Detailed Solutions D-05 June 2003

Q.1 a B Kirchoff's current law is applicable to only junctions in a network

b. D The capacity of a cell is measured in Ampere –hours i.e. product of discharging current and time in hours during which the cell is delivering current

c B The dynamic impedance of an R-L and C parallel circuit at resonance is L/CR

d. A The power factor of a.c. circuit is equal to Cosine of the phase angle

e. B If the line current in a delta connected system is I_L, then phase current will be equal to $I_L / \sqrt{3}$

f. B Flemings left hand rule is applicable to DC motors.

g. B A three point starter is considered suitable for dc shunt motors

h B The two winding of a transformer are inductively linked.

PART-I

2.(a) In a dc circuit it states that the power transferred to a load resistance R_L connected across a voltage Vs and internal resistance Rs, is maximum when $R_L = Rs$

In an a c circuit the power at source & load are as follows:

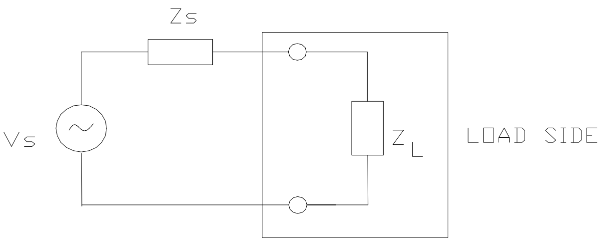


Fig 2(a)

Let $Z_S = Rs + jXs$

$Z_L = R_L + jX_L$

$I = Vs/Zs+Z_L$

$= Vs/ (R_L + jX_L) +(Rs + jXs)$

$= Vs/ (R_L +Rs) + j(X_L + Xs)$

$|I| = Vs/\sqrt{(R_L + Rs)^2 + (X_L + Xs)^2}$

$|I|^2 = Vs^2 / (R_L + Rs)^2 + (X_L + Xs)^2$

Power delivered to load $(P_L) = |I|^2 R_L$

$= Vs^2 R_L / (R_L + Rs)^2 + (X_L + Xs)^2$

For max power transfer: $\partial / \partial R_L . (P_L) = 0$

& $\partial / \partial X_L . (P_L) = 0$

Now solve and find that $R_L = Rs$ & $X_L = -Xs$

2b. i.)

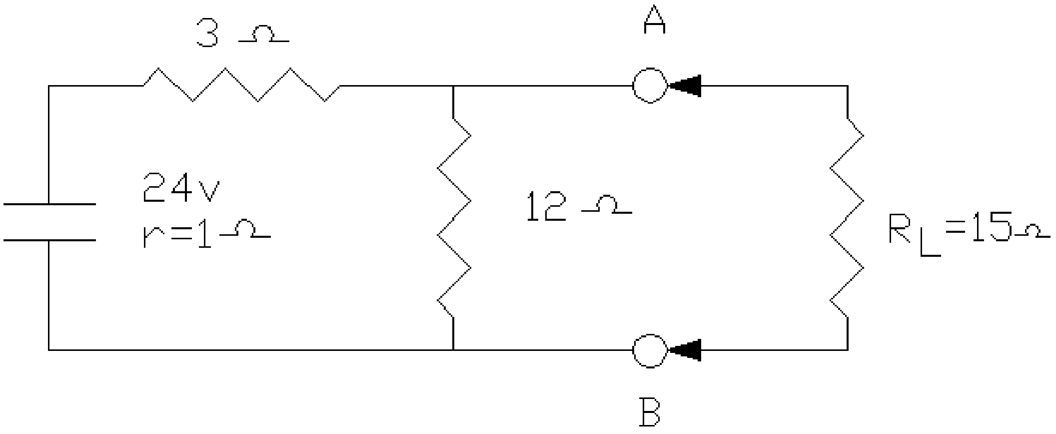


Fig 2(b)

In the given network the equivalent e.m.f of the net work when viewed from terminal A and B

i.e $V_{Th} = 24 \times \dfrac{12}{15+1}$

$= 24 \times 12/16$

$= 18V$

ii.) $R_{Th} = \dfrac{4 \times 12}{16} = 3\ \Omega$

iii) $I_{Th} = V_{Th} / (R_{Th} + R_L)$

$= \dfrac{18}{3+15} = \dfrac{18}{18} = 1$Amp.

Q3a) **Advantages and disadvantages of three phase system over single phase System.**

i) In a single phase circuit the power delivered is pulsating. In three phase system the total power delivered is constant if the loads are balanced though the power of any one phase or circuit may be negative. So three – phase system is highly desirable particularly for power loads.

ii) The rating of a given machine increases with the increase in number of phases. For example the output of a three phase motor is 1.5 times the output of single phase motor of the same size.

iii) Single –phase induction motors, have no starting torque and so it is necessary to provide these motors with an auxiliary means of starting, but in case of three phase motors except synchronous motors there is no need of providing an auxiliary means for starting.

iv) Power factor of single phase motor is lower than that of three phase motor of the same rating (output & speed). The efficiency of a three phase motor is also higher than that of a single phase motor.

v) Three phase system requires 3/4th weight of copper, which is required by single- phase system to transmit the same amount of power at a given voltage and over a given distance.

vi) Rotating magnetic field can be set up, by passing three- phase balanced current through stationary 3-phase balanced coils.

vii) Polyphase system is more capable and reliable than single phase system.

viii) Parallel operation of three-phase alternators is simple as compared that of single phase alternators because of pulsating reaction in single phase alternators.

However, three phase operation is not as practical for domestic applications where motors are usually smaller than 1 kW and where lighting circuits supply most of the load.

3 b) In star connection

Phase current I_{ph} = Line current $I_L = 20A$

$V_{ph} = V_L/\sqrt{3} = 400/\sqrt{3}$ V

$$\text{Power } P_L = 3\, V_{ph} \times I_{ph} \cos\phi$$
$$= \sqrt{3}\, V_L\, I_L \cos\phi$$
$$= \sqrt{3} \times 400 \times 20 \times \cos\phi$$
$$P_L = 12 \times 10^3 = \sqrt{3} \times 400 \times 20 \times \cos\phi$$

$$\cos\phi = \frac{12 \times 10^3}{\sqrt{3} \times 400 \times 20}$$

power factor = $\sqrt{3}/2$

$$Z_{ph} = \frac{V_{ph}}{I_{ph}} = \frac{400/\sqrt{3}}{20} = \frac{20}{\sqrt{3}}\ \Omega$$

$$Z_{ph} = \frac{20}{\sqrt{3}}\ \Omega\ ;\ I_{ph} = 20\text{ A}\ ;\ \text{P.F} = \sqrt{3}/2$$

Q4a) **Core type Transformers**: in this type of transformer the windings surround the core (fig .given below). Both the windings are divided and half of each winding is placed on each limb to make the leakage flux as small as possible. Since insulation of low voltage winding is easy so low voltage winding is placed next to core and then high voltage winding is placed around the low voltage coils. In such an arrangement only one layer of high voltage insulation is required and removal or repair of the high voltage winding, which is more liable to faults than the low voltage winding, is easy and convenient.

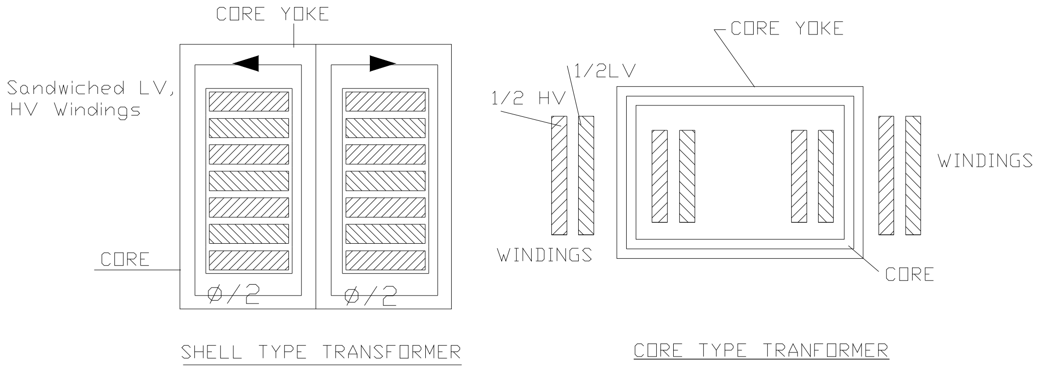


Fig (4a)

Shell type transformers. In this type of transformer the iron core surrounds the copper windings (fig given above). The core is in the form of numeral 8. The entire flux passes through the central part of the iron core, but outside this central core it divides into two parts half going in each direction. Sandwich type winding is used in which the sections of the primary winding are sandwiched in between the sections of the secondary winding. In this manner the leakage flux is reduced to very small value. To minimize the amount of high voltage insulation low voltage coils are placed adjacent to the iron core.

Q4 b)

Given Sec. Induced emf (E_2) = 250 V
Terminal Voltage (V_2) = 230 V
Rated current (I) = 50A
P.F = 0.8 (lagging)
% Voltage regulation (% R) = ?

$$= \left\{ \frac{(I R_{01} \cos\phi + I X_{01} \sin\phi)}{V_2} \times 100 \right\}$$

Or

$$\% R = \frac{E_2 - V_2}{V_2} \times 100$$

$$= \frac{250-230}{230} \times 100$$

$$= \frac{20 \ x10}{230}$$

$$= 8.7\ \%$$

Q5

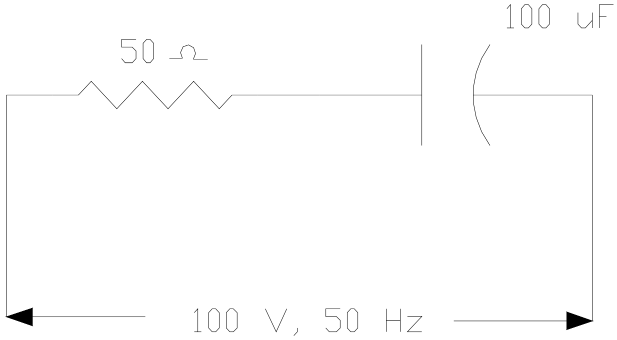


Fig (5)

i) Impedance of the given circuit

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

$X_C = 1/\omega_C = 1/\ 2\pi f \times 100 \times 10^{-6}$

$= 1/\ 2 \times \pi \times 50 \times 100 \times 10^{-6}$

$= 7 / 22 \times 10^{-2}$

$= 0.318 \times 10^{2} = 31.8\Omega$

$Z = \sqrt{[2500 + (31.8)^2]}$

$= 59.255\Omega$

ii) $I = V/Z = 100/59.25 = 1.68A$

iii) $\cos\phi = R/Z = 0.84$

iv) Phase angle $\phi = \cos^{-1} 0.84 = 32.86^0$

v) Voltage across resistor I.R

$= 1.68 \times 50 = 84$ V

vi) Voltage across Capacitor $V_C = I.\ X_C$

$= 1.68 \times 31.8$

$= 53.67$ V

Q6

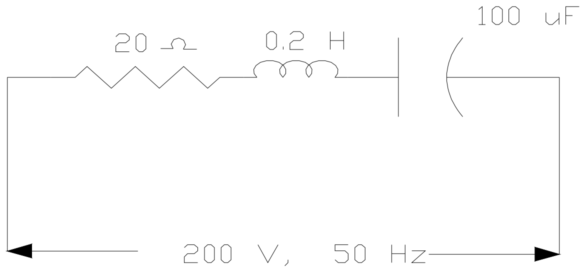


Fig (6)

The given circuit is series R-L-C circuit.

