Solution to Question Bank

MODULE-1

1. State and explain Faraday's laws of electromagnetic induction.

[June/July 2014, June/July 2015]

Faraday's First law: Whenever the flux linking the coil or conductor changes, an emf is induced in it.

Faraday's Second law: The magnitude of induced emf in a coil is directly proportional to the rate of change of flux linkages.

If there are N turns in a coil, then each flux line will link with these coil N times

i.e., flux linkage = NΦ.

If flux in a coil change from Φ_1 Wb to Φ_2 Wb in't' sec, then according to faraday's second laws the induced emf is given by

$$e = \frac{N(\emptyset_2 - \emptyset_1)}{t} \text{ V}$$

Where N Φ_1 = Initial flux linkages

N Φ_2 = Final flux linkages

Therefore in differential form

$$e = \frac{Nd(\emptyset_2 - \emptyset_1)}{dt} \text{ V}$$

$$e = -\frac{Nd\Phi}{dt} \text{Where } \Phi = \Phi2 - \Phi1$$

2. An air cored solenoid has a length of 50cm and a diameter of 2cm.Calculate its inductances if it has 1000 turns and also find the energy stored in it, if the current rises from zero to 5A.

[June/July 2014, June/July 2015]

$$L = \frac{N^2 \mu_0 \mu_r a}{l} \quad \text{Henries}$$

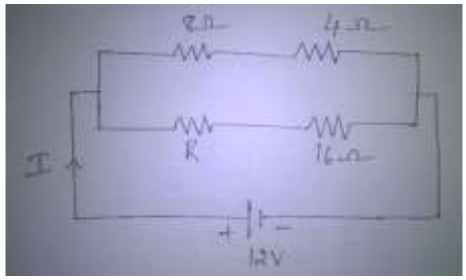
$$= \frac{4\pi\times10^{-7}\times1\times\pi\times(1\times10^{-2})^2\times1000^2}{50\times10^{-2}} = 789.6\,\mu\text{ H}$$

$$\text{Energy stored} = \frac{1}{2} L\, I^2$$

$$= ½* (789.6\times 10^{-6})\,(5^2)$$

= 9.87 mJ

3. If the total power dissipated in the circuit shown is 18W, find the value of 'R' and its current. [June/July 2015]



P = 18W

I = P/V = 18/12 = 1.5 A

I_1 = V/ (8+4) (Since it is a parallel circuit).

= 12/12 = 1A

$I_2 = I - I_1$

= 1.5 – 1 = 0.5A

Voltage across 16Ω resistor is $V_{16\Omega} = I_2 \times 16 = 0.5 \times 16 = 8V$

So voltage Across R is 12- 8 = 4 V

$R = V/ I_2 = 4/0.5 = 8\Omega$

4. State Fleming's right hand rule and Fleming's left hand rule. [June/July 2015]

Fleming's right hand rule: The Fleming's left hand rule is used to get direct of force experienced by conductor carrying current placed in magnetic field while Fleming's right hand rule can be used to get direction of induced emf. When conductor is moving at right angles to the magnetic field.

According to this rule, out stretch the three fingers of right hand namely the thumb, fore finger and the middle finger, perpendicular to each other. Arrange the right hand so that finger point in the direction of flux lines (from N to S) and thumb in the direction of motion of conductor with respect to the flux then the middle finger will point in the direction of the induced emf. (or current).

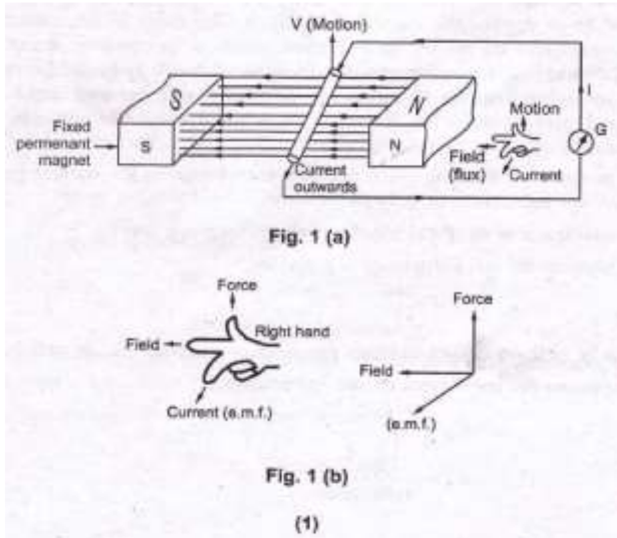


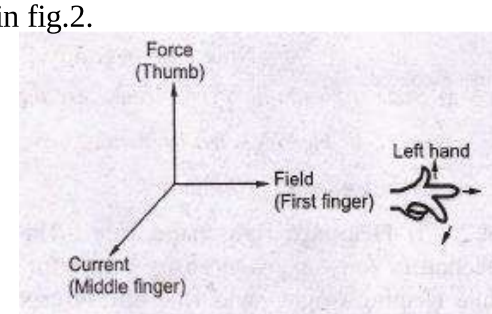
Fig. 1 (a)

Fig. 1 (b)

(1)

Fleming's left hand rule: The direction of the force experienced by the current carrying conductor placed in magnetic field can be determined by a rule called 'Fleming's left hand rule'. The rule states that 'outstretch the three fingers on the left hand namely the first finger, middle finger and thumb such that they are mutually perpendicular to each other. Now point the first finger in the direction of magnetic field and middle finger in the direction of the current then the thumb gives the direction of the force experienced by the conductor.'

The rule is explained in the diagrammatic form in fig.2.



Applications: Fleming's right and rule is used to get the direction of induced emf in case of generators and alternators while left hand rule is used to get the direction of torque induced in motors.

5. **A closed iron ring of mean diameter 12cm is made from round iron bar of diameter 2cm.It has a uniform winding of 1000 turns. Calculate the current required to produce a flux density of 1.5Wb/m^2 given that relative permeability is1250.Hence calculate the self-inductance.** **[June/July 2015]**

Solution:

Area = $\frac{\pi d^2}{4}$ = $3.14\times10^{-4}m^2$

Mean diameter d = 12 cm =12 × 10 $^{-2}$×10^{-2}m

l = π * d = 0.377 m

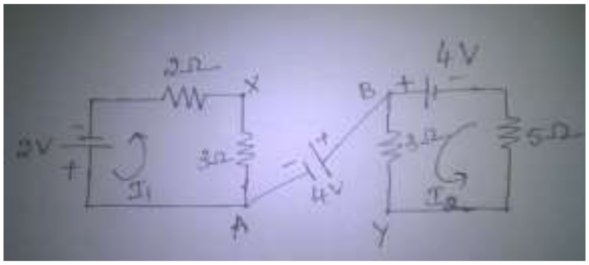
S = $\frac{l}{\mu_0\mu_r a}$ = $\frac{0.377}{4\pi\times10^{-7}\times1250\times3.14\times10^{-4}}$ = 764.34K AT/Wb

Φ = B*A = 1.5 * 3.14×10^{-4} = 4.71×10^{-4} Wb

I = $\frac{\emptyset S}{N}$ = $\frac{4.71\times10^{-4}\times76.43\times10^{4}}{1000}$ = 0.3599A

L = $\frac{N\emptyset}{I}$ = $\frac{1000\times4.71\times10^{-4}}{0.36}$= 1.314 H

6. **What is the potential difference between the point x and y in the network shown?** **[June/July 2015]**



I_1 = 2/ (2+3) = 0.4A

I_2 = 4/ (3+5) = 0.5A

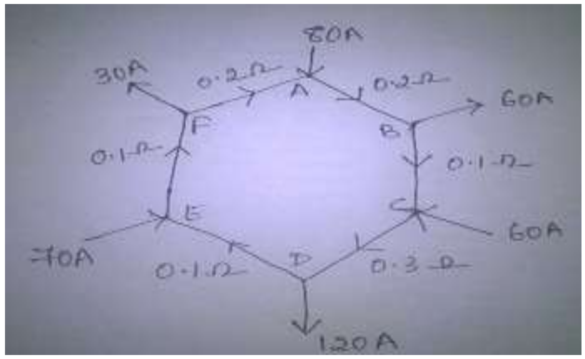
V_{xy} = $3I_1$ + 4 – $3I_2$

= (3* 0.4) + 4 - (3*0.5)

= 3.7 V

7. Find the values of currents in all the branches of the network shown in figure

[Dec 2014/Jan2015, June/July 2016]



-0.2I-0.1(I-60)-0.3I-0.1(I-120)-0.1(I-50)-0.2(I-80) = 0

-0.2I-0.1I-0.3I-0.1I-0.1I-0.2I+6+12+5+16 = 0

-I = -39

I = 39

8. A current of 20A flows through two ammeters A and B in series. The potential difference across A is 0.2V and across B is 0.3V.Find how the same current will divide between A and B when they are in parallel. [Dec 2014/Jan2015]

Case I:

V1 = 0.2 V

V2 = 0.3 V

Resistance of ammeter A, R1 = V1/I = 0.2/20 = 0.01 ohms

Resistance of ammeter B, R2 = V2/I = 0.3/20 = 0.015 ohms

Case II:

I1 = I* (R2/ (R1+R2)) = 20*(0.015/ (0.015+0.01)) = 12A

I2 = I* (R1/ (R1+R2)) = 20*(0.01/ (0.015+0.01)) = 8A

9. **Coils A and B in a magnetic circuit have 600 turns and 500 turns respectively. A current of 8A in coil A produces a flux of 0.04Wb.If co-efficient of coupling is 0.2, calculate i)self-inductance of the coil A with B open circuited,(ii)flux linking with the coil B (iii)the average emf induced in coil B when flux with it changes from zero to full value in 0.02 seconds,(iv)mutual inductance. [Dec 2014/Jan2015]**

Solution:

N_A = 600, N_B = 500, I_A = 8A, Φ_A = 0.04 Wb, K = 0.2

1. $L_A = \frac{N_A \emptyset_A}{I_A} = \frac{600 \times 0.04}{8} = 3H$
2. $\emptyset_B = \emptyset_A K = 0.2 \times 0.04 = 0.008H$
3. emf in coil B, $= -N_B \frac{d\emptyset_B}{dt} = -500 \times \frac{\emptyset_B - 0}{dt} = -500 \times \frac{0.008}{0.02} = -200$ V
4. $M = \frac{N_B \emptyset_B}{I_B} = \frac{500 \times 0.008}{8} = 0.5H$

10. **A circuit consists of 2 parallel resistors having resistances 20Ω and 30Ω respectively, connected in series with a 15Ωresistor. If the current through 30Ωresistor is 1.2A, Find (i)Currents in 20Ω and 15Ω resistors(ii)The voltage across the whole circuit(iii)voltage across 15 Ω resistor and 20 Ω resistor(iv) total power consumed in the circuit.**

[Dec 2014/Jan2015]

Solution : Voltage across 30 Ω is = I R = 1.2 × 30 = 36V

Current in 20 Ω is = V/R = 36/ 20 = 1.8 A (Since 20 Ω and 30 Ω are in parallel)

Total current in the circuit is = 1.8 +1.2 = 3 A

Voltage in 15 Ω is = 3 ×15 = 45 V

Total voltage is = 45 +36 = 81 V

Power in the circuit is = VI = 81 ×3 = 243 W

11. **Obtain the relation between self-inductance, mutual inductance and co-efficient of coupling [Dec 2014/Jan2015, June/July 2016]**

The coefficient of coupling is defined as the ratio of the actual mutual inductance present between the two coils as the maximum possible value of the mutual inductance. It gives an idea about magnetic coupling between the two coils. This coefficient indicates the amount of linking with other coil which is produced by one coil.

Let N_1 = Number of turns of first coil : N_2 = number of turns of second coil

I_1 = current through first coil

I_2 = current through by first coil

ϕ_1 = flux produced by first coil

ϕ_2 = flux produced by second coil

$$\therefore \quad M = \frac{N_2 K_1 \phi_1}{I_1} \text{ and } M = \frac{N_1 K_2 \phi_2}{I_2}$$

Multiplying the two expressions,

$$M \times M = \frac{N_2 K_1 \phi_1}{I_1} \times \frac{N_1 K_2 \phi_2}{I_2}$$

$$M_2 = K_1 K_2 \left[\frac{N_1 \phi_1}{I_1}\right] \left[\frac{N_2 \phi_2}{I_2}\right]$$

But $\frac{N_1 \phi_1}{I_1}$ = L_1 = self-inductance of first coil

And $\frac{N_2 \phi_2}{I_2}$ = L_2 = self-inductance of second coil

$$\therefore \quad M_2 = K_1 K_2 L_1 L_2$$

$$\therefore \quad M = \sqrt{K_1 K_2}\sqrt{L_1 L_2}$$

Let $K = \sqrt{K_1 K_2}$ = coefficient of coupling

$$\therefore \quad M = K\sqrt{L_1 L_2}$$

$$K = \frac{M}{\sqrt{L_1 L_2}}$$

12. A coil consists of 600 turns and a current of 10A in the coil gives rise to a magnetic flux of 1mWb. Calculate (i) self-inductance (ii) induced emf (iii) energy stored when the current is reversed in 0.01second. [Dec 2014/Jan2015]

$$L = \frac{N\emptyset}{I}$$

$$= \frac{600\times1\times10^{-3}}{10} = 0.06 \text{ H}$$

$$e = -L\frac{di}{dt} = -\ 0.06 \times (-10-10)/0.01 = 120\text{V}$$

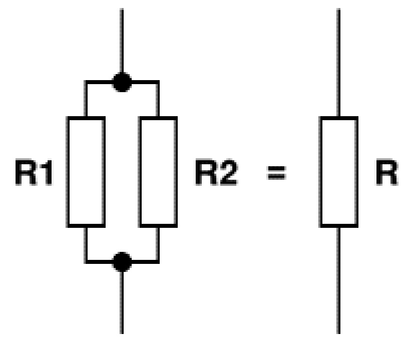
$$\text{Energy stored} = \frac{1}{2}L\,I^2 = (1/2)^*\ (0.06)^*\ 10^2 = 3 \text{ J}$$

13. Show that the equivalent resistance of two resistors connected is the ratio of product of these two resistances divided by the sum of those two resistance values.

[June/July 2014]

When resistors are connected in parallel their combined resistance is less than any of the individual resistances. There is a special equation for the combined resistance of two resistors R1 and R2:

Combined resistance of **two resistors in parallel**: $\mathbf{R = \dfrac{R1 \times R2}{R1 + R2}}$



For more than two resistors connected in parallel a more difficult equation must be used. This adds up the **reciprocal** ("one over") of each resistance to give the **reciprocal** of the combined resistance, R:

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

The simpler equation for **two** resistors in parallel is much easier to use. Note that the **combined resistance in parallel** will always be **less** than any of the individual resistances.

(P)Power is the amount of current times the voltage level at a given point measured in wattage or watts. **Electrical energy** - energy made available by the flow of electric charge through a conductor; "they built a car that runs on electricity" measured in k Watt Hour.

Energy=VI KWH

14. Derive an expression for dynamically induced emf. [June/July 2014]

The change in the flux linking with a coil, conductor or circuit can be brought about by its motion relative to magnetic field. This is possible by moving flux with respect to coil conductor or circuit or it is possible by moving conductor, coil, and circuit with respect to stationary magnetic flux. Such an induced emf which is due to physical movement of coil, conductor with respect to flux or movement of magnet with respect with to stationary coil, conductor is called dynamically induced emf or motional induced emf. This type of induced emf is available in the rotating machines such as alternators, generator etc.

15. Two coils having 1000 turns and 1600 turns respectively are placed close to each other such that 60% of the flux produced by one coil links the other. If a current of 10A, flowing in the first coil produces a flux of 0.5mWb.Find the inductance of the second coil.

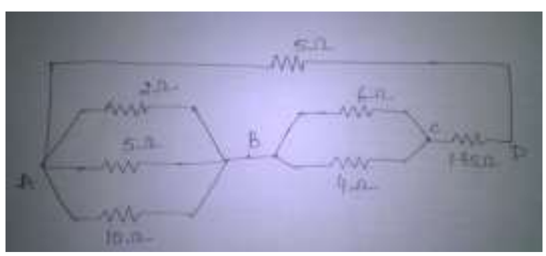
[June/July 2014]

Solution: N_A = 1000, N_B = 1600, I_A = 10A, Φ_A = 0.5mWb. L_B= ?

Φ_B = 60% of Φ_A = 0.6× 0.5mWb = 0.3mWb

$L_B = \frac{N_B \emptyset_B}{I_B} = \frac{1600 \times 0.0003}{10}$ = 0.048 H

16. Find the resistance of the circuit shown (R_{AD}). [June/July 2014]



((2 Ω || 5 Ω || 10 Ω) + (6 Ω || 4 Ω) + 1.35) || 5 Ω

(1.25 + 2.4 +1.35) || 5 Ω

= 2.5Ω

17. State and explain Kirchoff's Laws. [June/July 2014, June/July 2016]

"In any network, the algebraic sum of the voltage drops across the circuit elements of any closed path (or loop or mesh) is equal to the algebraic sum of the emf s in the path"

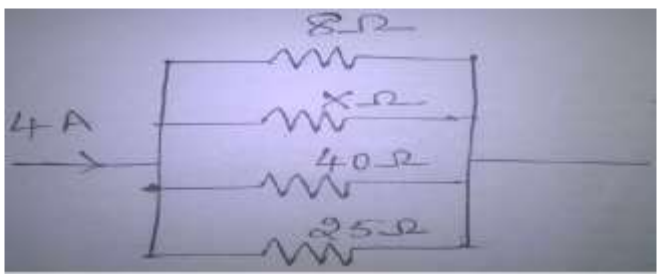
In other words, "the algebraic sum of all the branch voltages, around any closed path or closed loop is always zero."

Around a closed path $\sum V = 0$

1. The law states that if one starts at a certain point of a closed path and goes on tracing and noting all the potential changes (either drops or rises), in any one particular direction, till the starting point reached again, he must be at the same potential with which he started tracing a closed path.
2. Sum of all the potential rises must be equal to sum of all the potential drops while tracing any closed path of the circuit. The total change in potential along a closed path is always zero.
3. This law is very useful in loop analysis of the network.

18. In the parallel arrangement of resistors shown the current flowing in the 8Ω resistor is 2.5A. Find current in others resistors, resistor X, the equivalent resistance.

[June/July 2014]



V=IR=2.5*8=20V

$I_{40}=\frac{V}{R}=\frac{20}{40}=0.5A$

$I_{25}=\frac{20}{25}=0.8A$

$I_x = 4-(2.5+0.8+0.5) = 0.2A$

Therefore, $X (\Omega) = \frac{V}{I} = \frac{20}{0.2} = 100\Omega$

19. Derive the expression for energy stored in an inductor. [June/July 2014]

Let the induced emf in a coil be,

$$e = -L\frac{dI}{dt}$$

This opposes a supply voltage. So supply voltage 'V' supplies energy to overcome this, which ultimately gets stored in the magnetic field.

∴ $V = -e = -\left[-L\frac{dI}{dt}\right] = L\frac{dI}{dt}$

∴ Power supplied = $V \times I = L\frac{dI}{dt} \times I$

∴ Energy supplied in time dt is,

$$E = \text{power x time} = L\frac{dI}{dt} \times I \times dt$$

$$= L\, di \times I \text{ joules.}$$

This is energy supplied for a change in current of dI but actually current changes from zero to I.

∴Integrating above total energy stored is,

$E = \int_0^I L dI \; I$

Energy stored = $\frac{1}{2} L\, I^2$

20. State Ohm's law. Mention its limitation. [Dec2015/Jan2016, June/July 2016]

Ohm's Law : the current flowing through the electric the electric circuit is directly proportional to the potential difference across the circuit and inversely proportional to the resistance of the circuit, provided the temperature remains constant.

The limitations of the Ohm's law are,

1) It is not applicable to the nonlinear devices such as diodes, zener diodes, voltage regulators
2) It does not hold good for non-metallic conductors such as silicon carbide.

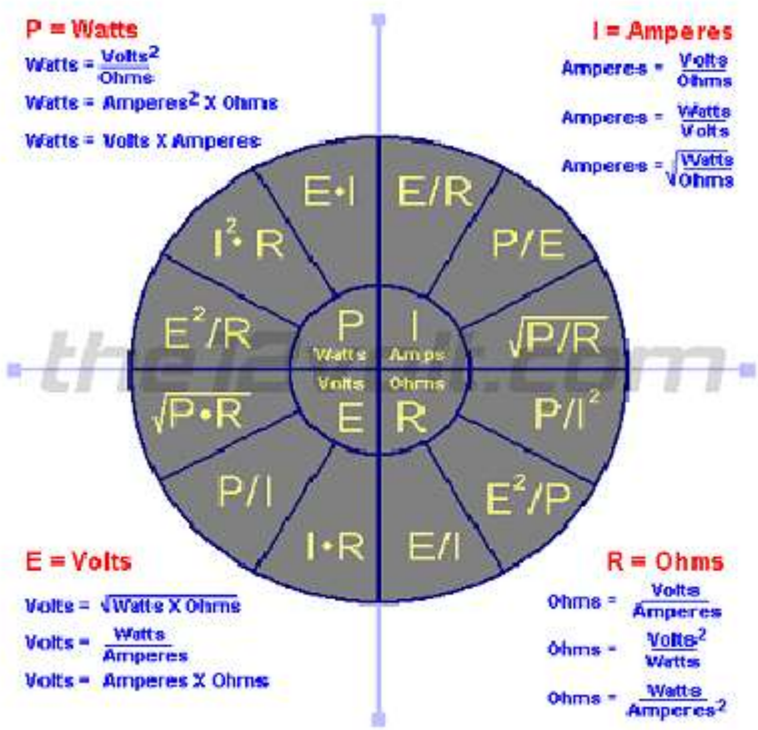
The law for such conductors is given by,

$V = K I^m$ where k, m are constants.

