UNIT-II

MEASUREMENT OF POWER AND ENERGY

Single phase dynamometer wattmeter:

An electro dynamo meter type wattmeter is used to measure power. It has two coils, fixed coil which is current coil and moving coil which is pressure coil or voltage coil. The current coil carries the current of the circuit while pressure coil carries current proportional to the voltage in the circuit. This is achieved by connecting a series resistance in voltage circuit. The connections of an electrodynamometer wattmeter in the circuit are shown in fig

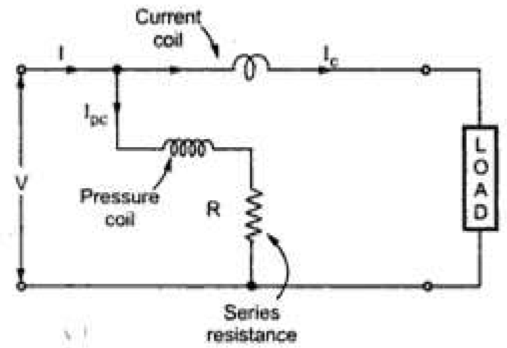


Fig: electro dynamometer wattmeter

I_C = current through current coil

I_{PC} = current through pressure coil

R = series resistance.

V= R.M.S. value of supply voltage

I= R.M.S. value of current.

Torque equation:

According to theory of electrodynamics instruments

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

Let v = instantaneous voltage = $V_m \sin\omega t = \sqrt{2} V \sin\omega t$

Due to the high resistance, pressure coil is treated to be purely resistive.

I_{PC}= instantaneous value = $\frac{V}{R_P}$

Where $R_P = r_{Pc} + R$

$I_{PC} = \frac{\sqrt{2}V}{R_P}$ sin ωt

If current coil lags the voltage by angle ∅ then its instantaneous value is

$i_c = ¿\ \sqrt{2} I_C$sin (ωt- ∅)

Now $i_1 = i_c$ and $i_2 = i_{pc}$ hence

$T_i = ¿\ ¿$sin ωt][$\sqrt{2} I_C$sin (ωt- ∅)] $\frac{dM}{d\theta}$

= 2$I_{PC} I_C$sin(ωt)sin(ωt- ∅)$\frac{dM}{d\theta}$

$T_i = I_{PC} I_C$[cos∅ - cos(2ωt-∅)$\frac{dM}{d\theta}$

T_d= average deflecting torque = $\frac{1}{T}\int_0^T T_i$d¿t)

= $\frac{1}{T}\int_0^T I_{PC} I_C$¿ ¿d¿t)

$T_d = I_{PC} I_C$cos∅$\frac{dM}{d\theta}$

Where $I_{PC} = \frac{V}{R_P}$

For a spring controlled wattmeter

T_c= k θ But $T_d = T_c$

$I_{PC} I_C$ cos∅ $\frac{dM}{d\theta}$ = k θ

$\theta = \frac{1}{K}$ $I_{PC} I_C$cos∅ $\frac{dM}{d\theta}$ = $K_1 I_{PC} I_C$ cos∅

Where $K_1 = \frac{1}{K}\frac{dM}{d\theta}$

$\theta = K_1 I_C \frac{V}{R_P}\cos\varnothing = K_2 P$

$K_2 = \frac{K_1}{R_P}$ and P $= V I_C \cos\varnothing$ = power

$\theta \propto P$

THREE PHASE DYNAMOMETER WATTMETER:

Similar to single phase dynamometer wattmeter, a three phase dynamometer wattmeter is available. It consists of two sets of fixed and moving coils, mounted together in one case. The moving coils are placed on the same spindle. The fig shows the construction of a three phase wattmeter.

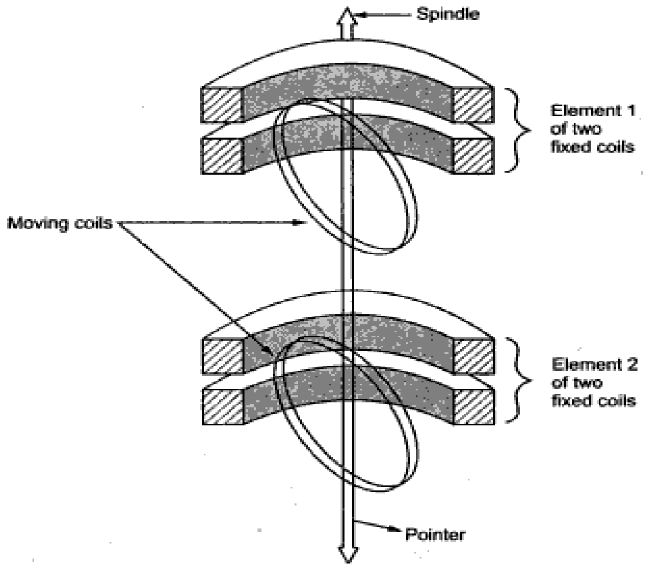


Fig: three phase two element wattmeter

Due to two sets of current and pressure coils, its connections are similar to the connections of two single phase wattmeters to measure three phase power. Each element experiences a torque which is proportional to the power measured by that element. The net torque on the moving system is the sum of the deflecting torques produced on each of the two elements.

$T_{d1} \propto W_1$ and $T_{d2} \propto W_2$

$T_d \propto (T_{d1} + T_{d2}¿ \propto (W_1 + ¿ W_2 ¿ \propto W$

T_d= total deflecting torque

W_1= power measured by element 1

W_2= power measured by element 2

W = total power

Thus the total deflecting torque is proportional to the total power.

As the coils are maintained very near each other, errors due to mutual interference are possible. To eliminate such errors, the laminated iron shield is placed between the two elements.

The compensation for mutual interference can be obtained by using the resistances as shown in fig. The value of R can be adjusted using R' to compensate the errors due to mutual effects between the two elements.

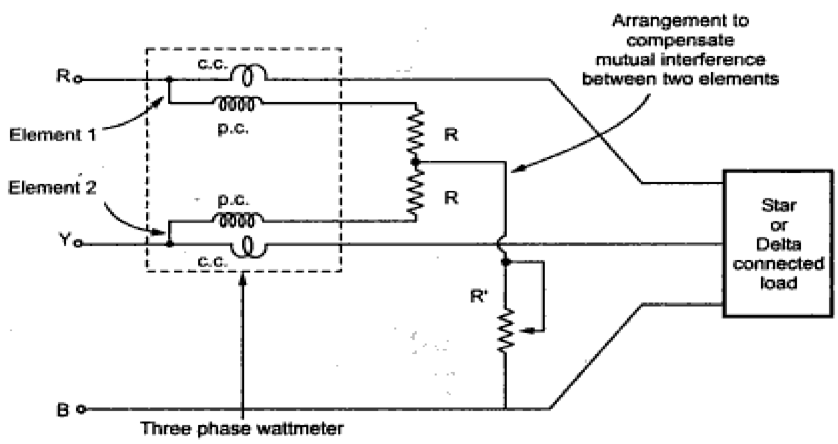


Fig: connections of three phase wattmeter

<u>Extension of range of wattmeter using instrument transformer:</u>

For very high voltage circuits, the high rating wattmeters are not available to measure the power. The range of wattmeter can be extended using instrument transformers, in such high voltage circuits. The connections are as shown in fig.