$X_L = \omega_L = 2\pi f L$
$= 2 \times \pi \times 50 \times 0.2$
$= 62.83\ \Omega$

$X_L = 1/\omega_C = 1/2\pi f C$
$= 31.8\ \Omega$

i) Impedance $Z = \sqrt{} R^2 + (X_L - X_C)^2$
$= \sqrt{}20^2 + (62.83\text{-}31.8)^2$
$= \sqrt{}20^2 + (31.03)^2$
$= \sqrt{}\ 400 + 962.86$
$= \sqrt{}1362.86$
$= 36.91\ \Omega$

ii) Current (I) = V/Z = 220/36.91 = 5.96 A

iii) Voltage (V) = $\sqrt{}\ V_R^2 + (V_L - V_C)^2$

Voltage across resistance (V_R) = I x R = 5.96 x 20 = 119.2 V

Voltage across Capacitor (V_C) = I x X_C = 5.96 x 31.8 = 189.5 V

Voltage across Inductance (V_L) = I x X_L = 5.96 x 62.83 = 374.46 V

iv) Power (P) = VI cos ϕ
Power factor (cos ϕ) = R/Z = 20/36.91 = 0.54
P = 220 x 5.96 x 0.54 = 710 W

v) Power factor cosϕ = 0.54

PART-II

Q7 Disadvantage of low Power Factor

We know that

$P = V I \cos \phi,$

for certain amount of power at constant voltage, Power (P) and voltage (V) in the above expression of power are constant, so

$I \propto 1/\cos \phi$

From the above relation it is clear that current is inversely proportional to the power factor of the load. Therefore low power factor results in higher current, more losses, more voltage drop, greater size of conductor and high rating of the equipments used in the power system.

In brief poor power factor results in an uneconomical power system.

Now with the help of power triangle low power factor means $\cos \phi < 1$

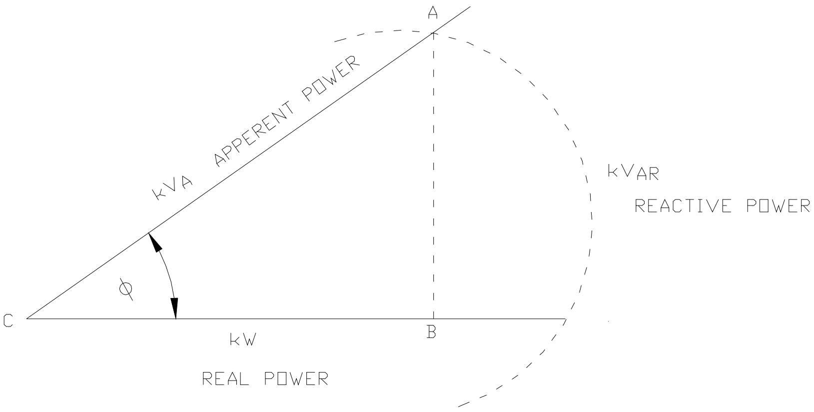


Fig -7(i)

Therefore, kVAR or reactive power will be more, so user machine will require more kVA power for desired kW load, therefore

$kVA = \sqrt{(kVAR^2 + kW^2)}$

$kW^2 = kVA^2 - kVAR^2$

if $kVAR = 0$

$kW = kVA$

it means

- Wastage of power in reactive component
- More kVA input power is required to real (kW) load.
- Loss of energy.

Causes of Low power factor

The main causes of low power factor in the electric supply system are as follows.

- Due to reactive load
  Most of the AC motors used in industry or with domestic appliances are of induction type which works at low power factor.

- Low R/Z ratio:
  Arc lamp, arc furnaces, induction furnaces etc. used in industry operates at poor power factors.

- Low kW/kVA ratio
  Modern alternator, transformers, certain protective devices and even AC transmission and distribution lines are of inductive nature and further decreases the power factor of the electrical power system.

Step to improve Power Factor

i) By using static capacitor:
Static capacitor is generally used to improve the power factor of the power system. Since the capacitor draws leading current which partly or completely neutralizes the lagging wattless component of the least current, thus increasing the over all power factor of the load. For improving the power factor , capacitor is connected in parallel with the load.

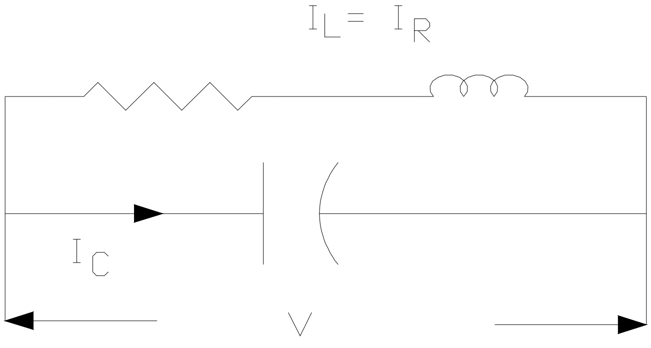


Fig-7(ii)

ii) Another way of improving the power factor is the use of synchronous motor with the load. Synchronous motor can operate at any power factor i.e. lagging, unity or at leading power factor. Synchronous motor when used to improve the power factor only is called as “ Synchronous Condenser” and is operated at no load with overexcited field.

Q 8 (a) Working Principle of D.C Motor

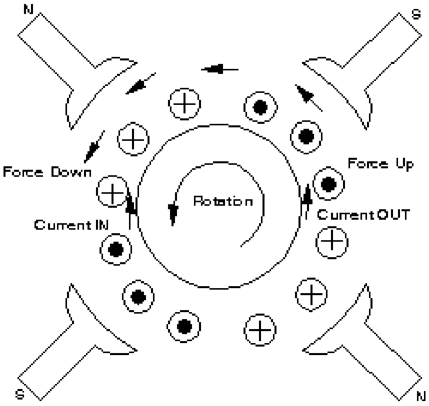


Fig -8(a)

- An electric motor is a machine which converts electrical energy into mechanical energy.

- When a current carrying conductor is placed in a magnetic field, it experience a mechanical force whose direction is given by “ Flemings Left hand rule” & magnitude is given by F= B.I.L Newton

- When field magnets are excited and armature conductors are supplied with current from supply main, they experience a force tending to rotate the armature. Armature conductors under N-Pole are assumed to carry current in (crosses) and those under S-Pole to carry current out (dots). By applying “ Flemings Left hand rule” ,the direction of force on each conductor can be found. It is shown by small arrows placed above each conductors. It will be seen that each conductor experiences a force F which tends to rotate armature in anticlockwise direction. These forces collectively produce a driving torque which sets the armature rotating.

(b)

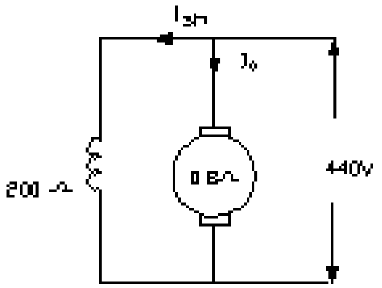


Fig – 8 (b)

$E_b = ?$
$V = 440V$
$P_O = 7.46$ kW
$\eta \;\; = 85\%$
$\eta \;\; = \frac{P_O}{P_i}$
$P_I = P_0 / \eta$
Therefore $P_i \; = \frac{7.46 \text{ x } 10^3}{0.85} = 8.776$ kW

$I \qquad = \frac{8.776 \text{ x } 10^3}{440} = 19.95$ Amp.
$I_{sh} \qquad = \frac{440}{200} \qquad = 2.2$ A

$I_a \qquad = I - I_{sh} \qquad = 17.75$ A

$E_b \qquad = V - I_a R_a$
$= 440 - (17.75 \text{ x } 0.8)$
$= 440 - 14.2$
$= 425.8$ V

Q9 a) **Construction of a 3-Phase Induction Motor:**

It consists essentially of two main parts:

i) A stator
ii) A rotor

STATOR: It is made up of a number of stampings which are slotted to receive windings. The stator carries 3ϕ windings and is fed from 3ϕ supply. It will be for a definite number of poles as p=2n, where n is the number of stator slot/pole/phase, the exact number of poles is determined by requirement of speed. As Ns = 120f / p , when 3ϕ supply is fed to stator, it produces a magnetic flux which is of constant magnitude but revolves at synchronous speed Ns= (120f)/P. This revolving magnetic flux induces an e.m.f. in the rotor by mutual induction.

ROTOR:
(i) squirrel –cage rotor
(ii) phase-wound or wound-rotor

90% of Induction Motor are squirrel cage type because this type of rotor has a simplest and the most rugged construction and is almost indestructible. Rotor consists of a cylindrical laminated core with parallel slots for carrying rotor conductors. Rotor bars are permanently short circuited on themselves; hence it is not possible to add any external resistance in series with the rotor circuit for starting purposes. The rotor slots are usually not quite parallel to shaft but purposely given slight skew so that

- It helps to make motor run quietly by reducing magnetic hum and
- It helps in reducing locking tendency of rotor i.e. the tendency of the rotor teeth to remain under the stator teeth due to direct magnetic attraction between the two.

