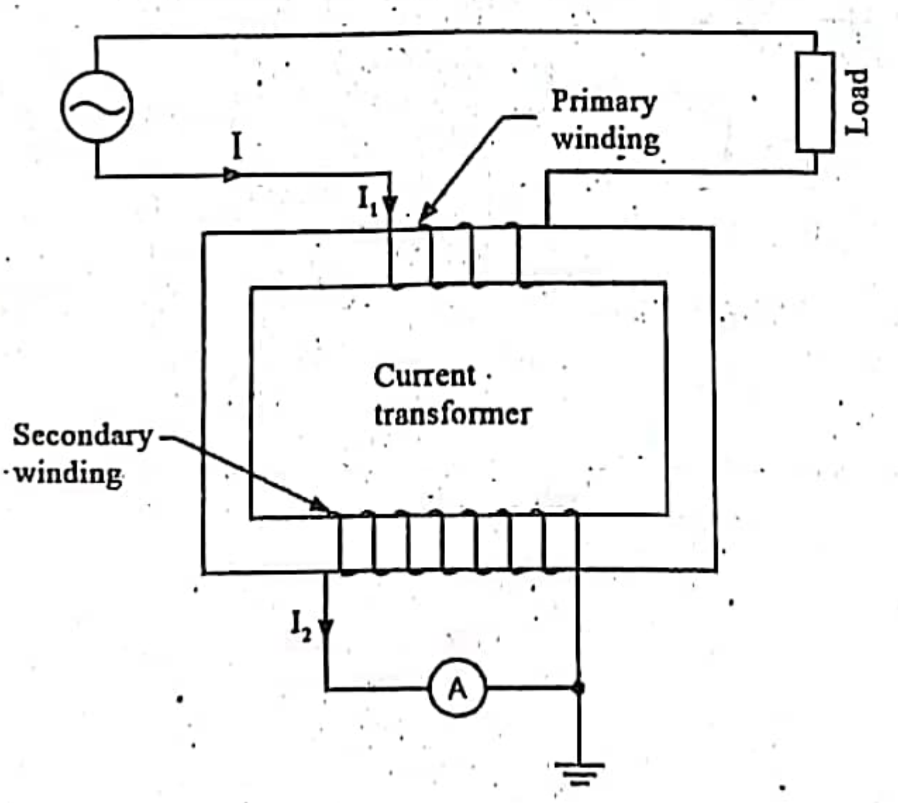

Figure 7.10 Connections diagram of current transformer.

We know,

$N_1 I_1 = N_2 I_2$

or, $\frac{I_1}{I_2} = \frac{N_2}{N_1}$

Here, $N_2 >> N_1$

So, $I_2 << I_1$

Thus, by using low range ammeter, we can measure the high current of circuit.

Effect of secondary open circuit of current transformer

Current transformers are always used with the secondary winding circuit closed through ammeters, wattmeter current coils, or relay coils. A precaution which should always be observed in using current transformers is the following:

Never open the secondary winding circuit of a current transformer while its primary winding is energized.

Failure to observe this precaution may lead to serious consequences both to the operating personnel and to the transformer. This is clear from the following:

Under normal operating conditions, both primary and secondary windings produce mmfs which act against each other. The secondary mmf is slightly less than the primary mmf, and consequently, the resultant mmf is small. This resultant mmf being the magnetizing mmf required for maintenance of flux in the core and to supply the iron losses. This resultant mmf is responsible for the production of flux in the core, and as this mmf is small, the flux density is quite low under normal operating conditions, and hence, a small voltage is induced in the secondary winding.

If the secondary winding is open-circuited when the primary winding is carrying current, the primary winding mmf remains the same while the opposing secondary winding mmf reduces to zero. Therefore, the resultant mmf is equal to the primary winding mmf I_1N_1 which is very large. This large mmf produces a large flux in the core till it saturates. This large flux linking the turns of the secondary winding would induce a high voltage in the secondary winding which could be dangerous to the transformer insulation (although modern current transformers are designed to withstand this voltage) and to the person who has opened the circuit. Also, the eddy current and hysteresis losses would be very high under these conditions, and due to this, the transformer may be overheated and completely damaged. Even if it does not happen, the core may become permanently magnetized and this gives appreciable ratio and phase angle errors.

ii. Potential transformer

Potential transformer is used wherever and whenever the voltage of an ac circuit exceeds 750 V as it is not easy to provide adequate insulation on measuring instruments for voltage above 750 V. It is step-down transformer having many number of turns of thin wires on primary side and one or two turns of thick wire on secondary side.

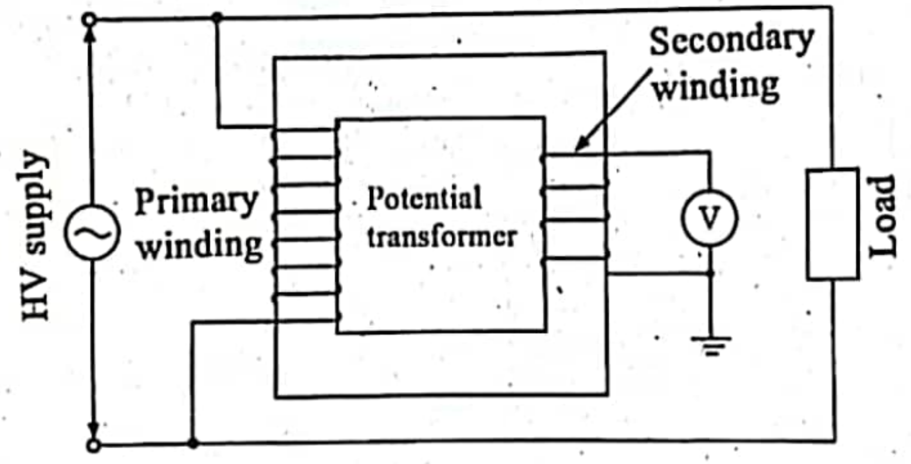

Figure 7.11 Connection diagram of a potential transformer

We know,

$$V_1 = \frac{N_1}{N_2} V_2$$

Here, $N_1 >> N_2$

So, $V_2 << V_1$

Thus, by using low range voltmeter, we can measure the high voltage of circuit.