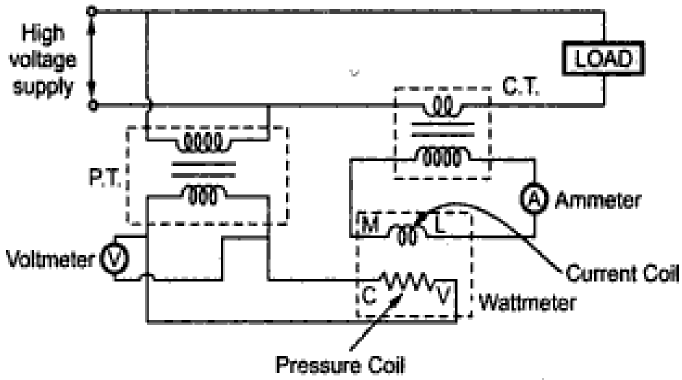


Fig: power measurement using C.T and P.T

The primary winding of C.T is connected in series with the load and secondary is connected in series with an ammeter and the current coil of a wattmeter.

The primary winding of P.T is connected across the supply and secondary is connected across voltmeter and the pressure coil of the wattmeter. One secondary terminal of each transformer and the casings are grounded.

Now both C.T and P.T have errors like ratio and phase angle error. For precise measurements, these errors must be considered. If not considered, these errors may cause inaccurate measurements. The correction must be applied to such errors to get the accurate results.

REACTIVE POWER MEASUREMENTS

A single wattmeter can also be used for three phase reactive power measurements. For example, the connection of a single wattmeter for 3-phase reactive power measurement in a balanced three phase circuit is as shown in figure 4.6.The current coil of the wattmeter is inserted in one line and the potential coil is connected across the other two lines. Thus, the voltage applied to the voltage coil is $V_{RB}=V_R-V_B$, where V_R and V_B are the phase voltage values of lines R and B respectively, as illustrated by the phasor diagram of figure

The reading of the wattmeter, W3ph for the connection shown in figure 3.6 can be obtained based on the phasor diagram of figure, as follows:

Wattmeter reading, **Wph** = Iy VRB

$= I_y V_L \cos(90+Ø)$

$= -\sqrt{3} V_{ph} I_{ph} \sin Ø$

$= -\sqrt{3}$ (Reactive power per phase)

Thus, the three phase power, $\mathbf{W_{3ph}}$ is given by,

W3ph = (VArs/phase)

$= 3 [W_{ph}/-\sqrt{3}]$

$= -\sqrt{3}$ (wattmeter reading)

THREE PHASE REAL POWER MEASUREMENTS

The three phase real power is given by,

$$P_{3ph} = 3 V_{ph} I_{ph} \cos Ø$$

or

$$P_{3ph} = \sqrt{3} V_L I_L \cos Ø$$

The three phase power can be measured by using one wattmeter, two wattmeters or three wattmeters in the measuring circuit. Of these, the two wattmeter method is widely used for the obvious advantages of measurements involved in it as discussed below.

1. Single Wattmeter Method

Here only one wattmeter is used for measurement of three phase power. For circuits with the balanced loads, we have: W_{3ph}=3(*wattmeter reading).* For circuits with the unbalanced loads, we have: W_{3ph}=sum of the three readings obtained separately by connecting wattmeter in each of the three phases. If the neutral point is not available (3 phase 3 wire circuits) then an artificial neutral is created for wattmeter connection purposes. Instead three wattmeters can be connected simultaneously to measure the three phase power. However, this involves more number of meters to be used for measurements and hence is not preferred in practice. Instead, the three phase power can be easily measured by using only two wattmeters, as discussed next.

2. Two Wattmeter Method

The circuit diagram for two wattmeter method of measurement of three phase real power is as shown in the figure 34.7. The current coil of the wattmeters W_1 and W_2 are inserted respectively in R and Y phases. The potential coils of the two wattmeters are joined together to phase B, the third phase. Thus, the voltage applied to the voltage coil of the meter, W_1 is $V_{RB}= V_R-V_B$, while the voltage applied to the voltage coil of the meter, W_2 is $V_{YB}=V_Y-V_B$, where, V_R, V_B and V_C are the phase voltage values of lines R, Y and B respectively, as illustrated by the phasor diagram of figure 3.8. Thus, the reading of the two wattmeters can be obtained based on the phasor diagram of figure 4.8, as follows:

$$W_1 = IR\ VRB$$

$$= I_L\ V_L \cos(30 - Ø)$$

$$W_2 = IY\ VYB$$

$$= I_L\ V_L \cos(30 + Ø)$$

Hence, $W_1+W_2 = \sqrt{3}\ V_L\ I_L \cos Ø = P_{3ph}$

And $W_1-W_2 = V_L\ I_L \sin Ø$

So that then,

$$\textbf{Tan Ø} = \sqrt{3}\ [W_1-W_2]/[W_1+W_2]$$

<u>Types of power factor meters:</u>

The power in single phase A.C circuit is given by

$$P = VI \cos\varnothing$$

$\cos\varnothing$ = power factor of the circuit.

Thus by using precise voltmeter, ammeter and wattmeter in the circuit, the readings of V, I and P can be obtained. Then power factor can be calculated as

$$\cos\varnothing = \frac{P}{VI}$$

(i) Single phase electrodynamometer type power factor meter:

The construction of electrodynamometer type power factor meter is similar to the construction of electrodynamometer type wattmeter. The basic construction of electrodynamometer type power factor meter is shown in fig.

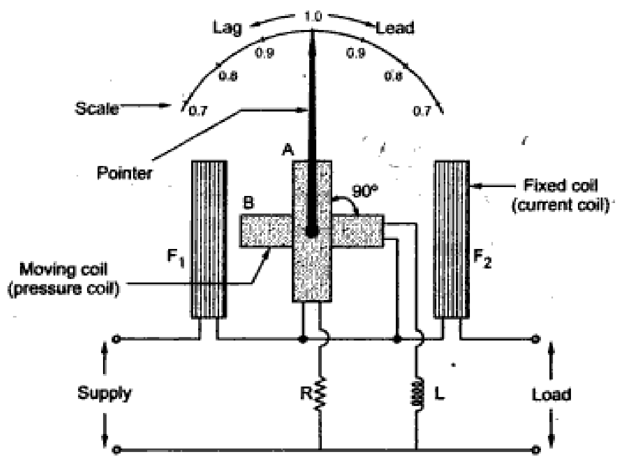


Fig: single phase electrodynamometer type power factor meter

The F1 and F2 are the two fixed coils which are connected in series. The A and B are the two moving coils which are rigidly connected to each other so that their axes are at 90 degrees to each other. The moving coils A-B move together and carry the pointer which indicates the power factor of the circuit.