Torque Speed Characteristics

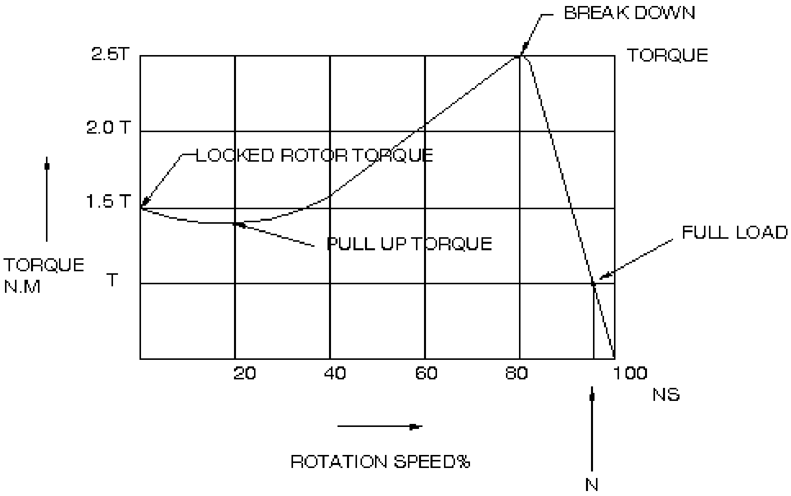
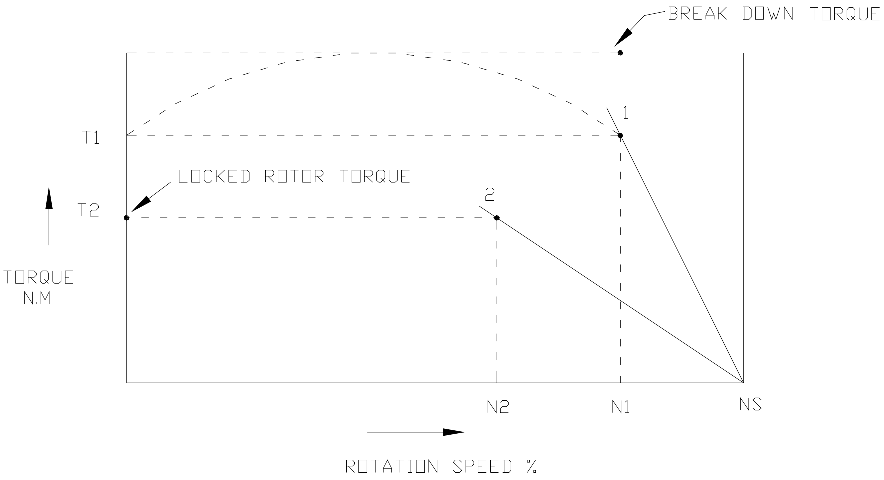


Fig-9(a)

At full load motor runs at speed N. when mechanical load increases, motor speed decreases till motor torque again becomes equal to the load torque. As long as two torque are in balance, the motor will run at constant but lower speed. However, if load torque exceeds 2.5 T, motor will suddenly stop.



Stable operation of induction motor lies over linear portion of its Torque/speed curve. The slope of this straight line depends mainly on rotor resistance. Sharper the slope as

$$S_2 = S_1 \frac{T_2 . R_2}{T_1 . R_1} (V_1 / V_2)^2$$

Q9 b) 3 phase Induction motor

$p = 4$

$f = 50$ Hz , $S = 4\%$

$$N_s = \frac{120 f}{p} = \frac{120 \times 50}{4} = 1500 \text{r.p.m}$$

$$N = N_s (1 - S)$$
$$= 1500 (1-0.04)$$
$$= 1500 \times 0.96$$
$$= 1440 \text{ rpm}$$

Q10 **Comparison of Steam Power Plant, Hydro-Electric Plants, Diesel Power Plant &Nuclear Power Plant.**

	Steam Power Plant	Hydroelectric plant	Diesel power plant	Nuclear power plant
Application	Used for Base & Peak load	Used for base as well as peak load	Used for peak load supply	Always used for base load
Running cost	More cost	Very less	Very costly	Less but more than hydro power plant
Initial cost for same capacity	Less cost	More costly	Very less cost	Moderately cost
Life	20-25 yrs	50-60 yr Max.	15-20 yrs	30-35 yrs

		life		
Staff required for same capacity	Max. staff require comparative to other power plant of same	Less staff required but more than nuclear	More staff require	Very less staff required
Size of plant for same capacity	Very big size of plant	small size	Big size	Very small size
Efficiency	25-35%	More than 70%	28-32%	More than 80%
Gestation period or period of installation	More time (3-4yrs)	Very much time (7-10 yrs)	Very less time	Less time
Maintenance Cost	More costly	Very less	Less costly	Less costly than thermal power station
Source/Fuel	Coal/Gas	Water	Diesel	Radioactive element (U,Pu,Th)

Q11 (i) **Chemical changes during:**

(a) Discharging:

The current will flow from positive to negative plate in the external circuit. As current now enters through negative plate, the negative plate becomes anode and the positive plate cathode. Hence, hydrogen ions will move towards PbO_2 plate and sulphate ions towards Pb plate. Thus, following actions take place:

At positive plate:

$$\begin{array}{l} PbO_2 + H_2 = PbO + H_2O \\ PbO + H_2SO_4 = PbSO_4 + H_2O \\ \hline PbO_2 + H_2 + H_2SO_4 = PbSO_4 + 2H_2O \end{array}$$

At negative plate:

$$2H_2O + 2SO_4 = 2H_2SO_4 + O_2$$

Hence:

$$\begin{array}{c} 2Pb + O_2 = 2PbO \\ 2PbO + 2H_2SO_4 = 2\,PbSO_4 + 2H_2O \\ \hline 2Pb + O_2 + 2H_2SO_4 = 2PbSO_4 + 2H_2O \\ \hline \end{array}$$

It is observed that during discharge, water is produced, hence electricity is diluted.

b. <u>During charging:</u> After discharge, both plates contain $PbSO_4$. Then to charge the cell, the current should be passed through the cell from a suitable low voltage DC supply

c. <u>At positive plate</u>: $PbSO_4 + SO_4 + 2H_2O \rightarrow PbO_2 + 2H_2SO_4$

<u>At negative plate:</u> $PbSO_4 + H_2 \rightarrow Pb + 2H_2SO_4$

It is observed that during charging H_2SO_4 is produced and hence the electrolyte becomes concentrated.

ii) Necessity Of A Starter For D.C Motors

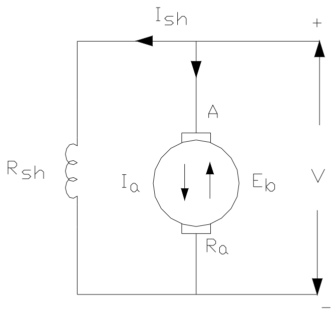


Fig 11(ii)

In the above fig, we have

$I_a = (V-E_b)/R_a$

When motor is at rest , then N=0 and because E_b is directly proportional to N, so

At start E_b = zero

Therefore armature current at the time of starting

$I_{as} = (V-0)/R_a = V/R_a$

i.e. at start armature, current can be calculated by simply applying ohm's law,
As the resistance of the armature winding is very small then the motor will take large amount of current at the time of starting i.e. if supply voltage is 220 V and armature resistance is 0.5 Ω, then starting current will be equal to 220/0.5 = 440A

This large amount of starting current may harm the motor, but more than this it is harmful for all other motors connected to the same distributor. Because of this heavy current, voltage drop in the distributor will be more, due to this each other motor will draw more current, resulting in still more voltage drop and finally it may lead to interruption of the supply. Therefore suitable means must be used at the time of starting for limiting the starting current to safe value. Even starting current equal to 4 to 5 times of full load current is considered as safe value of the starting current, since this current flows for very-very short duration. The simplest way of reducing the starting current is to increase the effective resistance of the armature circuit. This is done by connecting an additional resistance in series of the armature. The device used for performing this function is called as starter. So DC starter is nothing but a resistance box. However for protection of the motor from overloading and low voltage, overload release and No voltage release are also provided in the starter.

iii) Selection of motors for different Engg. application

1. For Cement industry:
    - Several types of motors for pumps, fans, conveyors ,crushers, kilns an mills
    - Main mill motor may be synchronous motor.
    - Motors should be dust protected, highly reliable automatically controlled.

2. Chemical, Rubber, Petrochemical Industry
    - Needs all types of motors, all size of motors
    - Needs non sparking, flame proof, increased safety
    - Variable frequency synchronous motors supplied by static frequency converters.
    - Direct coupled induction motors needs for compressor drive

3. Material handling applications.
    - Squirrel cage motors with high starting torque are used for conveyor applications.

4. Machine tools application
    - Generally fixed speed motors with gear selection are employed
    - Special purpose synchronous motors with direct drive supplied at appropriate high frequency are used for high speed
    - Complex duty cycle drives require special high accuracy servo system

5. Marine Application
    - Suitably designed single or double speed squirrel cage induction motors are used.

6. Metallurgical Industry
    - Variable speed DC drives are being use traditionally now variable frequency AC drives using squirrel cage motors

7. Mines
    - Flame proof squirrel cage induction motors are used in coal mines

8. Printing Paper Industry:
    - Synchronous motors are used in grinders.
    - DC drives are used for pumping pulp and refining it.

9. Textile industry:
    - High speed drives are necessary with wide range of control, small & medium motors are employed.
    - Commutator motors and synchronous motors are used.

10 Traction application

- Specially developed traction motors with high mechanical and thermal stresses, axle drive are used.
- For 16.67 Hz AC commutator motors are used with 25kV , single phase AC supply (in Europe)
- 25 kV, single phase, 50Hz voltage stepped down and rectified. DC series motors are used in India.
- DC or AC motors with special design feature and with variable voltage, variable frequency thyristor converters are use in today traction applications.

11. Battery powered vehicles

- Used DC series motors is the first choice. Recently AC motors with frequency converters are being considered.

Detailed Solutions D- 05 December 2003

Q1. a. D Both Ohms law & Kirchoff's current law.
b. C Current.
c. B Line current.
d. A Two – Phase motor.
e. C N_2/N_1 Number of turns in the secondary winding
Number of turns in the primary winding
f. C Cast iron.
g. B Current required for a given load power is higher.
h. B Electric clock.

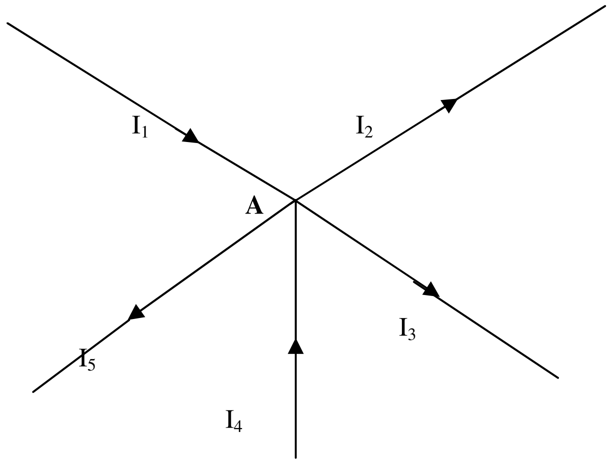
PART-I

Q2a. **Kirchoff's Current Law** states that in any electrical network, the algebraic sum of the currents meeting at a point (or junction) is zero, which means that the total current leaving a junction is equal to the total current entering that junction.

