

## SECOND SEMESTER THEORY EXAMINATION 2010-11

### ELECTRICAL ENGINEERING

*Time : 3 Hours*

*Total Marks : 100*

**Note:** Attempt questions in all Sections. Assume any missing data if any.

#### SECTION—A

1. Attempt all parts of this questions. Answer (xvi) to (xx) by True or False. (1×20=20)

(i) Any closed path formed by branches in a network is .....

Ans. circuit or loop

(ii) Three resistances of 3 ohm each are connected in delta. The value of equivalent star is .....

Ans.  $\frac{1}{3}\Omega$  each

(iii) Time constant of RL circuit is .....

Ans.  $\frac{L}{R}$

(iv) The highest speed of 50 Hz ac generator can be .....

Ans. 3000 rpm

(v) In delta-connected generator, the sum of instantaneous voltages around the delta is equal to .....

Ans. Zero

(vi) The power factor in a RLC series circuit will be lagging if. ....

Ans. Inductive circuit

(vii) Common condition to both series and parallel resonance is .....

Ans. Unity Power factor

(viii) If  $W_1$ ,  $W_2$  and  $W_3$  are the readings of three Wattmeters used to measure the

power in 3-phase 4-wire circuit, the total power of load circuit will be.....

Ans.  $W_1 + W_2 + W_3$  watts

(ix) The current drawn by a 120 V dc motor of armature resistance 0.4  $\Omega$  and back emf 112 V is .....

Ans. 20 Amperes

(x) The rotor speed of a six pole 50 Hz induction motor is 960 rpm, the percentage slip is .....

Ans. 4% or .04 pu

(xi) What will happen if the back emf of DC motor vanishes?

Ans. Motor Starts drawing heavy current which may damage the motor.

(xii) ..... motor has self-load properties.

Ans. Differentially Compound Motor

(xiii) ..... motor will be preferred for elevators.

Ans. Cumulatively compound motor

(xiv) Type of cooling fan motor is .....

Ans. Single Phase Induction Motor

(xv) A moving coil ammeter has a full scale deflection of 50  $\mu\text{A}$  and a coil resistance of 100  $\Omega$ . The value of shunt resistance required for the instrument to be converted to read a full-scale reading of 1A will be .....

Ans. 100.05  $\Omega$

(xvi) After very long time, a capacitor behaves as short circuit. (True/False)

Ans. False

(xvii) Principle of homogeneity shows linear circuit. (True/False)

Ans. True

(xviii) Transient analysis can be performed in purely resistive circuit. (True/False)

Ans. False

(xix) Shunt capacitors are employed for power factor improvement. (True/False)

(True/False)

Ans. True

(xx) A highly selective circuit has high Q-factor. (True/False)

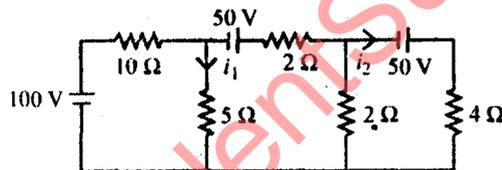
Ans. True

### SECTION — B

Q.2. Attempt any three parts of the following:

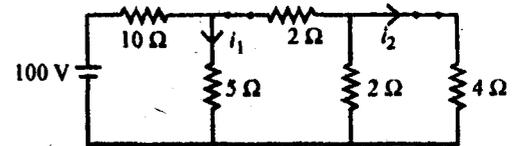
(10×3=30)

(a) State superposition theorem in dc network. Determine the current  $i_1$  and  $i_2$  in the following network shown in figure



Ans. In any linear bilateral network containing two or more independent sources (voltage or current sources or combination of voltage and current sources), the resultant current / voltage in any branch is the algebraic sum of currents / voltages caused by each independent sources acting along, with all other independent sources being replaced meanwhile by their respective internal resistances.

Consider 100 V source only and replace all other independent sources by their internal resistances. The circuit reduces to



Net Resistance =  $(3.33 \parallel 5) + 10 = 12 \Omega$

Now current supplied by 100 V battery is

$$= \frac{100}{12} = 8.33 \text{ Amp.}$$

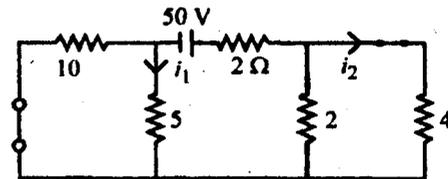
$i_1$  contribution due to 100 V source is

$$= 8.33 \times \frac{3.33}{8.33} = 3.33 \text{ Amps}$$

$i_2$  contribution due to 100 V source is

$$i_2 = 5 \times \frac{2}{6} = 1.66 \text{ Amp}$$

Now consider middle 50 V source only and replace all other independent sources by their internal resistances.



Net Resistance =  $6.66 \Omega$

Current given by 50V battery is

$$= \frac{50}{6.66} = 7.507 \text{ Amps}$$

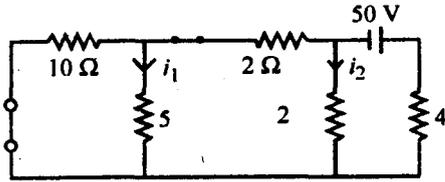
$i_1$  contribution due to 50 V source is

$$= -7.50 \times \frac{10}{15} = -5 \text{ amps}$$

$i_2$  contribution due to 50 V source is

$$= 7.50 \times \frac{2}{6} = 2.5 \text{ amps}$$

Now consider right side 50 V source only and replace all other independent sources by their internal resistances



Net resistance =  $5.45 \Omega$

Current supplied by 50 volt battery is

$$= \frac{50}{5.45} = 9.174 \text{ amps}$$

$i_1$  contribution due to right side 50 V source is

$$= -2.50 \times \frac{10}{15} = -1.66 \text{ amp}$$

$i_2$  contribution due to right side 50 V source is

$$= -9.174 \times \frac{5.33}{7.33} = -5.67 \sigma \text{ amp.}$$

$\therefore i_2$  due to contribution of all sources  
 $= 3.33 - 5 - 1.66 = -3.33 \text{ Amp}$  Ans.

$i_2$  due to contribution of all sources  
 $= 1.66 + 2.5 - 6.67 = -2.51 \text{ Amp.}$

(b) What are the necessity and advantages of 3-phase system? Derive  $I_L = \sqrt{3}I_{ph}$  for delta connected system.

**Ans. Advantages of Three Phase System:** In the three phase system, the alternator armature has three windings and it produces three independent alternating voltages. The magnitude and frequency of all of them is equal but they have a phase difference of  $120^\circ$  between each other. Such a three phase system has following advantages over single phase system.

1. The output of three phase machine is always greater than single phase machine of same size, approximately 1.5 times. So for a given size and voltage a three phase alternator occupies less space and has less cost too than single phase having same rating.

2. For a transmission and distribution, three

phase system needs less copper or less conducting material than single phase system for given volt amperes and voltage rating, so transmission becomes very much economical.

3. It is possible to produce rotating magnetic field with stationary coils by using three phase system. Hence three phase motors are self starting.

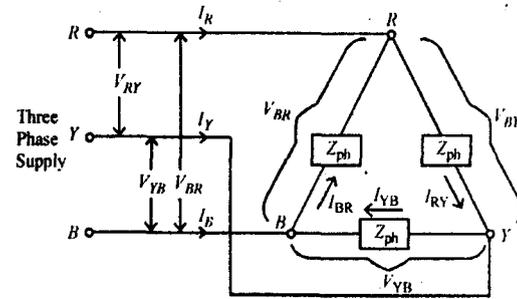
4. In single phase system, the instantaneous power is a function of time and hence fluctuates w.r.t time. This fluctuating power causes considerable vibrations in single phase motors. Hence performance of single phase motors is poor. While instantaneous power in symmetrical three phase system is constant.