The fixed coils F1 and F2 carry the main current in the circuit. If the current is large, the fraction of the current is passed through the fixed coils. Thus the magnetic field produced by the fixed coils is proportional to the main current.

The moving coils A and B are identical. These are connected in parallel across the supply voltage and hence called pressure coils or voltage coils. The currents through coils A and B are proportional to the supply voltage. The coil A and B are proportional to the supply voltage. The coil A has non-inductive resistance R in series with it while the coil B has an inductance L in series with it.

The values of Rand L are so adjusted that the coils A and B carry equal currents at normal frequency.

So at normal frequency R= ωL. The current through coil A is in phase with the supply voltage while the current through coil B lags the supply voltage by nearly 90 degrees due to highly inductive nature of the circuit. Due to L, current through coil B is frequency dependent while current through coil A is frequency independent.

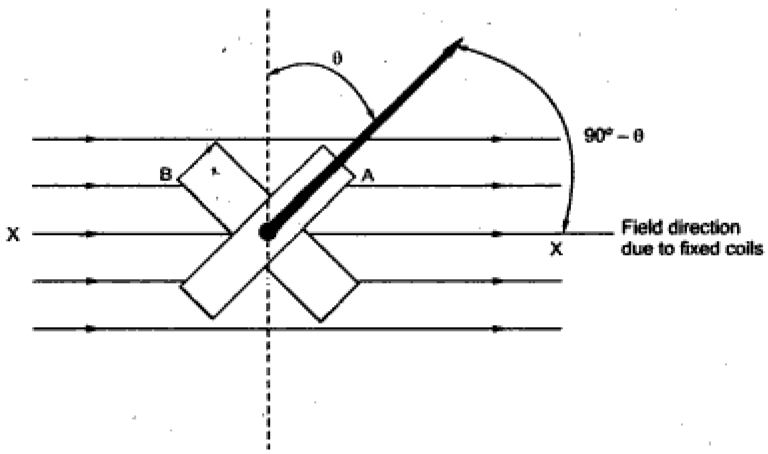
<u>Working of meter:</u>

Consider the position of the moving system as shown in fig.

Assume that the current through coil B lags the voltage exactly by 90 degrees.

Also assume that the field produced by the fixed coils is uniform and in the direction X-X as shown in fig.

Due to interaction of the fields produced by the currents through various coils, both the coils A and B experience a torque. The windings are arranged in such a manner that the torques experienced by coil A and B are opposite to each other. Hence the pointer attains equilibrium position when these two torques are equal



The torque on each coil, for a given coil current will be maximum when the coil is parallel to the field produced by F1-F2 i.e. direction x-x.

Let ∅ = power factor angle

θ= angle of deflection

The θ is measured from the vertical axis, in the equilibrium position.

Similar to a dynamometer type wattmeter, torque on coil A is given by

T_A= KVI cos ∅ cos(90-θ)

Where K = constant

The equation is similar to the torque equation of a dynamometer type instrument. The current through coil A is in phase with system voltage V and it moves in a magnetic field which is proportional to system current I and $\frac{dM}{d\theta}$ which is generally constant for radial field is not constant for parallel field and is proportional to cos(90-θ). Similarly current in coil B lags the supply voltage by 90degrees and it moves in same field. Hence the torque on B is proportional to cos(90-∅) i.e. sin∅ and cosθ.

T_B= KVI sin ∅ cosθ

In equilibrium position $T_A = T_B$

$$\cos\varnothing \cos(90-\theta) = \sin\varnothing \cos\theta$$

$$\sin\theta = \tan\varnothing \cos\theta$$

$$\tan\theta = \tan\varnothing$$

Thus the angular position taken up by the moving coils is equal to the system power factor angle. The scale of the instrument can then be calibrated in terms of power factor values.

<u>Three phase electrodynamometer type power factor meter</u>:

In three phase electrodynamometer type power factor meter also there are two fixed coils F1 and F2. The two moving coils A and B are so arranged that the angle between their planes is 120^0. These coils are connected between R and Y while the coil B is connected between R and B as shown in fig. as the phase difference between the current through two moving coils is automatically created due to phase difference between the supply lines hence external Rand L are not required as in case of single phase circuit.

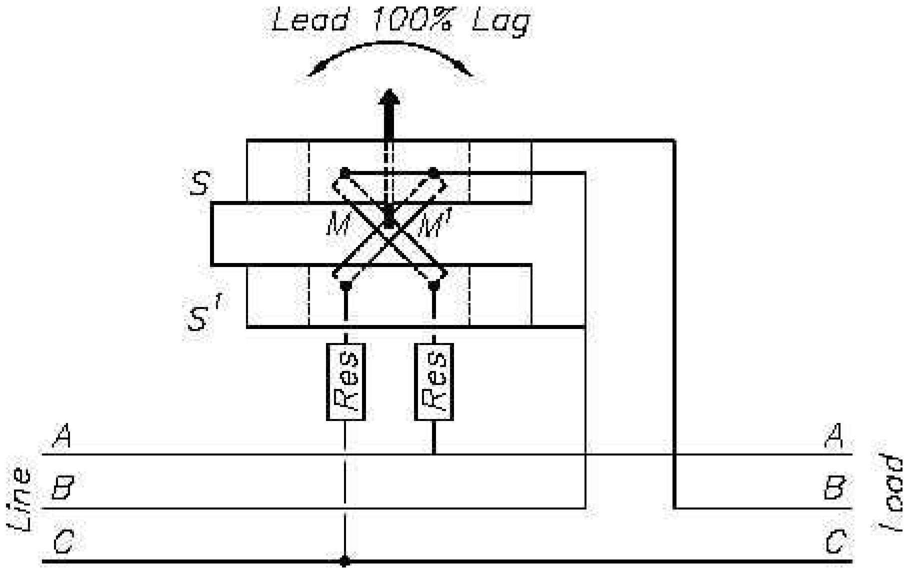


Fig: Three phase electrodynamometer type power factor meter:

The moving coils A and B are connected to the supply lines Y and B through series resistance.