Consider a few conductors meeting at a point A as in fig. Some conductors have currents leading to point A, where as some have currents leading away from point A. Assuming the incoming currents to be positive and outgoing currents negative,

$$I_1 + (-I_2) + (-I_3) + (+I_4) + (-I_5) = 0$$

or $I_1+I_4-I_2-I_3-I_5 = 0$ or $I_1+I_4= I_2+I_3+I_5$ or incoming currents = outgoing currents.



Kirchoff's Voltage Law states that the algebraic sum of the products of currents and resistances in each of the conductors in any closed path in a network plus the algebraic sum of the e.m.f"s in that path is zero. $\sum IR + \sum e.m.f. = 0$

Consider the closed path ABCDA in fig., as we move around the mesh in the clockwise direction, different voltage drops will have the following signs:

I_1R_1 is -ve (fall in potential)

I_2R_2 is - ve (fall in potential)

I_3R_3 is + ve (rise in potential)

I_4R_4 is –ve (fall in potential)

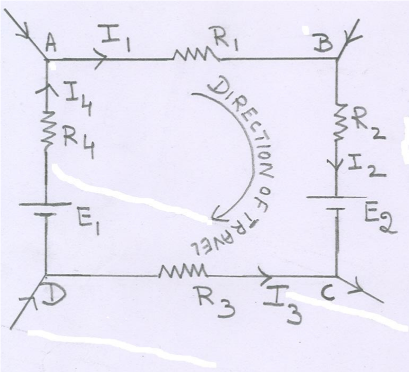
E_2 is –ve (fall in potential)

E_1 is + ve (rise in potential)

Using Kirchoff’s voltage law, we get

$$- I_1R_1 - I_2R_2 + I_3R_3 - I_4R_4 - E_2 + E_1 = 0$$

$$I_1R_1 + I_2R_2 - I_3R_3 + I_4R_4 = E_1 - E_2$$



Q2b. Applying KVL to the closed circuit CDEFC, we get

$-12 + 2x - 1y + 8 = 0$ or $2x - y = 4$----------(1)

Similarly, from the closed circuit CFEGC, we get

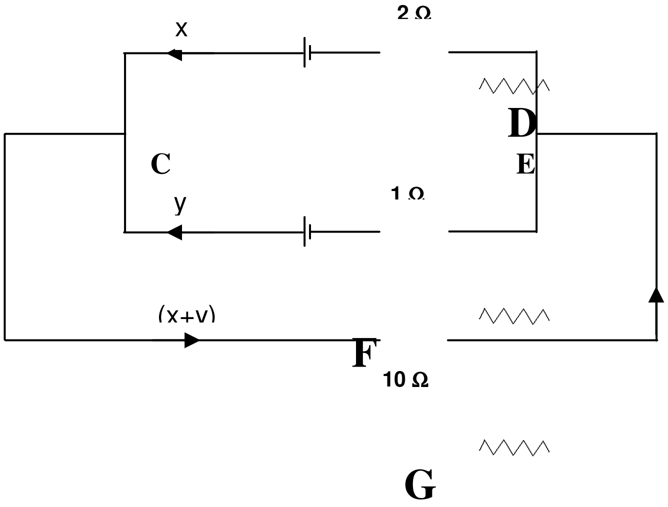
$- 8 + 1y + 10 (x+y) = 0$ or $10x + 11y = 8$ ---------(2)

From Eq. (1) and (2) we get $x =$ **1.625 A** and $y =$ **- 0.75 A** **Ans.**

The negative sign of y shows that the current is flowing into the 8V battery and not out of it. It is a charging current and not discharging current.

Current flowing in the external resistance = x + y = 1.625 – 0.75 = **0.875 A** **Ans.**

P.D. across the external resistance = 10 X 0.875 = **8.75 V** **Ans.**



Q3a. The losses occurring in a transformer are I) iron loss II) copper loss

I) **Core losses or Iron losses**: These losses consist of hysteresis and eddy current losses, which occur due to pulsation of flux in the core. These losses depend upon the maximum flux density in the core and frequency. Since from no load to full load the flux linking with core and frequency remains constant so these losses remain constant.

II) **Copper losses**: These losses occur due to ohmic resistance of the transformer windings. If I_1 and I_2 are primary and secondary currents respectively and $R_1$and R_2 are the respective resistances of primary and secondary windings then copper losses occurring in primary and secondary windings will be $I_1^2 R_1$ and $I_2^{\ 2} R_2$. Total copper losses will be $(I_1^2 R_1 + I_2^{\ 2} R_2)$.These losses vary as the square of the load current.

Q3b. **EMF Equation**: As shown in the fig magnetic flux Φ increases from zero to its maximum value, Φ_{max} in one-fourth of cycle i.e. dt = 1/4f second.

Average rate of change of flux, $d\Phi/dt = \Phi_{max}/1/4f = 4f\Phi_{max}$

Average induced emf is equal to the product of the number of turns and rate change of flux.

Average induced emf, $E_{av} = N\ d\Phi/dt = N \times 4\ f\ \Phi_{max}$

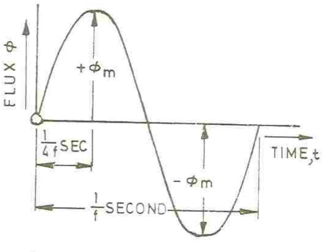
Since flux Φ varies sinusoidally, therefore, the rms induced emf is 1.11 times of average induced emf.

$E_{ms} = 1.11\ Eav = 4.44\ f\ N\ \Phi_{max}$.

If Φ_{max} is in webers, then E will be in volts.

If the number of turns on primary and secondary windings are N_1 and N_2respectively, then induced emf's in primary and secondary windings are given as

$E_1 = 4.44\ f\ N_1\Phi_{max}$ volts. and $E_2 = 4.44\ f\ N_2\ \Phi_{max}$ volts.



Sinusoidal Variation of Flux With Time

Q4. The supply voltage is assumed as **400 V 50Hz**

Star connected

Line voltage, E_L = 400 volts

Phase voltage, $E_P = 400/\surd 3 = 230$ volts.

Phase current, $I_P = E_P/R = 230/5 = 46$ Amps.

Line current = phase current = 46 Amps.

Power factor = 1 (In case of resistive load, power factor is always unity)

Power = $\surd 3\ E_L\ I_L \cos\phi$ watts

= $\surd 3 \times 400 \times 46 \times 1$ = **31.869 Kw. Ans.**

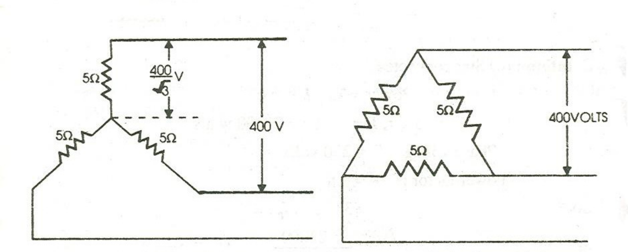
Delta connected

Phase current, I_P = 400/5 = 80 Amps.

Line current, $I_L = \sqrt{3} \times 80 = 138.56$ Amps.

Power = $\sqrt{3}\, E_L\, I_L \cos\phi$ watts

Power = $\sqrt{3} \times 400 \times 138.56 \times 1$ = **96 Kw.Ans.**



Star Connected   Delta Connected

Q5) In order to find the circuit current, we must first find the equivalent impedance of the whole circuit.

$$Z_{BC} = (5+j12) \parallel (-j20) = \frac{(5+j12)(-j20)}{5+j12-j20} = \frac{13\angle 67.4^0 \times 20\angle -90^0}{9.43\angle -58^0}$$

$$= 27.57\angle 35.4^0 = (22.47 + j15.97)$$

$$Z_{AC} = (10+j0) + (22.47 + j\,15.97) = (32.47 + j\,14.97) = 36.2\angle 26.2^0$$

$$I = \frac{V}{Z} = \frac{50\angle 0^0}{36.2\angle 26.2^0} = 1.38\angle -26.2^0 \text{ A}$$

Power developed in 10Ω resistor = $I^2R = 1.38^2 \times 10$ = **19 W Ans**

Potential difference across 10Ω resistor is

$$IR = 1.38\angle -26.2^0 \times 10 = 13.8\angle -26.2^0 = (12.38 - j\,6.1)$$

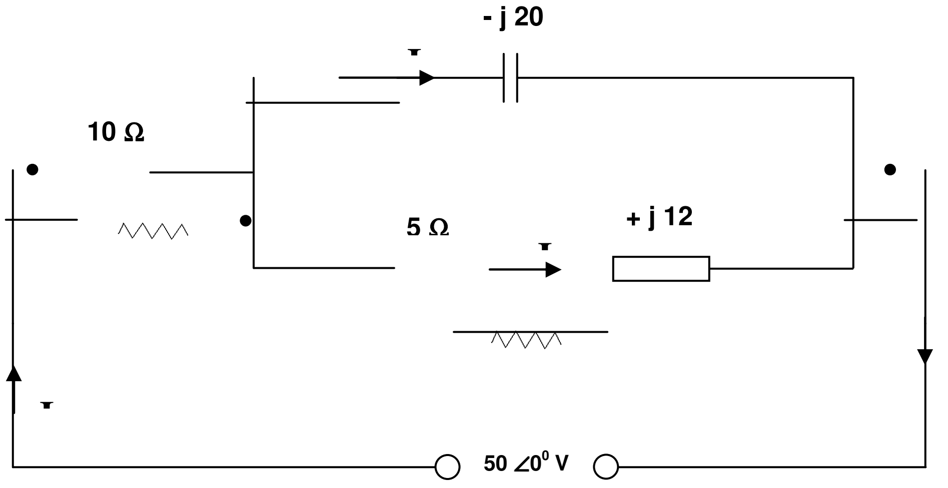
V_{BC} = supply voltage – drop across 10Ω resistor

$$= (50 + j\,0) - (12.38 - j\,6.1) = (37.62 + j\,6.1) = 38.1\angle 9.21^0$$

$$I_2 = \frac{V_{BC}}{(5+j\,12)} = \frac{38.1\angle 9.21^0}{13\angle 67.4^0} = 2.93\angle -58.2^0$$

Power developed = $I_2^2 \times 5 = 2.93^2 \times 5$ = **43 W Ans.**

No power is developed in the capacitor branch because it has no resistance.



Q6) The phase difference between the applied voltage and circuit current is $(55^0-10^0) = 45^0$ with current lagging. The angular frequency is $\omega = 3000$ radian/second. since current lags, $X_L > X_C$. Net reactance $X = (X_L - X_C)$. Also $X_L = \omega L = 3000 \times 0.01 = 30\Omega$.