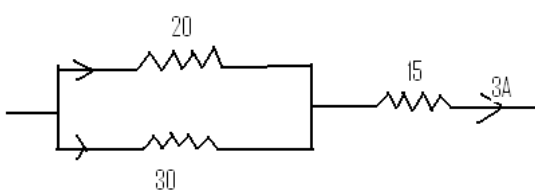
(I) Current is what flows on a wire or conductor like water flowing down a river. Current flows from negative to positive on the surface of a conductor. Current is measured in (A) amperes or amps.

(E) Voltage Ohm's Law defines the relationships between (P) power, (E) voltage, (I) current, and (R) resistance. One ohm is the resistance value through which one volt will maintain a current of one ampere is the difference in electrical potential between two points in a circuit. It's the push or pressure behind current flow through a circuit, and is measured in (V) volts.

(R) Resistance determines how much current will flow through a component. Resistors are used to control voltage and current levels. A very high resistance allows a small amount of current to flow. A very low resistance allows a large amount of current to flow. Resistance is measured in Ωohms.



21. A Circuit of two parallel resistors having resistance of 20Ω and 30Ω respectively, connected in series with 15Ω. If the current through 15Ω resistor is 3A, find (i) current in 20Ω and 30Ω resistor, (ii) voltage across the whole circuit, (iii) the power and power consumed in all resistors. [Dec2015/Jan2016]



$$I_1 = 3\times30/(30+20) = 1.8A$$

$$I_2 = 3\times20/(30+20) = 1.2A$$

$$R_{equ} = 20\times30/(20+30) = 27\Omega$$

$$V = IR = 3\times27 = 81V$$

$$\text{Total power} = I^2R = (3)^2\times27 = 243W$$

$$P_{20} = (1.8)^2\times20 = 64.8W$$

$$P_{30} = (1.2)^2 \times 30 = 43.2W$$

$$P_{15} = (3)^2 \times 15 = 135W$$

22. Define dynamically induced emf and statically induced emf with examples

[Dec2015/Jan2016, June/July 2016]

Dynamically induced emf

The emf induced in a coil due to relative motion of the conductor and the magnetic field is called dynamically induced emf.

Example: dc generator works on the principle of dynamically induced emf in the conductors which are housed in a revolving armature lying within magnetic field

Statically induced e.m.f

The change in flux lines with respect to coil can be achieved without physically moving the coil or the magnet. Such induced e.m.f. in a coil which is without physical movement of coil or a magnet is called **statically induced e.m.f.**

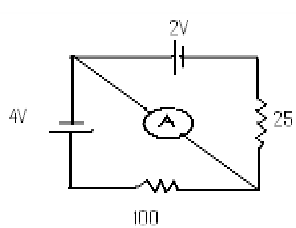
To have an induced e.m.f there must be change in flux associated with a coil. Such a change in flux can be achieved without any physical movement by increasing and decreasing the current producing the flux rapidly, with time.

Consider an electromagnet which is producing the necessary flux for producing e.m.f. Now let current through the coil of an electromagnet be an alternating one. Such alternating current means **it changes its magnitude periodically with time**. This produces the flux which is also alternating i.e. changing with time. Thus there exists $\frac{d\phi}{dt}$ associated with coil placed in the viscinity of an electromagnet. This is responsible for producing an e.m.f in the coil. This is called statically induced e.m.f.

There is no physical movement of magnet or conductor; it is the alternating supply which is responsible for such an induced e.m.f.

Such type of an induced e.m.f. is available in transformers.

23. In the network shown in fig., determine current flow in the ammeter 'A' having resistance of 10Ω. **[Dec2015/Jan2016]**



$$-100I - 4 - 10(I-I_1) = 0$$

$$110I - 10I_1 = -4 \text{ ......(1)}$$

$$-2 - 25I_1 + 10(I - I1) = 0$$

$$10\,I - 35I_1 = 2 \text{ .... (2)}$$

Solving eq (1) & (2)

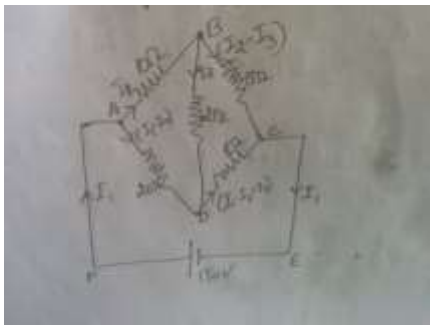
I = -0.043A

I_1 = -0.0693A

I – I_1 = 0.0263A

24. In the network shown in fig, find the currents flowing in each branch using Kirchhoff's laws.

[**June/July 2016]**



Loop ABDA,

-10I2 - 25I3 + 20(I1-I2) = 0

20I1 – 30I2 – 25I3 =0 .... (1)

Loop BCDB,

5I1 – 20I2 – 45I3 = 0 ....(2)

Loop ADCEFA,

-25I1 + 25I2 – 5I3 + 150 =0 ...(3)

From (1), (2) & (3)

I1= 12.68A , I2= 7.02A, I3= 1.71A

MODULE-2

1. Explain the characteristics of DC series motor with a neat diagram.

[June/July 2015]

Characteristics of D.C.Motors: To study the performance of a motor it is necessary to study the variation of its speed and torque with the variations of the load on it.

There are two types of characteristics: (i) Speed v/s load characteristics

(ii) Torque v/s load characteristics

Series Motor:

In a series motor the flux is solely dependent on the armature current hence the speed variation with load is not like shunt motor. At no load condition only residual flux is in action which is very very small resulting in a dangerously high speed. Therefore, series motors are not to be started on no load, which result in the initial speed of dangerously high value called **RUN AWAY SPEED** which severely damages the motor. Hence in series motors there is a provision of a fly wheel fixed to the shaft which acts like a mechanical load to prevent the motor to attain this high speed.

DC series motor :

i) N=1 characteristics :

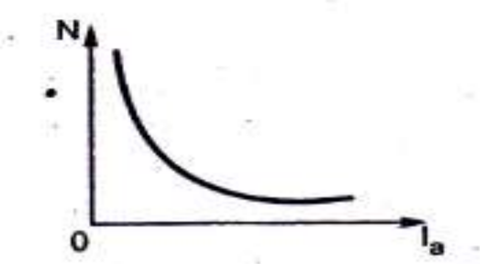


Fig. 2 N Vs I_a for series motor

ii) T-I characteristics :

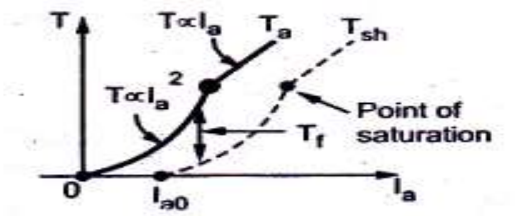


Fig. 3 T Vs I_a for series motor

2. Explain the significance of back EMF in a DC motors. [June/July 2015, June/July 2016]

Back EMF:

Whenever a current coil is placed under a magnetic field the coil experiences a mechanical force due to which the coil starts rotating. This rotating coil again cuts the magnetic lines of force resulting an EMF induced in it whose direction is to oppose the applied EMF (as per Fleming's right hand rule), and hence the name **BACK EMF** or **Counter Emf.**

Significance of Back EMF: Back EMF is a must in a motor which helps to regulate the armature current and also the real cause for the production of torque.

Expression for the back Emf is given by **E=V-IaRa,**

Where E is the back emf, V is the applied emf, Ia is the armature current and Ra is the armature circuit resistance. And also **E= PZNΦ/60A** volts, from the machine parameters.

3. A 4 pole DC shunt motor takes 22.5 A from 250V supply R_a =0.5ohms, R_{sh}=125ohms, the armature is wave wound with 300 conductors. If the flux per pole is 0.02Wb, calculate speed, torque and power developed. [June/July 2015]

Solution: P = 4, IL = 22.5A, V = 250V, R_a =0.5ohms, R_{sh}=125ohms

$$I_{sh} = \frac{V}{R_{Sh}} = \frac{250}{125} = 2A$$

$$I_a = I_L - I_{sh} = 22.5 - 2 = 20.5A$$

$$E_b = V - I_aR_a = 250 - (20.5*0.5) = 239.75\ V$$

$E_b = \frac{\Phi ZNP}{60A}$ where Z = 300, A= 2 as wave wound, Φ = 0.02Wb

$239.75 = \frac{0.02*300*N*4}{60*2}$

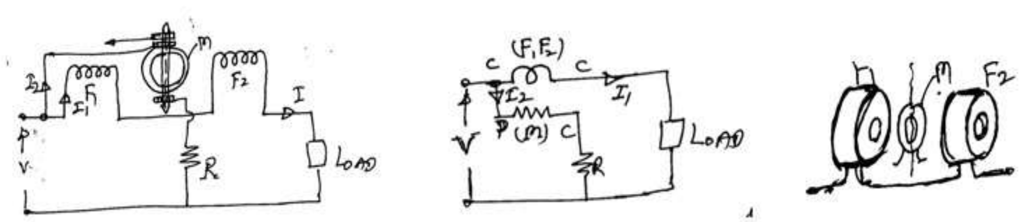
N = 1199 RPM

Torque, T = 0.159 $\Phi I_a \frac{PZ}{A}$ = 39.114 Nm.

Power developed, P = $E_b I_a$ = 239.75*20.5 = 4.9KW

4. With the neat diagram explain the construction and working of Dynamometer type wattmeter. [Dec2014/Jan 2015, June/July 2015, Dec 2015/Jan2016, June/July 2016]

In this type there will not be any permanent magnets and there will be a pair of fixed coils connected in series when energized gives the same effect as that of the permanent magnets. In the field of these fixed coils there will be a moving coil which when energized acted upon by a torque by which it deflects



F_1 F_2: Fixed coils

M: Moving coil

R: High resistance in series with m

I_1 : load current

I_2: current through

The two fixed coils in series act as the current coil and the moving coil in series with R act as the potential coil. The moving coil is pivoted between the two fixed coils carries a current I_2 proportional to V. This current is fed to m through two springs which also provides the necessary controlling torque. This instrument can be used on both ac and dc circuits as both the coils are energized simultaneously by a common source due to which a unidirectional torque is produced.

5. **A 4 pole generator with wave wound armature has 51 slots, each having 24 conductors,The flux per pole is 0.01 Wb. At what speed must the armature rotate to give a induced emf of 220V. What will be the voltage developed if the winding is lap and armature rotates at same speed. [June/July 2015]**

Solution:P = 4, wave wound hence A = 2, Φ = 0.01Wb, N = ?, Eg = 220V.

Z= 51*24 = 1224.

Eg = $\frac{\Phi ZNP}{60A}$

220 = $\frac{0.01\times1224\times N\times4}{60\times2}$

N = 539.22rpm.

When winding is Lap Connected

$$Eg = \frac{\Phi ZNP}{60A} = \frac{0.01\times1224\times539.22\times4}{60\times4} = 110V$$

6. **Explain with diagram the construction features of various parts of a DC generators. [June/July 2015, June/July 2016]**

Salient parts of a D.C.machine are:

- Field system (poles)
- Coil arrangement (armature)
- Commutator
- Brushes
- Yoke

Fig shows the details of a four pole D.C. machine with both shunt and series field windings.

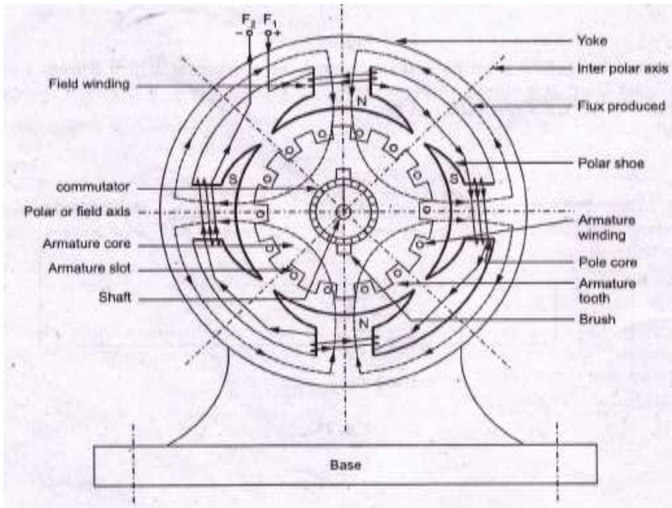


Fig. 26 A cross section of typical d.c. machine

It consists of the following parts:

Yoke:i) It serves the purpose of outermost cover of the d.c. machine. So that the insulating materials get protected from harmful atmospheric elements like moisture, dust and various gases like SO_2, acidic fumes etc.

ii) It provides mechanical support to the poles.

iii) It forms a part of the magnetic circuit. It provides a path of low reluctance for magnetic flux. The low reluctance path is important to avoid wastage of power to provide same flux. Large current and hence the power is necessary if the path has high reluctance, to produce the same flux.

Poles:

Each pole is divided into two parts Namely,

a) pole core and b) pole shoe

i) pole core basically carries a field winding which is necessary to produce the flux.

ii) It directs the flux produced through air gap to armature core, to the next pole.

iii)pole shoe enlarges the area of armature core to come across the flux, which is necessary to produce larger induced e.m.f. to achieve this, pole shoe has given a particular shape.

Armature:

It is further divided into two parts namely,

I) Armature core and II) Armature winding

Armature core is cylindrical in shape mounted on the shaft. It consists of slots on its periphery and the air ducts to permit the air flow through armature which serves cooling purpose.

Commutator:

i) To facilitate the collection of current from the armature conductors.

ii) To convert internally developed alternating e.m.f. to unidirectional (d.c.) e.m.f.

iii) To produce unidirectional torque in case of motors.

Brushes and brush gear:

Brushes and stationary and resting on the surface of the commutator.

i) To collect current from commutator and make it available to the stationary external circuit.

Bearings:

Ball bearings are usually as they are more reliable. For heavy duty machines, roller bearings are preferred.

7. Derive the expression for armature torque developed in a dc motor.

[Dec2014/Jan 2015, June/July 2016]

Let P be the total number of poles; Z be the total number of armature conductors arranged in A number of parallel paths. Let **Φ** be the flux per pole, N be the speed of rotation in rpm, and T be the torque in Nm.

We know that the back emf **E=V-IaRa**

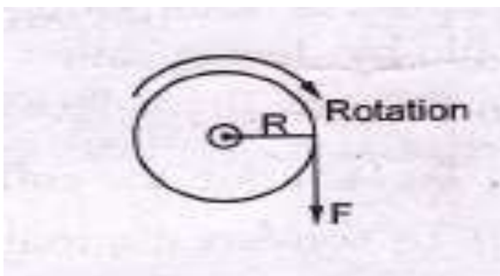


Fig. 30

It is seen that the turning or twisting force about anaxis is called torque.

Consider a wheel of radius R meters, acted upon by a

Circumferential force of F Newton's as shown in fig. 30.

The wheel is rotating at a speed of N r.p.m.

Then angular speed of the wheel is,

$$\omega = \frac{2\pi N}{60} \text{rad/sec}$$

So work done in one revolution is,

W = F× distance travelled in one revolution

= F× 2πR joules

And P_m = power developed = $\frac{\text{work done}}{\text{time}}$

$$= \frac{F \times 2\pi R}{\text{time for 1rev}}$$

$$= \frac{F \times 2\pi R}{\frac{60}{N}} = (F \times R) \times \left(\frac{2\pi N}{60}\right)$$

$P_m = T \times \omega$

where T = Torque in N-m = $(F \times R)$

ω = angular speed in rad/sec = $(2\pi N/60)$

Let Ta be the gross torque developed by the armature of the motor. It is also called armature torque. The gross mechanical power developed in the armature is $E_b I_a$, as seen from the power equation. So if speed of the motor is N r.p.m. then,

Power in armature = Armature torque × ω

$$E_b I_a = T_a \frac{2\pi N}{60}$$

But E_b in a motor given by, $E_b = \frac{\emptyset PNZ}{60\ A}$

$$\therefore \quad \frac{\emptyset PNZ}{60\ A} \times I_a = T_a \times \frac{2\pi N}{60}$$

$$\therefore T_a = \frac{1}{2\pi} \emptyset\ I_a \times \frac{PZ}{A}$$

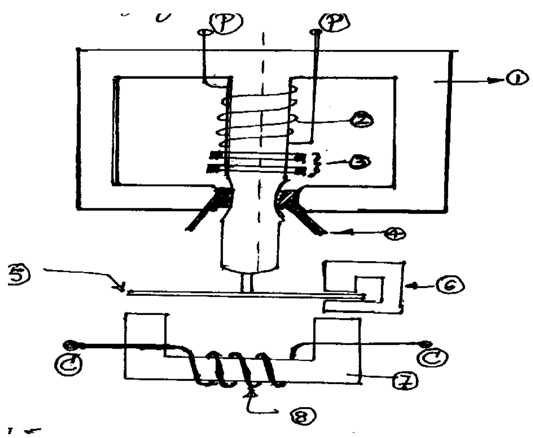
$$\therefore T_a = 0.159\ \emptyset\ I_a \frac{PZ}{A} \text{ N-m}$$

This is the torque equation of a d.c.motor.

8. With the help of a neat diagram. Explain the construction and principle of operation of induction type single phase energy meter.

[Dec2014/Jan 2015, June/July 2014, June/July 2014, Dec 2013/Jan 2014, June/July 2016]

This is a measuring instrument/device which works on the principle of induction and measures the energy consumed over a definite period.



1) Upper Magnet/ shunt magnet (P.P)

2) Potential coil/ Voltage coil

3) Copper Shading bands

4) Friction compensator

5) Aluminium disc

6) Brake magnet

7) Lower magnet/Series magnet

8) Current coil (C-C)

This instrument consisting two electromagnets as in fig.

1. **Upper magnet or Shunt magnet**: This carries the potential coil on its central limb which also carries one or two copper shading bands for the power factor adjustment.
2. **Lower magnet or Series magnet:** Which carries the current coil as shown. An aluminium disc is between the fields of the upper and lower electro magnets. There is a friction

compensator in the upper magnets for the measurement at very low loads. The aluminum disc rotates in the field of a brake magnet whose position can be set so that the disc rotates at proper speeds at higher loads.

This instrument works on the principle of induction that when both the shunt and series coils are energized by ac, there will be tow alternative fluxes are in the shunt coil and one in the series coil these time varying fluxes are cut by a stationary disc. Inducing currents in the disc. These currents interact with the fluxes and results in a torque which is given by $T\alpha\left(k1\varphi_{sh}i_{se} + K_2\varphi_{se}i_{sh}\right)$there by the disc rotates in a particular direction and the number and speed of rotations depends on the energy consumed by the load. Sometimes the energy meters disc rotates slowly even on no load conditions as the potential coil is continuously energized and this effect is called the 'CREEP' and the speed is called the 'CREEP SPEED' to minimum this creep one pair of diametrically opposite holes are made in the aluminium disc which alters the reluctance and minimizes the creep effect.

9. A 200V, 4 pole, lap wound DC shunt motor has 800 conductors on its armature, the resistance of the armature winding is 0.5ohms and that of field winding is 200ohms, the motor takes a current of 21A, the flux per pole is 30mWb. Find the speed and torque developed by the motors. [Dec2014/Jan 2015]

P = A, I_L = 21A, V = 200V, R_a =0.5ohms, R_{sh}=200ohms, Ish = V/Rsh = 200/200 = 1A

$I_a = I_L - I_{sh} = 21 - 1 = 20A$

$E_b = V - I_aR_a = 200 – (20*0.5) = 190$ V

$E_b = \frac{\Phi ZNP}{60A}$ where Z = 800, A= P as Lap wound, Φ = 0.03Wb

$190 = \frac{0.03*800*N*P}{60*P}$

N = 475rpm

Torque, $T = 0.159\ \Phi I_a \frac{PZ}{A} =$ 76.32Nm.

10. A 30 KW, 300 V DC shunt generator has armature and field resistance of 0.05ohms and 100 ohm respectively. Calculate the total power developed by armature when it delivers full output power. [Dec2014/Jan 2015]

$\mathbf{I_L = P_{out}/V_t = \frac{30\times10^3}{300} = 100A}$

$I_{sh} = V_t/R_{sh} = 300/100 = 3A$

$I_a = I_L+I_{sh}= 103A$

$E = V_t + I_aR_a = 300+(103+0.05) = 305.15V$

Total power developed by the armature = $E\times I_a$ = 305.15×103 = 31.43

11. Derive the expression for EMF of a DC generator. [June/July 2014, Dec2014/Jan 2015, June/July 2016]

Generated E.M.F. or E.M.F. Equation of a Generator

Let
Φ = flux/pole in weber
Z = total number of armature conductors
= No. of slots × No. of conductors/slot
P = No. of generator poles
A = No. of parallel paths in armature
N = armature rotation in revolutions per minute (r.p.m.)
E = e.m.f. induced in any parallel path in armature

Generated e.m.f. E_g = e.m.f. generated in any one of the parallel paths *i.e.* E.