Moving iron type power factor meter:

There are two types of moving iron power factor meters

(i) Rotating field type

(ii) Alternating field type

Rotating field type moving iron power factor meter:

It consists of three fixed coils whose axes are displaced from each other by 120^0. The coils are supplied from a three phase supply through current transformers (C.T). The fig shows the construction of rotating field type moving iron power factor meter. The coils F1, F2 and F3 are the fixed coils. The coil F1 is supplied from phase R, coil F2 is from phase Y and coil F3 is from phase B. the coil Q is placed at the centre of the three fixed coils and is connected across any two lines of the supply through a series resistance.

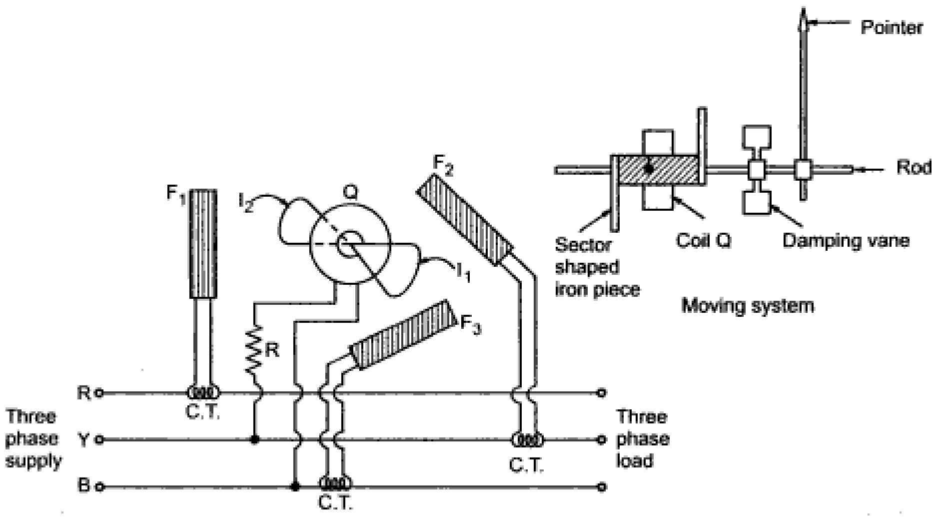


Fig: Rotating field type moving iron power factor meter

Inside coil Q, there is a short provided iron rod. The rod carries two sector shaped vanes I1, I2 at its ends. The same rod carries damping vanes and a pointer. The control springs are absent. The moving system is shown in fig.

The coil Q and the iron system produce an alternating flux which interacts with the flux produced by the coils F1, F2 and F3. Due to resistance R, the current in the coil Q is in phase with the supply voltage. So the deflection of the moving system is approximately equal to the power factor angle of the three phase circuit. The flux produced by the coils F1,F2,F3 is rotating magnetic flux which creates an induction motor action. It tries to keep moving system continuously rotating. But it sets moving system in a definite position due to use of high resistivity iron parts. Such high resistivity parts reduce the induced currents and stops the continuous rotation.

The meter can be used for balanced loads. It is also called Westinghouse power factor meter.

Alternating field type moving iron power factor meter:

This instrument consists of 3 moving irons and vanes, which are fixed to the common spindle. The spindle carries the damping vanes and the pointer. The moving iron vanes are sector shaped similar to those used in the rotating field type meter. The arcs of these sectors have an angle of 120^0 with respect to each other. These iron sectors are separated from each other on the spindle by the non-magnetic pieces denoted as S. the fig shows the construction of this instrument where Q1, Q2, Q3 are the iron sectors. These iron sectors are magnetized by the coils P1, P2, P3. These are voltage coils.

These coils are connected across the three phases. Thus the currents through them are proportional to the phase voltages of the three phase system.

The current coil is divided into two equal parts F1,F2, parallel to each other. The current coil carries one of the three line currents. One part F1of the current coil is on one side of the moving system and other F2 on the other side.

When connected in the circuit, the moving system moves and attains such a position in which mean torque on one of the iron pieces gets naturalized by the torques produced by the other two iron pieces. In this position, the deflection of the pointer is equal to phase angle between the currents and voltages of the three phase system. The instrument is used for the balanced loads but can be modified for unbalanced loads. The voltage coils are at different levels hence the resultant flux is not rotating but alternating.

This instrument is also called nalder-lipman power factor meter.

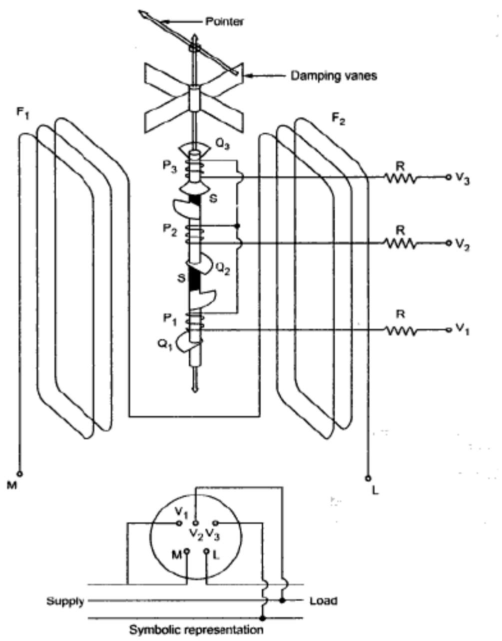


Fig: Alternating field type moving iron power factor meter

Single phase induction type energy meter

It works on the principle of induction i.e. on the production of eddy currents in the moving system by the alternating fluxes. These eddy currents induced in the moving system interact with each other to produce a driving torque due to which disc rotates to record the energy.

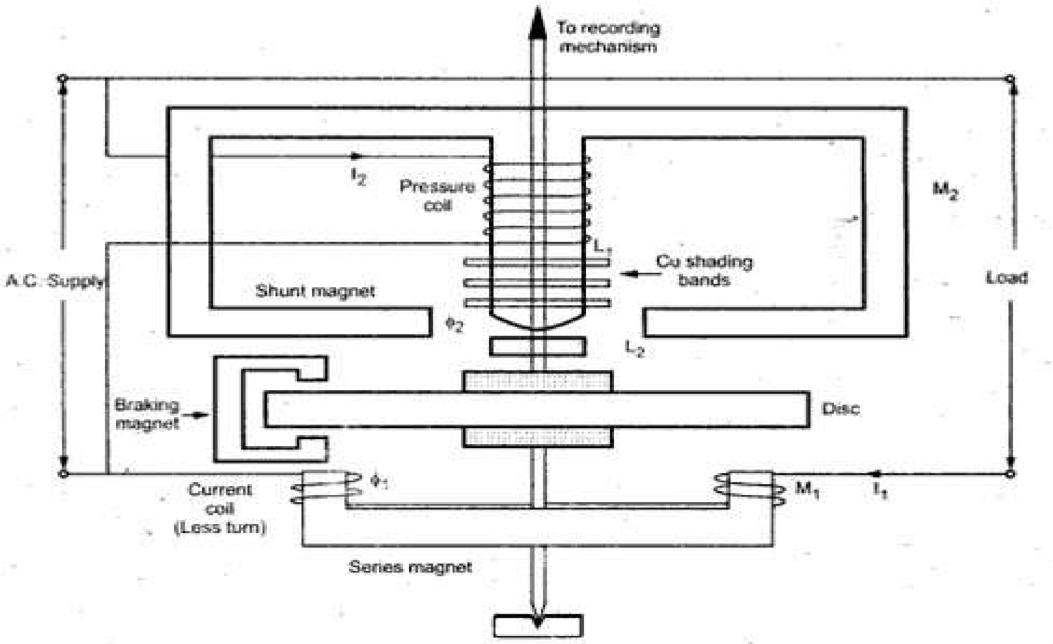


Fig. 4.1 Induction type single phase energymeter

In the energy meter there is no controlling torque and thus due to driving torque only, a continuous rotation of the disc is produced. To have constant speed of rotation braking magnet is provided.