$\tan\phi = X/R$ or $\tan 45^0 = X/R$. Therefore $X = R$. Now, $Z = V_m / I_m = 400/10\sqrt{2} = 28.3\Omega$

$Z^2 = R^2 + X^2 = 2R^2$. Therefore **R** $= Z / \sqrt{2} = 28.3 / \sqrt{2} =$ **20 Ω Ans.**

$X = X_L - X_C = 30 - X_C = 20$.

$X_C = 10\Omega$ or $1/\omega C = 10$ or $1/3000C$ or **C = 33.3 µ F Ans**

PART-II

Q7a. **Functions of the commutator:**

A commutator is a device, which under certain conditions converts ac into dc and vice versa.

The commutator is a form of rotating switch placed between the armature and external circuit and so arranged that it reverses the connections to the external circuits at the instant of each reversal of the current in the armature coil. Thus it converts induced alternating currents in armature coils into direct currents in the external load circuits.

In the case of dc motor, a direct current passes through the brushes and commutator to the armature winding; while it passes through the commutator it is converted into ac so that the group of conductors under successive field poles carry currents in opposite directions.

Q7b. Let Φ be the flux per pole in webers, Z the total number of armature conductors or coil sides on the armature, P the number of poles, A the number of parallel paths in armature and N be the rotational speed of armature in rpm.

The induced emf is proportional to the time rate of change of the magnetic flux

i.e. $e = - d\Phi / dt$.

During one revolution of the armature in a P - pole generator each armature conductors cuts the magnetic flux P times, so flux cut by one conductor in one revolution = PΦ webers.

Since the number of revolutions made by the armature per minute is N, so number of revolutions made per second is N / 60 and, therefore, flux cut by each conductor per second = Flux cut by one conductor per revolution X number of revolutions of armature/second $= P\Phi \times N / 60$ webers.

Consequently the average emf induced in one conductor will be

$= P\Phi N / 60$ volts.

The number of conductors in series between a +ve brush and –ve brush is equal to the total number of conductors divided by the number of parallel paths i.e. number of armature conductors per parallel path = Z / A

The total emf generated between the terminals,

E = Average emf induced in one conductor X number of conductors in each circuit or parallel path

$$E = P\Phi N / 60 \times Z / A = \Phi Z N / 60 \times P/A \text{ volts.}$$

From the above expression it is obvious that the induced emf in a machine depends upon I) flux per pole, which depends upon the excitation of the machine ii) number of armature conductors, iii) number of poles iv) number of parallel paths and v) the speed of rotation of armature.

The induced emf is fundamental phenomenon to all dc machines whether they are operating as a generator or motor. When the machine is operating as a generator this induced emf is called the generated emf, E_g where as in case of a machine operating as a motor it is called the counter or back emf, E_b.

Q8a. **Comparison of Squirrel Cage and Phase Wound Induction Motor.**

Basis of comparison	Squirrel cage induction motor	Phase wound induction motor
1.Manufacturing Cost	Cheaper	Higher
2.Physical aspect	Simple and robust in construction.	Rotor is not simple.
3.Maintenance Requirement	Not much	Slip ring and brushes require maintenance.
4.Efficiency	Less.	High, as rotor resistance is lower.
5.Starting Torque	Poor.	Very high with addition of external resistance in the rotor.

Q8b. Supply frequency, f = 50 HZ

Number of poles on the motor, P = 4

i) Synchronous speed, $N_s = \frac{120\,f}{P} = \frac{120 \times 50}{4} =$ **1500 rpm Ans**

ii) Slip, S = 4% = 0.04

Actual speed of the motor, N = Ns (1-S)

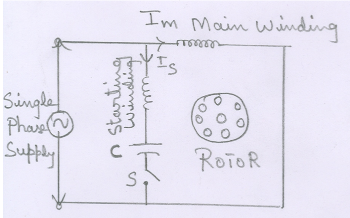
= 1500 (1-0.04) = **1440 rpm Ans**

iii) Motor speed N = 600 rpm

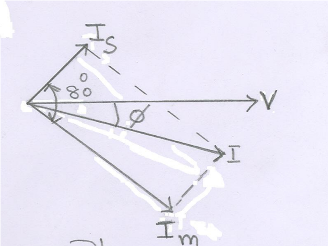
Slip, $S = \frac{1500 - 600}{1500} = 0.6$

Frequency of motor $f_s = S \times f = 0.6 \times 50 =$ **30 Hz Ans**

Q9a. In these motors, the necessary phase difference between I_s the current in the starting winding and I_m current in the main winding, is produced by connecting a capacitor in series with the starting winding as shown in the figure (a). The capacitor is generally of electrolytic type and is connected in series with the starting winding along with a centrifugal switch. When the motor reaches about 75 percent of full speed, the centrifugal switch S opens and cuts out both the starting winding and the capacitor. As shown in the fig (b), I_m drawn by the main windings lags the supply voltage V by a large angle whereas I_s leads V by a certain angle. The two currents are out of phase with each other by about 80^0. Their resultant current I is small and is almost in phase with V as shown. Since the torque developed is proportional to the sine of the angle between I_s and I_m, the increase in the angle increases the starting torque.

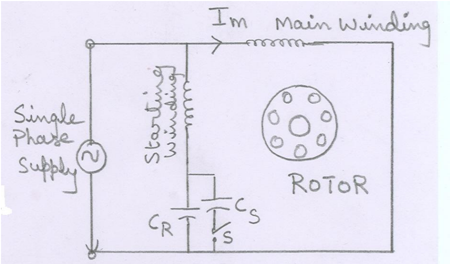


Capacitor Start Motor
fig (a)



Phasor Diagram
fig (b)

Q9b. **Capacitor-start-capacitor-run single-phase motor:** In this case, two capacitors are used one for starting and other for running purpose as shown. The capacitor used for starting purposes C_S, is of electrolytic type and is disconnected from the supply when the motor reaches 75 percent full load speed with the help of the centrifugal switch S. Whereas, the other capacitor C_R which remains in the circuit of starting winding during operation is a paper capacitor. In this way both optimum starting and running performance is achieved. The second capacitor helps in providing improved p.f, improved efficiency and higher breakdown torque.



Capacitor Start and Capacitor run Motor

Q10a. **Disadvantages of Low Power factor**

The power factor plays an important role in a.c. circuits since power consumed depends upon this factor. The disadvantages of low power factor are:

i) Large KVA rating of the equipment: The electrical machinery (e.g. alternators, transformers, switchgear) is always rated in KVA. $\text{KVA} = \dfrac{\text{KW}}{\cos\phi}$

The lower the power factor, the larger is the KVA rating. Therefore, at low power factor, the KVA rating of the equipment of the equipment has to be more, making the equipment larger and expensive.

ii) Greater conductor size: To transmit or distribute a fixed amount of power at constant voltage, the conductor will have to carry more current at low power factor. This necessitates large conductor size.

iii) Large copper losses: The large current at low power factor causes more I^2R losses in all the elements of the supply system. This results in poor efficiency.

iv) Poor voltage regulation: The large current at low lagging power factor causes greater voltage drops in alternators, transformers, transmission lines and distributors. This results in decreased voltage available at the supply end, thus impairing the performance of utilisation devices. In order to keep the receiving end voltage within permissible limits, extra equipment (voltage regulators) is required.

v) Reduced handling capacity of system: The lagging power factor reduces the handling capacity of all the elements of the system. It is because the reactive component of current prevents the full utilisation of installed capacity.

Power factor improvement: The low power factor is due to the fact that most of the power loads are inductive and therefore take lagging currents. In order to improve the power factor, some devices taking leading power should be connected in parallel with the load. Some of the equipments that are used to improve the power factor are Static capacitors, Synchronous condenser and Phase advancers.

Static Capacitors: The power factor can be improved by connecting capacitors in parallel with the equipment operating at lagging power factor. The capacitor draws a leading current and partly or completely neutralises the lagging reactive component of load current. This raises the power factor of the load.

Synchronous Condensers: A synchronous motor takes a leading current when over-excited and therefore behaves as a capacitor. An over-excited synchronous motor running on no load is known as synchronous condenser. When such a machine is connected in parallel with the supply, it takes a leading current which partly neutralises the lagging reactive component of the load. Thus the power factor is improved.

Phase advancers: Phase advancers are used to improve the power factor of induction motors. The low power factor of an induction motor is due to the fact that its stator winding draws exciting current, which lags behind the supply voltage by 90^0. If the exciting ampere turns can be provided from some other a.c. source, then the stator winding will be relieved of exciting current and the power factor of the motor can be improved.

10b. **Advantages of high transmission voltage**

The transmission of electric power is carried at high voltages due to following reasons:

(i) **Reduces volume of conductor material:** Consider the transmission of electric power by a three - phase line. Let

P = power transmitted in watts

V = line voltage in volts

cos ϕ = power factor of the load

l = length of the line in metres

R = resistance per conductor in ohms
ρ = resistivity of conductor material
a = area of cross section of conductor
Load current, $I = \frac{P}{\sqrt{3}\, V \cos\phi}$

Resistance/conductor, $R = \frac{\rho l}{a}$

Total power loss, $W = 3 I^2 R$

$$= 3\left\{\frac{P}{\sqrt{3}\, V \cos\phi}\right\}^2 \times \frac{\rho l}{a}$$

$$= \frac{P^2 \rho l}{V^2 \cos^2\phi\, a}$$

∴ Area of cross section, $a = \frac{P^2 \rho l}{W V^2 \cos^2\phi}$

Total volume of conductor material required = 3 al

$$= 3 \times \frac{P^2 \rho l}{W V^2 \cos^2\phi} \times l$$

$$= \frac{3 P^2 \rho l^2}{W V^2 \cos^2\phi}$$

It is clear from the above expression that for given values of P, l, ρ and W, the volume of the conductor material required is inversely proportional to the square of transmission voltage and power factor. In other words, the greater the transmission voltage, lesser is the conductor material required.

(ii) **Increase in transmission efficiency**

Input power = P + Total losses

$$= P + \frac{P^2 \rho l}{V^2 \cos^2\phi\, a}$$

Assuming J to be the current density of the conductor, then a = I/J

∴ Input power $= P + \frac{P^2 \rho l J}{V^2 \cos^2\phi\, I} = P + \frac{P^2 \rho l J}{V^2 \cos^2\phi} \times \frac{1}{I}$

$$= P + \frac{P^2 \rho l J}{V^2 \cos^2\phi} \times \frac{\sqrt{3}\, V \cos\phi}{P}$$

$$= P + \frac{\sqrt{3} P J \rho l}{V \cos\phi} = P\left[1 + \frac{\sqrt{3} P J \rho l}{V \cos\phi}\right]$$

Transmission efficiency, $\eta = \frac{\text{Output power}}{\text{Input power}} = \frac{P}{P\left[1 + \frac{\sqrt{3} P J \rho l}{V \cos\phi}\right]}$

$$= \frac{1}{\left[1 + \frac{\sqrt{3} P J \rho l}{V \cos\phi}\right]}$$

As J, ρ and l are constants, therefore transmission efficiency increases when the line voltage is increased.