5. Three phase systems give steady output.

6. Single phase supply can be obtained from three phase but three phase can not be obtained from single phase.

7. Power factor of single phase motors is poor than three phase motors of same rating.

Consider the balanced delta connected load as shown in the fig.



Line voltages  $V_L = V_{RY} = V_{YB} = V_{BR}$

Line currents  $I_L = I_R = I_Y = I_B$

Phase voltages  $V_{ph} = V_{RY} = V_{YB} = V_{BR}$

Phase currents  $I_{ph} = I_{RY} = I_{YB} = I_{BR}$

As seen earlier,  $V_{ph} = V_L$  for delta connected load. To derive the relation between  $I_L$  and  $I_{ph}$ , apply the KCL at the node R of the load shown in the figure.

$$\sum I_{\text{entering}} = \sum I_{\text{leaving}} \text{ at node R}$$

$$\therefore \bar{I}_R + \bar{I}_{BR} = \bar{I}_{RY}$$

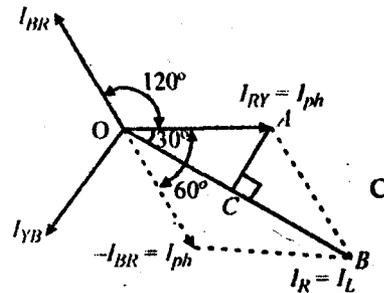
$$\therefore \bar{I}_R = \bar{I}_{RY} - \bar{I}_{BR} \quad \dots(1)$$

Applying KCL at node  $Y$  and  $B$ , we can write equations for line currents  $I_Y$  and  $I_B$  as,

$$\bar{I}_Y = \bar{I}_{YB} - \bar{I}_{RY} \quad \dots(2)$$

$$\bar{I}_B = \bar{I}_{BR} - \bar{I}_{YB} \quad \dots(3)$$

The phasor diagram to obtain line current  $I_R$  by carrying out vector subtraction of phase currents  $I_{RY}$  and  $I_{YB}$  is shown in the figure.



The three phase currents are displaced from each other by  $120^\circ$ .

$I_{BR}$  is reversed to get  $-I_{BR}$  and then added to  $I_{RY}$  to get  $I_R$ .

The perpendicular  $AC$  drawn on vector  $OB$ , bisects the vector  $OB$  which represents  $I_L$ . Similarly  $OB$  bisects angle between  $-I_{YB}$  and  $I_{RY}$  which is  $60^\circ$ .

$$\therefore \angle BOA = 30^\circ \text{ and } OC = CB = \frac{I_L}{2}$$

From triangle  $OAB$ ,

$$\cos 30^\circ = \frac{OC}{OA} = \frac{I_L/2}{I_{RY}}$$

$$\therefore \frac{\sqrt{3}}{2} = \frac{I_L/2}{I_{ph}}$$

$$\therefore I_L = \sqrt{3} I_{ph} \quad \text{for delta connection.}$$

(c) Explain the main components of power supply system. Also discuss the concept of grid power system.

**Ans. Elements of Power System:** The power system is comprised of various elements such as generator, transformer, transmission lines, bus bars, circuit breakers, isolators etc. Now we will discuss in brief about these elements.

**Generators:** The generator or alternator is the important element of power system. It is of synchronous type and is driven by turbine thus converting mechanical energy into electrical energy. The two main parts of generator are stator and rotor. The stationary part is called stator or armature consisting of conductors embedded in the slots. The conductors carry current when load is applied on the generator. The rotating part or rotor is mounted on the shaft and rotates inside the stator. The winding on rotor is called field winding.

**Transformers:** For stepping up or down the system voltage, power transformers are used in the substations. At generating end, the voltage is only stepped up for transmission of power while at all the subsequent substations the voltage is gradually stepped down to reach finally to working voltage level.

Instead of using a bank of 3 single phase transformers, a single three phase transformer is used nowadays. The advantage of using this transformer is the easiness in its installation and only one three phase load tap changing mechanism can be used.

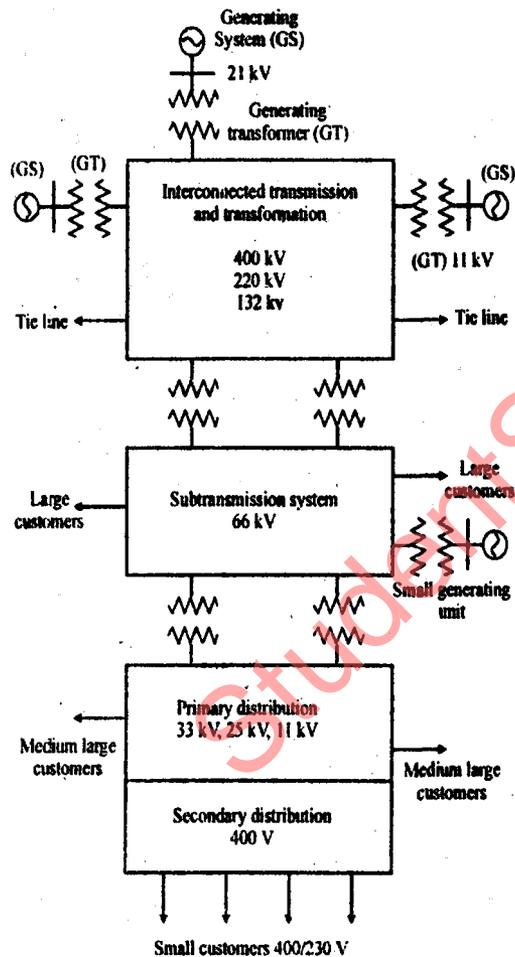
**Transmission Line:** The transmission line forms the connecting link between the generating stations and the distribution systems. It carries the power generated by generating stations and makes it available for distribution through distribution network.

Any electrical transmission line has four major parameters which are important from the point view of its proper operation. These parameters are namely resistance, inductance, capacitance and conductance.

**Bus Bars:** Bus bars are the common electrical component that connect electrically number of lines which are operating at the same

voltage directly. These bars are of either copper or aluminium generally of rectangular cross-section. They can be of other shapes such as round tubes, round solid bars or square tubes.

An interconnected power system covering a major portion of a country's territory (or state) is called a grid. The different grids may be interconnected through transmission lines (called Tie lines) to form a regional grid. When the different regional grids are interconnected, they form a national grid.



Layout of Typical Power System

(d) Derive the quality factor  $Q$  of the series RLC circuit at resonance. Define the bandwidth for the same.

**Ans. Quality Factor:** The quality factor of R-L-C series circuit is the voltage magnification in the circuit at resonance.

Voltage magnification

$$= \frac{\text{Voltage across L or C}}{\text{Supply voltage}}$$

Now  $V_L =$  voltage across  $L = I_m X_L = L_m \omega_r L$  at resonance

And at resonance,

$$I_m = \frac{V}{R} \quad \text{and} \quad V_L = \frac{V \omega_r L}{R}$$

$$\therefore \text{Voltage magnification} = \frac{V \omega_r L}{R} \div \frac{V}{R} = \frac{\omega_r L}{R}$$

This is nothing but quality factor  $Q$ .

$$\therefore Q = \frac{\omega_r L}{R} \quad \text{but} \quad \omega_r = \frac{1}{\sqrt{LC}}$$

$$\therefore Q = \frac{1}{R} \sqrt{\frac{L}{C}} \quad \text{while} \quad \text{B.W.} = \frac{R}{2\pi L}$$

$$\therefore Q \times \text{B.W.} = \frac{1}{R} \sqrt{\frac{L}{C}} \times \frac{R}{2\pi L} = \frac{1}{\pi \sqrt{LC}} = f_r$$

$$\therefore Q = \frac{f_r}{\text{B.W.}}$$

The significance of quality factor can be stated as,

1. It indicates the selectivity or sharpness of the tuning of a series circuit.

2. It gives the correct indication of the selectivity of such series R-L-C circuit which are used in many radio circuits.