Construction:

There are four main parts of operating mechanism

1) Driving system

2) Moving room

3) Braking system

4) Registering system.

1) Driving system: It consists of two electromagnets whose core is made up of silicon steel laminations. The coil of one of the electromagnets, called current coil, is excited by load current which produces flux further. The coil of another electromagnetic is connected across the supply and it carries current proportional to supply voltage. This is called pressure coil. These two electromagnets are called as series and shunt magnets respectively.

The flux produced by shunt magnet is brought in exact quadrature with supply voltage with the help of copper shading bands whose position is adjustable.

2) Moving system: Light aluminum disc mounted in a light alloy shaft is the main part of moving system. This disc is positioned in between series and shunt magnets. It is supported between jewel bearings. The moving system runs on hardened steel pivot. A pinion engages the shaft with the counting mechanism. There are no springs and no controlling torque.

3) Braking system: a permanent magnet is placed near the aluminum disc for barking mechanism. This magnet reproduced its own field. The disc moves in the field of this magnet and a braking torque is obtained. The position of this magnet is adjustable and hence braking torque is adjusted by shifting this magnet to different radial positions. This magnet is called braking magnet.

4) Registering mechanism: It records continuously a number which is proportional to the revolutions made by the aluminum disc. By a suitable system, a train of reduction gears, the pinion on the shaft drives a series of pointers. These pointers rotate on round dials which an equally marked with equal division.

Working: since the pressure coil is carried by shunt magnet M2 which is connected across the supply, it carries current proportional to the voltage. Series magnet M1 carries current coil which carries the load current. Both these coils produced alternating fluxes ∅1 and ∅2 respectively. These fluxes are proportional to currents in their coils. Parts of each of these fluxes link the disc and induce e.m.f. in it. Due to these e.m.f.s eddy currents are induced in the disc. The eddy current induced by the electromagnet M_2 react with magnetic field produced by M_1 react with magnetic field produced by M_2. Thus each portion of the disc experiences a mechanical force and due to

Motor action, disc rotates. The speed of disc is controlled by the C shaped magnet called braking magnet. When disc rotates in the air gap, eddy currents are induced in disc which opposes the cause producing them i.e. relative motion of disc with respect to magnet. Hence braking torque Tb is generated. This is proportional to speed N of disc. By adjusting position of this magnet, desired speed of disc is obtained. Spindle is connected for recording mechanism through gears which record the energy supplied.

<u>Driving and braking torques:</u>

The phasor diagram is shown in below

V= supply voltage.

I= load current

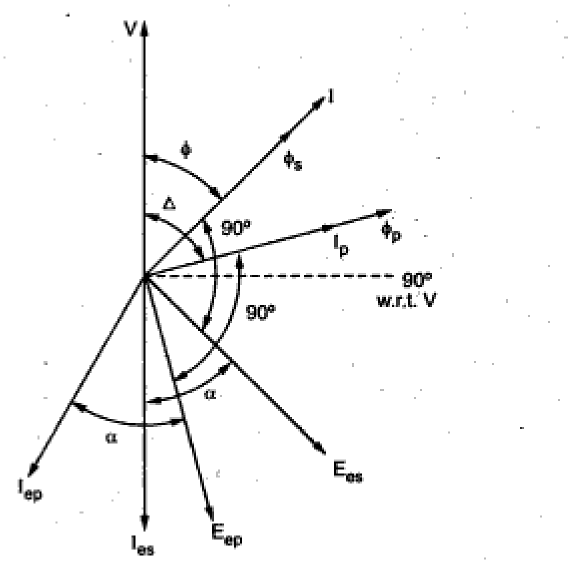


Fig: phasor diagram of single phase induction type energy meter

I_P= pressure coil current.

Δ= phase angle between v and I_P

$\Delta=90^0$

E_{ep}= eddy e.m.f induced due to $\varnothing_p$

E_{es}= eddy e.m.f induced due to $\varnothing_s$

α= phase angle of eddy currents.

I_{ep}= eddy current due to E_{ep}

I_{es}= eddy current due to E_{es}

The current $I_p$lags V by Δ and Δ is made 90^0 using copper shading bands. The current I lags by $\varnothing$ which is depends on the load. The flux $\varnothing_s$ and I are in phase. The E_{ep} lags $\varnothing_p$ by 90^0 while E_{es} lags $\varnothing_s$ by 90^0. The eddy currents $I_{ep}$and I_{es} lags E_{ep} and E_{es} respectively by angleα.

The interaction between $\varnothing_p$ and I_{es} produces torque T1.

The interaction between $\varnothing_s$ and I_{ep} produces torque T2.

T1$\propto\varnothing_p\, I_{es}$cos($\varnothing_p^{¿}\, I_{es}$) and T2$\propto\varnothing_s\, I_{ep}$cos($\varnothing_s^{¿}\, I_{ep}$)

$\varnothing_p^{¿}\, I_{es} = \alpha+\varnothing$ and $\varnothing_s^{¿}\, I_{ep}$ = 180-$\varnothing$+α

$T_d\propto$ t1-t2 $\propto$ {[$\varnothing_p I_{es}\cos(\alpha+\varnothing)$]-[$\varnothing_s I_{ep}$cos(180-$\varnothing$+$\alpha$)]}

Now $\varnothing_p\propto$ V, $\varnothing_s\propto I$, $I_{es}\propto\varnothing_s\propto I$, $I_{ep}\propto\varnothing_p\propto V$

$T_d\propto$VI[cos($\alpha+\varnothing$¿-cos (180-$\varnothing$+α)]

$\propto$VI[cosαcos$\varnothing-$¿sinαsin$\varnothing$-(cos(180-$\varnothing$)cosα-sin(180-$\varnothing$)sinα
]

$\propto$VI cosαcos$\varnothing$

$T_d = K_3$ VIcos∅

If Δ is considered

$T_d \propto$ VI[sin(Δ − ∅¿

The breaking torque is due to eddy currents induced in the aluminum disc. Magnitude of eddy currents is proportional to the speed N of the disc. Hence the braking torque T_b is also proportional to the speed N.