Average e.m.f. generated/conductor = $\frac{d\Phi}{dt}$ volt $(\because n = 1)$

Now, flux cut/conductor in one revolution $d\Phi = \Phi P$ Wb

No. of revolutions/second = $N/60$ ∴ Time for one revolution, $dt = 60/N$ second

Hence, according to Faraday's Laws of Electromagnetic Induction,

E.M.F. generated/conductor = $\frac{d\Phi}{dt} = \frac{\Phi PN}{60}$ volt

For a simplex wave-wound generator

No. of parallel paths = 2

No. of conductors (in series) in one path = $Z/2$

∴ E.M.F. generated/path = $\frac{\Phi PN}{60} \times \frac{Z}{2} = \frac{\Phi ZPN}{120}$ volt

For a simplex lap-wound generator

No. of parallel paths = P

No. of conductors (in series) in one path = Z/P

∴ E.M.F. generated/path = $\frac{\Phi PN}{60} \times \frac{Z}{P} = \frac{\Phi ZN}{60}$ volt

In general generated e.m.f. $E_g = \frac{\Phi ZN}{60} \times \left(\frac{P}{A}\right)$ volt

where A = 2-for simplex wave-winding
= P-for simplex lap-winding

12. Sketch the various characteristics of DC shunt motors and mention its application. [June/July 2014, Dec2015/Jan2016]

To study the performance of a motor it is necessary to study the variation of its speed and torque with the variations of the load on it.

There are two types of characteristics: (i) Speed v/s load characteristics

(ii) Torque v/s load characteristics

Speed/Load characteristics: (a) D.C. Shunt Motor:

In a shunt motor the flux is considered to be constant because of the reason that the field circuit is connected across a constant power supply. Also as the applied voltage is constant the speed is directly proportional to the armature current only, and also as the load is increased the armature current also increases at the same rate and the speed becomes constant. But due to the increased friction at the bearings with the increase of the load there is a small decrease in the speed. The characteristic is shown in the fig. and is compared with the ideal characteristics. The drop in the speed can be reduced by slightly de-exciting the field flux, there by the speed is controlled.

DC shunt motor :

i) N-I characteristics

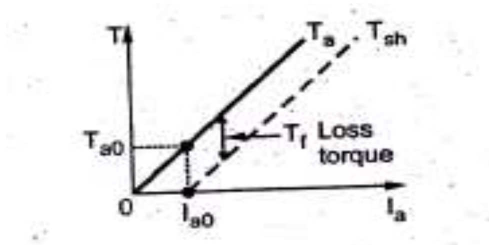


Fig. 4 T Vs I_a for shunt motor

ii) T-I characteristics:

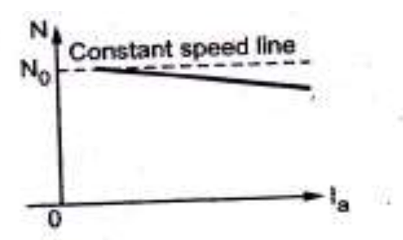


Fig. 5 N Vs I_a for shunt motor

13. A DC shunt motor takes an armature current of 110A at 480V. The armature resistance is 0.2 ohms, The machines has 6 poles, and armature is lap connected with 864 conductors. The flux per pole is 0.05 Wb, Calculate speed and torque developed by the armature. [June/July 2014]

$P = A = 6$, $I_a = 110A$, $V = 480V$, $R_a = 0.2ohms$,

$E_b = V - I_aR_a = 480 – (110*0.2) = 458$ V

$E_b = \frac{\Phi ZNP}{60A}$ where Z = 864, A= P = 6 as Lap wound, $\Phi = 0.05Wb$

$458 = \frac{0.05*864*N*6}{60*6}$

N = 636rpm

Torque, $T = 0.159\ \Phi Ia\frac{PZ}{A} = 755.57Nm$.

14. The emf generated in the armature of a shunt generator is 625 V, when delivering its full load current of 400A to the external circuit. The field current is 6 A and the armature resistance is 0.06 ohms. What is the terminal voltage? [June/July 2014]

Eg = 625V, $I_L = 400A$, Ish = 6A, Ra = 0.06 ohms

$Ia = I_L + Ish = 400+6 = 406A$

V = Eg – IaRa = 625 –(406*0.06) = 600.64V

15. 220 V series motor is taking a current of 40A, resistance of armature 0.5 ohms, resistance of series field is 0.25 ohms. Calculate voltage at the brushes, back Emf, power wasted in armature, and power wasted in series field. [June/July 2014]

Voltages at brushes = V – IaRse = 220 – (40*0.25) = 210V

Eb = V – Ia(Ra +Rse) = 220 – (40(0.5+0.25)) = 190V

Power wasted in armature = I_a^2Ra = 40*40*0.5 = 800W

Power wasted in Fields = I_a^2 Rse = 40*40*0.25 = 400W

16. An 8 pole generator has a 500 armature conductor and has useful flux per pole of 0.065Wb. What will be the emf generated if it is lap connected and runs at 1000 rpm. What must be the speed at which it should be driven to produce the same emf if it is wave

wound. **[Dec 2013/Jan 2014, Dec2015/Jan2016]**

$E_g = \frac{\Phi\, ZNP}{60A} = \frac{0.065\times500\times1000\times8}{60\times8}$; Lap winding P = A = 8

= 541.67V

When wave connected, Speed is

$N = \frac{60A\, Eg}{\Phi\, ZNP} = \frac{60\times2\times541.67}{0.065\times500\times8} =$ 250rpm

MODULE 3

1. What is meant by power factor in ac circuit? What is its significant in Ac circuits?

[June/July 2015]

Power Factor may be defined as the cosine of the angle of lead or lag. In Fig. 3.47, the angle of lag is shown.Thus power Factor = cosϕ.

In addition to having a numerical value, the power factor of a circuit carries a notation that signifies the nature of the circuit, i.e., whether the equivalent circuit is resistive, inductive or capacitive. Thus, the p.f. might be expressed as 0.8 lagging. The lagging and leading

refers to the phase of the current vector with respect to the voltage vector. Thus, a lagging power factor means that the current lags the voltage and the circuit is inductive in nature. However, in the case of leading power factor, the current leads the voltage and the circuit is capacitive.

2. Draw and explain the wiring diagram for 3 way control of lamp [June/July 2015]

In case of very long corridors it may be necessary to control the lamp from 3 different points. In such cases, the circuit connection requires two; two-way switches $\mathbf{S_1}$and $\mathbf{S_2}$ and an intermediate switch $\mathbf{S_3}$. An intermediate switch is a combination of two, two way switches coupled together. It has 4 terminals ABCD. It can be connected in two ways

a) Straight connection

b) Cross connection

In case of straight connection, the terminals or points AB and CD are connected as shown in figure 1(a) while in case of cross connection, the terminals AB and

C D is connected as shown in figure 1(b). As explained in two –way control the lamp is ON if the circuit is complete and is OFF if the circuit does not form a closed loop.

Three -way control of lamp

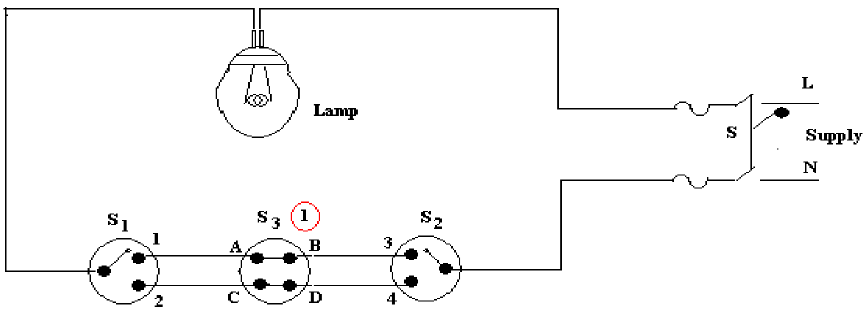


Figure 1 (a) Straight connection

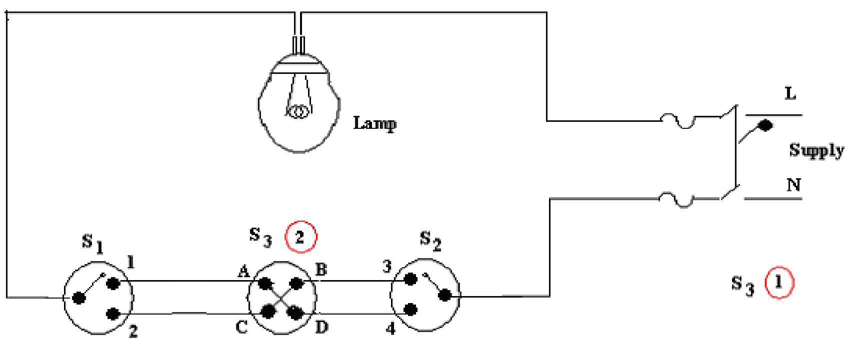


Figure 1 (b) Cross connection

The condition of the lamp is given in the table depending on the positions of the switches $\mathbf{S_1}$, $\mathbf{S_2}$ and $\mathbf{S_3}$.

3. A series circuit with resistance of 10ohms, inductance of 0.2 H and capacitance 40micro F is supplied with a 100 V supply at 50 Hz. Find current, power and power factor. [June/July 2015]

Circuit resistance R=**10Ω**

Inductive reactance of the circuit, $X_L=2\pi fL$

$$=2\pi\times50\times0.2=\mathbf{62.83\Omega}$$

Capacitive reactance of the circuit, $X_c=\frac{1}{2\pi fC}=\frac{1}{2\pi\times50\times40\times10-6}=\mathbf{79.57\ \Omega}$

Impedance of the circuit Z $=\sqrt{R^2+(XL-Xc)^2}$ $=\sqrt{10^2+(79.57-62.83)^2}$ $=\sqrt{100+280.2276}=\mathbf{19.49\ \Omega}$

Circuit Current, $I=\frac{V}{Z}=\frac{100}{19.49}=\mathbf{5.1308A}$

Circuit power factor, CosΦ = $\frac{R}{Z}$ = $\frac{10}{19.49}$ = **0.513**

Power consumed P =VICosΦ = 100×5.1308×0.513 = **263.21Watts**

4. State form factor of an alternating quantity. Derive the expression for it. [June/July 2015]

A definite relationship exists between crest value (or peak value), average value and r.m.s. value of an alternating quantity.

Form Factor: The ratio of effective value (or r.m.s. value) to average value of an alternating quantity (voltage or current) is called form factor, i.e.

$$\text{From Factor, } K_f = \frac{\text{rms value}}{\text{average value}}$$

For sinusoidal alternating current,

$K_f = \frac{0.707 I_m}{0.637 I_m} = 1.11$

For sinusoidal alternating voltage,

$K_f = \frac{0.707 I_m}{0.637 I_m} = 1.11$

Hence, the R.M.S. value (of current or voltage) is 1.11 times its average value.

5. Show that the average power consumed in pure capacitances is 0. Draw the neat wave form for the voltage, power and current. [June/July 2015]

When an alternating voltage is applied across the plates of a capacitor, the capacitor is charged in one direction and then in the opposite direction as the voltage reverses. With reference to Fig. 3.38,

Let alternating voltage represented by $v = V_m \sin \omega t$ be applied across a capacitor of capacitance C Farads.

Instantaneous charge, $q = cv = CV_m \sin \omega t$

Capacitor current is equal to the rate of change of charge, or

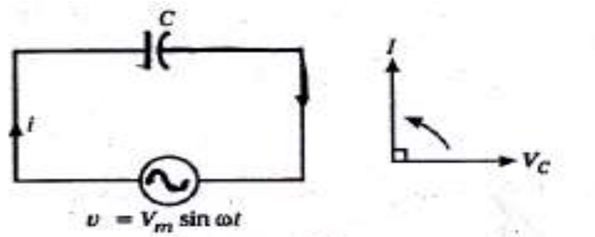


Fig. 3.38

$$i = \frac{dq}{dt} = \frac{d}{dt}(CV_m \sin \omega t)$$

$$= \omega CV_m \cos\omega t$$

or $$i = \frac{V_m}{\frac{1}{\omega c}} \sin\left(\omega t + \frac{\pi}{2}\right)$$

The current is maximum when t = 0

$$\therefore I_m = \frac{V_m}{\frac{1}{\omega c}}$$

Substituting $\frac{V_m}{\frac{1}{\omega c}} = I_m$ in the above expression for instantaneous current, we get

$$i = I_m \sin\left(\omega t + \frac{\pi}{2}\right)$$

Capacitive Reactance: $\frac{1}{\omega C}$ in the expression $I_m = \frac{V_m}{\frac{1}{\omega C}}$ is known as capacitive reactance and is denoted by X_c.

i.e., $X_c = \frac{1}{\omega C}$

If C is farads and 'ω' is in radians, then X_c will be in ohms.

It is seen that if the applied voltage is given by $v = V_m \sin \omega t$, then the current is given by $i = I_m \sin\left(\omega t + \frac{\pi}{2}\right)$; this shows that the current in a pure capacitor leads its voltage by a quarter cycle as shown in Fig. 3.39, or phase difference between its voltage and current is $\frac{\pi}{2}$ with the current leading.

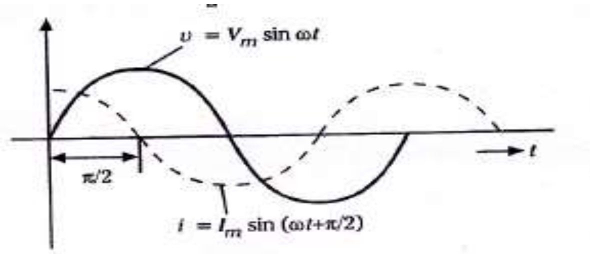


Fig. 3.39

Power: Instantaneous Power,

$$P = vi$$

$$= V_m \sin \omega t.\ I_m \sin\left(\omega t + \frac{\pi}{2}\right)$$

$$= V_m I_m \sin \omega t \cos \omega t$$

$$= \frac{1}{2} V_m I_m \int_0^{2\pi} \sin 2\,\omega t$$

Power for the complete cycle

$$= \frac{1}{2} V_m I_m \int_0^{2\pi} \sin 2\,\omega t dt = 0$$

Hence power absorbed in a capacitive circuit is zero.

Power curves (Fig. 3.40)

At the instants b,d, the current is zero, so that power is zero; it is also zero at the instants a,c and e, when the voltage is zero. Between a and b, voltage and current are in the same direction, so that power is positive and is being put back in the circuit. Between b and c, voltage and current are in the opposite directions, so that power is negative and energy is taken from the circuit. Similarly, between c and d, power is put back into the circuit, and between d and e it is taken from the circuit.

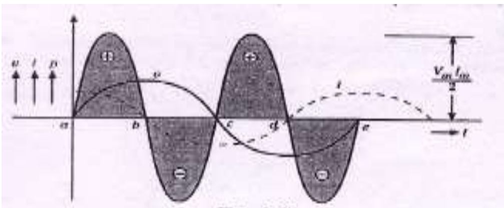


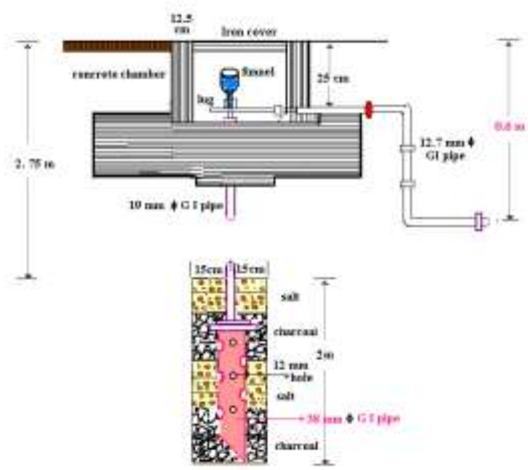
Fig. 3.40

Therefore, power absorbed in a pure capacitive circuit is zero.

6. With a neat diagram explain pipe earthing. [June/July 2015, June/July 2016]

Earth electrode made of a GI (galvanized) iron pipe of 38mm in diameter and length of 2m (depending on the current) with 12mm holes on the surface is placed upright at a depth of 4.75m in a permanently wet ground. To keep the value of the earth resistance at the desired level, the area (15 cms) surrounding the GI pipe is filled with a mixture of salt and coal.. The efficiency of the earthing system is improved by pouring water through the funnel periodically. The GI earth wires of sufficient cross- sectional area are run through a 12.7mm diameter pipe (at 60cms below) from the 19mm diameter pipe and secured tightly at the top as shown in the following figure.

When compared to the plate earth system the pipe earth system can carry larger leakage currents as a much larger surface area is in contact with the soil for a given electrode size. The system also enables easy maintenance as the earth wire connection is housed at the ground level.



PIPE EARTHING

7. Obtain the expression for current through pure inductor, if the voltage across it is $v=V_m\sin(wt)$. [Dec2014/Jan 2015]

An inductive coil is a coil with or without an iron core and has negligible resistance. In practice, pure inductance can never be had as the inductive coil has always a small resistance. However, a coil of thick copper wire wound on a laminated iron core has negligible resistance, so, for the purpose of our study, we will consider a purely inductive coil.

On the application of an alternating voltage (Fig.3.34) to a circuit containing a pure inductance, a back e.m.f. is produced due to the self-inductance of the coil. This back e.m.f. opposes the rise or fall o f current, at every stage. Because of the absence of voltage drop, the applied voltage has to overcome this self-induced e.m.f. only.

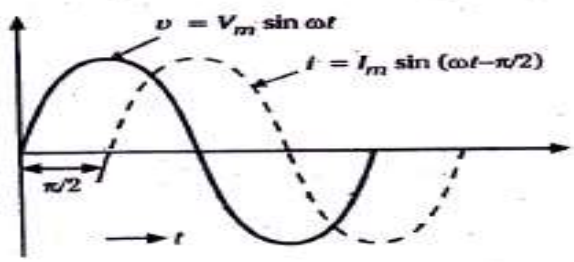


Fig. 3.35

Inductive Reactance: ωL in the expression $I_m = \frac{V_m}{\omega L}$ is known as inductive reactance and is denoted by X_L, i.e., $X_L = \omega L$. If 'L' is in henry and 'ω' is in radians per second, then X_L will be in ohms. So, inductive reactance plays the part the part of resistance.

Power: Instantaneous Power,

$$P = v \times i = V_m \sin \omega t \, . \, I_m \sin\left(\omega t - \frac{\pi}{2}\right)$$

$$= - V_m I_m \sin \omega t \cos \omega t$$

$$= \frac{-V_m I_m}{2} \sin 2\omega t$$

The power measured by a wattmeter is the average value of 'p', which is zero since average of a sinusoidal quantity of double frequency over a complete cycle is zero. Put in mathematical terms,

Power for the whole cycle, $P = - \frac{-V_m I_m}{2} \int_0^{2\pi} \sin 2\omega t dt = 0$

Hence, power absorbed in a pure inductive circuit is zero.

Power curve

The power curve for a pure inductive circuit is shown in Fig. 3.36. This indicates that power absorbed in the circuit is zero. At the instants a,c and e, voltage is zero, so that power is zero: it is also zero at points b and d when the current is zero. Between a and b voltage and current are in opposite directions, so that power is negative and energy is taken from the circuit.

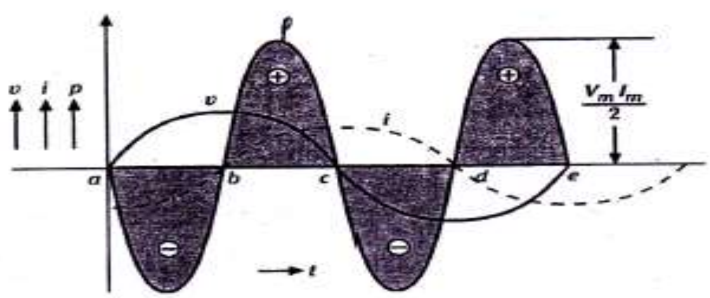


Fig. 3.36

Between b and c voltage and current are in the same direction, so that power is positive and is put back into the circuit. Similarly, between c and d, power is taken from the circuit and between d and e it is put into the circuit. Hence, net power is zero.

8. A voltage v=100sin (314t) is applied to a circuit consisting of a 25ohm resistance and 80microF capacitor in series. Determine peak value of the current, power factor, total power consumed by the circuit. [Dec2014/Jan 2015]

Comparing given voltage with $V_m \sin\omega t$, $V_m = 100V$, $\omega = 314$ rad/s

$X_C = \frac{1}{\omega C} = \frac{1}{314\times80\times10^{-6}} = \mathbf{39.8089\Omega}$

$Z = R - jX_C = 25 - j39.8089$

$= \mathbf{47\angle -57087\ \Omega}$

$I_m = \frac{V_m}{|Z|} = \frac{100}{47} = \mathbf{2.1276A}$

$\cos\Phi = R/Z = 25/47 =$ **0.5319 leading**

$P = VI\cos\Phi = \frac{V_m}{\sqrt{2}} \times \frac{I_m}{\sqrt{2}} \times \cos\Phi = (100*2.1276*0.5319)/2$ **= 56.5851 W**

9. Write a short note on necessity of earthing, and precaution to be taken to prevent electric shock. [Dec2014/Jan 2015]

<u>Necessity of Earthing</u>:

1. To protect the operating personnel from danger of shock in case they come in contact with the charged frame due to defective insulation.
2. To maintain the line voltage constant under unbalanced load condition.
3. Protection of the equipments
4. Protection of large buildings and all machines fed from overhead lines against lightning.