(iii) **Decreases percentages line drop**

Line drop = IR

$$= I \times \frac{\rho\, l}{a}$$

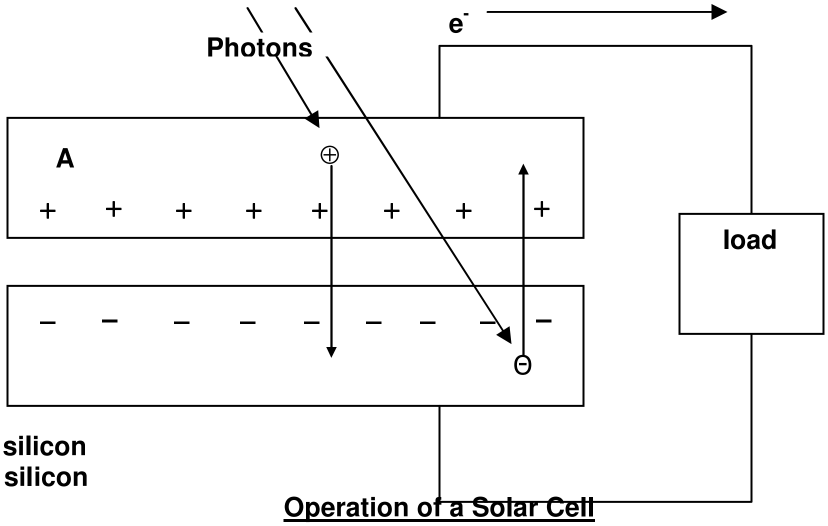
$$= I \times \rho\, l \times \frac{J}{I}$$

$$= \rho\, l\, J$$

Percentage line drop $= \frac{\rho\, l\, J}{V}$

As J, ρ and l are constants, therefore, percentage line drop decreases when the transmission voltage increases.

11a. **Solar Cells:** The solar cells that we see on calculators and satellites are **photovoltaic cells** or **modules** (modules are simply a group of cells electrically connected and packaged in one frame). Photovoltaics, as the word implies (photo = light, voltaic = electricity), convert sunlight directly into electricity. Photovoltaic (**PV**) cells are made of special materials called **semiconductors** such as silicon, which is currently the most commonly used. Basically, when light strikes the cell, a certain portion of it is absorbed within the semiconductor material. This means that the energy of the absorbed light is transferred to the semiconductor. The energy knocks electrons loose, allowing them to flow freely. PV cells also all have one or more electric fields that act to force electrons freed by light absorption to flow in a certain direction. This flow of electrons is a current, and by placing metal contacts on the top and bottom of the PV cell, we can draw that current off to use externally. For example, the current can power a calculator. This current, together with the cell's voltage (which is a result of its built-in electric field or fields), defines the power (or wattage) that the solar cell can produce. The electron flow provides the **current**, and the cell's electric field causes a **voltage**. With both current and voltage, we have **power**, which is the product of the two.



A -- n-type silicon
B--- p-type silicon

Operation of a Solar Cell

11b) This is the most common type of secondary cell used in practice. The electrolyte is a solution of sulphuric acid (H_2So_4) and pure water, of density 1.250 to 1.300 when charged (i.e. about 30% by weight of H_2So_4) and 1.100 when discharged (i.e. about 25% by weight of H_2So_4). The electrodes are made from lead; hence the name is lead acid cell.

Charging: During charging the device is connected across a source of D.C. supply having a voltage of about 3 volts. When the circuit is switched on the current flows inside the cell through ions and outside the cell through electrons. The acid molecules break into negative ions represented by (SO^-_4) and positive ions given by (H^+) which are two in number against each negative ion, $H_2SO_4 \longrightarrow SO^-_4 + 2H^+$

Each negative ion has two extra electrons and each positive ion is short of one electron. The negative ions go towards the positive electrode and vice versa. Each negative ion transfers two electrons to the external circuit after coming in contact with the positive electrode. The ion becomes radical after departing with its extra electrons. It now reacts with water as

$$SO_4 + H_2O \longrightarrow H_2So_4 + O$$

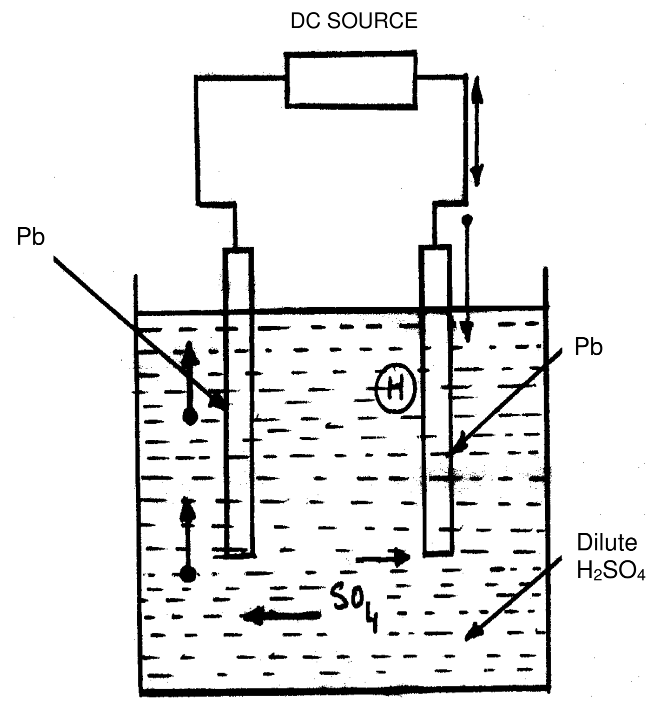
Which shows formation of sulphuric acid and nascent oxygen. Two such oxygen atoms react with lead of the positive electrode of anode forming lead peroxide on the surface of the electrode.

$$Pb + 2O \longrightarrow PbO_2$$

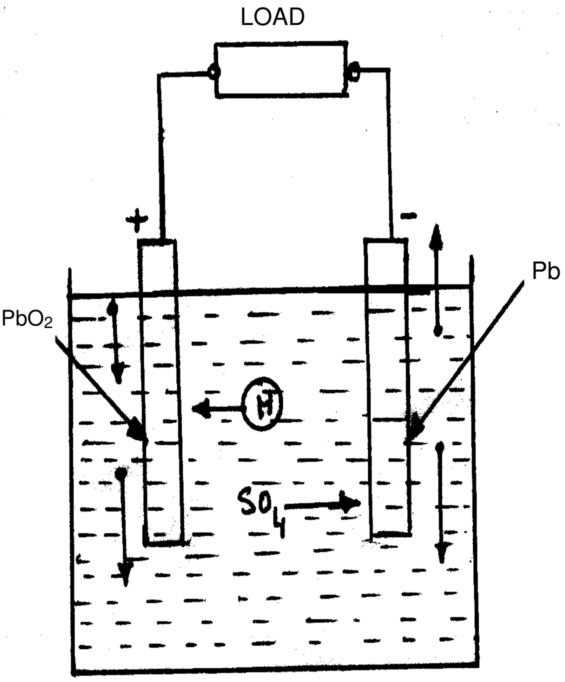
As the charging precedes a layer of brown coloured lead peroxide is formed on the positive plate. The electrons supplied by the negative ions reach the negative plate. The H^+ ions move towards the cathode and receive one electron each, when coming in contact with the electrode. These ions become hydrogen atoms. Two such atoms combine together to form hydrogen molecules, which escape into the atmosphere.

Discharging: The cell is connected across some load during discharging. Since the direction of current through the cell is reversed during discharging the negative ions go towards the negative electrode and vice versa. This is opposite to the movement of ions during charging. After passing on two electrons to the external circuit, the negative ions become SO_4 radical, which reacts with lead of the negative electrode so that $Pb + SO_4 \longrightarrow Pb\,SO_4$ or the negative electrode is coated with a layer of white coloured lead sulphate. The H^+ ions receive electrons from the external circuit to become hydrogen atoms. The reaction on positive electrode is

$$PbO_2 + 2H + H_2So_4 \longrightarrow Pb\,SO_4 + 2H_2O.$$



Charging



Discharging

Detailed Solutions D-05 June 2004

Q1. a. C Transformer for constant voltage application should have a low regulation. (The change in secondary terminal voltage from no-load to full load with respect to full load voltage should be a minimum).

b. B If the frequency is increased to 100Hz, reactance becomes 5Ω. ($X_C = 1/2\pi f\, C$)

c. C Phase currents change in angle but not in magnitude. (Only the angles differ but the magnitude remains the same.)

d. D For ceiling fans generally the single phase motor used is a permanent capacitor type.

e. C The rotating part of a dc machine is called the armature.

f. C When ωL is equal to $1/\omega C$ then net reactance is zero. (At resonance $X_C = X_L$; net reactance is zero.)

g. A One kilo-watt-hour (1kWh) is equal to 36×10^5 Joules. (One hour = 3600 seconds and one kilo= 1000; 3600 X 1000)

h. A The basic function of a transformer is to change the level of voltage. (Transformers are used to step up or step down the voltages.)

PART-I

2a) (i) **Passive network** can be defined as a network, which contains no source of e.m.f. in it.

(ii) **Active network** can be defined as a network, which contains one or more than one source of e.m.f. in it.

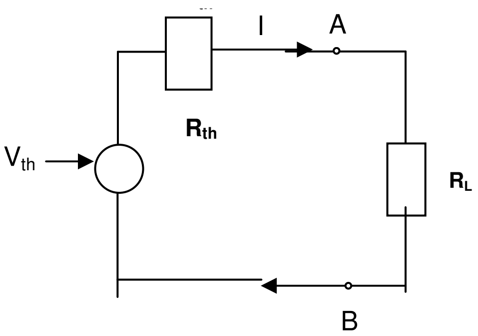
(iii) **Linear circuit** can be defined as one, whose parameters are constant i.e. they do not change with voltage or current.

(iv) **Non- Linear circuit** can be defined as that circuit whose parameters change with voltage or current.