(e) A three phase 50 Hz Induction motor has a full-load speed of 1440 rpm. Calculate:

(i) Slip

(ii) Number of poles.

(iii) Frequency of rotor induced emf

(iv) Speed of rotor field with respect to rotor structure.

(v) Speed of rotor field with respect to stator field.

$$\text{Ans. (i)} \quad \text{Slip} = \frac{N_s - N_r}{N_s} \times 100\%$$

$$\text{Also} \quad N_s = 1500 \text{ rpm}$$

$$\therefore \text{Slip (s)} = \frac{1500 - 1440}{1500} = 4\% \text{ Ans.}$$

(ii) Number of poles ( $P$ ) = 4

(iii) Frequency of rotor induced emf

$$f_2 = sf_1 = 0.04 \times 50 = 2 \text{ Hz}$$

(iv) Speed of rotor field with respect to rotor structure =  $1500 - 1440 = 60 \text{ rpm}$

(v) Speed of rotor field with respect to stator field =  $0 \text{ rpm}$ .

### SECTION—C

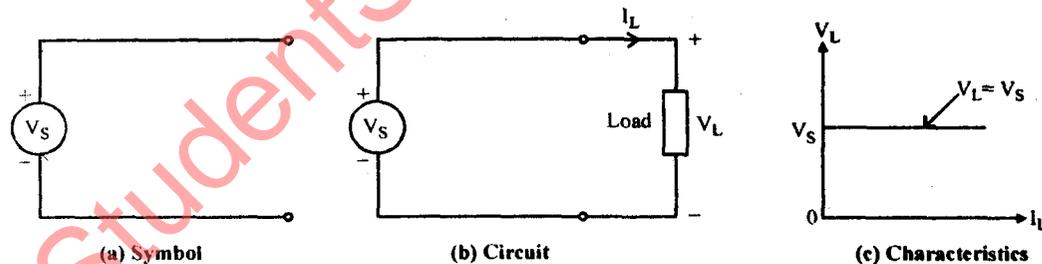
Attempt all questions in this section.

(10×5=50)

Q.3. Answer any two parts of the following:

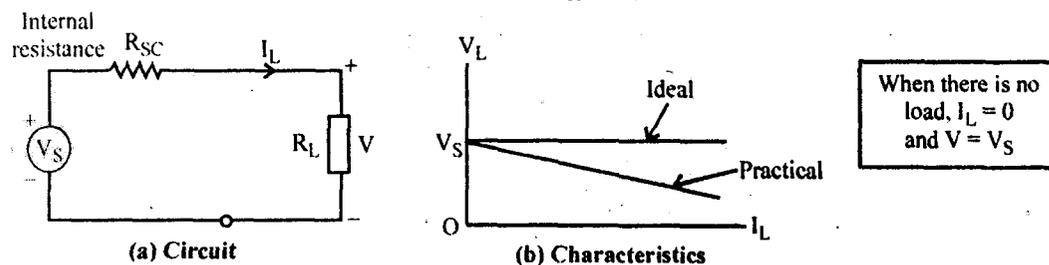
(a) Draw V-I characteristic of voltage and current sources. Explain source transformation theory in any circuit.

**Ans. Voltage Source:** Ideal voltage source is defined as the energy source which gives constant voltage across its terminals irrespective of the current drawn through its terminals. The symbol for ideal voltage source is shown in the fig. (a). This is connected to the load as shown in fig. (b). At any time the value of voltage at load terminals remains same. This is indicated by V-I characteristics shown in the fig. (c).



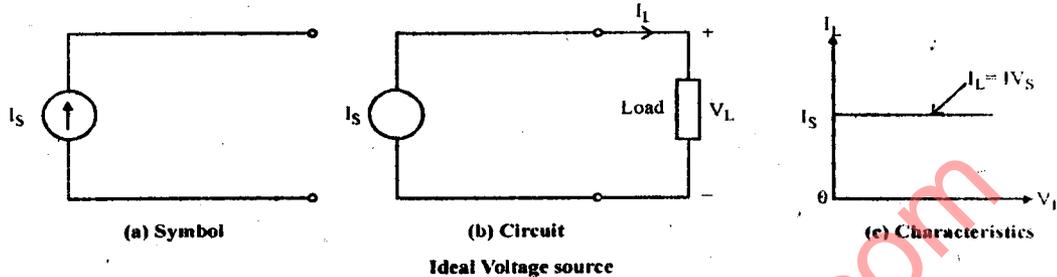
Ideal Voltage source

**Practical voltage source:** But practically, every voltage source has small internal resistance shown in series with voltage source and is represented by  $R_{sc}$  as shown in the fig.



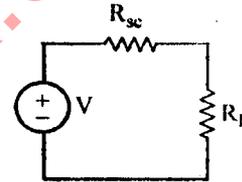
Practical voltage source.

**Current Source:** Ideal current source is the source which gives constant current at its terminals irrespective of the voltage appearing across its terminals. The symbol for ideal current source is shown in the fig. (a). This is connected to the load as shown in the fig. (b). At any time, the value of the current flowing through load  $I_L$  is same i.e. is irrespective of voltage appearing across its terminals. This is explained by V-I characteristics shown in the fig. (c).



But practically, every current source has high internal resistance, shown in parallel with current source and it is represented by  $R_{sh}$ . This is shown in the fig.

**Source Transformation:** Consider a practical voltage source shown in the fig. (a) having internal resistance  $R_{SC}$  connected to the load having resistance  $R_L$ .



(a) Voltage source

Now we can replace voltage source by equivalent current source.

**Key Point:** The two sources are said to be equivalent, if they supply equal load current to the load, with same load connected across its terminals.

The current delivered in above case by voltage source is,

$$I = \frac{V}{(R_{SC} + R_L)}, \quad R_{SC} \text{ and } R_L \text{ in series} \quad \dots(1)$$

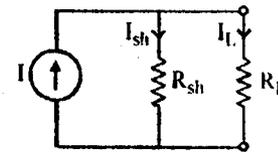
If it is to be replaced by a current source then load current must be  $\frac{V}{(R_{SC} + R_L)}$ .

Consider an equivalent current source shown in fig. (b).

The total current is  $I$ .

Both the resistances will take current proportional to their values.

From the current division in parallel circuit we can write.



(b) Current source

$$I_L = I \times \frac{R_{sh}}{(R_{sh} + R_L)} \quad \dots(2)$$

Now this  $I_L$  and  $\frac{V}{R_{SC} + R_L}$  must be same, so equating (1) and eq. (2),

$$\therefore \frac{V}{R_{SC} + R_L} = \frac{I \times R_{sh}}{R_{sh} + R_L}$$

Let internal resistance be,

$$R_{sc} = R_{sh} = R \text{ say}$$

Then,

$$V = I \times R_{sh} = I \times R$$

or

$$I = \frac{V}{R_{sh}}$$

$$I = \frac{V}{R} = \frac{V}{R_{sc}}$$

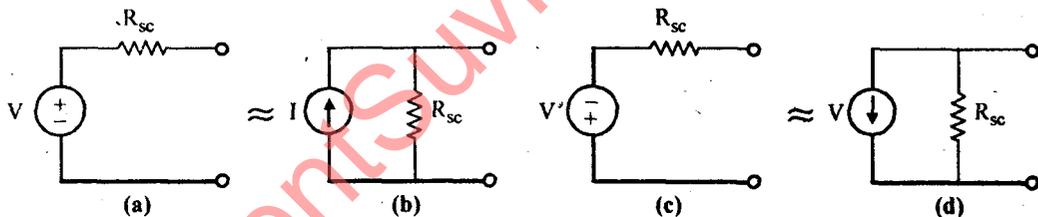
**Key Point:** If voltage source is converted to current source, then current source  $I = \frac{V}{R_{sc}}$  with

parallel internal resistance equal to  $R_{sc}$ .