It is necessary to observe some safety precautions while using the electric suppi avoid serious problems like shocks and fire hazards. Some of the safety precautions are as follows

1) Insulation of the conductors used must be proper and in good condition. If it is not so the current carried by the conductors may leak out. The person coming in contact with such faulty insulated conductors may receive a shock.
2) Megger tests should be conducted and insulation must be checked. With the help of megger all the tests discussed above must be performed, on the new wiring before starting use of it.
3) Earth connection should be always maintained in proper condition.
4) Make the mains supply switch off and remove the fuses before starting work with any installation.
5) Fuses must have correct ratings.
6) Use rubber soled shoes while working. Use some wooden supper under the fee removes the contact with the earth.
7) Use rubber gloves while touching any terminals or removing insulation layer from a conductor.
8) Use a line tester to check whether a 'live' terminal carries any current still better method is to use a test lamp.
9) Always use insulated screw drivers, pliers, line testers etc.
10) Never touch two different terminals at the same time.
11) Never remove the plug by pulling the wires connected to it.
12) The sockets should be fixed at a height beyond the reach of the children.

10. Voltage of 200 V is applied to a series circuit consisting of a resistor, inductor, and capacitor. The respective voltages across these components are 170V, 150 V, and 100V and the current is 4A. Find power factor, resistance, and impedance, inductive and capacitive reactance. **[Dec2014/Jan 2015]**

Solution:

V_R = 170V, V_L = 150V, V_C = 100V

V_R = IR i.e. R = 170/4 = **42.5Ω**

|Z| = |V| / |I| = 200/4 = **50Ω**

Let R_X be the resistance of an inductor

$Z_L = R_X + J X_L = |Z_L| \angle \Phi_L$ and $|Z_L| = |V| / |I|$ = 37.5Ω

$\sqrt{R_X^2 + X_L^2}$ = **37.5Ω**

And |Xc| = |Vc| / |I| = 100/4 = **25Ω**

$| Z | = \sqrt{(R + R_x)^2 + (X_L - X_C)^2}$ and | Z | = **50 Ω**

X_L = **37.01Ω**

R_X = **6.035Ω**

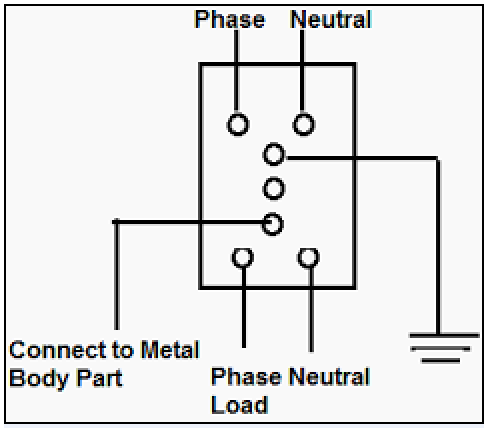
cosΦ = cos (13.898) = **0.9702 lagging**

11. Explain the necessity and the operation of earth leakage circuit breaker.

[Dec2014/Jan 2015]

<u>Necessity of ELCB:</u>

- There are situations where leakage current flows through the metal bodies of appliances. Thus person touching such appliances may get a shock.
- There is risk of fire due to such leakage current flowing to the earth.
- The MCB and fuse cannot provide protection against earth leakage currents.
- Hence there is need of a device which can directly detect the earth leakage currents and cut the supply if such currents exceed a pre-set value. Such a device is called Earth leakage circuit breaker (ELCB).



ELCB

Operation of ELCB:

- Basic ELCB is a voltage operated device.
- It detects the rise in potential due to the touching of phase wire to metal part of the device or due to failure of insulation of the device.
- For giving protection against such a condition, the earth circuit is modified using ELCB.
- The connection to earth reference electrode is passed through ELCB,by connecting two earth terminals of ELCB as shown in figure.
- When the voltage between metal body part of the device and earth electrode rises beyond 50V then ELCB circulates current through the relay coil which opens the main circuit breaker to isolate the supply from faulty device.
- The ELCB remains off till manually reset.

12. Two impedances Z1= (6-j8) ohms and Z2= (16+j12) ohms are connected in parallel. If the total current of the combination is 20+j10 A, find voltage across the combination and currents in the two branches. [Dec2014/Jan 2015]

$I = 20 + j10 = \mathbf{22.36 \llcorner 26.565 A}$

$Z_1 \parallel Z_2 = \frac{Z_1 Z_2}{Z_1 + Z_2} = \mathbf{Z_T}$

$Z_T = \frac{(10\llcorner -53.13)(20\llcorner 36.86)}{6-j8+16+j12} = \frac{200\llcorner -16.27}{22.36\llcorner 10.304} = \mathbf{8.9445\llcorner -26.574\Omega.}$

$V = I \times Z_T$

$= (22.36 \llcorner 26.56) \times (8.945\llcorner - 26.57) = \mathbf{200\llcorner 0 \ V}$

$I_1 = \frac{V}{Z1} = \frac{200 \angle 0}{10 \angle -53.13}$ = **10∟ -53.13 A**

$I_2 = \frac{V}{Z2} = \frac{200 \angle 0}{10 \angle -536.86}$ = **10∟ -36.86 A**

13. Define instantaneous value, amplitude, cycle, period, with respect to sinusoidally varying quantities. [June/July 2014]

Instantaneous value: The value of an alternating quantity at any instant is called instantaneous value.

Amplitude: The maximum value, positive or negative, which an alternating quantity attains during one complete cycle is called amplitude or peak value or maximum value. The amplitude of alternating voltage and current is represented by $E_m$and I_m respectively.

Alternation and cycle: When an alternating quantity goes through one half cycle (complete set of +ve or –ve values) it completes an alternation, and when it goes through a complete set of +ve and –ve values, it is said to have completed one cycle.

Periodic Time and Frequency: The time taken in seconds by an alternating quantity to complete one cycle is known as periodic time and is denoted by T.

The number of cycles completed per second by an alternating quantity is know as frequency and is denoted by 'f'. in the SI system, the frequency is expressed in hertz.

The number of cycles completed per second = f.

Periodic Time T – Time taken in completing one cycle = $\frac{1}{f}$

Or $f = \frac{1}{T}$

In India, the standard frequency for power supply is 50 Hz. It means that alternating voltage or current completes 50 cycles in one second.

14. Two impedances (150-j157) ohms and (100+j110) ohms are connected in parallel across 200V, 50 Hz supply. Find branch currents, total currents, and total power consumed in the circuit. Draw the phasor diagram. [June/July 2014]

Z1=150-j157 Ω = 217.13∟-46.3 Ω

Z2=100+j110 Ω = 148.66∟47.73 Ω

I1= $\frac{200}{217.13 \angle -46.3}$ = (0.6367+j0.666) A = 0.922∟46.3 A

$I2= \frac{200}{148.66\angle-47.7.3}$ = (0.9049-j0.996) A = 1.345∟-47.73A

I=I1+I2=(0.6367+j0.666)+ (0.9049-j0.996)=(1.542-j0.33)A=1.576∟-12.06 A

15. Show that power consumed in RC series circuit is VIcosΦ.Draw the waveform for the voltage, current and power. [June/July 2014]

Series R – C circuit

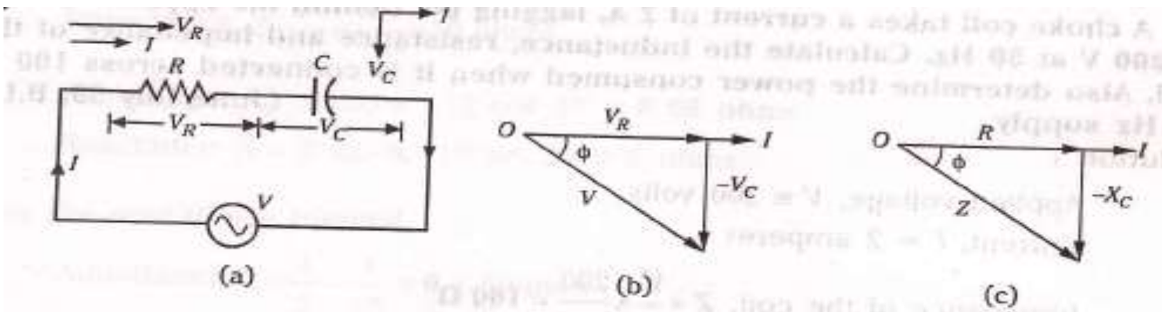


Fig. 3.52

Consider an a.c. circuit containing resistance R ohms and capacitance C farads, as shown in the fig. 3.52(a).

Let V = r.m.s. value of voltage
I = r.m.s. value of current

∴voltage drop across R, $V_R = IR$ - in phase with I
Voltage drop across C, $V_C = IX_C$ - lagging I by $\frac{\pi}{2}$

The capacitive resistance is negative, so V_C is in the negative direction of Y – axis, as shown in the fig. 3.52(b).

We have $V = \sqrt{V_R^2 + (-V_C)^2} = \sqrt{(IR)^2 + (-IX_C)^2}$

$= \sqrt{R^2 + {X_C}^2}$

Or $I = \frac{V}{\sqrt{R^2+{X_C}^2}} = \frac{V}{Z}$

The denominator, Z is the impedance of the circuit, i.e., $Z = \sqrt{R^2 + {X_C}^2}$. fig. 3.52(c) depicts the impedance triangle.

Power factor, $\cos\phi = \frac{R}{Z}$

Fig. 3.52(b) shows that I leads V by anangleϕ, so that $\tan\phi = \frac{-X_C}{R}$

This implies that if the alternating voltage is $v = V_m \sin\omega t$, the resultant current in the R – C circuit is given by

$i = I_m \sin(\omega t + \phi)$, such that current leads the applied voltage by the angle ϕ. The waveforms of fig. 3.53 depict this.

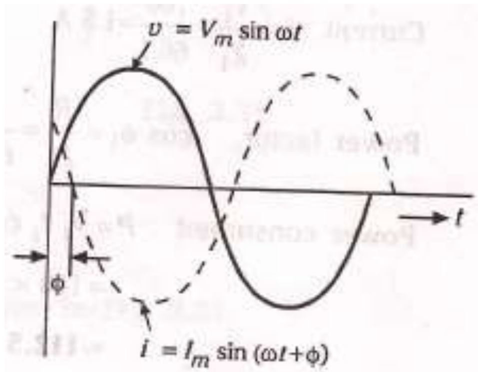


Fig. 3.53

Power: Average power, $P = v \times I = VI\cos\phi$(as in sec. 3.17).

Power curves: The power curve for R – C series circuit is shown in fig. 3.54. The curve indicates that the greater part is positive and the smaller part is negative, so that the net power is positive.

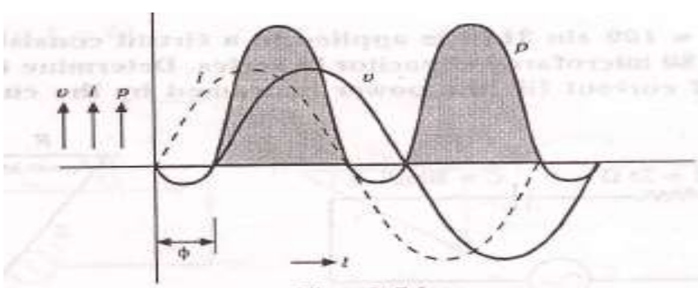
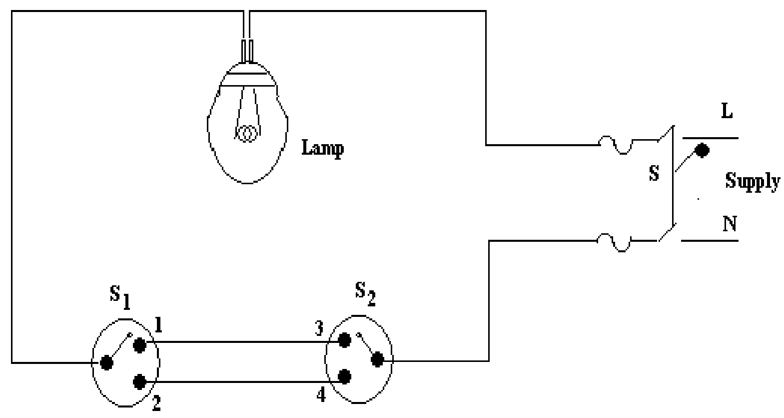


Fig. 3.54

16. Write the circuit diagram and switching table for 2 way and 3 way control of lamp. Where it is used [June/July 2014, Dec2015/Jan2016]

<u>Two-way Control of lamp</u>:

Two-way control is usually used for staircase lighting. The lamp can be controlled from two different points: one at the top and the other at the bottom - using two- way switches which strap wires interconnect. They are also used in bedrooms, big halls and large corridors. The circuit is shown in the following figure.



Two -way control of lamp

Switches **S_1** and **S_2** are two-way switches with a pair of terminals 1&2, and 3&4 respectively. When the switch **S_1** is in position**1** and switch **S_2** is in position **4**, the circuit does not form a closed loop and there is no path for the current to flow and hence the lamp will be **OFF.** When **S_1** is changed to position **2** the circuit gets completed and hence the lamp glows or is **ON**. Now if **S_2** is changed to position **3** with **S_1** at position **2** the circuit continuity is broken and the lamp is off. Thus the lamp can be controlled from two different points.

17. Derive an expression for the impedance of an ac circuit consisting of a resistance, inductance and capacitance connected in series. [June/July 2014]

Consider an a.c. series circuit containing resistance R ohms, Inductance L henries and capacitance C farads, as shown in the fig. 3.59.

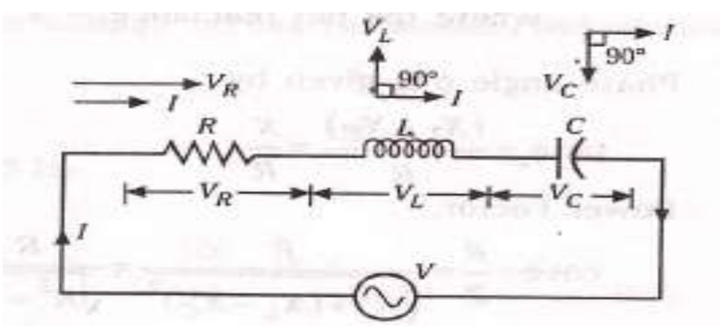


Fig. 3.59

Let V = r.m.s. value of applied voltage

I = r.m.s. value of current

∴ Voltage drop across R, VR = IR - in phase with I

voltage drop across L, VL = I.X_L - lagging I by 90^0

Voltage drop across C, V_C = IX_C - lagging I by 90^0

Referring to the voltage triangle of Fig. 3.60, OA represents V_R, AB and AC represent inductive and capacitive drops respectively. We observe that V_L and $V_C$are 180^0 out of phase.

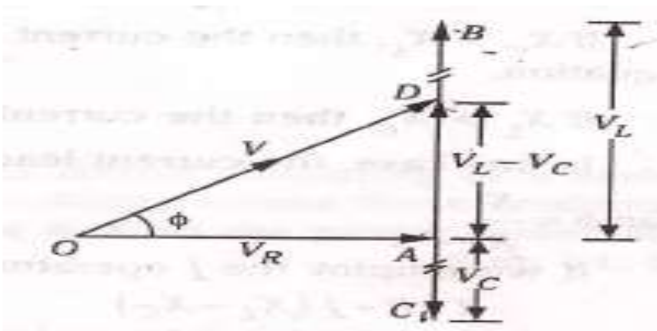


Fig. 3.60

Thus, the net reactive drop across the combination is

AD = AB – AC

= AB – BD (∵ BD = AC)

= $V_L – V_C$

= **I** (X_L - X_C)

OD, which represents the applied voltage V, is the vector sum of OA and AD.

∴ OD = $\sqrt{OA^2 + AD^2}$ OR V = $\sqrt{(IR)^2 + (IX_L - IX_C)^2}$

$= I\sqrt{R^2 + (X_L - X_C)^2}$

Or I = $\frac{V}{\sqrt{R^2+(X_L-X_C)^2}} = \frac{V}{\sqrt{R^2+X^2}} = \frac{V}{Z}$

The denominator $\sqrt{R^2 + (X_L - X_C)^2}$ is the impendence of the circuit.

So $(\text{impedance})^2 = (\text{resistance})^2 + (\text{net reactance})^2$

Or $Z^2 = R^2 + (X_L - X_C)^2 = R^2 + X^2$

Where the net reactance = X (fig. 3.61)

Phase angle ϕ is given by

$\tan\phi = \frac{(X_L - X_C)}{R} = \frac{X}{R}$

power factor,

$\cos\phi = \frac{R}{Z} = \frac{R}{\sqrt{R^2 + (X_L - X_C)^2}} = \frac{R}{\sqrt{R^2 + X^2}}$

Power = VI cosϕ

If applied voltage is represented by the equation $v = V_m \sin\omega t$, then the resulting current in an R – L – C circuit is given by the equation

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

If $X_C > X_L$, then the current leads and the +ve sign is to be used in the above equation.

If $X_L > X_C$, then the current lags and the –ve sign is to be used.

If any case, the current leads or lags the supply voltage by an angle ϕ, so that $\tan\phi = \frac{X}{R}$.

If we employ the j operator (fig. 3.62), then we have

$Z = R + j(X_L - X_C)$

The value of the impedance is

$Z = \sqrt{R^2 + (X_L - X_C)^2}$

The phase angle $\phi = \tan^{-1}\frac{(X_L - X_C)}{R}$

$Z\angle\phi = Z\angle\tan^{-1}\left[\frac{X_L - X_C}{R}\right]$

$= Z\angle\tan^{-1}\left[\frac{X}{R}\right]$

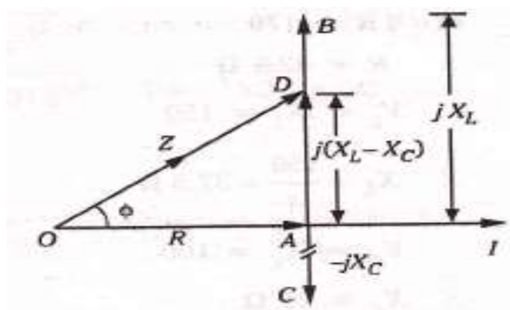


Fig. 3.62

18. 125V at 60 Hz is applied across a capacitance connected in series with a non-inductive resistor. Combination carries a current of 2.2A and causes a power loss of 96.8 W in the resistor. Power loss in the capacitor is negligible. Calculate the resistance and capacitance

[June/July 2014]

$P_R = I^2R = 96.8W$

Therefore, $R = \frac{96.8}{2.2^2} = 20\Omega$

$|I| = \frac{|V|}{|Z|}$

Where, $|Z| = \sqrt{R^2 + {X_c}^2}$

$$2.2=\frac{125}{\sqrt{20^2+{X_c}^2}} \text{ i.e. } Xc=45.8257\Omega=\frac{1}{2\pi f C}$$

$$\text{Hence, } C=\frac{1}{2\pi\times60\times45.8257} = 57.884\mu F$$

19. Mention different types of wiring used in domestic dwellings. [June/July 2014]

Depending upon the above factors various types of wiring used in practice are:

1. Cleat wiring
2. Casing wiring
3. Surface wiring
4. Conduit wiring

i) Clear wiring:

In this type V.I.R or P.V.C wires are clamped between porcelain cleats.

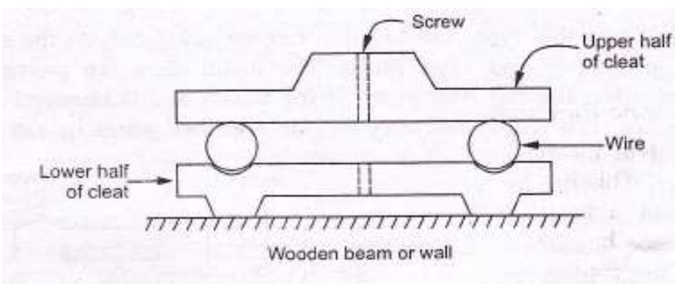


Fig. 16 Cleat wiring

The cleats are made up of two halves. One half is grooved through which wire passes while the other fits over the first. The whole assembly is then mounted on the wall or wooden beam with the help of screws.

This method is one of the cheapest method and most suitable for temporary work. It can be very quickly installed and can be recovered without any damage of material. Inspection and changes can be made very easily.

This method does not give attractive appearance. After some time due to sagging at some places, it looks shabby. Dust and dirt collects on the cleats. The wires are directly exposed to atmospheric conditions like moisture, chemical fumes etc. maintenance cost is very high.

Due to these disadvantages this type is not suitable for permanent jobs.

ii) Casing capping: This is very popularly used for residential buildings. In this method, casing is a rectangular strip made from teak wood or new a day's made up of P.V.C. It has two grooves into which the wires are laid. Then casing is covered with a rectangular strip of wood or P.V.C. of the same width, called capping. The capping is screwed into casing is fixed to the walls the help or porcelain discs or cleats.