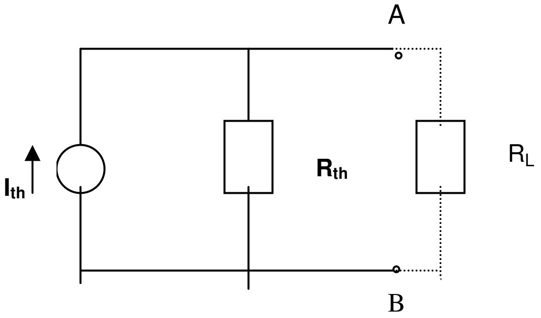
2b) **Nortan'sTheorem** can be stated as follows: Any two-terminal active network containing voltage source and resistances when viewed from its output terminals is equivalent to a constant-current source and a parallel resistance. The constant current is equal to the current, which would flow in short-circuit placed across the terminals and parallel resistance is the resistance of the network when viewed from these open- circuited terminals after all voltage and current sources have been removed and replaced by their internal resistances.

Thevenin's Theorem can be stated as follows: Any two terminal network containing a number of e.m.f. sources and resistances can be replaced by equivalent simple series circuit of one voltage and one resistance. The voltage (V_{th}) and the resistance (R_{th}) are called Thevenin's equivalent. The current flowing through the load resistance R_L connected across any terminal A and B of the network (shown in fig. below) is given by $I = \dfrac{V_{th}}{R_{th} + R_L}$ where V_{th} is open circuit Thevenin's equivalent voltage and R_{th} is equivalent resistance of the network when viewed from these open- circuited terminals after all voltage and current sources have been removed and replaced by their internal resistances.

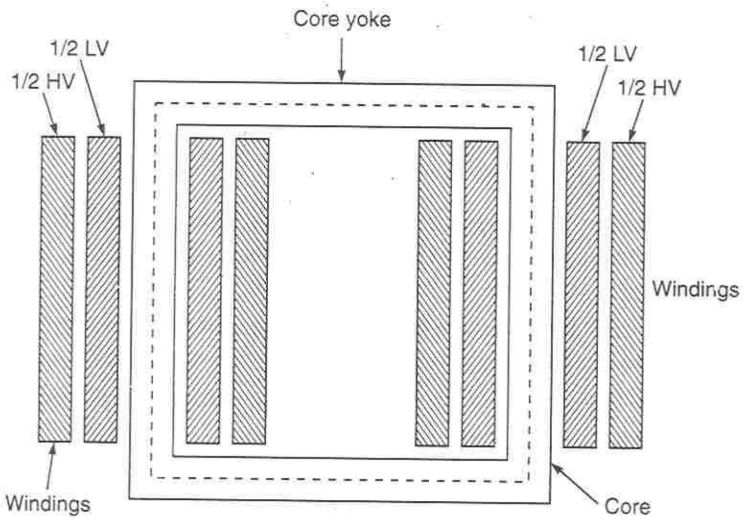
Thevenin's equivalent



Norton's equivalent

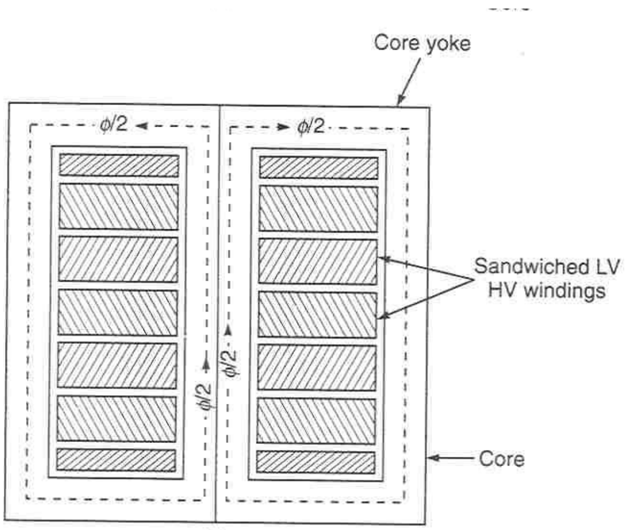


3a) **Core type Transformers**: In this type of transformer the windings surround the core (fig. given below). Both the windings are divided and half of each winding is placed on each limb to make the leakage flux as small as possible. Since insulation of low voltage winding is easy so low voltage winding is placed next to core and then high voltage winding is placed around the low voltage coils. In such an arrangement only one layer of high voltage insulation is required and removal or repair of the high voltage winding, which is more liable to faults than the low voltage winding, is easy and convenient.



Core Type Transformer

Shell type transformers: In this type of transformer the iron core surrounds the copper windings (fig. given below). The core is in the form of numeral 8. The entire flux passes through the central part of the iron core, but outside this central core it divides into two parts half going in each direction. Sandwich type winding is used in which the sections of the primary winding are sandwiched in between the sections of the secondary winding. In this manner the leakage flux is reduced to very small value. To minimize the amount of high voltage insulation low voltage coils are placed adjacent to the iron core.



Shell Type Transformer

3b) Primary turns N_1= 80

Supply frequency, f = 50Hz

Induced voltage in the primary winding, E_1 = supply voltage, V_1 = 240

Maximum value of flux in the core, $\phi_{max} = \dfrac{E_1}{4.44\, f\, N_1} = \dfrac{240}{4.44 \times 50 \times 80}$

= 13.51 mWb.

Cross sectional area of core, a = 200cm^2 = 0.02 m^2

i) Maximum value of flux density in the core, $B_{max} = \dfrac{\phi_{max}}{a} = \dfrac{13.51 \times 10^{-3}}{0.02}$

$= \mathbf{0.6757\ T}$

ii) Number of turns on secondary winding, N2 = 280

Emf induced in the secondary, $E_2 = E_1 \times \dfrac{N_2}{N_1} = 240 \times \dfrac{280}{80} = \mathbf{840\ V}$

4a) Advantages and disadvantages of three phase system over single phase system

1. In a single phase circuit the power delivered is pulsating. In three-phase system the total power delivered is constant if the loads are balanced though the power of any one phase or circuit may be negative. So three-phase system is highly desirable particularly for power loads.
2. The rating of a given machine increases with the increase in number of phases. For example the output of a three-phase motor is 1.5 times the output of a single-phase motor of the same size.
3. Single-phase induction motors, have no starting torque and so its is necessary to provide these motors with an auxiliary means of starting, but in case of three phase motors except synchronous motors there is no need of providing an auxiliary means for starting.
4. Power factor of single- phase motor is lower than that of three phase motor of the same rating (output and speed). The efficiency of a three- phase motor is also higher than that of a single- phase motor.
5. Three-phase system requires 3/4th weight of copper, which is required by single- phase system to transmit the same amount of power at a given voltage and over a given distance.
6. Rotating magnetic field can be set up, by passing three-phase current through stationary coils.
7. Polyphase system is more capable and reliable than single – phase system.
8. Parallel operation of three – phase alternators is simple as compared that of single-phase alternators because of pulsating reaction in single- phase alternators.

However, three-phase operation is not as practical for domestic applications where motors are usually smaller than 1 kW and where lighting circuits supply most of the load.

4b) Line voltage, V_L = Line to line voltage = **220V**

Phase voltage, $V_P = \frac{V_L}{\sqrt{3}} = \frac{220}{\sqrt{3}}$ = **127 V**

Impedance per phase, $Z_P = \sqrt{R_P^2 + X_P^2} = \sqrt{6^2 + 8^2} = 10\Omega$

Phase current, $I_P = \frac{V_P}{Z_P} = \frac{127}{10} = 12.7A$ = Line current = I_L = **12.7A**

Total active power, $P = 3 \times I_P^2 \times R = 3 \times (12.7)^2 \times 6$ = **2,904 watts**.

5) **Power factor may be defined as**

i)cosine of the angle of lead or lag of current on the voltage

ii)the ratio R/Z = resistance / impedance

iii) the ratio true power / apparent power = watts / volt-ampere.

True value of power = $P = V I \cos\phi = 250 \times 100 \times 0.8$ = **20 kW.**

Where V = voltage is given as 250V, I = current is given as 100 A, $\cos\phi$ = pf =0.8

Apparent power = $V \times I = \frac{250 \times 100}{1000}$ = **25 kVA**

Circuit impedance $Z = \frac{V}{I} = \frac{250}{100} = 2.5\ \Omega$

Resistance = $R = Z \cos\phi = 2.5 \times 0.8$ = **2 Ω**

Reactance = $X = \sqrt{Z^2 - R^2} = \sqrt{2.5^2 - 2^2}$ = **1.5 Ω (**inductive as power factor is lagging**)**

6) $V_R = I R$ = voltage drop across the resistance is 100 V.

Power = $I^2 \times R = IR \times I$ = 300 watts.

$300 = 100 \times I$; $I = \frac{300}{100} = 3$ A

$V_L = \sqrt{V^2 - V_R^2} = \sqrt{240^2 - 100^2} = 218.2$ V

$X_L = \frac{V_L}{I} = \frac{218.2}{3} = 72.7\ \Omega$

$L = \frac{X_L}{2\pi f} = \frac{72.7}{2 \times \pi \times 50}$ = **0.235 H**

PART-II

7a) **Dc machine consists of the following parts:**

Field system: The object of the field system is to create a uniform magnetic field, within which the armature rotates. It consists of four parts- yoke, pole core, pole shoe and field - coils.

The yoke acts as a frame of the machine and carries the magnetic flux produced by the poles. In small machines cast iron yokes are used, but for large machines yoke is made using fabricated steel.

Pole core is usually of circular cross-section and is used to carry the coils of insulated copper wires through which exciting current flows.

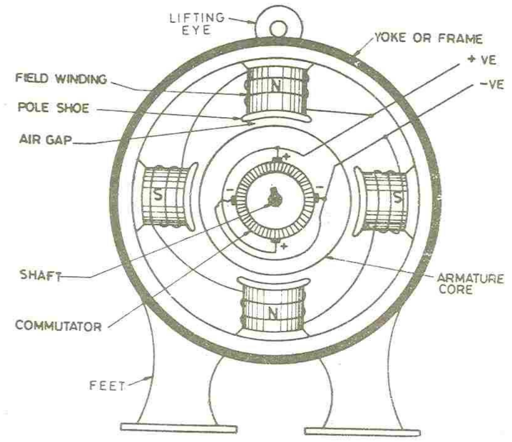
The pole shoe acts as a support to the field coils and spreads out the flux in the air gap and also being of larger cross-section reduces the reluctance of the magnetic path.

The field coils provide the number of ampere-turns of excitation required to give the proper flux through the armature.

Armature core: It houses the armature conductors or coils and causes them to rotate and hence cuts the magnetic flux of field magnets. It also provides a path of very low reluctance to the flux through the armature from north to south pole. It is cylindrical or drum shaped and is built of circular sheet steel discs or laminations.