$T_b \propto N$

$T_b = K_4 N$.

ERRORS AND COMPENSATION:

Speed error: Due to the incorrect position of the brake magnet, the braking torque is not correctly developed. This can be tested when meter runs at its full load current alternatively on loads of unity power factor and a low lagging power factor. 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 and the shielding loop. If the meter runs fast on inductive load and correctly on non-inductive load, the shielding loop must be moved towards the disc. On the other hand, if the meter runs slow on non-inductive load, the brake magnet must be moved towards the center of the disc.

Meter phase error: An error due to incorrect adjustment of the position of shading band results an incorrect phase displacement between the magnetic flux and the supply voltage (not in quadrature). This is tested with 0.5 p.f. load at the rated load condition. By adjusting the position of the copper shading band in the central limb of the shunt magnet this error can be eliminated.

Friction error: An additional amount of driving torque is required to compensate this error. The two shading bands on the limbs are adjusted to create this extra torque. This adjustment is done at low load (at about 1/4th of full load at unity p.f.).

v) Creeping: In some meters a slow but continuous rotation is seen when pressure coil is excited but with no load current flowing. This slow revolution records some energy. This is called the creep error. This slow motion may be due to (a) incorrect friction compensation, (b) to stray magnetic field (c) for over voltage across the voltage coil. This can be eliminated by drilling two holes or slots in the disc on opposite side of the spindle. When one of the holes comes under the poles of shunt magnet, the rotation being thus limited to a maximum of 180^0. In some cases, a small piece of iron tongue or vane is fitted to the edge of the disc. When the position of the vane is adjacent to the brake magnet, the attractive force between the iron tongue or vane and brake magnet is just sufficient to stop slow motion of the disc with full shunt excitation and under no load condition.

(v) Temperature effect: Energy meters are almost inherently free from errors due to temperature variations. Temperature affects both driving and braking torques equally (with the increase in temperature the resistance of the induced-current path in the disc is also increases) and so produces negligible error. A flux level in the brake magnet decreases with increase in temperature and introduces a small error in the meter readings. This error is frequently taken as negligible, but in modern energy meters compensation is adopted in the form of flux divider on the break magnet.

Energy meter constant K is defined as K = No. of revolutions/ kwh

In commercial meters the speed of the disc is of the order of 1800 revolutions per hour at full load.

THREE PHASE ENERGY METER:

In a three phase, four wire systems, the measurement of energy is to be carried out by a three phase energy meter. For three phase, three wire system, the energy measurement can be carried out by two element energy meter, the connections of which are similar to the connection of two wattmeters for power measurements in a three phase, three wire system. So these meters are classified as i) three element energy meter and ii) two element energy meter

Three phase energy meter:

This meter consists of three elements. The construction of an individual element is similar to that of a single phase energy meter. The pressure coils are denoted as P1,P2 and P3. The current coils are denoted as C1,C2, C3. All the elements are mounted in a vertical line in common case and have a common spindle, gearing and registering mechanism. The coils are connected in such a manner that the net torque produced is sum of the torques due to all the three elements. These are employed for three phase, four wire system. where fourth wire is a neutral wire.

The current coils are connected in series with the lines while pressure coils are connected across a line and a neutral. Fig shows the three phase energy meter.

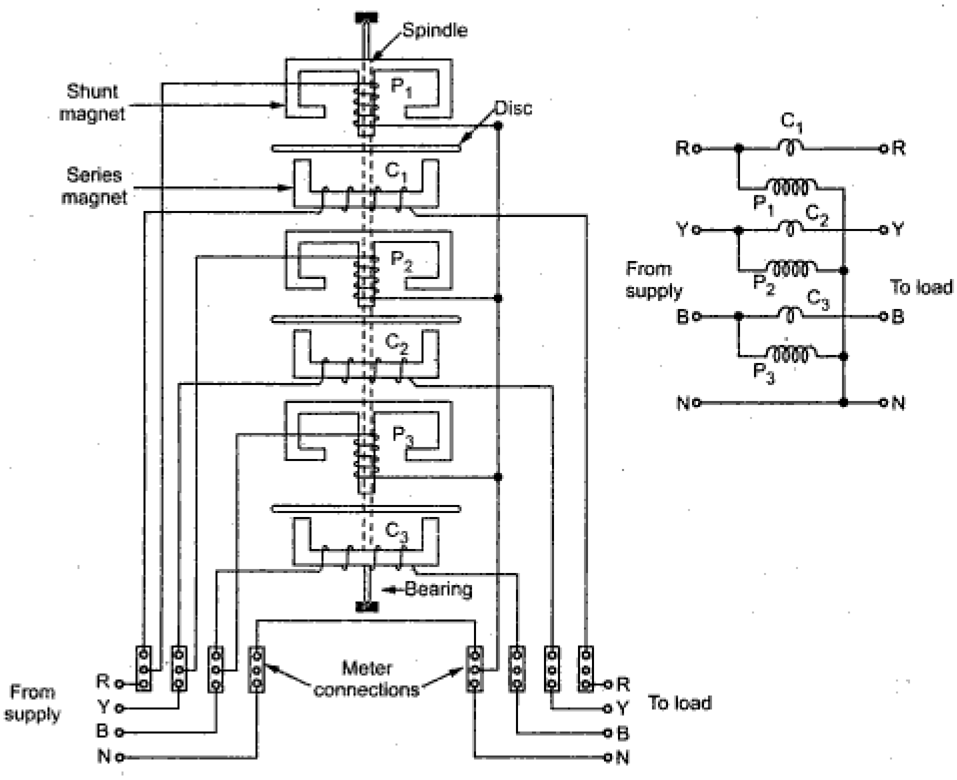


Fig: three phase energy meter

Testing by phantom loading using R.S.S. meter:

This test is conducted for short period of time hence called short period test. A rotating substandard meter (R.S.S) is used along with the meter under test. The current coils of two meters are connected in series while pressure coils in parallel. The two meters are started and stopped simultaneously for short period of time.

When the predetermined load is adjusted, then the meter under test is allowed to make certain number of revolutions. At the same time, the numbers of revolutions made by rotating substandard meter, in the same time are observed.

If the constants of meters are same then error can be directly obtained. But if meter constants are different then error is required to be calculated.

Let K_X= Meter constant in number of revolutions per Kwh for meter under test.

K_s=meter constant in number of revolutions per kwh for substandard meter.

N_X= number of revolutions made by meter under test.