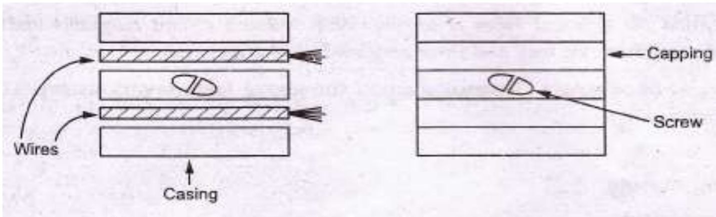


Fig. 17 Casing capping

Good protection to the conductors from dangerous atmospheric conditions, neat and clean appearance are the advantages of this type.

In case of wooden casing capping, there is high risk of fire along with the requirement of skilled labour. The method is costly.

Surface wiring: in this type, the wooden battens are fixed on the surface of the wall, by means of screws and rawl plugs. The metal clips are provided with the battens at regular intervals. The wire runs on the batten and is clamped on the batten using the metal clips. The wires used may lead sheathed wires or can tyre sheathed wires. Depending upon type of wire used surface wiring is also called lead sheathed wiring or cab tyre sheathed wiring. If the wire used is though rubber Sheathed then it is called T.R.S. wiring while if the wire used is cab tyre Sheathed Then it is called C.T.S wiring.

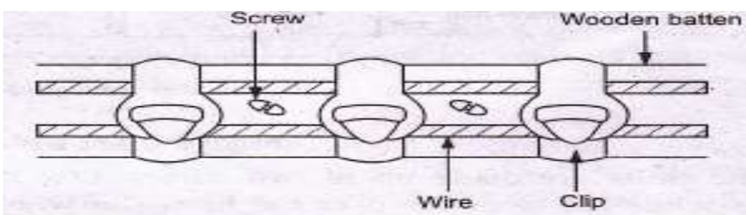


Fig. 18 Wooden batten wiring

Conduit wiring: In this method, metallic tubes called as conduits are used to run the wires. This is the best system of wiring as it gives full mechanical protection to the wires. This is most desirable for workshops and public Buildings. Depending on whether the conduits are laid inside the walls or supported on the walls, there are two types of conduit wiring which are:

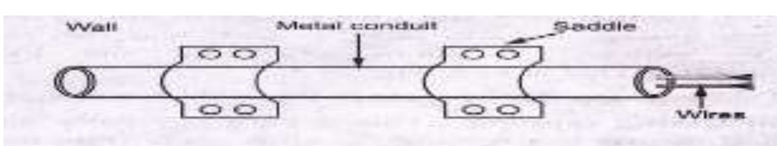


Fig. 19 Surface conduit wiring

i) **Surface conduit wiring:** in this method conduits are mounted or supported on the walls with the help of pipe books or saddles. In damp situations, the conduits are spaced apart from the wall by means of wooden blocks.

ii) **Concealed conduit wiring:** In this method, the conduit is buried under the wall at the some of plastering. This is also called recessed conduit wiring.

The beauty of the premises is maintained due to conduit wiring. It is durable and has long life. It protects the wires from mechanical shocks and fire hazards. Proper earthing of conduits makes the method electrical shock proof. It requires very less maintenance. The repairs are very difficult in case of concealed conduit wiring. This method is most costly and erection requires highly skilledlabour. These are few disadvantages of the conduit type of wiring. In concealed conduit wiring, keeping conduit at earth potential is must.

20. With a neat sketch, explain plate earthing. [June/July 2016]

In this method a copper plate of 60cm x 60cm x 3.18cm or a GI plate of the size 60cm x 60cm x 6.35cm is used for earthing. The plate is placed vertically down inside the ground at a depth of 3m and is embedded in alternate layers of coal and salt for a thickness of 15 cm. In addition, water is poured for keeping the earth electrode resistance value well below a maximum of 5 ohms. The earth wire is securely bolted to the earth plate. A cement masonry chamber is built with a cast iron cover for easy regular maintenance.

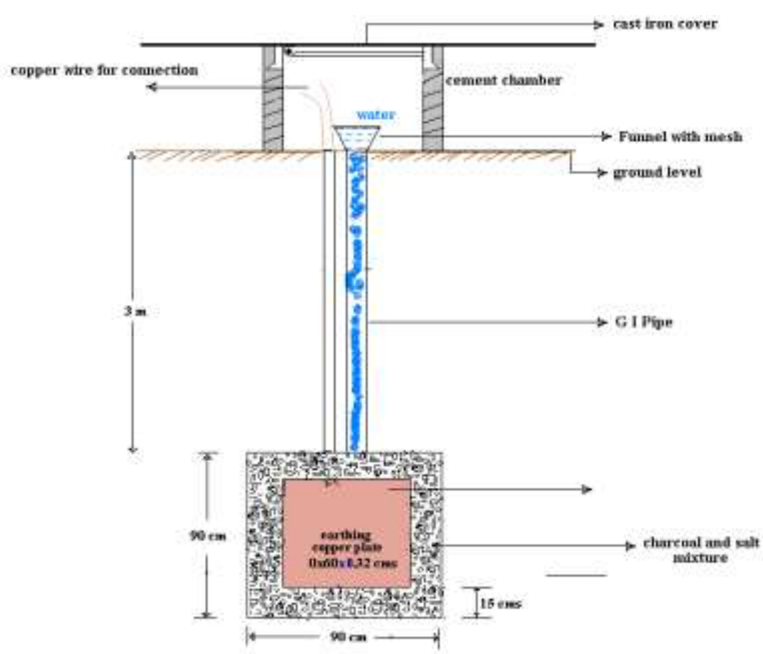


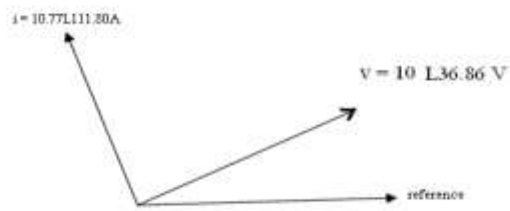
PLATE EARTHING

21. An alternating voltage (80+60j)V is applied to a circuit and the current flowing is (-4+10j) A. Find: (1) The impedance of the circuit, (ii) the phase angle, (iii) power consumed. [Dec2015/Jan2016]

V = (80 + j60)Ω : i = (- 4 + j10)Ω

Z = v/i = (80 + j60)/(- 4 + j10) = 9.284∟-74.93 Ω = 2.414- j8.96 Ω

V = 100∟36.86 V: i = 10.77∟111.80A



Phase angle , Φ = 74.94, Power Consumed = I^2 R = $(10.77)^2 \times 2.414$ = 283.02 W

22. Two impedances Z_1 = (10+15j)Ω and Z_2 = (6-8j)Ω are connected in parallel. If the total current supplied is 15 A, what is power taken by each branch? [Dec2015/Jan2016]

$$I = 15A$$

$$Z_1 \parallel Z_2 = \frac{Z_1 Z_2}{Z_1+Z_2} = \mathbf{Z_T}$$

$$Z_T = \frac{(10+j15)(6-j8)}{10+j15+6-j8} = \mathbf{10.322∟\text{-}20.45Ω.}$$

$$V = I \times Z_T$$

$$V = 15 \times (10.322∟-20.45) = \mathbf{154.83∟-20.45\ V}$$

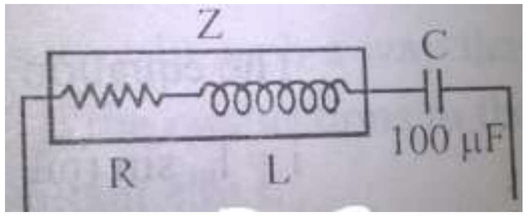
$$I_1 = \frac{V}{Z1} = \frac{\mathbf{154.83∟-20.45}}{\mathbf{10.322∟-20.45Ω}} = \mathbf{8.588∟\text{-}76.75\ A}$$

$$I_2 = \frac{V}{Z2} = \frac{\mathbf{154.83∟-20.45}}{\mathbf{10.322∟-20.45Ω}} = \mathbf{15.483∟\ 32.68\ A}$$

$$P_1 = I_1{}^2 \times R = (8.588)2 \times 10 = \mathbf{737.53W}$$

$$P_2 = I_2{}^2 \times R = (15.483)2 \times 6 = \mathbf{1438.34W}$$

23. A Coil of power factor 0.6 is in series with 100 µF capacitor. When connected to a 50 Hz supply, the potential difference across the coil is equal to potential difference across the capacitor. Find the resistance and inductance of the coil. [Dec2015/Jan2016]



$X_c = 1/(2\pi fC) = 1/(2\pi \times 50 \times 100\mu)$ **= 31.83Ω**

(Also equal to impedance of the coil because potential difference across the coil is equal to potential difference across the capacitor)

$\cos\Phi$ **= 0.6 so** $\sin \Phi$ **= 0.8**

$R = Z \cos\Phi = 31.83 \times 0.6 =$ **19.098Ω**

$X_L = Z \sin\Phi = 31.83 \times 0.8 =$ **25.46Ω**

$L = X_L/ 2\pi f = 25.46/2\pi\times 50 =$ **0.081 H**

24. Show that power consumed in an AC circuit is VI cosΦ. Where V is RMS value of the applied voltage, I is the RMS value of the current and Φ is the angle between voltage V and current I. [Dec2015/Jan2016]

Either RL or RC circuit can be written

25. Derive an expression for average value of an alternating quantity.[**June/July 2016**]

Average Value

The arithmetical average of all the values of an alternating quantity over one cycle is called **average value.**

In the case of a symmetrical wave e.g. sinusoidal current or voltage wave, the positive half is exactly equal to the negative half, so that the average value over the entire cycle is zero. Hence, in this case, the average value is obtained by adding or integrating the instantaneous values of current over one alternation (half-cycle) only.

The equation of a sinusoidally varying voltage

Is given by $e = E_m \sin \theta$.

Let us take an elementary strip of thickness dθ in the first half-cycle as shown in Fig.3.6. let the mid-ordinate of this strip be ‘e’.

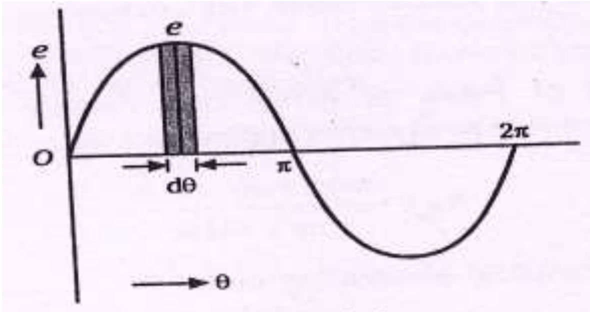


Fig. 3.6

Area of the strip = e dθ

Area of first half-cycle

$= \int_0^{\pi} e \, d\theta$

$= \int_0^{\pi} E_m \sin\theta \, d\theta$ (∵ $e = E_m \sin\theta$)

$= E_m \int_0^{\pi} \sin\theta \, d\theta$

$= E_m [-cos\theta]_0^{\pi} = 2E_m$

∴ Average value, $E_{av} = \frac{\text{Area of half cycle}}{\text{base}} = \frac{2E_m}{\pi}$

Or $E_{av} = 0.637$ Em

In a similar manner, we can prove that, for alternating current varying sinusoidally,

$I_{av} = 0.637\ I_m$

∴ **Average value of current = 0.637 x maximum value**

26. Derive RMS value of sinusoidally varying current and find its relation with its maximum value. [**June/July 2016**]

Root-mean-square (R.M.S.) Value:

The r.m.s. or effective value, of an alternating current is defined as that steady current which when flowing through a given resistance for a given time produces the same amount of heat as produced by the alternating current, when flowing through the same resistance for the same time.

Let us take two circuits with identical resistance, but one is connected to a battery and the other to a sinusoidal voltage source. Wattmeters are employed to measure heat power in each circuit. The voltage applied to each circuit is so adjusted that the heat power produced in each circuit is the same. In this event the direct current I will equal $\frac{I_m}{\sqrt{2}}$, which is termed r.m.s. value of the sinusoidal current.

The following method is used for finding the r.m.s. or effective value of sinusoidal waves.

The equation of an alternating current varying sinusoid ally is given by i= I_m sin θ.

Let us co squared wave, as shown in

Let i^2 be

Area

Area

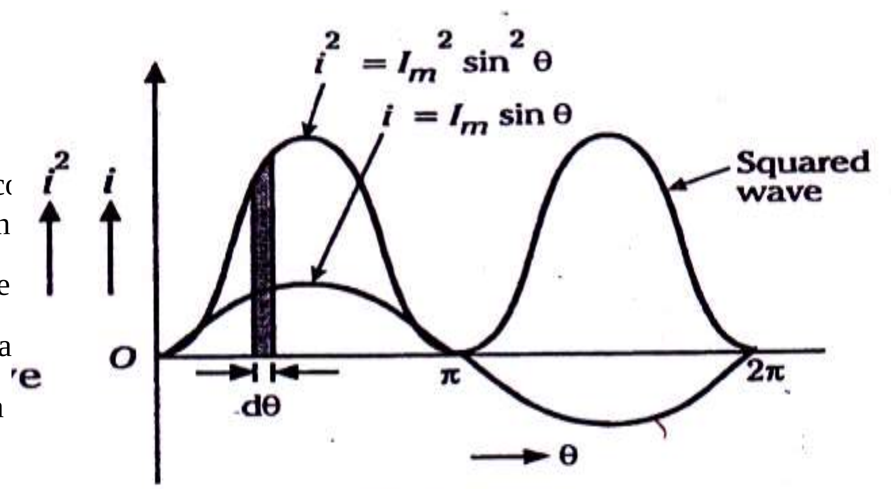


Fig. 3.5

$= \int_0^{\pi} (I_m \sin\theta)^2 \, d\theta$ (∵ i = I_m sin θ)

$= \int_0^{\pi} I_m{}^2 sin^2\theta \, d\theta$

$= I_m^2 \int_0^{\pi} \frac{1-cos2\theta}{2} \, d\theta$ (∵ $\sin^2\theta = \frac{1-cos2\theta}{2}$

$= \frac{I_m^2}{2} \int_0^{\pi} (1 - cos2\theta) d\theta$

$= \frac{I_m^2}{2} \left[\theta - \frac{sin2\theta}{2}\right]_0^{\pi}$

$= \frac{I_m^2}{2} [(\pi - 0) - (0 - 0)]$

$= \frac{\pi I_m^2}{2}$

$\therefore I = \sqrt{\frac{\text{Area of first half cycle of squared wave}}{\text{base}}}$

$= \sqrt{\frac{\pi I_m^2}{2} \times \frac{1}{\pi}}$

$= \sqrt{\frac{I_m^2}{2}}$

$= \frac{I_m}{\sqrt{2}} = 0.707 I_m$

Hence, for a sinusoidal current,

R.M.S. value of current = 0.707 x maximum value of current.

Similarly, $E = 0.707\ E_m$

27. A circuit consists of a resistance of 10Ω, an inductance of 16mH and a capacitance of 150µF connected in series. A supply of 100v at 50Hz is given to the circuit. Find the current, pf and power consumed by the circuit. Draw vector diagram. [**June/July 2016**]

$X_l = \omega L = 2\pi * 50 * 16 * 10^{-3}$

$= 5.026\ \Omega$

$X_c = 1/\omega C = 21.22\ \Omega$

$Z = 19.032\ \Omega$

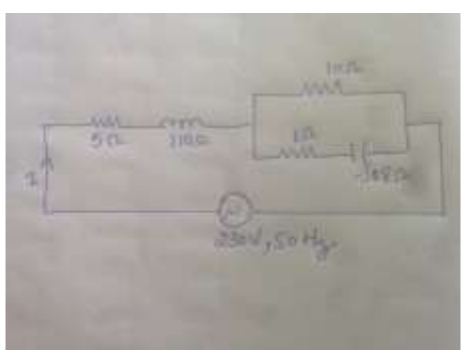
$I = 100/19.032 = 5.25A$

$Pf = R/Z = 10/19.032 = 0.525$

$P = VI\cos\Phi$

$= 275.625W$

28. Find the total current, power and power factor of the circuit.



$Z = 10 + j8\Omega$

$I = V/Z = 230/10+j8 = 14.02 - j11.2\ A$

$$P = 230*17.95 = 4128.5 \text{ W}$$

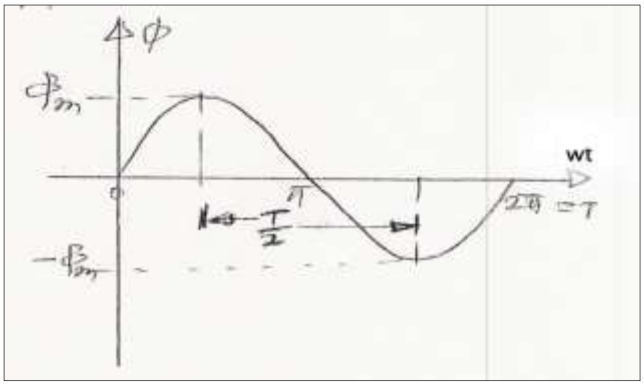
$$p.f = \cos(38.65) = 0.7809$$

MODULE 4

1. With the usual notation derive the expression for EMF equation of an alternator.

[June/July 2015, June/July 2014]

Let P be the total number of poles, Ns be the synchronous speed, f be the frequency of the induced EMF and the flux Φ considered to be sinusoidally distributed.



As we know that the induced emf is due to the rate of change of flux cut by coils, the average induced emf in Tph number of turns is

Eavg = Tph$d\Phi$ / dt volts.

For a flux change from Φm to Φm is d Φ = 2 Φm in time dt= T / 2 seconds,

The average induced Emf =Tph. 2 Φ m / (T/2) = 4 Tph .f. m volts.

For a sine wave we know that the form factor is of value 1.11= Erms / Eavg.

Therefore, Erms = 1.11.Eavg.

Erms = 4.44 f ΦmTph volts per phase. . . . .(1)

If the armature windings are connected in star the line emf is E_l = 3 Ephase.

If the armature windings are connected in delta the line emf is the phase emf itself.

Equation (1) represents the theoretical value of the induced emf in each phase but in practice the Induced emf will be slightly less than the theoretical value due to the following reasons:

(i) The armature windings are distributed throughout the armature in various slots and this is accounted by a factor called the "Distribution factor" Kd and is given by

$Kd = (Sin(m\alpha / 2) / mSin(\alpha / 2))$, where m is the number of slots per pole peer phase

and α is the slot angle.

$\boldsymbol{\alpha} =$ 180^0 / no. of slots per pole.

(ii) The span of the armature coil is less than a full pitch – This is done deliberately to eliminate some unwanted harmonics in the emf wave, this fact is accounted by a factor called the coil span factor or the pitch factor, Kp and is given by

$Kp = Cos\ (\beta / 2)$, where β is the angle by which the coils are short chorded.

The modified Emf equation with these two factors taken into account will be

$E = 4.44\ Kd.Kp.fTph$ volts per phase.

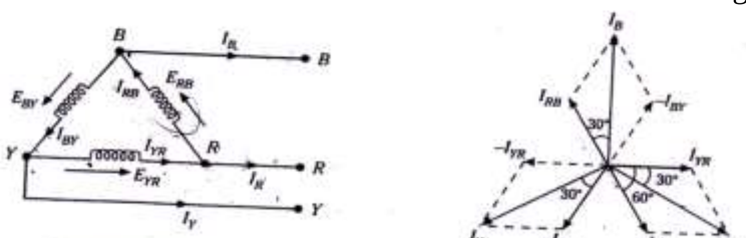
The product of K_d and K_p is called as the winding factor Kw .which is of value around 0.95.

2. Establish the relationship between phase and line value of voltage and currents in 3phase, delta connected circuit. Show the phasor diagram neatly.

[June/July 2015, June/July 2014, June/July 2016]

When the starting end of one coil is connection to the finishing end of another coil, as shown in Fig.3.83 (a), delta or mesh connection is obtained. The direction of the e.m.f.s is as shown in the diagram.

From Fig.3.83 it is clear that line current is the vector difference of phase currents of the two phases concerned. For example, the line current in red outer I_R will be equal to the vector difference of phase currents I_{YR} and IRB. The current vectors are shown in Fig.3.83 (b).



(a) Connection Diagram (b) Vector Diagram

Fig. 3.83

Referring to Fig.3.83 (a) and (b),

Line current, $I_R = I_{YR} - I_{RB}$ (vector difference)

$= I_{YR} + (-I_{RB})$ (vector sum)

As the phase angle between currents I_{YR} and $-I_{RB}$ is 600

$\therefore$ $I_R = \sqrt{I_{YR}^2 + I_{RB}^2 + 2I_{YR}I_{RB}\cos 60^0}$

For a balanced load, the phase current in each winding is equal and let it be $= I_P$.

$\therefore$ Line current, $I_R = \sqrt{I_{YR}^2 + I_{RB}^2 + 2I_PI_P x 0.5} = \sqrt{3}\, I_P$

Similarly, line current, $I_Y = I_{BY} - I_{YR} = \sqrt{3}\, I_P$

And line current, $I_B = I_{RB} - I_{BY} = \sqrt{3}\, I_P$

In a delta network, there is only one phase between any pair of line outers, so the potential difference between the outers, called the line voltage, is equal to phase voltage.

i.e. Line voltage, E_L = phase voltage, E_P

Power output per phase $= E_PI_P\cos\phi$,; where $\cos\phi$ is the power factor of the load.