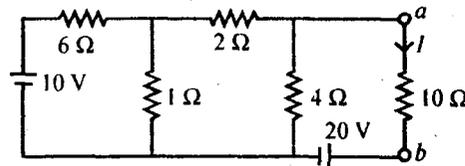
**Key Point:** If current source is converted to voltage source, then voltage source  $V = I R_{sh}$  with series internal resistance equal to  $R_{sh}$ .

The direction of current of equivalent current source is always from -ve to +ve, internal to the source. While converting current source to voltage source, polarities of voltage is always as +ve terminal at top of arrow and -ve terminal at bottom of arrow, as direction of current is from -ve to +ve, internal to the source. This ensures that current flows from positive to negative terminal in the external circuit.

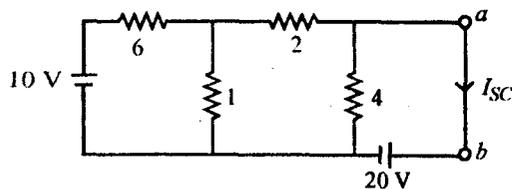
Note the directions of transformed sources, shown in fig. (a), (b), (c) and (d).



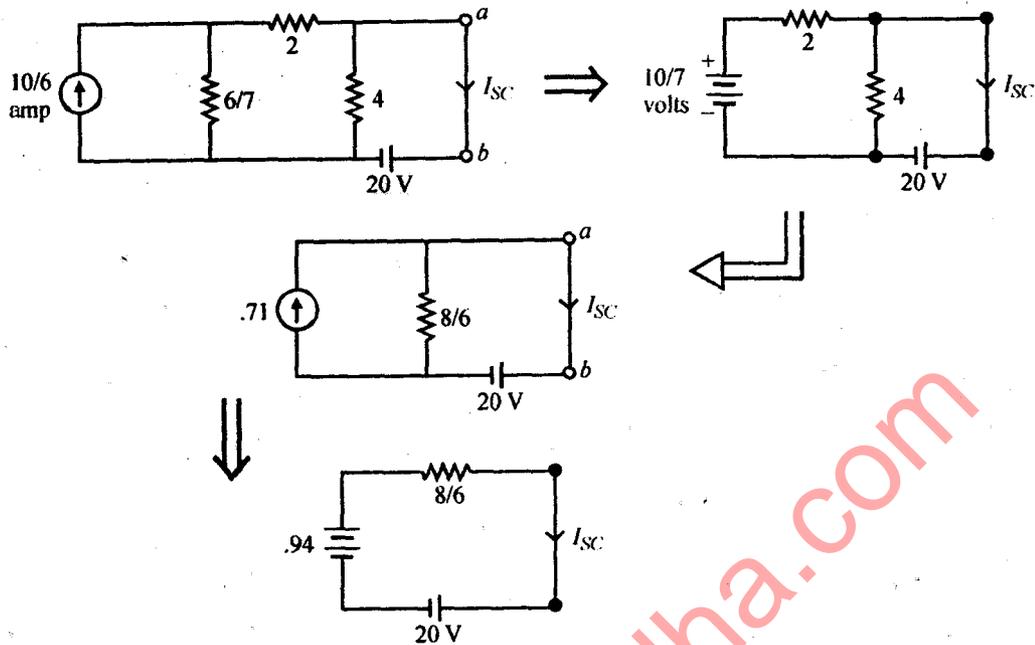
(b) Convert the network at terminals *ab* by its Norton's equivalent circuit. Hence determine *I* of the circuit shown in figure.



Ans. To find  $I_{sc}$ , short circuit the terminals as.



Using source transformation



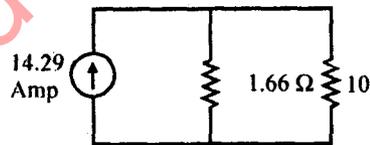
$$I_{sc}/I_N = 14.29 \text{ Amp}$$

Now  $R_N$  is calculated as:



$$R_N = 1.66 \Omega$$

Now, Norton's Equivalent Circuit is drawn as:

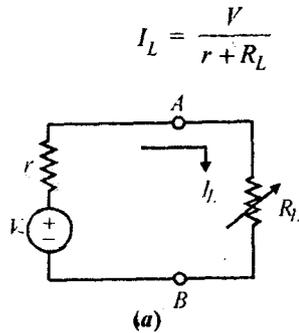


$$I_{10 \Omega} = 14.29 \times \frac{1.66}{11.66} = 2.03 \text{ Amp.}$$

(c) State and prove maximum power transfer theorem.

**Ans. Maximum Power Transfer Theorem:** A resistive load connected to a DC network receives maximum power when the load resistance is equal to the Thevenin equivalent resistance of the network as seen from the load terminals.

**Proof of Maximum Power Transfer Theorem:** Consider a dc source of voltage  $V$  volts and having internal resistance of  $r$  ohms connected to a variable load resistance  $R_L$  as shown in the fig. (a). The load current is  $I_L$  and is given by,



The power consumed by the load resistance  $R_L$ , is

$$P = I_L^2 R_L = \left[ \frac{V}{(r + R_L)} \right]^2 R_L$$

If  $R_L$  is changed,  $I_L$  is also going to change and at a particular value of  $R_L$ , power transferred to the load is maximum. Let us calculate value of  $R_L$  for which power transfer to load is maximum. To satisfy maximum power transfer we can write,

$$\frac{dP}{dR_L} = 0$$

$$\frac{dP}{dR_L} \left[ \frac{V}{(r + R_L)} \right]^2 R_L = 0$$

$$\therefore V^2 \frac{d}{dR_L} \left[ \frac{R_L}{(r + R_L)^2} \right] = 0$$

... as voltage is constant

$$\therefore (r + R_L)^2 \frac{d(R_L)}{dR_L} - R_L \frac{d}{dR_L} (r + R_L)^2 = 0$$

$$\therefore (r + R_L)^2 (1) - R_L 2(r + R_L) = 0$$

$$\therefore (r + R_L - 2R_L) = 0$$

$$R_L = r$$

Thus when load resistance is equal to the internal resistance of source the maximum power transfer takes place.

**Q.4. Answer any one part of the following:**

(a) Three voltages represented by the following equations are:

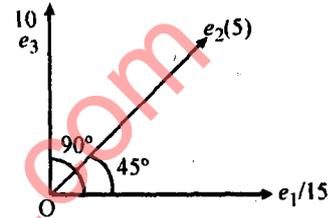
$e_1 = 15 \sin \omega t$ ,  $e_2 = 5 \sin (\omega t + \pi/4)$  and  $e_3 = 10 \cos \omega t$  together in an ac circuit. Represent these voltages by phasor and calculate an expression for the resultant voltage. Also cross-verify it.

Ans. Given  $e_1 = 15 \sin \omega t$

$$e_2 = 5 \sin (\omega t + \pi/4)$$

$$e_3 = 10 \cos \omega t = 10 \sin (\omega t + 90^\circ)$$

Their phasor representation is shown as



Now  $e_1$  is written as

$$E_1 = \frac{15}{\sqrt{2}} \angle 0^\circ$$

Similarly  $E_2 = \frac{5}{\sqrt{2}} \angle 45^\circ$

and  $E_3 = \frac{10}{\sqrt{2}} \angle 90^\circ$

So, resultant voltage

$$= \frac{15}{\sqrt{2}} \angle 0^\circ + \frac{5}{\sqrt{2}} \angle 45^\circ + \frac{10}{\sqrt{2}} \angle 90^\circ$$

$$= \frac{15}{\sqrt{2}} [\cos 0^\circ + j \sin 0^\circ]$$

$$+ \frac{5}{\sqrt{2}} [\cos 45^\circ + j \sin 45^\circ]$$

$$+ \frac{10}{\sqrt{2}} [\cos 90^\circ + j \sin 90^\circ]$$

$$= 13.10 + j9.57$$

$$= 16.22 \angle 36.14^\circ \text{ volts.}$$

$$\therefore e_r = 23 \sin (\omega t + 36.14^\circ) \text{ volts} \quad \text{Ans.}$$

- (b) A 46 mH inductive coil has a resistance of 10 Ω. How much current will it draw, if connected across 100 V, 50 Hz source? Also determine the value of capacitance that must be connected across the coil to make the power factor of the circuit to be unity.