N_s = number of revolutions made by substandard meter

E_r= energy recorded by meter under test = $\frac{N_X}{K_X}$

E_t= energy recorded by substandard meter = $\frac{N_s}{K_s}$

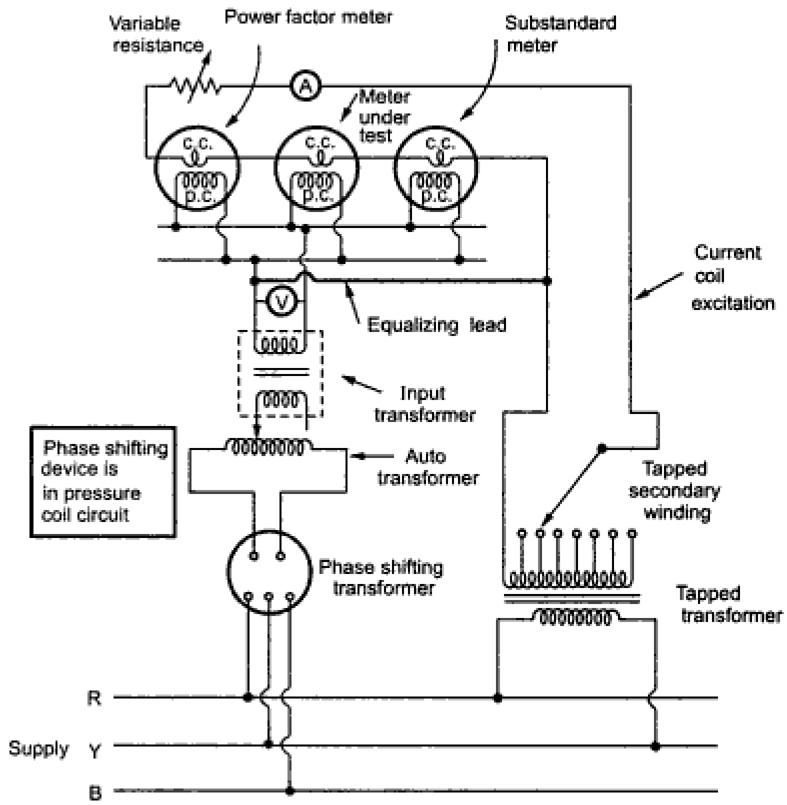


Fig. 4.19 Phantom loading of a.c. meter using rotating substandard meter

$$\%\text{error} = \frac{\frac{N_X}{K_X} - \frac{N_s}{K_s}}{\frac{N_s}{K_s}} * 100$$

Before conducting the test, the meters are allowed to rue for 15 to 30 minutes with full load, to attain steady state temperature.

Tri vector meter:

The meter which measures the kVAh and kVA of the maximum demand simultaneously is called a tri vector meter.

It consists of a kWh meter and a reactive kVARh meter together. A special summator arrangement is used in between them. Both the meters drive the summator via a complicated gearing arrangement such that the summator records the kVAh accurately at all the power factors.

kVAh = $\sqrt{kwh^2 + kVAR^2}$

fig shows the arrangement of tri vector meter

It uses five different gearing systems.

1. Watt-hour meter driving alone at normal speed, unity power factor condition.
2. Watt-hour meter speed slightly reduced and reactive meter speed is reduced considerably. This represents phase angle of 22.5^0 and power factor of 0.925.
3. Both speeds reduced by the same factor and corresponds to power factor of 0.707, phase angle 45^0
4. Watt-hour meter speed is considerably reduced and speed of reactive meter is slightly reduced. This corresponds to phase angle 67.5^0 and power factor 0.38.
5. Reactive meter driving alone at normal speed representing zero power factors.

Maximum demand meters:

The meters used to record the maximum power consumed by the consumer during a particular period are called maximum demand indicators.

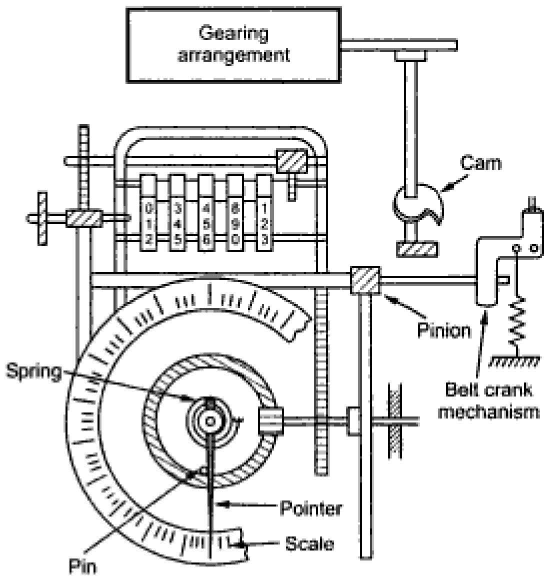


Fig. 4.16 Merz price maximum demand indicator

It consists of special disc mechanism which drives the pointer through gearing arrangement, which is coupled to the energy meter spindle. The dial system is coupled to the energy meter spindle for a fixed interval of time. Generally this time interval is of 30 minutes duration. After the end of this interval, reset device resets the driving mechanism bringing to zero position. But the pointer is held by special friction device which indicates the energy consumed during that interval of time.

This pointer position remains fixed unless and until in next intervals of time, the energy consumed exceeds the one indicated by pointer. Thus pointer then indicates new energy consumption which is more than the previous.

The pin provided drives the pointer forward for the set period of time interval. When the period ends, the cam controlled by timing gear momentarily disengages the pinion with thw help of bell crank mechanism. Under the spring force, the driving mechanism and pin comes to zero position. The pin provided drives the pointer forward for the set period of time interval. When the period ends, the cam controlled by a timing gear momentarily disengages the pinion with the help of bell crank mechanism. Under the spring force, the driving mechanism and pin comes to zero position. The pointer remains at its position indicating the energy consumed during the past interval of time.

Electrical resonance type frequency meter:

It consists of a laminated iron core. On one end of the core 43 fixed coil is wound which is called magnetizing coil. This coil is connected across the supply whose frequency is to be measured. This coil carries current which has same frequency as that of supply. On the same core, a moving coil is pivoted which carries a pointer. A capacitor C is connected across the terminals of the fixed coil.

I= current through the magnetizing coil.

∅= flux in the iron core.

The flux is assumed as in phase with the current I.

The flux indicates the voltage in the moving coil which always lags ∅ by 90^0.