Total power output, $P = 3E_PI_P\cos\phi$

$= 3E_L\frac{I_L}{\sqrt{3}}\cos\phi$

$= \sqrt{3}\, E_LI_L\cos\phi$

i.e. Total power output = $\sqrt{3}$ x Line voltage x Line current x p.f.

Apparent power of 3-phase delta-connected system

= 3 x apparent power per phase

$= 3\, E_PI_P = 3E_L\frac{I_L}{\sqrt{3}} = \sqrt{3}\, E_LI_L$

3. A balanced star connected load of 8+j6 ohms per phase is connected to 3phase 230V supply. Find the line current, power factor, power reactive volt ampere and total volt ampere. [June/July 2015]

Zp = 8+j6

E_L = 230 V

For Star Connection: Ep = $\frac{E_L}{\sqrt{3}} = 230/\sqrt{3}$ = 132.79 V

Zp = $\sqrt{8^2 + 6^2}$ = 10Ω

Ip = $\frac{E_P}{Z_P} =$ 132.79/10 = 13.279 A

I_L = Ip = 13.279A

PF, cosΦ = $\frac{R_P}{Z_P} = \frac{8}{10} =$ 0.8

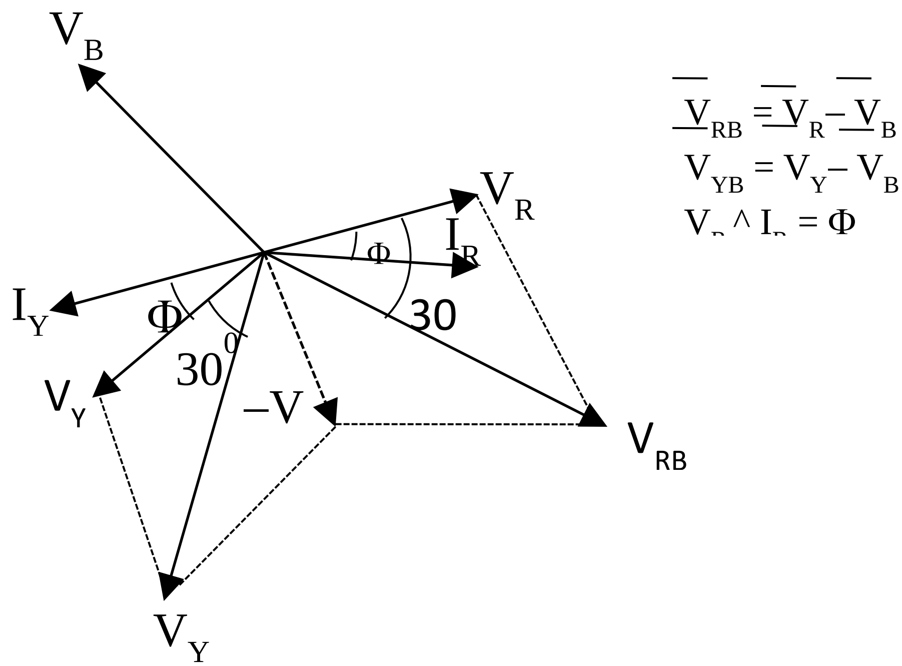
Power = $\sqrt{3}$ E_L $I_L$cosΦ = 4232W

Reactive volt-amperes = 3 EpIpSinΦ = 317 VAR

Total Volt amps = total power in watts/ cosΦ = 5290A.

4. Show that the power in a balanced 3phase circuit can be measured by two wattmeters. Draw the circuit and vector diagram. [June/July 2015]

The current coils of the two wattmeters are connected in any two lines while the voltage coil of each wattmeters is connected between its own current coil terminal and line without current coil. Consider star connected balanced load and two wattmeters connected as shown in fig. 13. Let us consider the rms values of the currents and voltages to prove that sum of two wattmeter gives total power consumed by three phase load.



$V_{RB} = V_R – V_B$; $V_{YB} = V_Y – V_B$; $V_R \wedge I_R = \Phi$

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

$V_{RB} = V_R – V_B$, $I_R = I_Y = I_L = I_{ph}$

$V_{YB} = V_Y – V_B = V_{RB} = V_L$

From fig. 14, $I_R \wedge V_{RB} = 30 – \Phi$ and $I_R \wedge V_{RB} = 30 + \Phi$

$W_1 = I_R V_{RB} \cos(30 – \Phi) = V_L I_L \cos(30 – \Phi)$

$W_2 = I_Y V_{YB} \cos(30 + \Phi) = V_L I_L \cos(30 + \Phi)$

$W_1 + W_2 = V_L I_L[\cos(30 – \Phi) + \cos(30 + \Phi)]$

$= V_L I_L[\cos 30 \cos\Phi + \sin 30 \sin\Phi + \cos 30 \cos\Phi – \sin 30 \sin\Phi]$

$= 2V_L I_L \cos 30 \cos\Phi = 2V_L I_L \frac{\sqrt{3}}{2} \cos\Phi$

$= \sqrt{3}\, V_L I_L \cos\Phi$ = total power

5. Explain the generation of 3-phase ac voltage. [June/July 2015]

In the 3-phase system, there are three equal voltages of the same frequency but displaced from one another by 120^0 electrical. These voltages are produced by a three-phase generator which has three identical windings or phases displaced 120^0 electrical apart. When these windings are rotated in a magnetic field, e.m.f. is induced in each winding or phase. Thesee.m.f. s are of the same magnitude and frequency but are displaced from one another by 120^0 electrical.

Consider three electrical coils a_1a_2, b_1b_2 and c_1c_2 mounted on the same axis but displaced from each other by 120^0 electrical. Let the three coils be rotated in an anticlockwise direction in a bipolar magnetic field with an angular velocity of ω radians/sec, as shown in Fig. 3.80. Here, a_1,b_1 and c_1 are the start terminals and a_2, b_2 and$c_2$are the end terminals of the coils.

When the coil a_1a_2 is in the position AB shown in Fig. 3.80, the magnitude and direction of the e.m.f. s induced in the various coils is as under:

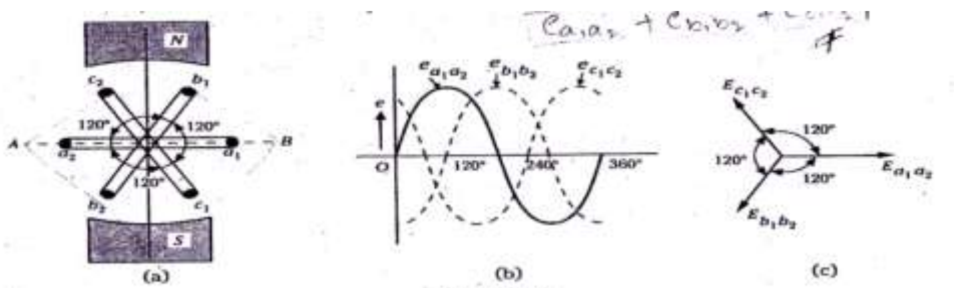


Fig. 3.80

a) Emf. induced in coil a_1a_2 is zero and is increasing in the positive direction. This is indicated by $e_{a1\,a2}$ wave in Fig. 3.80 (b).

b) The coil b_1b_2 is 120^0 electrically behind coil a_1a_2 . the e.m.f. induced in this coil is negative and is approaching maximum negative value. This is shown by the $e_{b1\,b2}$ wave.

c) The coil c_1c_2 is 240^0 electrically behind a_1a_2 or 120^0 electrically behind coil b_1b_2 . The e.m.f. induced in this coil is positive and is decreasing. This is indicated by wave $e_{c1\,c2}$.Thus, it is apparent that the e.m.f.'s induced in the three coils are of the same magnitude and frequency but displaced 120^0 electrical from each other.

Vector Diagram: The r.m.s. values of the three phase voltage are shown vectorially in Fig. 3.80(c).

Equations: The equations for the three voltages are:

$$e_{a1\,a2} = E_m \sin \omega t$$

$e_{b1\,b2} = E_m \sin\left[\omega t - \frac{2\pi}{3}\right]; e_{c1\,c2} = E_m \sin\left[\omega t - \frac{4\pi}{3}\right]$

6. A 3 phase, 50 Hz, 16 pole generator with star connected winding has 144 slots with conductor per slot is 10. The Flux per pole is 24.8 mWb is sinusoidally distributed. The coils are full pitched. Find the speed, line EMF. [June/July 2015, June/July 2016]

P=16, slots=144, conductors/slot= 10, Φ = 24.8mWb, f = 50Hz, K_c=1

Slots/phase =144/3 =48

m = 3(three phase); β = slot angle = $= \frac{180}{3m} = \frac{180}{3\times3} = 20^{\circ}$,

$K_d = \frac{\sin(\frac{m\beta}{2})}{m\sin(\frac{\beta}{2})} = \frac{\sin(\frac{3\times20^{\circ}}{2})}{3\sin(\frac{20^{\circ}}{2})}$ = 0.96

$N_s = \frac{120f}{P} = \frac{120\times50}{16} =$ **375rpm**

Z=slots× conductors/slot = 144 × 10=**1440**

$Z_{ph} = \frac{Z}{3} = \frac{1440}{3} =$ **480**

$T_{ph} = \frac{Zph}{3} =$ **240**

$E_{ph} = 4.44K_cK_d\Phi fT_{ph} = 4.44\times1\times0.96\times24.8\times10^{-3}\times50\times240 =$ **1268.5V**

$E_L = \sqrt{3}E_{ph} = \sqrt{3}\times1268.5=$ **2196.2V**

7. Establish the relationship between phase and line value of voltage and currents in 3phase, star connected circuit. [Dec2014/Jan 2015, June/July 2014, June/July 2016]

This system is obtained by joining together similar ends, either the start or the finish; the other ends are joined to the line wires, as shown in Fig.3.82 (a). The common point N at which similar (start or finish) ends are connected is called the neutral or star point. Normally, only three wires are carried to the external circuit, giving a 3-phase, 3-wire, star-connected system; however, sometimes a fourth wire known as neutral wire, is carried to the neutral point of the external load circuit, giving a 3-phase, 4-wire connected system.

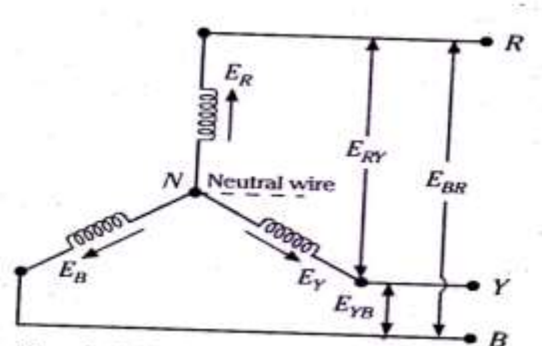


Fig. 3.82 (a) Connection Diagram

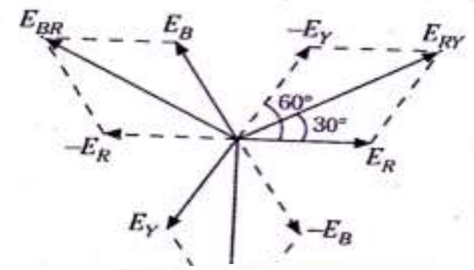


Fig. 3.82 (b) Vector Diagram of Line and Phase voltages. 3-Phase Star-Connected System

The voltage between any line and the neutral point, i.e., voltage across the phase winding, is called the phase voltage; while the voltage between any two outers is called line voltage. Usually, the neutral point is connected to earth. In Fig.3.82 (a), positive directions of e.m.f.s. are taken star point outwards. The arrow heads on e.m.f.s. and currents indicate the positive direction. Here, the 3-phases are numbered as usual: R,Y and B indicate the three natural colours red, yellow and blue respectively. By convention, sequence RYB is taken as positive and RYB as negative.

In Fig.3.82 (b), the e.m.f.s induced in the three phases, are shown vectorially. In a star-connection there are two windings between each pair of outers and due to joining of similar ends together, the e.m.f.s induced in them are in opposition.

Hence the potential difference between the two outers, know as line voltage, is the vector difference of phase e.m.f.s of the two phases concerned.

For example, the potential difference between outers R and Y or

Line voltage E_{RY}, is the vector difference of phase e.m.f.s E_R and E_Y or vector sum of phase e.m.f.s E_R and ($-E_Y$).

i.e. $E_{RY} = E_R - E_Y$ (vector difference)

or $E_{RY} = E_R + (-E_Y)$ (vector sum)

as phase angle between vectors E_R and ($-E_Y$) is 600,

$\therefore$ from vector diagram shown in Fig.3.82(b),

$$E_{RY} = \sqrt{E_R^2 + E_Y^2 + 2E_RE_Y\cos60^0}$$

Let $E_R = E_Y = E_B = E_P$ (phase voltage)

Then line voltage $E_{Ry} = \sqrt{E_P^2 + E_P^2 + (2E_PE_P \times 0.5)} = \sqrt{3}\ E_P$

Similarly, potential difference between outers Y and B or line. Voltage $E_{YB} = E_Y - E_B = \sqrt{3}\ E_P$ and potential difference between outers B and R, or line voltage $E_{BR} = E_B - E_R = \sqrt{3}\ E_P$.

In a balanced star system, E_{RY}, E_{YB} and E_{BR} are equal in magnitude and are called line voltages.

$\therefore \quad E_L = \sqrt{3}\ E_P$

Since, in a star-connected system, each line conductor is connected to a separate phase, so the current flowing through the lines and phases are the same.

i.e. Line current I_L = phase current I_P

If the phase current has a phase difference of ϕ with the voltage,

Power output per phase = $E_PI_P\cos\phi$

Total power output, $P = 3E_PI_P\cos\phi$

$$= 3\frac{E_L}{\sqrt{3}} I_P \cos\phi$$

$$= \sqrt{3}\ E_L\ I_L\cos\phi$$

i.e. power = $\sqrt{3}$ x line voltage x line current x power factor

Apparent power of 3-phase star-connected system

= 3 x apparent power per phase

$$= 3E_PI_P = 3\text{x}\ \frac{E_L}{\sqrt{3}}\ \text{x}\ I_L = \sqrt{3}\ E_L\ I_L$$

8. A 3phase delta connected balanced load consumes a power of 60KW taking a lagging current of 200 A at a line voltage of 400V, 50Hz. Find parameter of each phase.

[Dec2014/Jan 2015]

Delta, P=60KW, I_L = 200 A, V_L = 400V

$P = \sqrt{3}\, V_L\, I_L \cos\Phi$

$60\times10^3 = \sqrt{3} \times 400 \times 200 \times \cos\Phi$

$\cos\Phi = 0.433$, i.e., $\Phi = 64.341$,

For delta connection :Vph = V_L = 400V, Iph = $I_L/\sqrt{3}$ = 115.47 A

| Zph | = Vph / Iph = 400/115.47 = 3.4641Ω

Zph = | Zph |∟Φ = 3.4641∟64.341 = 1.5 + j 3.1225 Ω

= Rph + j $X_L$ph hence Rph = 1.5Ω, $X_L$ph = 3.1225Ω

$X_L$ph = 2πfLph

Lph = 3.1225 / (2π×50) = 9.9392mH

9. Define phase sequence and list out the advantages of 3 phase system as compared to single phase systems. **[Dec2014/Jan 2015, June/July 2014]**

The order in which the voltages in the voltages in the phases reach their maximum positive values is called the phase sequence. For example, in Fig. 3.80(a), the three coils a_1a_2, b_1b_2 and c_1c_2 are rotating in anticlockwise direction in the magnetic field. The coil a_1a_2 is 120^0 electrical ahead of coil b_1b_2 and 240^0 electrical ahead of coil c_1c_2. Therefore, e.m.f. in coil a_1a_2 leads the e.m.f. in coil b_2b_2 by 120^0 and that in coil c_1c_2 by 240^0. It is evident from Fig. 3.80(b) that $e_{a1\,a2}$ attains maximum positive first, then $e_{b1\,b2}$and $e_{c1\,c2}$. In other words, the order in which the e.m.f. s in the three phases a_1a_2 , b_1b_2 and c_1c_2 attain their maximum positive values is a,b,c. Hence, the phase sequence is a,b,c.

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 1200 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 system give steady output.
6) Single phase supply can be obtained from three phase but three phase can not be obtained

10. A 3 phase, 400V, motor takes an input of 40 KW at 0.45pf lag. Find the reading of each of the two single phase wattmeters connected to measure the input. [June/July 2014]

VL = 400V, Power input = 40KW, PF = cosΦ = 0.45 lagging

Input power = W1 + W2 = 40000 W ……. (1)

cosΦ = 0.45, Φ = 63.2563˚

tan Φ = 1.9845

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

$1.9845 \frac{\sqrt{3}(W_1 - W_2)}{40000}$

$W_1 - W_2$ = 45.83kW………….. (2)

Solving (1) and (2), we get,

W_1 = 42.915KW; W_2 = -2.915KW

11. Define regulation of an alternator. [June/July 2014]

The voltage regulation of an alternator is defined as the change in the terminal voltage between no load and full load at a specified power factor, without any change in the speed and excitation.

$$\text{\% Voltage regulation} = \frac{\text{(No load terminal voltage – Full load terminal voltage)}}{\text{Full load terminal voltage}} \times 100$$

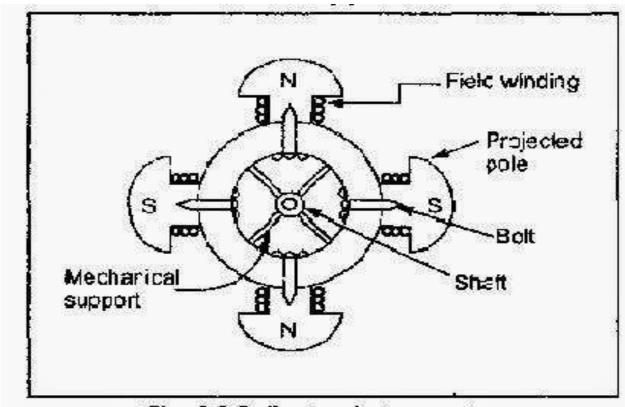
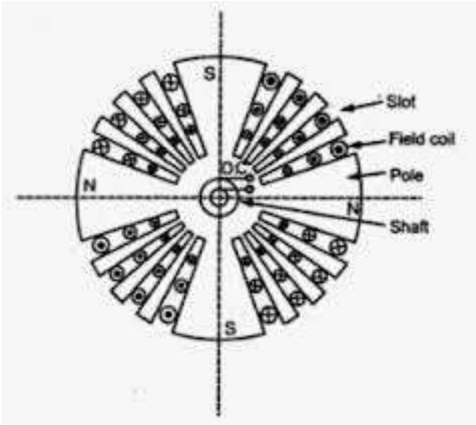
$$\text{\% Voltage regulation} = \frac{E - V}{V} \times 100$$

The idea of voltage regulation is necessary to judge the performance of an alternator. Lesser the value of the regulation better will be the load sharing capacity at better efficiency.

12. How are alternators classified? With a neat diagram, show the difference between them. [June/July 2014]

There are two types of alternators. They are:

- Salient pole or projected pole type
- Smooth cylindrical or non-salienttype

Sl.No.	Salient pole or projected pole type	Smooth cylindrical or non-salient type
1	 Fig. 6.3 Salient pole type rotor	
2	poles are projected out from the surface	Unslotted portion of the cylinder acts as poles hence poles are non-projecting
3	Air-gap is non-uniform	Air-gap is uniform due to smooth cylindrical periphery
4	Diameter is high and axial length is small	Small diameter and small axial length is the feature
5	Mechanically weak	Mechanically robust
6	Preferred for low speed alternators	Preferred for high speed alternators
7	Prime mover used are water turbines, I.C. engines	Prime movers used are steam turbines, electric motors
8	For same size, the rating is smaller than cylindrical type	For same size, the rating is higher than salient pole type
9	Separate damper winding is provided	Separate damper winding is not necessary

13. A 2 – pole, 3 – phase alternator running at 3000 rpm has 42 armature slots with 2 conductors in each slot. Calculate the flux per pole required to generate a line voltage of 2300 V. Distribution factor is 0.952 and pitch factor is 0.956. [June/July 2014]

Given P=2, Ns=3000rpm, E_{line}=2300V,K_d=0.952,K_c=0.956

Ns= $\frac{120f}{P}$ = i.e. f= $\frac{2*3000}{120}$ = 50Hz

E_{ph}= $\frac{Eline}{\sqrt{3}} = \frac{2300}{\sqrt{3}} =$ 1327.9056V

Total slots = 42, 2 conductors/slot

Z=slots* conductors/slot = 2*42=84

Z_{ph}= $\frac{Z}{3} = \frac{84}{3}$ =28, T_{ph}= $\frac{Zph}{2} = \frac{28}{2} = 14$

E_{ph}= 4.44 $K_c K_d$ Φ f T_{ph}

1327.9056=4.44 × Φ ×50×0.952×0.956×14

Φ=0.4694Wb

14. Explain construction and working principle of synchronous generator. [June/July 2014]

Principle: Whenever a coil is rotated in a magnetic field an EMF will be induced in the coil. This is called the dynamically induced EMF.

Alternators are also called as Synchronous Generators due to the reason that under normal conditions the generator is to be rotated at a definite speed called “SYNCHRONOUS SPEED”, Ns R.P.M. in order to have a fixed frequency in the output EMF wave.

Ns is related with the frequency as Ns = 120f / P, where f is the frequency and P is the total number of poles.