Ans. The inductance of the coil  $X_L = 2\pi fL$   
 $= 2 \times 3.14 \times 50 \times 46 \times 10^{-3} = 14.44 \Omega$

The current drawn by the coil is

$$I = \frac{V}{Z} = \frac{100}{17.56} = 5.69 \text{ Ampere}$$

The capacitance connected across the coil to make the power factor unity

$$C = \frac{L}{Z^2} = \frac{46 \times 10^{-3}}{\sqrt{10^2 + 14.44^2}}$$

$$= \frac{46}{17.56 \times 10^3} = 2.6 \times 10^{-3} \text{ Farads}$$

**Q.5. Answer any one part of the following:**

- (a) Explain the two-Wattmeter method for determination of power and power factor of three-phase load with suitable diagram.

**Ans. Two Wattmeter Method:**

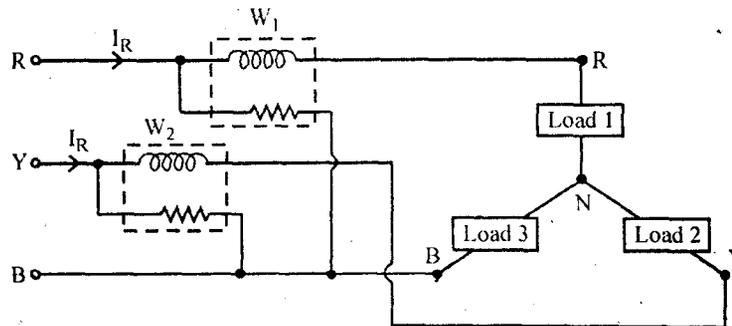
**Method of Connection:** The current coils of the two wattmeters are connected in any two lines while the voltage coil of each wattmeter is connected between its own current coil terminal and the line without a current coil. For example, the current coils are inserted in the lines R and Y then the pressure coils are connected between R – B for one wattmeter and Y – B for other wattmeter, as shown in the figure.

The connections are same for star or delta connected load. It can be shown that when two wattmeters are connected in this way, the algebraic sum of the two wattmeter readings gives the total power dissipated in the three phase circuit.

If  $W_1$  and  $W_2$  are the two wattmeter readings then total power

$$W = W_1 + W_2 = \text{Three Phase Power}$$

**Proof of Two Wattmeter Method:** Consider star connected load and two wattmeters connected as shown in the figure.



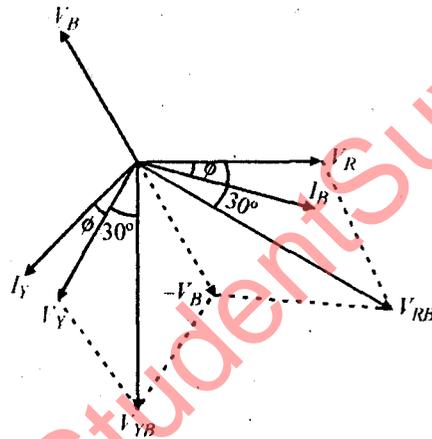
Note that instantaneously power is always fluctuating and wattmeter pointer also tries to show this fluctuating power. But due to inertia of the moving system, pointer can not respond to these fluctuations. And hence wattmeter reads average value of the power and hence  $W_1 + W_2$  give the average value of the total power consumed by 3 phase load.

(b) For balanced load: Let us consider the r.m.s. values of the currents and voltages to prove that sum of two wattmeter gives total power consumed by three phase load.

$$W_1 = I_R \times V_{RB} \times \cos(I_R \wedge V_{RB})$$

$$W_2 = I_Y \times V_{YB} \times \cos(I_Y \wedge V_{YB})$$

To find angle between  $(I_R \text{ and } V_{RB})$  and  $(I_Y \text{ and } V_{YB})$  let us draw phasor diagram. (Assuming load p.f. be cos  $\phi$  lagging)



$$\vec{V}_{RB} = \vec{V}_R - \vec{V}_B$$

and  $\vec{V}_{YB} = \vec{V}_Y - \vec{V}_B$

$$V_R \wedge I_R = 0 \text{ and } V_Y \wedge I_Y = 0$$

$$V_R = V_Y = V_B = V_{ph}$$

and  $V_{RB} = V_{YB} = V_L$

So from the phasor diagram the required angles are

$$(I_R \wedge V_{RB}) = (30^\circ - \phi)$$

$$(I_Y \wedge V_{YB}) = (30^\circ + \phi)$$

$$\therefore W_1 = I_R V_{RB} \cos(30^\circ - \phi)$$

$$\therefore W_1 = V_L I_L \cos(30^\circ - \phi)$$

and  $W_2 = I_Y V_{YB} \cos(30^\circ + \phi)$

$$\therefore W_2 = V_L I_L \cos(30^\circ + \phi)$$

$$\begin{aligned} \therefore W_1 + W_2 &= V_L I_L [\cos(30^\circ - \phi) + \cos(30^\circ + \phi)] \\ &= V_L I_L [\cos 30^\circ \cos \phi + \sin 30^\circ \sin \phi \\ &\quad + \cos 30^\circ \cos \phi - \sin 30^\circ \sin \phi] \\ &= 2V_L I_L \cos 30^\circ \cos \phi \end{aligned}$$

$$\therefore W_1 + W_2 = \sqrt{3} V_L I_L \cos \phi = \text{Total 3 phase power}$$

**Power Factor Calculation by Two Wattmeter Method:** In case of balanced load, the p.f. can be calculated from  $W_1$  and  $W_2$  readings.

For balanced, lagging p.f. load,

$$W_1 = V_L I_L \cos(30^\circ + \phi)$$

$$W_2 = V_L I_L \cos(30^\circ - \phi)$$

$$W_1 + W_2 = \sqrt{3} V_L I_L \cos \phi \quad \dots(1)$$

$$\begin{aligned} W_1 - W_2 &= V_L I_L [\cos(30^\circ - \phi) - \cos(30^\circ + \phi)] \\ &= V_L I_L [\cos 30^\circ \cos \phi + \sin 30^\circ \sin \phi \\ &\quad - \cos 30^\circ \cos \phi + \sin 30^\circ \sin \phi] \\ &= V_L I_L [2 \sin 30^\circ \sin \phi] \\ &= V_L I_L \left[ 2 \times \frac{1}{2} \times \sin \phi \right] \end{aligned}$$

$$\therefore W_1 - W_2 = V_L I_L \sin \phi \quad \dots(2)$$

Taking ratio of (1) and (2),

$$\frac{W_1 - W_2}{W_1 + W_2} = \frac{V_L I_L \sin \phi}{\sqrt{3} V_L I_L \cos \phi} = \frac{\tan \phi}{\sqrt{3}}$$

$$\therefore \tan \phi = \frac{\sqrt{3}(W_1 - W_2)}{(W_1 + W_2)}$$

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

$$\therefore \text{p.f. } \cos \phi = \cos \left\{ \tan^{-1} \left[ \frac{\sqrt{3}(W_1 - W_2)}{(W_1 + W_2)} \right] \right\}$$

(b) A balanced delta connected load of  $(12 + j9) \Omega$ /phase is connected to 3-phase 400 V supply. Find:

- (i) Line current
- (ii) Power factor
- (iii) Power drawn
- (iv) Reactive Volt-Amperes
- (v) Total Volt-Amperes