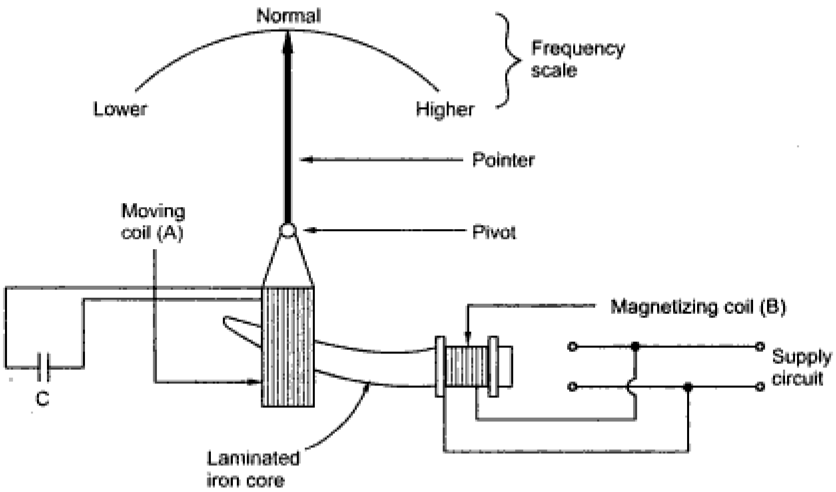
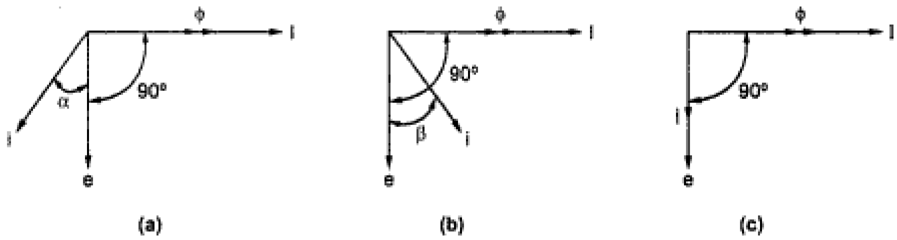


Fig. 2.19 Electrical resonance type frequency meter

The phase current I depend on the inductance of the moving coil and the capacitance C.

Consider the different cases and the corresponding phasor diagrams to understand the working of the meter as shown in fig.



In fig (a) the circuit of moving coil A is assumed to be inductive, hence current I lags the induced voltage e by angleα. Hence the torque acting on the moving coil is given by

$$T_d \propto I\,i\cos(90+\alpha)$$

In fig (b) the circuit of moving coil A is assumed to be largely capacitive, hence current I lead the induced voltage e by angleβ. Hence the torque to be largely capacitive, hence current I leads the induced voltage e by angleβ. Hence the torque acting on the moving coil is given by

$$T_d \propto I\,i\cos(90+\beta)$$

This torque is in opposite direction to the torque produced in case of inductive nature of the moving coil circuit. The fig© shows the resonance condition where the inductive reactance is equal to the capacitive reactance. So current I is in phase with the e and the torque acting on the moving coil is given by

$$T_d \propto I\,i\cos(90) = 0$$

Hence under the resonance condition, torque acting on the moving coil is zero. Now the capacitive reactance $X_C = \frac{1}{\omega C} = \frac{1}{2\pi f C}$ is constant for a given frequency.

If frequency is higher than the normal frequency then$X_C = \frac{1}{2\pi f C}$ decreases.

If frequency is lower than the normal frequency then$X_C = \frac{1}{2\pi f C}$ increases.

So to achieve $X_L = X_C$ the moving coil moves towards the magnetizing coil where inductance increases. Thus pointer moves to the left of the mean position, indicating the lower frequency. An important advantage of the instrument is that the great sensitivity is achieved as the inductance of the moving coil changes slowly with variation of its position on the core. This meter is also called Ferro-dynamic frequency meter.

Weston type synchroscope

Static Part: It consists of three limbed transformer. One of the outer limbs is excited by bus bar voltage VI while the outer limb is excited by the incoming machine voltage V2. The central limb carries the lamp. The fluxes produced by the two outer limbs are forced through the central limb. The phasor stun of these two times is the net flux in the central limb. This is responsible to induce an e.m.f in the central limb which operates the lamp.

The outer limb windings are so arranged that if the two voltages V_1 and V2 are in phase. Two fluxes in the central limb help each other and maximum e.m.f. gets induced in the central Limb. This makes lamp glow with maximum brightness. If the two voltages V1 *and V.2 are* 180°' out of phase, two fluxes in the central limb oppose each outer and resultant flux in the central limb is zero. Thus no e.m.f. is induced in it and lamp remains. Dark

If the frequency of V2 is different than the frequency of V1, then lamp flickers i.e. lamp becomes alternately dark and bright. The flickering frequency is equal to difference in the frequencies of V1 and V2. Thus when the lamp is flickering with very slow rate and when the lamp is maximum bright than the synchronizing switch must be closed. But this part does not detect whether incoming machine is faster or slower. This cart be known using the synchnoscope

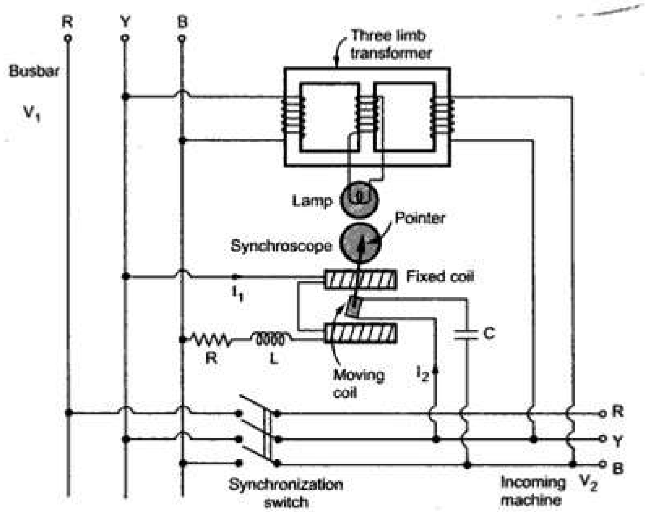


Fig. 2.26 Electrodynamometer type synchroscope

Dynamic Part: This consists of an electrodynamometer type synchroscope. It consists of fixed coil divided into two parts while the moving coil consists of a pointer. The fixed coil is connected to bus bar with a resistor and inductor in series with it. The moving coil is connected to the terminals of incoming machine with a capacitor in series.

The inductor and capacitor are used in fixed coil and moving coil circuit respectively because when the two voltages are in phase then due to L and C_1 the two currents are in exact quadrature (91r) to each other. Thus no torque will act on the pointer. The control springs are arranged such that under this condition, pointer remains in vertical position. This is shown in the Fig. The current 1_1 lags V_1 while I2 leads V2 such that I1 and I2 are in quadrature. If VI and V2 are 1syn out of phase, still the currents I_l and 1_2 will be in quadrature and pointer will remain stationary. But in this situation, the lamp will be dark. Practically it is very difficult to achieve exact stationary position of the pointer. It oscillates about its vertical position on the scale.