The following table gives the idea of the various synchronous speeds for various numbers of poles for the fixed frequency of 50 Hz.

P	2	4	6	8	10	12	16	……….
Ns rpm	**3000**	**1500**	**1000**	**750**	**600**	**500**	**375**	**……….**

Their two basic parts in an alternator:

(i) Stator,

(ii) Rotor.

Stator is the stationary part and Rotor is the revolving part.

There are two possibilities that (i) The armature can be the stator and the field system can be the rotor, and (ii) The armature can be the rotor and the field system be the stator. In practice large alternators are of the first type where in the stator is the armature and the rotor is the field system. And this type is called the “REVOLVING FIELD TYPE”.

Revolving field types are preferred due to the following reasons:

(i) More conductors can be easily accommodated and with these high voltage and higher power capacitycan be achieved.

(ii) Armature conductors can be easily braced over a rigid frame.

(iii) It is easier to insulate a stationary system.

(iv) Cooling of the conductors will be very effective with proper cooling ducts / vents in the stationary part.

(iv) Power can be tapped easily without any risk from the stationary part through terminal bushings.

(v) The armature conductors are totally free from any centrifugal force action which tends to drag the conductors out of the slots.

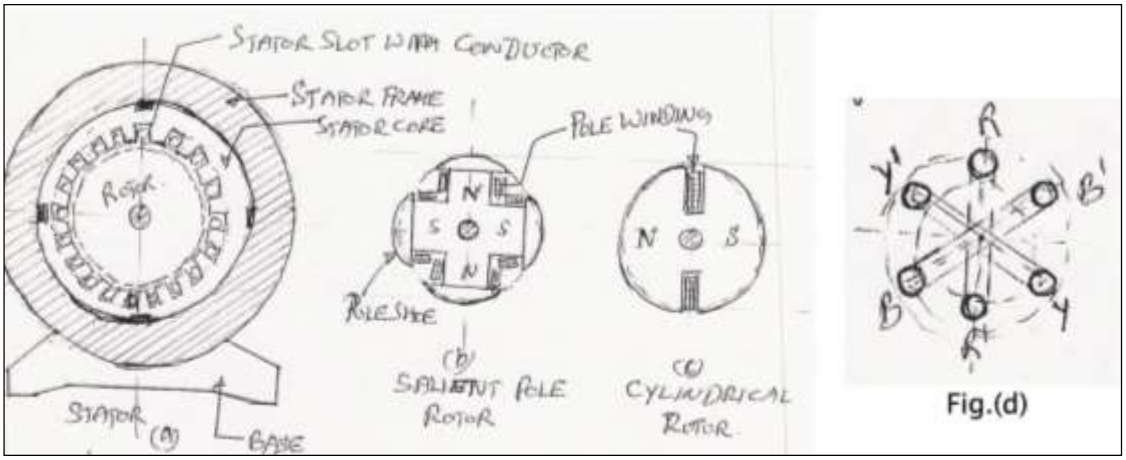


Fig.(d)

CONSTRUCTION:

Revolving field type alternators are further classified into two types:

(i) Salient pole type,

(ii) Non-salient pole type or cylindrical rotor type.

Figs. (a), (b) and (c) shows the constructional features of the Alternator. Fig. (a) Represents the stator, the core of which is made of steel laminations with slots cut in its inner periphery and all the stator stampings are pressed together and are fixed to the stator frame. Three phase windings are accommodated in these slots. These coils are identical to each other and are physically distributed such that they are displaced from each other by 120 degrees as shown in fig. (d).

Fig. (b) Represents the structure of a salient pole rotor where the poles are of projected type and are mounted on a spider and the field or the pole windings are wound over the pole core as shown. This type is preferred where the running speeds are low. Fig.(c) represents the structure of a non-salient pole rotor where the overall structure is like a cylinder having 2 or 4 poles. This type is preferred where the running speeds are very high. The armature windings in the stator are made of copper and are normally arranged in two layers and are wound for lap or wave depending on the requirements and are usually connected in star with the neutral terminal brought out.

15. **A 3- phase, 6 pole star connected alternator revolves at 1000 rpm. The stator has 90 slots and 8 conductors per slot. The flux per pole is 0.05 Wb. calculate the voltage generated by the machine if the winding factor is 0.96 line and phase value.** [**June/July 2016]**

P=6, slots=90, conductors/slot= 8,Φ = 0.05Wb, K_w=0.96, N = 1000 rpm

Slots/phase =144/3 =48

m = 3(three phase); β = slot angle = $= \frac{180}{3m} = \frac{180}{3\times3} = 20^\circ$,

$N_s = \frac{120f}{P} =$ i.e., $f = \frac{500\times12}{120} =$ **50rpm**

Z=slots× conductors/slot = 90× 8= 720

$Z_{ph} = \frac{Z}{3} = \frac{720}{3} =$ **240**

$T_{ph} = \frac{Zph}{3} =$ **120**

E_{ph}= 4.44 K_cK_d Φ f T_{ph}= 1224.424**V**

$E_L = \sqrt{3}\ E_{ph} = \sqrt{3}\times1268.5=$**2120.7652V**

16. A three phase load of three equal impedance connected in delta across a balanced 400V supply, takes a line current of 10 A at a power factor of 0.7 lagging. Calculate: (i) the phase current, (ii) the total current, (iii) the total reactive volt ampere.

[Dec2014/Jan 2015]

P=6, slots=90, conductors/slot= 8,Φ = 0.05Wb, K_w=0.96, N = 1000 rpm

Slots/phase =144/3 =48

m = 3(three phase); β = slot angle = $= \frac{180}{3m} = \frac{180}{3\times3} = 20^\circ$,

$N_s = \frac{120f}{P} =$ i.e., $f = \frac{500\times12}{120} =$ **50rpm**

Z=slots× conductors/slot = 90× 8= 720

$$Z_{ph}=\frac{Z}{3}=\frac{720}{3}=\mathbf{240}$$

$$T_{ph}=\frac{Zph}{3}=\mathbf{120}$$

E_{ph}= 4.44 $K_c K_d$ Φ f T_{ph}= 1224.424**V**

$E_L = \sqrt{3}\ E_{ph} = \sqrt{3}\times 1268.5=$**2120.7652V**

17. Explain the effect of power factor on the two wattmeter readings connected to measure three phase power. [**June/July 2016**]

Wattmeter readings at different Power Factors

(i) upf

$$\Phi = 0^\circ$$

$$W_1 = E_L I_L \cos(30+\Phi) = E_L I_L \cos(30) = \frac{\sqrt{3}}{2} E_L I_L$$

$$W_2 = E_L I_L \cos(30-\Phi) = E_L I_L \cos(30) = \frac{\sqrt{3}}{2} E_L I_L$$

$$W_1 = W_2$$

(ii) $pf = 0.866$

$$\Phi = 30^\circ$$

$$W_1 = E_L I_L \cos(30+\Phi) = E_L I_L \cos(30+30) = \frac{E_L I_L}{2}$$

$$W_2 = E_L I_L \cos(30-\Phi) = E_L I_L \cos(30-30) = E_L I_L$$

$$W_2 = 2W_1$$

$(iii)\, pf = 0.5$

$\Phi = 60^{\circ}$

$W_1 = E_L I_L \cos(30+\Phi) = E_L I_L \cos(30+60) = 0$

$W_2 = E_L I_L \cos(30-\Phi) = E_L I_L \cos(30-60) = \frac{\sqrt{3}}{2} E_L I_L$

$(iv)\, pf < 0.5$

$\Phi > 60^{\circ}$

$W_1 = E_L I_L \cos(30+\Phi) < 0$

$W_2 = E_L I_L \cos(30-\Phi) > 0$

$(v)\, pf = 0$

$\Phi = 90^{\circ}$

$W_1 = E_L I_L \cos(30+\Phi) = E_L I_L \cos(30+90) = \frac{E_L I_L}{2}$

$W_2 = E_L I_L \cos(30-\Phi) = E_L I_L \cos(30-90) = -\frac{E_L I_L}{2}$

$W_1 = -W_2$

MODULE 5

1. Explain the construction and working principle of a transformer with a neat sketch.
[June/July 2015, June/July 2014]

PRINCIPLE:- A transformer works on the principle of mutual induction. "Whenever a change in current takes place in a coil there will be an induced emf in the other coil wound over the same magnetic core". This is the principle of mutual induction by which the two coils are said to be coupled with each other.

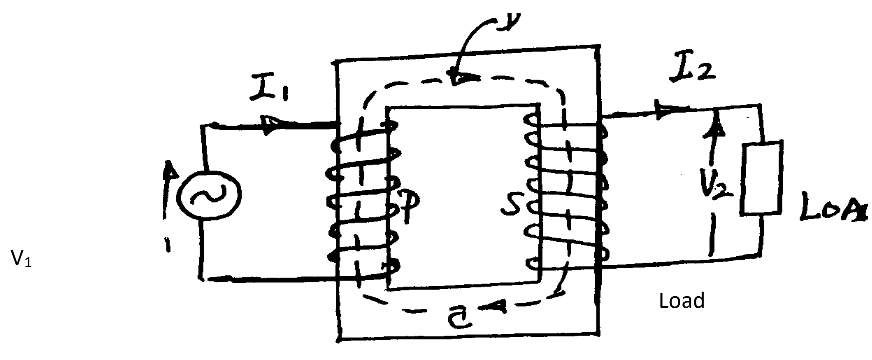


Fig.1

TYPES AND CONSTRUCTION OF TRANSFORMERS

There are two basic circuits in a transformer

1) **Magnetic circuit**
2) **Electric circuit**

The core forms the magnetic circuit and the electric circuit consists of two windings primary and secondary and is made of pure copper. There are two types of single phase transformers.

a) **CORE TYPE**

b) **SHELL TYPE**

Figs (a) and (b) shows the details of the elevation and plan of a core type transformer. The limbs are wound with half the L.V. and half the H.V. windings with proper insulation between them. The whole assembly taken inside a steel tank filled with oil for the purpose of insulation and cooling.

CORE TYPE TRANSFORMER.

In the core type the core is surrounded by the coils but in the shell type the core is on the either side of the coils. There are three limbs and the central limb is of large cross section than that of outer limbs, and both the LV and HV windings are wound on the central limb and the outer limb is only for providing the return path for the flux.The windings are of concentric type (i.e. LV on which the HV windings) or Sandwich type.The core is made of very thin laminations of high grade silicon steel material to reduce the eddy current loss and Hysteresis losses in the core.

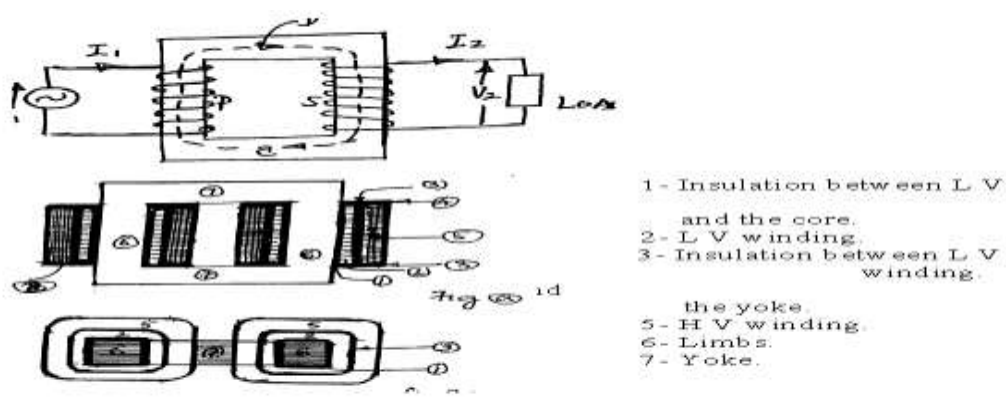
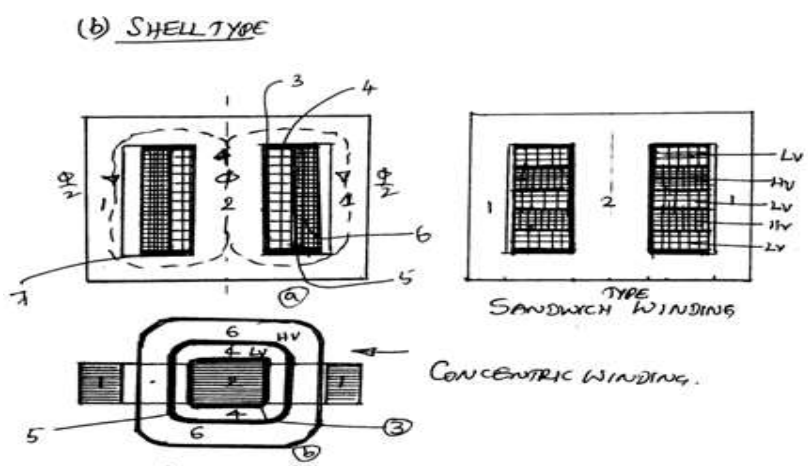


FIG. (b)

SHELL TYPE TRANSFORMER.



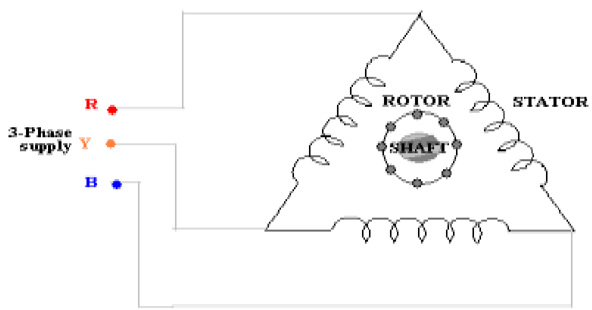
In the shell type transformers the core is of different type having three limbs with the central limb of larger cross section compared to the two outer limbs and carries both the L V and H V windings wound over each other with proper insulation between them. The entire assembly is immersed in a steel tank filled with oil for the cooling purpose.

2. Explain the concept of rotating magnetic field in a 3 phase induction motor.

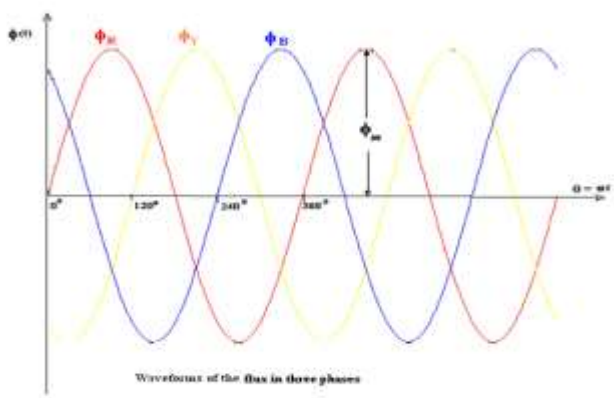
[June/July 2015], [June/July 2014]

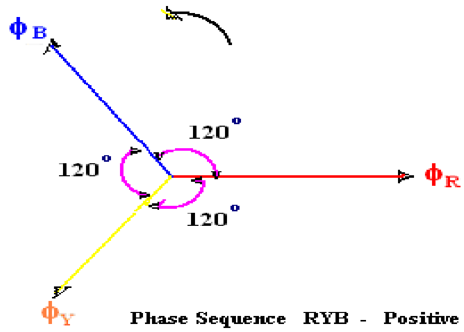
Production of a rotating magnetic field

Consider a 3- phase induction motor whose stator windings mutually displaced from each other by 120° are connected in delta and energized by a 3- phase supply.



The currents flowing in each phase will set up a flux in the respective phases as



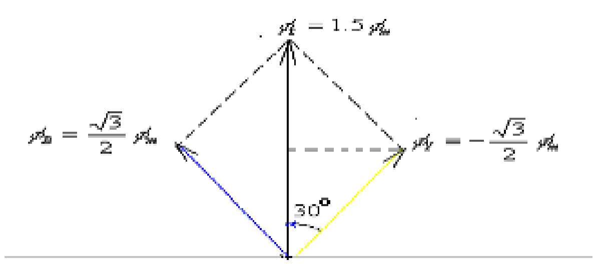


The corresponding phase fluxes can be represented by the following equations

$$\Phi_R = \Phi_m \sin \omega t = \Phi_m \sin\theta \quad \Phi_B = \Phi_m \sin(\omega t - 240°)$$
$$\Phi_Y = \Phi_m \sin(\omega t - 120°) \quad \Phi_B = \Phi_m \sin(\theta - 240°)$$
$$\Phi_Y = \Phi_m \sin(\theta - 120°)$$

The resultant flux at any instant is given by the vector sum of the flux in each of the phases. (i) When $\theta = 0^\circ$, from the flux waveform diagram ,we have

$$\phi_R = 0$$
$$\phi_Y = \phi_{km}\sin(-120^\circ) = -\frac{\sqrt{3}}{2}\phi_m$$
$$\phi_B = \phi_m \sin(-240^\circ) = \frac{\sqrt{3}}{2}\phi_m$$



Resultant flux at θ = 0°

The resultant flux ϕ_r is given by,

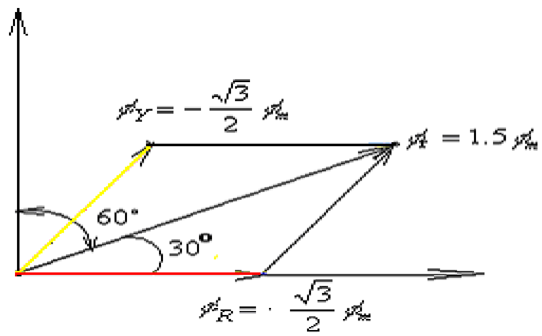
$$\phi_r = 2 * \frac{\sqrt{3}}{2}\phi_m \cos(30^\circ) = 1..5\phi_m$$

$$\phi_B = \frac{\sqrt{3}}{2}\phi_m$$

$$\phi_Y = -\frac{\sqrt{3}}{2}\phi_m$$

$\phi_r = 1.5\phi_m$

(ii) *When* $\theta = 60^\circ$



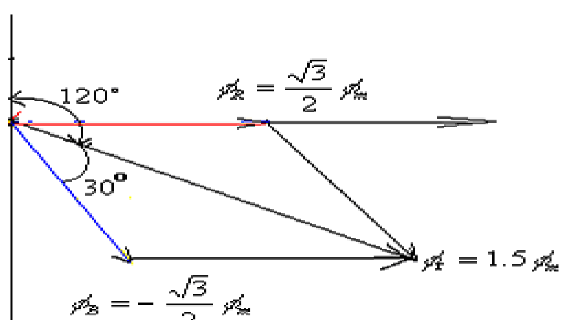
Resultant flux at $\Theta = 60^\circ$

$$\phi_R = \frac{\sqrt{3}}{2}\phi_m$$

$$\phi_Y = -\frac{\sqrt{3}}{2}\phi_m$$

$$\phi_B = 0$$

(iii) *When* $\theta = 120^\circ$



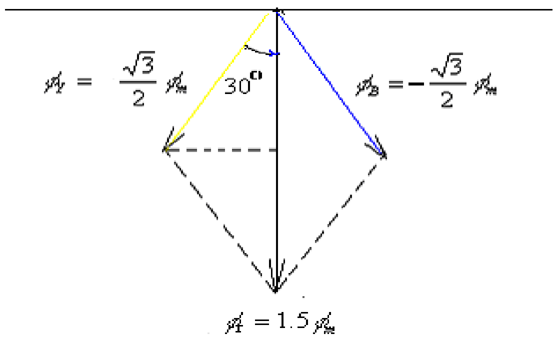
Resultant flux at $\Theta = 120^\circ$

$$\phi_R = \frac{\sqrt{3}}{2}\phi_m$$

$$\phi_Y = 0$$

$$\phi_B = -\frac{\sqrt{3}}{2}\phi_m$$

(iv) *When* $\theta = 180^{\circ}$



Resultant flux at θ = 180°

$$\phi_R = 0;$$

$$\phi_Y = \frac{\sqrt{3}}{2}\phi_m$$

$$\phi_B = -\frac{\sqrt{3}}{2}\phi$$

From the above discussion it is very clear that when the stator of a 3-phase induction motor is energized, a magnetic field of constant magnitude (1.5 φ_m) rotating at synchronous speed(**N_s)** with respect to stator winding is produced.

3. The frequency of the emf in the stator of a 4-pole induction motor is 50Hz and in the rotor is 1.5Hz.What is the slip and at what speed is the motor running? [June/July 2015]

f= 50Hz; f' = 1.5Hz

$$S = \frac{f'}{f} = \frac{1.5}{50} = 0.03 = 3\%$$

$$Ns = \frac{120f}{P} = 1500\text{rpm}$$

N = Ns (1-S) = **1445rpm**

4. What is slip in an induction motor? Explain why slip is never zero in an induction motor.

[June/July 2015, June/July 2014]

According to Lenz's law, the direction of rotor current will be such that they tend to oppose the cause producing it. The cause producing the rotor current is the relative speed between the rotating field and the stationary rotor. Hence, to reduce this relative speed, the rotor starts running in the same direction as that of stator field and tries to catch it. In practice the rotor can never reach the speed of the rotating magnetic field produced by the stator. This is because if rotor speed equals the synchronous speed, then there is no relative speed between the rotating magnetic field and the rotor. This makes the rotor current zero and hence no torque is produced and the rotor will tend to remain stationary. In practice, windage and friction losses cause the rotor to slow down. Hence, the rotor speed (N) is always less than the stator field speed (N_S). Thus the induction motor cannot run with **ZERO SLIP. The frequency of the rotor current**

f_r= sf. The difference between the synchronous speed (N_S) of the rotating stator field and the actual rotor speed (N) is called the **slip speed.**

Slip speed = $(Ns - N)$ depends upon the load on the motor

$$\%S = \frac{Ns-N}{Ns} * 100$$

Note: In an induction motor the slip value ranges from 2% to 4%

5. A single phase transformer has 400 turns primary and 1000 secondary turns. The net cross-sectional area of the core is $60cm^2$ .The primary winding is connected to a 500V, 50Hzsupply. Find peak value of flux density, emf induced in the secondary winding.