Ans.  $Z_{L/\text{phase}} = (12 + j9) \Omega$

$$= \sqrt{12^2 + 9^2}$$

$$= \sqrt{225} = 15 \angle 36.86^\circ \Omega$$

$$V_{ph} = 400 \text{ Volts} = V_L$$

$$\therefore I_{ph} = \frac{400 \angle 0^\circ}{15 \angle 36.86^\circ}$$

$$= 26.66 \angle -36.86^\circ \text{ Amps.}$$

(i)  $I_L$  (Line Current) =  $\sqrt{3} I_{ph}$

$$= 46.17 \angle -36.86^\circ \text{ Amps}$$

(ii)  $\cos \phi = \cos (-36.86^\circ) = .80$  (lag)

(iii)  $P = \sqrt{3} V_L I_L \cos \phi$

$$= \sqrt{3} \times 400 \times 46.17 \times .80$$

$$= 25590 \text{ Watts Ans.}$$

(iv)  $\phi = \sqrt{3} V_L I_L \sin \phi$

$$= \sqrt{3} \times 400 \times 46.17 \times .60$$

$$= 19,192.5 \text{ VAR Ans.}$$

(v)  $S = \sqrt{3} V_L I_L$

$$= \sqrt{3} \times 400 \times 46.17$$

$$= 31,987.5 \text{ Volt amperes Ans.}$$

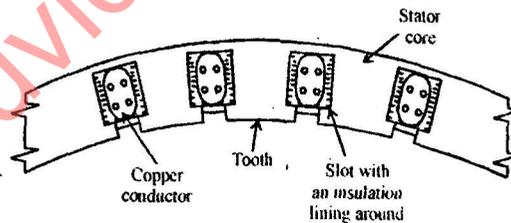
Q.6. Answer any two parts of the following:

(a) Explain construction and principle of operation of synchronous alternator.

Ans. A Synchronous Generator basically consists of:

(i) Stator, (ii) Rotor

**Stator:** The stator is a stationary armature. This consists of a core and the slots to hold the armature winding similar to the armature of a dc generator. The stator core uses a laminated construction. It is built up of special steel stampings insulated from each other with varnish or paper. The laminated construction is basically to keep down eddy current losses. Generally choice of material is steel to keep down hysteresis losses. The entire core is fabricated in a frame made of steel plates. The core has slots on its periphery for housing the armature conductors. Frame does not carry any flux and serves as the support to the core. Ventilation is maintained with the help of holes cast in the frame. The section of an alternator stator is shown in the figure.

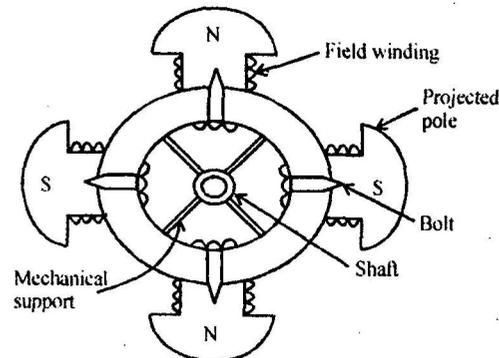


Section of an alternator stator.

**Rotor:** There are two types of rotors used in alternators:

(i) Salient pole type, (ii) Smooth cylindrical type

(i) **Salient pole type:** This is also called projected pole type as all the poles are projected out from the surface of the rotor.



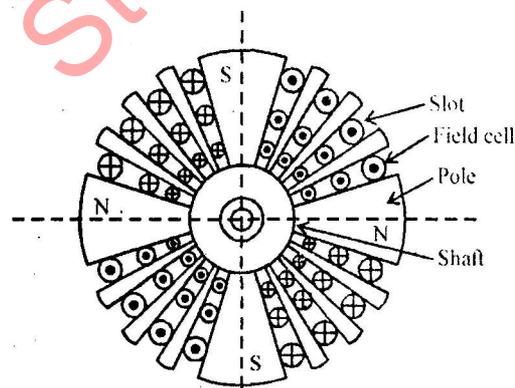
Salient pole type rotor.

The poles are built up of thick steel laminations. The poles are bolted to the rotor as shown in the figure. The pole face has been given a specific shape. The field winding is provided on the pole shoe. These rotors have large diameters and small axial lengths. The limiting factor for the size of the rotor is the centrifugal force acting on the rotating member of the machine. As mechanical strength of salient pole type is less, this is preferred for low speed alternators ranging from 125 r.p.m. to 500 r.p.m. The prime movers used to drive such rotor are generally water turbines and I.C. engines.

**Smooth Cylindrical Type:** This is also called non-salient type or non-projected pole type of rotor.

The rotor consists of smooth solid steel cylinder, having number of slots to accommodate the field coil. The slots are covered at the top with the help of steel or manganese wedges. The unslotted portions of the cylinder itself act as the poles. The poles are not projecting out and the surface of the rotor is smooth which maintains uniform air gap between stator and the rotor. These rotors have small diameters and large axial lengths. This is to keep peripheral speed within limits. The main advantage of this type is that these are mechanically very strong and thus preferred for high speed alternators ranging between 1500 to 3000 r.p.m. Such high speed alternators are called 'turboalternators'. The prime movers used to drive such type of rotors are generally steam turbines, electric motors.

The figure shows smooth cylindrical type of rotor.



Smooth cylindrical rotor

The rotor of alternator is run at its proper speed by prime mover. The prime mover is a machine which supplies the mechanical energy input to the alternator. The prime movers used for slow and medium speed alternators are water wheels or hydraulic turbines. Steam and gas turbines are used as prime movers in large alternators and run at high speeds. The steam turbine driven alternators are called turbo-alternators. As the poles of the rotor moves under the armature conductors on the stator, the field flux cuts the armature conductors. Therefore, voltage is generated in these conductors. This voltage is of alternating nature, since poles of alternate polarity successively pass by a given stator conductor. In this way a synchronous generator generates a three phase voltage.

(b) Sketch and explain speed-torque characteristics of following dc motor:

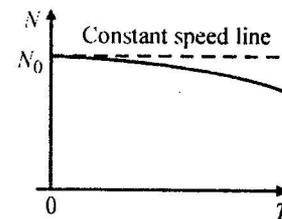
(i) Shunt motor

(ii) Compounded motor

**Ans. Characteristics of DC Shunt Motor:**

Speed — Torque characteristics

This graph is similar to speed-armature current characteristics as torque is proportional to the armature current. This curve shows that the speed almost remains constant though torque changes from no load to full load conditions. This is shown in the figure.



**N Vs. T for shunt motor.**

**Characteristics of DC Compound Motor:**

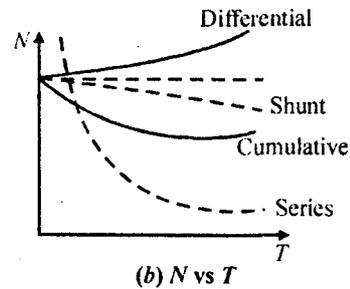
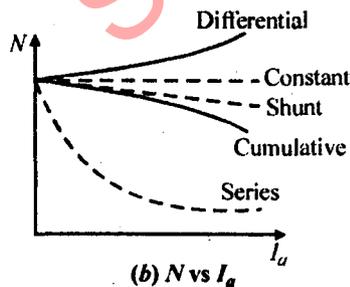
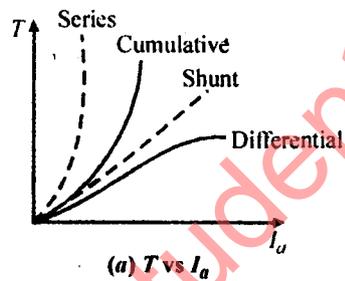
Compound motor characteristics basically depend on the fact whether the motor is cumulatively compound or differential compound. All the characteristics of the compound motor are the combination of the shunt and series characteristic.

Cumulative compound motor is capable of developing large amount of torque at low speeds just like series motor. However, it is not having a disadvantage of series motor even at light or no load. The shunt field winding produces the definite flux and series flux helps the shunt field flux to increase the total flux level.