[June/July 2015, June/July 2016]

N_1=400

N_2=1000

$A=60cm^2=60\times10^{-2}\times10^{-2}m^2$

E_1=500V

f=50Hz

$E_1=4.44f\ \Phi m N_1$ V

$\Phi m = 5.63\times10^{-3}$Wb

$B_m = \frac{\Phi m}{A} = \frac{5.63\times10-3}{60\times10-4} = 0.938 Wb/m^2$

$\frac{E2}{E1} = \frac{N2}{N1}$

E_2=1250V

6. **The maximum efficiency at full load and unity p.f of a single phase 25KVA,500/1000V, 50Hz transformer is 98%.Determine its efficiency at i)75% load,0.9p.f and ii)50% load,0.8p.f [June/July 2015, Dec2015/Jan2016]**

Efficiency is maximum when iron loss (W_i) equals copper loss (W_{cu})

E1=500V;E2=1000V;f=50Hz;η=0.98

I_2= $(25\times10^3)/1000$=25A

0.98=(1×25×1000×1)/((1×25×1000×1)+ W_i+ W_{cu}))

Therefore, $W_i = W_{cu}$=255.1W

$$\eta = \frac{outputpower}{outputpower + Ironloss + copperloss}$$

$$= \frac{V_2 I_2 \cos\phi}{V_2 I_2 \cos\phi + W_{eron} + W_{copper}}$$

$$\eta = \frac{(0.75\times25\times1000\times0.9)}{(0.75\times25\times1000\times0.9)+255.1+(0.75\times0.75\times255.1)}$$

η=96.9%

7. **Explain principle of operation of a single phase transformer and derive the EMF equation. [June/July 2014, Dec2014/Jan 2015, June/July 2016]**

Whenever a coil is subjected to alternating flux, there will be an induced emf in it and is called the statically induced emf $e = \frac{Nd\phi}{dt}$

Let N_1, N_2 be the no. of turns of the primary and secondary windings, E_1, E_2 the induced emf in the primary and secondary coils. ϕ be the flux which is sinusoidal f be the frequency in Hz

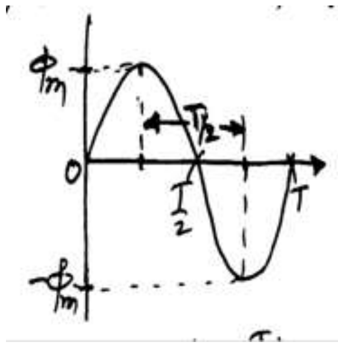


Figure showing the sinusoidally varying flux of peak value **Φ_m.**

Whenever a coil of **N** no- of tunes are linked by a time varying flux ϕ , the average emf induced in this coil is

$$e = \frac{Nd\phi}{dt}$$

As the flux is sinusoidal the change in flux from **$+\phi_m$ to $-\phi_m$** is $d\phi = 2\phi_m$, and this change takes place in a duration dt = T/2 seconds.

The average induced emf in these N numbers of turns is

$E_{avg} = N.d\phi/dt = N.2\phi_m / (T/2) = 4\phi_m N/T = 4f\phi_m N$ volts (as f =1/T)

We know that the Form factor of a pure sine wave **F.F. =E_{rms}/E_{avg}= 1.11**

Therefore, **E_{rms}= 1.11 E_{avg}.**

$= (1.11)(4f\phi_m N) = 4.44 f\phi_m N$ volts.

In the primary coil**,** **$N = N_1$, $E1 = 4.44f\phi_m N_1$ volts**

In the secondary coil, N **= N_2, $E_2 = 4.44f\phi_m N_2$ volts**

8. **In a 25KVA 2000/200V single phase transformer, the iron and full load copper losses are 350W and 400W respectively. Calculate the efficiency at unity power factor on full load and half load. [Dec2014/Jan 2015]**

KVA=25KVA

E_1=2000V

E_2=200V

W_i=350W

W_{cu}=400W

I_2= $(25\times10^3)/200$=125A

$$\eta = \frac{outputpower}{outputpower + Ironloss + copperloss}$$

$$= \frac{V_2 I_2 \cos\phi}{V_2 I_2 \cos\phi + W_{eron} + W_{copper}}$$

$$\eta = \frac{(1\times200\times125\times1)}{(1\times200\times125\times1)+350+(1\times1\times400)}$$

η=97.08%

$$\eta = \frac{(0.5\times200\times125\times1)}{(0.5\times200\times125\times1)+350+(0.5\times0.5\times400)}$$

η=96.52%

9. **An 8 pole alternator runs at 750rpm and supplies power to a 6 pole induction motor which runs at 970rpm.What is the slip of the induction motor? [Dec2014/Jan 2015]**

Alternator data: poles=8; N=750rpm

So, f=$\frac{PN}{120}$Hz

$= \frac{8*750}{120}$ =50Hz

Induction motor: poles = 6; N = 970rpm

Ns=$\frac{120f}{P}=\frac{120*50}{6}$=1000rpm

$$S = \frac{Ns-N}{Ns} * 100 = \frac{1000-970}{1000} * 100 = 0.03 = \mathbf{3\%}$$

10. A 600KVA transformer has an efficiency of 92% at full load, unity power factor and half full load, 0.9 pf. Determine its efficiency at 75% of full load,0.9pf. [Dec2014/Jan 2015]

S = 600 KVA, %η = 92% on full load and half load both

On full load, $\% \eta = \frac{n \times VAcos\varphi}{n \times VAcos\varphi + n^2 W_{cu} + W_i}$

$$0.92 = \frac{1 \times 600 \times 100^3 \times 1}{600 \times 100^3 \times 1 + 1W_{cu} + W_i}$$

$$W_{cu} + W_i = 52173.913$$

On half load, $n = \frac{1}{2} = 0.5$

$$\% \eta = \frac{n \times VAcos\varphi}{n \times VAcos\varphi + n^2 W_{cu} + W_i}$$

$$0.92 = \frac{0.5 \times 600 \times 100^3 \times 0.9}{0.5 \times 600 \times 100^3 \times 0.9 + (0.5^2) W_{cu} + W_i}$$

$0.25W_{cu} + W_i$ = 23478.26 …………. (2)

Subtracting (2) from (1),

$0.75W_{cu}$ = 28695.64

W_{cu} = 38260.86 watts

and W_i = 13913.04 watts

Now n = 0.75 i.e., 75% of full load and cosΦ = 0.9

(W_{cu}) new = n^2 (W_{cu}) F.L. = $(0.75)^2 \times W_{cu}$.

$$\% \eta = \frac{n \times VAcos\varphi}{n \times VAcos\varphi + n^2 W_{cu} + W_i}$$

$$= \frac{0.75 \times 600 \times 100^3 \times 0.9}{0.75 \times 600 \times 100^3 \times 0.9 + (0.75^2)86 + 13916.04}$$

= 91.95%

11. Derive the condition for which the efficiency of a transformer is maximum.

[Dec2014/Jan 2015]

- The load current at which the efficiency attains maximum value is denoted as I_{2m} and maximum efficiency is denoted as η_{max}.
- The efficiency is a function of load i.e. loads current I_2 assuming $\cos\Phi_2$ constant. The secondary terminal voltage V_2 is also assumed constant.
- So for maximum efficiency,

$\frac{d\eta}{dI2}$ = 0 while $\eta = \frac{V_2 I_2 cos\Phi_2}{V_2 I_2 cos\Phi_2 + W_i + I_2^2 R_{2e}}$ = 0

$(V_2 I_2 cos\Phi_2 + W_i + I_2^2 R_{2e})$ $(V_2 cos\Phi_2)$-$(V_2 I_2 cos\Phi_2)$ $(V_2 cos\Phi_2 + 2I_2^2 R_{2e})$ =0

Cancelling $V_2 cos\Phi_2$ from both the terms we get,

$V_2 I_2 cos\Phi_2 + W_i + I_2^2 R_{2e}$ $-(V_2 I_2 cos\Phi_2 - 2I_2^2 R_{2e})$ =0

i.e., $W_i - 2I_2^2 R_{2e}$= 0

$W_i = 2I_2^2 R_{2e}$= W_{cu},

So the condition for maximum efficiency is that,

Copper losses = Iron losses i.e.,$W_i = W_{cu}$

12. An 8 pole alternator runs at 750rpm and supplies power to a 4 pole induction motor. The frequency of rotor current is 1. 5Hz.Determine the speed of the motor. [Dec2014/Jan 2015]

Alternator data: poles=8; N=750rpm

So, f= $\frac{PN}{120}$Hz

= $\frac{8*750}{120}$ =50Hz

Induction motor: poles =4; f' =1.5 Hz

Ns=$\frac{120f}{P}$=$\frac{120*50}{4}$=1500rpm

S=$\frac{f'}{f}$=$\frac{1.5}{50}$=0.03=3%

Hence, N=Ns (1-S)

=1500(1-0.03)

N=1455rpm

13. **A 10 pole induction motor is supplied by a 6 – pole alternator which is driven at 1200 rpm. If the motor runs with a slip of 3%, what is its speed? [June/July 2014]**

Alternator data: poles=6; N=1200rpm

So, f= $\frac{PN}{120}$Hz = $\frac{6*1200}{120}$ =**60Hz**

Induction motor: poles =10; S=3%=**0.03**

Ns=$\frac{120f}{P}$=$\frac{120*60}{10}$=**720rpm**

Hence, N=Ns (1-S)=720(1-0.03)

N=698.4rpm

14. **Why does an induction motor need a starter? [June/July 2014]**

When a 3- phase motor of higher rating is switched on directly from the mains it draws a starting current of about 4 -7 times the full load (depending upon on the design) current. This will cause a drop in the voltage affecting the performance of other loads connected to the mains. Hence starters are used to limit the initial current drawn by the 3 phase induction motors.

The starting current is limited by applying reduced voltage in case of squirrel cage type induction motor and by increasing the impedance of the motor circuit in case of slip ring type induction motor.

15. **Find the number of turns on the primary and secondary side of a 440/230 V, 50 Hz single phase transformer, if the net area of cross section of the core is 30 cm2 and the maximum flux density is 1Wb/m2. [June/July 2014, June/July 2016]**

V_1=440V

V_2= 230V

f = 50 Hz

A= 30cm^2= 30×10^{-2}×10^{-2}m^2

B_m= 1 Wb/ m^2

E_1=4.44f $\Phi m N_1$ V

Φm= $B_m A$

E_1=4.44fB_mA N_1 V

400 = 4.44 *50*N1* $30\times10^{-2}\times10^{-2}$

N1 = 660

$\Phi m = 5.63\times10^{-3}$Wb

$$\frac{E2}{E1} = \frac{N2}{N1}$$

N_2=345

16. A single phase transformer working at 0.8 pf has efficiency 94% at both three fourth full load and full load of 600 kW. Determine the efficiency at half full –load, unity power factor. [June/July 2014]

On full load, % η = $\frac{n\times VAcos\varphi}{n\times VAcos\varphi + n^2W_{cu}+W_i}$

0.94 = $\frac{1\times600\times100^3\times0.8}{1\times600\times100^3\times0.8 + 1W_{cu} + W_i}$

$W_{cu} + W_i$ = 30638.3………… (1)

On half load, n = $\frac{3}{4}$ = 0.75

$$\% \ \eta = \frac{n\times VAcos\varphi}{n\times VAcos\varphi + n^2W_{cu}+W_i}$$

92 = $\frac{0.75\times600\times100^3\times0.8}{0.75\times600\times100^3\times0.8+(0.75^2)W_{cu} + W_i}$

$0.5625W_{cu} + W_i$= 22978.72 ………….. (2)

Subtracting (2) from (1),

W_{cu} = 17.51K watts

andW_i = 13.13K watts

Now n = 0.5 i.e., 75% of full load and cosΦ = 1

$$\% \eta = \frac{n \times VAcos\varphi}{n \times VAcos\varphi + n^2 W_{cu} + W_i}$$

$$= \frac{0.5 \times 600 \times 100^3 \times 1}{0.5 \times 600 \times 100^3 \times 1 + (0.5^2)17.51K + 13.13K}$$

= 90.73%

17. A single phase, 20KVA transformer has 1000primary turns and 2500 secondary turns. The net cross sectional area of the core is 100cm^2 .when the primary winding is connected to 500V, 50Hz supply, calculate)the maximum value of the flux density in the core, the voltage induced in the secondary winding and the primary and the secondary full load currents [June/July 2014, June/July 2016]

KVA = 20KVA

N_1= 1000V

N_2= 2500V

f = 50 Hz

A = 100cm^2 = $100 \times 10^{-2} \times 10^{-2}$m^2

V1 = 500V

E_1= 4.44f $\Phi m N_1$ V

500 = 4.44*50* Φm*1000

Φm = 2.25mWb

$$\frac{E2}{E1} = \frac{N2}{N1}$$

E_2=1250V

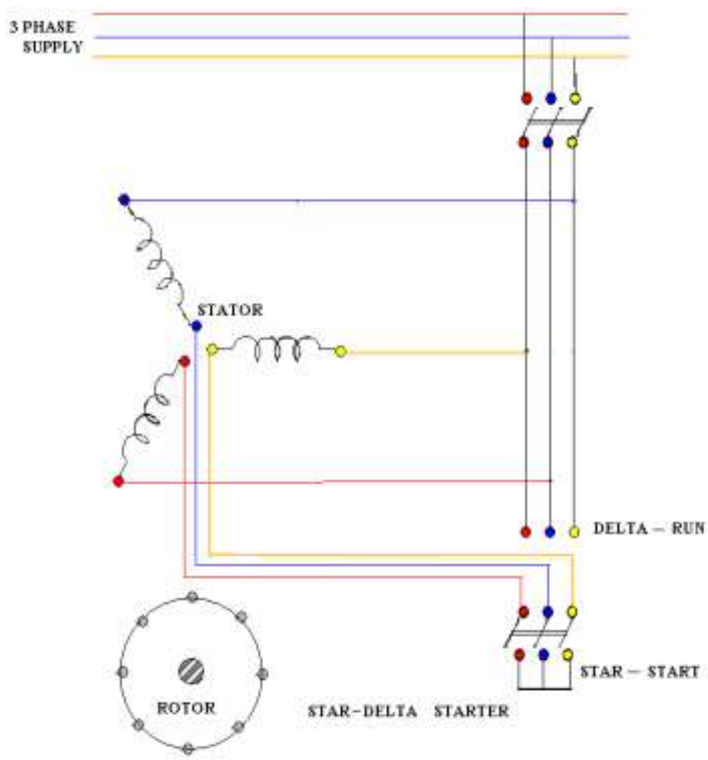
$$I_1 = \frac{KVA}{V1} = \frac{20 \times 10^3}{500} = 40A$$

$$I_2 = \frac{KVA}{V2} = \frac{20\times10^3}{1250} = 16A$$

18. Explain construction and working principle of star-delta starter.

[June/July 2014]

The star delta starter is used for squirrel cage induction motor whose stator winding is delta connected during normal running conditions. The two ends of each phase of the stator winding are drawn out and connected to the starter terminals as shown in the following figure.



When the switch is closed on the star-start side

(1) The winding is to be shown connected in star

(2) The current I = 1/3 * ($I_{direct\ switching}$)

(3) Reduction in voltage by1/√3

$$V = V_{supply} * 1/\sqrt{3}$$

When the switch is closed on to delta –run side

(1) the winding to be shown connected in delta

(2) application of normal voltage V_{supply}

(3) normal current I

During staring the starter switch is thrown on to the **STAR -START**. In this position the stator winding is connected in star fashion and the voltage per phase is **1/√3** of the supply voltage. This will limit the current at starting to **1/3** of the value drawn during direct switching. When the motor accelerates the starter switch is thrown on to the **DELTA - RUN** side. In this position the stator winding gets connected in the **Δ** fashion and the motor draws the normal rated current.

19. A transformer is rated at 100 kVA. At full load its copper loss is 1200W and its iron loss is 960 W. Calculate: the efficiency at full load, UPF, the efficiency at half load, 0.8pf, the load kVA at which maximum efficiency will occur. [Dec 2013/Jan 2014]

On full load, $\% \eta = \frac{n\times VAcos\varphi}{n\times VAcos\varphi + n^2 W_{cu} + W_i}$

$$= \frac{1\times 100\times 100^3\times 1}{100\times 100^3\times 1\times 1 + 1\times 1200 + 960} = \mathbf{97.88\%}$$

On half load, n= 0.5 $\% \eta = \frac{n\times VAcos\varphi}{n\times VAcos\varphi + n^2 W_{cu} + W_i}$

$$0.92 = \frac{0.5\times 100\times 100^3\times 0.8}{100\times 100^3\times 0.5\times 0.8 + 0.5^2 \times 1200 + 960} = \mathbf{96.94\%}$$

$$\text{kVA at } \eta_{max} = (\text{kVA})\times\sqrt{\frac{W_i}{(W_{cu})FL}} = 100\times\sqrt{\frac{960}{1200}} = \mathbf{89.44kVA}$$

20. A 3- phase, 6 pole, 50Hz induction motor has a slip of 1% at no load. Determine: synchronous speed, no- load speed, full load speed, full- load speed, and frequency of rotor current at stand still, frequency of rotor current at full load. [Dec 2013/Jan 2014]

P = 6, f = 50 Hz, s_o = 1%, s_f = 3%

$$Ns = \frac{120f}{P} = (120*50)/6 = 1000rpm$$

No = Ns(1 - s_o) = 1000(1 – 0.01) = 990 rpm

Ns = Nf (1 –s_f) = 1000(1-0.03) = 970 rpm

At stand still, f_r = f = 50Hz

At full load, f_r= s_f × f = 0.03×50 = 1.5 Hz

21. Define Slip. Drive an expression for frequency of rotor current. [Dec2015/Jan 2016]

When the rotor is stationary, the frequency of the rotor current is same as the supply frequency. When the induction motot is rotating, the frequency of teh current induced in the rotor conductors is proportional to the relative speed or slip speed. If f' is the frequency of the induced current in the rotor, then

Ns – N = 120f'/P;

But Ns =120f/P;

Where, f = frequency of the supply

From eq (1) & (2), we get

Ns – N/ Ns = f'/f = S

f' = S f

The frequency of the rotor current is slip times the frequency of the supply.

22. A three phase 6 pole, 50 Hz induction motor has a slip of 1 % at no load and 3% at full load. Determine: (i) Synchronous speed, (ii) No load speed, (iii) Full load speed, (iv) Frequency of rotor current at stand still, (v) frequency of rotor current at full load.

[Dec2015/Jan 2016]

On No load:

N_s = 120f/P = 120×50/6 = **1000 rpm**

S = N_s – N_o/ N_s

0.01 = 1000- No/1000

10 = 1000 – No

N_o = **990 rpm**.

f' = s f = 0.01×50 = **0.5Hz**

On full load

$S = N_s – N/ N_s$

0.03 = 1000 – N/ 1000

N = **970 rpm**.

f' = s f = 0.03×50 **= 1.5 Hz**

23. If a 6 pole induction motor supplied from a three phase 50Hz supply has a rotor frequency 2.3 Hz, calculate (i) the percentage slip (ii) the speed of the motor.

S = f'/f = 2.3 / 50 = 0.046 × 100 = **4.6 %**

Ns = 120f/P = 120 × 50 / 6 = **1000 rpm.**

S = Ns – N / Ns

0.046 = 1000 – N / 1000

N = **954 rpm**

24. Explain the losses occurring in a transformer. **[June/July 2016]**

There a two types of power losses occur in a transformer

1) Iron loss

2) Copper loss

1) Iron Loss: This is the power loss that occurs in the iron part. This loss is due to the alternating frequency of the emf. Iron loss in further classified into two other losses.

a) Eddy current loss b) Hysteresis loss

a) EDDY CURRENT LOSS: This power loss is due to the alternating flux linking the core, which will induced an emf in the core called the eddy emf, due to which a current called the eddy current is being circulated in the core. As there is some resistance in the core with this eddy current circulation converts into heat called the eddy current power loss. Eddy current loss is proportional to the square of the supply frequency.

b) **HYSTERISIS LOSS**: This is the loss in the iron core, due to the magnetic reversal of the flux in the core, which results in the form of heat in the core. This loss is directly proportional to the supply frequency.

Eddy current loss can be minimized by using the core made of thin sheets of silicon steel material, and each lamination is coated with varnish insulation to suppress the path of the eddy currents.

Hysteresis loss can be minimized by using the core material having high permeability.

2) **COPPER LOSS:** This is the power loss that occurs in the primary and secondary coils when the transformer is on load. This power is wasted in the form of heat due to the resistance of the coils. This loss is proportional to the sequence of the load hence it is called the Variable loss whereas the Iron loss is called as the Constant loss as the supply voltage and frequency are constants.