So cumulative compound motor can run at a reasonable speed and will not run with dangerously high speed like series motor, on light or no load condition.

In differential compound motor, as two fluxes oppose each other, the resultant flux decreases as load increases, thus the machine runs at a higher speed with increase in the load. This property is dangerous as on full load, the motor may try to run with dangerously high speed. So differential compound motor is generally not used in practice.

The various characteristics of both the types of compound motors cumulative and the differential are shown in the fig. (a), (b) and (c).

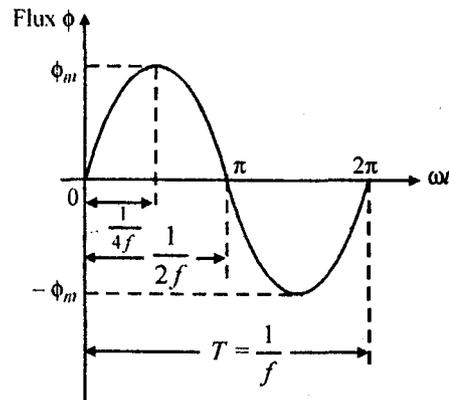


**Characteristics of dc compound motor.**

(c) Derive an emf/voltage expression of power transformer. Also draw an equivalent circuit of it.

**Ans. E.M.F. Equation of a Transformer:** When the primary winding is excited by an alternating voltage  $V_1$ , it circulates alternating current, producing an alternating flux  $\phi$ . The primary winding has  $N_1$  number of turns. The alternating flux  $\phi$  linking with the primary winding itself induces an emf in it denoted as  $E_1$ . The flux links with secondary winding through the common magnetic core. It produces induced emf  $E_2$  in the secondary winding. This is mutually induced emf. Let us derive the equations for  $E_1$  and  $E_2$ .

The primary winding is excited by purely sinusoidal alternating voltage. Hence the flux produced is also sinusoidal in nature having maximum value of  $\phi_m$  as shown in the figure.



**Sinusoidal flux.**

The various quantities which affect the magnitude of the induced emf are:

$\phi$  = flux

$\phi_m$  = Maximum value of flux

$N_1$  = Number of primary winding turns

$N_2$  = Number of secondary winding turns

$f$  = Frequency of the supply voltage

$E_1$  = R.M.S. value of the primary induced emf

$E_2$  = R.M.S. value of the secondary induced emf.

From Faraday's law of electromagnetic induction the average emf induced in each is proportional to the average rate of change of flux.

$\therefore$  average emf per turn = average rate of change of flux

$$\therefore \text{average emf per turn} = \frac{d\phi}{dt}$$

Now

$$\frac{d\phi}{dt} = \frac{\text{Change in flux}}{\text{Time required for change in flux}}$$

Consider the 1/4th cycle of the flux as shown in the fig. Complete cycle gets completed in  $1/f$  seconds hence for 1/4th time, the change in flux is from 0 to  $\phi_m$ .

$$\therefore \frac{d\phi}{dt} = \frac{\phi_m - 0}{\left(\frac{1}{4f}\right)} = 4f\phi_m \text{ Wb/sec}$$

$\therefore$  Average e.m.f. per turn =  $4f\phi_m$  volts

As  $\phi$  is sinusoidal the induced e.m.f. in each turn of both the windings is also sinusoidal in nature. For sinusoidal quantity.

$$\text{Form factor} = \frac{\text{R.M.S. value}}{\text{Average value}} = 1.11$$

$\therefore$  R.M.S. value =  $1.11 \times \text{Average value}$

$\therefore$  R.M.S. value of induced e.m.f. per turn =  $1.11 \times 4f\phi_m = 4.44f\phi_m$

There are  $N_1$  number of primary turns hence the R.M.S. value of induced e.m.f. of primary denoted as  $E_1$  is,

$$E_1 = N_1 \times 4.44f\phi_m \text{ volts}$$

While as there are  $N_2$  number of secondary turns the R.M.S. value of induced e.m.f. of secondary denoted  $E_2$  is,

$$E_2 = N_2 \times 4.44f\phi_m \text{ volts}$$

The expressions of  $E_1$  and  $E_2$  are called e.m.f. equations of a transformer.

Thus e.m.f. equations are,

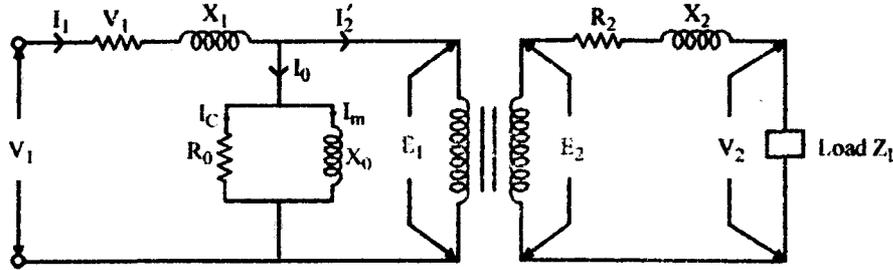
$$E_1 = 4.44f\phi_m N_1 \text{ volts}$$

...(1)

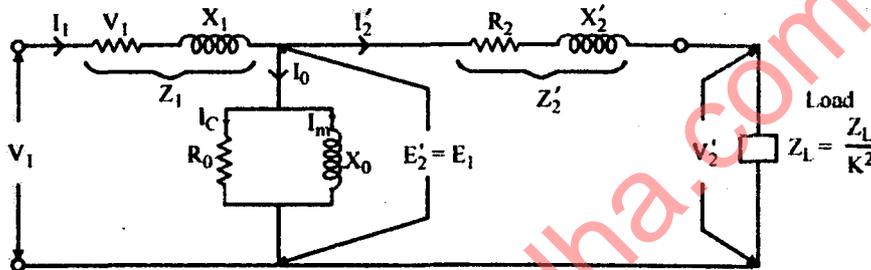
$$E_2 = 4.44f\phi_m N_2 \text{ volts}$$

...(2)

The Equivalent Circuit of Transformer is shown as below:



Thus the exact equivalent circuit referred to primary can be shown as in the figure.



**Q.7. Answer any one part of the following:**

**(a) Discuss construction and principle of operation of moving iron type measuring instruments.**

**Also enlist advantages and disadvantages of it.**

**Ans. Moving Iron Instruments:** The moving iron instruments are classified as:

- (i) Moving iron attraction type instruments and
- (ii) Moving iron repulsion type instruments

**(i) Moving iron attraction type instruments:** The basic working principle of these instruments is very simple that a soft iron piece if brought near the magnet gets attracted by the magnet.

It consists of a fixed coil C and moving iron piece D. The coil is flat and has a narrow slot like opening. The moving iron is a flat disc which is eccentrically mounted on the spindle. The spindle is supported between the jewel bearings. The spindle carries a pointer which moves over a graduated scale. The number of turns of the fixed coil are dependent on the range of the instrument. For passing large current through the coil only few turns are required.

The controlling torque is provided by the springs but gravity control may also be used for vertically mounted panel type instruments.

The damping torque is provided by the air friction. A light aluminium piston is attached to the moving system. It moves in a fixed chamber. The chamber is closed at one end. It can also be provided with the help of vane attached to the moving system.

The operating magnetic field in moving iron instruments is very weak. Hence eddy current damping is not used since it requires a permanent magnet which would affect or distort the operating field.

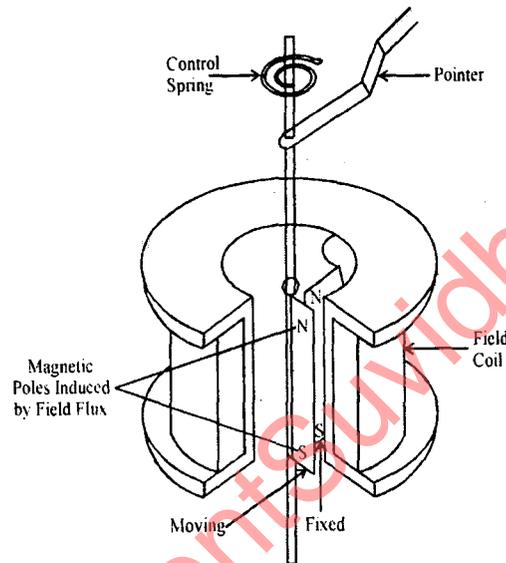
**Moving Iron Repulsion Type Instrument:** These instruments have two vanes inside the coil, the one is fixed and other is movable. When the current flows in the coil, both the vanes are magnetised with like polarities induced on the same side. Hence due to the repulsion of like polarities, there is a force of repulsion between the two vanes causing the movement of the moving vane. The repulsion type instruments are the most commonly used instruments.

The two different designs of repulsion type instruments are:

- (i) Radial vane type and (ii) Co-axial vane type

**Radial Vane Repulsion Type Instrument:** The figure shows the radial vane repulsion type instrument. Out of the other moving iron mechanisms, this is the most sensitive and has most linear scale.

The two vanes are radial strips of iron. The fixed vane is attached to the coil. The movable vane is attached to the spindle and suspended in the induction field of the coil. The needle of the instrument is attached to this vane.



Eventhough the current through the coil is alternating, there is always repulsion between the line poles of the fixed and the movable vane. Hence the deflection of the pointer is always in the same direction. The deflection is effectively proportional to the actual current and hence the scale is calibrated directly to read amperes or volts. The calibration is accurate only for the frequency for which it is designed because the impedance is different for different frequencies.

**Advantages:** The various advantages of moving iron instruments are:

1. The instruments can be used for both ac and dc measurements.
2. As the torque to weight ratio is high, errors due to the friction are very less.
3. A single type of moving element can cover the wide range hence these instruments are cheaper than other type of instruments.

4. There are no current carrying parts in the moving system hence these meters are extremely rugged and reliable.

5. These are capable of giving good accuracy. Modern moving iron instruments have a dc error of 2% or less.

6. These can withstand large loads and are not damaged even under severe overload conditions.

7. The range of instruments can be extended.

**Disadvantages:** The various disadvantages of moving iron instruments are:

1. The scale of the moving iron instruments is not uniform and is cramped at the lower end. Hence accurate readings are not possible at this end.

2. There are serious errors due to hysteresis, frequency changes and stray magnetic fields.

3. The increase in temperature increases the resistance of coil, decreases stiffness of the springs, decreases the permeability and hence affect the reading severely.

4. Due to the non linearity of B-H curve, the deflecting torque is not exactly proportional to the square of the current.

5. There is a difference between ac and dc calibrations on account of the effect of inductance of the meter. Hence these meters must always be calibrated at the frequency at which they are to be used. The usual commercial moving iron instrument may be used within its specified accuracy from 25 to 125 Hz frequency range.

**(b) Discuss the principle of operation of a single-phase induction motor. How the motor is started? Explain any one method of starting of it.**

**Ans.** The double/two revolving field theory of single phase induction motor basically states that a stationary pulsating magnetic field can be resolved into two rotating magnetic fields, each of equal magnitude but rotating in opposite directions. The induction motor responds to each magnetic field separately, and the net torque in the motor is equal to the sum of the torques due to each of the two magnetic fields.

The equation for an alternating magnetic field whose axis is fixed in space is given by

$$b(\alpha) = \beta_{\max} \sin \omega t \cos \alpha \quad \dots(1)$$

where  $\beta_{\max}$  is the maximum value of the sinusoidally distributed air-gap flux density produced by a properly distributed stator winding carrying an alternating current of frequency  $\omega$  and  $\alpha$  is the space displacement angle measured from the axis of the stator winding.

Since  $\sin A \cos B = \frac{1}{2} \sin (A - B) + \frac{1}{2} \sin (A + B)$

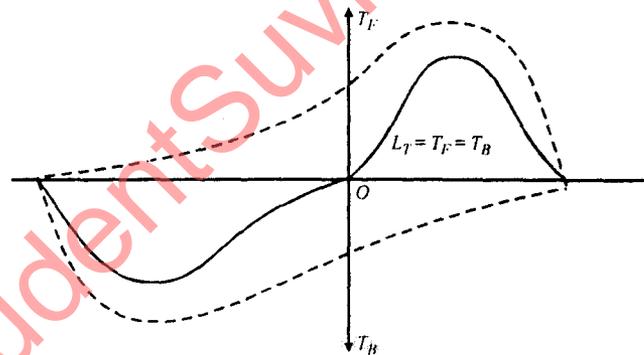
Equation (1) can be written as

$$b(\alpha) = \frac{1}{2} \beta_{\max} \sin(\omega t - \alpha) + \frac{1}{2} \beta_{\max} \sin(\omega t + \alpha) \quad \dots(2)$$

The first term on the right hand side of eq. (2) represents the equation of a revolving field moving in the positive  $\alpha$  direction and has a maximum value equal to  $\frac{1}{2} \beta_{\max}$ . The second term on the right side of eq. (2) represents the equation of a revolving field moving in the negative  $\alpha$  direction and has a maximum value equal to  $\frac{1}{2} \beta_{\max}$ .

The field moving in the positive  $\alpha$  direction is called the forward revolving field and the field moving in the negative  $\alpha$  direction is called backward revolving field. It is to be noted that both fields rotate at synchronous speed  $\omega_s$  in the opposite directions.

When the rotor is stationary, the induced voltages are equal and opposite. Consequently, the two torques are also equal and opposite. Hence, at standstill, the net torque is zero. In other words, a single phase induction motor with single stator winding has inherently no starting torque.



The above figure also reveals that single phase induction motor can run in either direction if an external torque, greater than friction and load torque, is applied to its shaft.

### Various Starting Methods of Single Phase Induction Motor:

#### 1. Split Phase Starting Method

- Resistance Split Phase Starting
- Capacitor Start Motor
- Capacitor Start Capacitor Run Motor
- Capacitor Run Motor

#### 2. Shaded Pole Starting

**Shaded Pole Starting Method:** The shaded-pole induction motor is another single-phase motor. It uses a unique method to start the rotor turning. The effect of a moving magnetic field is produced by constructing the stator in a special way. This motor has projecting pole pieces just like some dc motors. In addition, portions of the pole piece surfaces are surrounded by a copper strap called a shading coil. A

pole piece with the strap in place is shown in figure. The strap causes the field to move back and forth across the face of the pole piece. Note the numbered sequence and points on the magnetization curve in the figure. As the alternating stator field starts increasing from zero (1), the lines of force expand across the face of the pole piece and cut through the strap. A voltage is induced in the strap. The current that results generates a field that opposes the cutting action (and decreases the strength) of the main field. This produces the following actions: As the field increases from zero to a maximum at  $90^\circ$ , a large portion of the magnetic lines of force are concentrated in the unshaded portion of the pole (1). At  $90^\circ$  the field reaches its maximum value. Since the lines of force have stopped expanding, no emf is induced in the strap, and no opposing magnetic field is generated. As a result, the main field is uniformly distributed across the pole (2). From  $90^\circ$  to  $180^\circ$ , the main field starts decreasing or collapsing inward. The field generated in the strap opposes the collapsing field. The effect is to concentrate the lines of force in the shaded portion of the pole face (3). You can see that from  $0^\circ$  to  $180^\circ$ , the main field has shifted across the pole face from the unshaded to the shaded portion. From  $180^\circ$  to  $360^\circ$ , the main field goes through the same change as it did from  $0^\circ$  to  $180^\circ$ ; however, it is now in the opposite direction (4). The direction of the field does not affect the way the shaded pole works. The motion of the field is the same during the second half-cycle as it was during the first half of the cycle.