Commutator: The commutator is a form of rotating switch placed between the armature and external circuit and so arranged that it will reverse the connection with the external circuit at the instant of each reversal of current in the armature. It consists of a series of hard drawn copper bars or segments arranged side- by -side forming a cylinder and insulated from each other by mica segments.

Brushes and Brush gears: The function of brushes is to collect current from the commutator and supply it to the external load circuit. The brushes may be of carbon, graphite, copper, metal graphite, carbon graphite. The brushes are housed in brush holders, which are mounted on brush holder studs. The brush holder studs are in turn mounted on a brush yoke. The brush yoke, brush holders and brushes make the brush gear.



Parts of a DC Machine

7b) Flux per pole, ϕ = 50 m Wb.

Number of armature conductors

Z = Number of armature slots X number of conductors per slot. = 90 X 6 = 540

Number of poles, P = 6

Number of parallel paths, A = P = 6 (generator is lap wound)

Armature speed, N = 1200 rpm.

Emf generated, $E_g = \phi \times Z \times \frac{N \times P}{60 \times A}$ volts.

$$= 0.05 \times 540 \times \frac{1200 \times 6}{60 \times 6} = \mathbf{540\ volts}$$

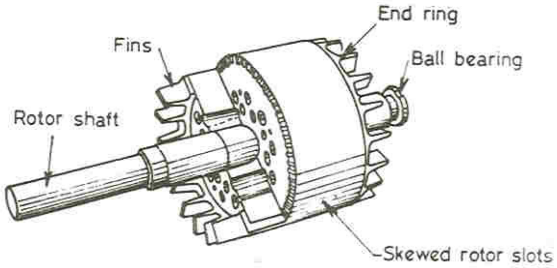
8a) **Construction of three-phase induction motor:** An induction motor consists of two main parts :

(i) **Stator** is an outer stationary, hollow, cylindrical structure made of laminated sheet-steel. The laminations are slotted on their inner periphery. In these slots, a normal three-phase winding is placed, which constitutes the stator winding. Stator is wound for a definite number of poles, whose number depends upon the speed requirement. Greater the number of poles, lesser the speed, and vice versa.

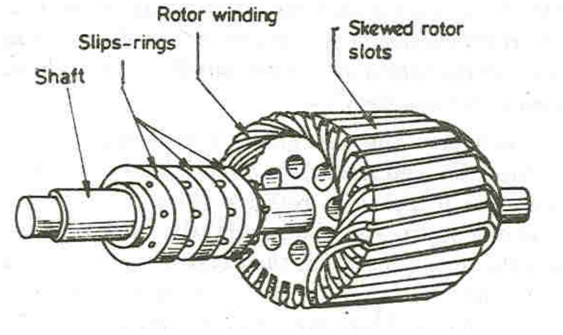
(ii) **Rotor** is the rotating part of the motor. The rotor is mounted on the rotor shaft. When properly assembled, the rotor is free to turn within the stator. There are two types of rotor:

Squirrel- cage rotor consists of a slotted laminated core of sheet-steel. The slots of the rotor are not always parallel to the slots on the stator, but they are given a twist known as skew. (Skew reduces noise, eliminates cogging and increases the starting torque). The windings are placed in the slots. Each slot carries a thick copper or aluminum bar. These bars are short-circuited on either end by a solid copper or aluminum ring called **end-ring**. Most of the 3-phase induction motors are of squirrel cage type, because its rotor is simple and rugged in construction and is cheaper.

Slip-ring (or phase- wound) rotor consists of a slotted laminated core of sheet steel. A three- phase winding is placed in the rotor slots. The rotor winding is usually connected in star, though it may be connected in delta also. The free-ends of the rotor windings are brought out, and connected to three **slip-rings** mounted on the rotor shaft. In this case, depending upon the requirement any external resistance can be added in the rotor circuit.



Squirrel Cage Rotor



Slip Ring Rotor

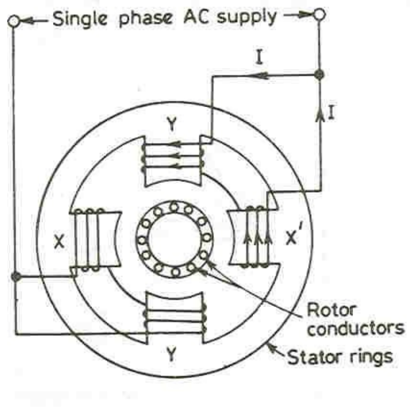
8b) In practice, the rotor in an induction motor never succeeds in catching up with the stator field. If it did so then there would be no relative speed between the two, hence no emf, no current and so no torque to maintain rotation. That is why the rotor runs at a speed, which is always less than the speed of the stator field. The difference in speeds depends upon the load on the motor. The difference between the synchronous speed N_s and actual speed N of the rotor is known as **slip**. It is expressed as percentage of the synchronous speed.

$$\% \text{ Slip } s = \frac{N_s - N}{N_s} \times 100$$

9a) **Working :** Construction of a single -phase motor is similar to that of a three -phase induction motor except that the stator is provided with a single- phase winding. Thus, it has a stator with slots, and squirrel cage rotor with a small air-gap in between.

When it is connected to single- phase ac supply, alternating current flows in its stator winding and the polarity of stator poles would alternately be N and S. The field so produced will be pulsating i.e. polarities will be alternating with the flux rising and falling in strength. The current induced in the rotor will tend to turn it in both directions alternately and thus the rotor will be at standstill due to inertia. If rotor is given a push by hand or by another means in any direction, it will rotate in the same direction developing operating torque. Thus a single –phase induction is not self- starting and requires special starting means.

Applications: Due to their relatively simple construction, availability in variety of designs, and characteristics and promoted by economics as well as meeting the special requirements, single-phase induction motors are widely used, particularly where fractional horse power range is less than 2 H.P. For example motors in 1/8 to 3/4 H.P. ranges are used in fans, refrigerators, washing machines, blowers, centrifugal pumps.1/30 to 1/20 H.P. range are used in toys, hair dryers, vending machines, etc.



Single Phase Induction Motor

10) **Advantages of D.C. transmission of power**

1. It requires only two conductors as compared to three for a.c. transmission.
2. There is no inductance, capacitance, phase displacement and surge problems in d.c. transmission.
3. Due to the absence of inductance, the voltage drop in a d.c. transmission line is less than the a.c. line for the same load and sending end voltage. For this reason, a d.c. transmission line has better voltage regulation.
4. There is no skin effect in a d.c. system. Therefore, entire cross-section of the line conductor is utilized.
5. For the same working voltage, the potential stress on the insulation is less in case of d.c. system than that in a.c. system. Therefore, a d.c. line requires less insulation.
6. A d.c. line has less corona loss and reduced interference with communication circuits.
7. The high voltage d.c. transmission is free from the dielectric losses, particularly in the case of cables.
8. In d.c. transmission , there is no stability problem and synchronizing difficulties.

Disadvantages of D.C. Transmission of power

1. Electric power cannot be generated at high d.c. voltages due commutation problem.
2. The d.c. voltage cannot be stepped up for transmission of power at high voltages.
3. The d.c. switches and circuit breakers have their own limitations.

Advantages of A.C. transmission of power

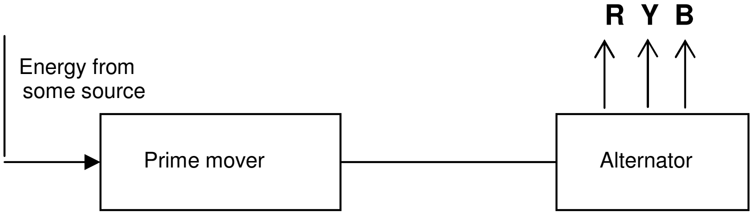
1. The power can be generated at high voltages.
2. The maintenance of a.c. sub-stations is easy and cheaper.
3. The a.c. voltage can be stepped up or stepped down by transformers with ease and efficiency. This permits to transmit power at high voltages and distribute it at safe potentials.

Disadvantages of A.C. Transmission of power

1. An a.c. line requires more copper than a d.c. line.
2. The construction of an a.c. transmission line is more complicated than d.c. transmission line.
3. Due to skin effect in the a.c. system, the effective resistance of the line is increased.
4. An a.c. line has capacitance. Therefore, there is a continuous loss of power due to charging current even when the line is open.

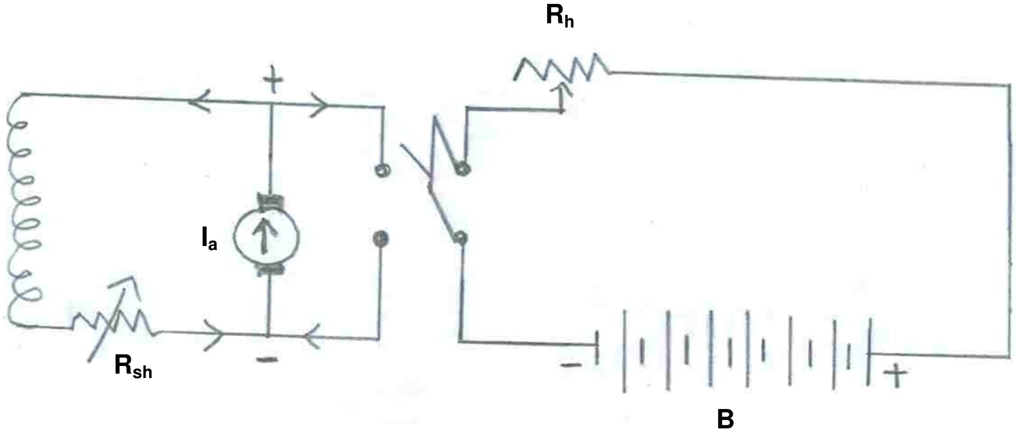
11) (i) **Generation of electrical energy:** The conversion of energy available in different forms in nature into electrical energy is known as “Generation of electrical energy”. The electrical energy must be produced and transmitted to the point of use at the instant it is needed. The entire process takes only a fraction of a second.

Energy is available in various forms from different natural sources such as pressure head of water, chemical energy of fuels, nuclear energy of radioactive substances etc. All these forms of energy can be converted into electrical energy by using suitable arrangements. This employs an alternator coupled to a prime mover. The prime mover is driven by the energy obtained from various sources such as burning of fuel, pressure head of water, force of wind etc. For example chemical energy of a fuel (coal) can be used to produce steam at high temperature and pressure. This steam is fed to a prime mover, which may be a steam engine or a steam turbine. The turbine converts heat energy of steam into mechanical energy, which is further converted into electrical energy by the alternator. Similarly, other forms of energy can be converted into electrical energy by employing suitable machinery and equipment.



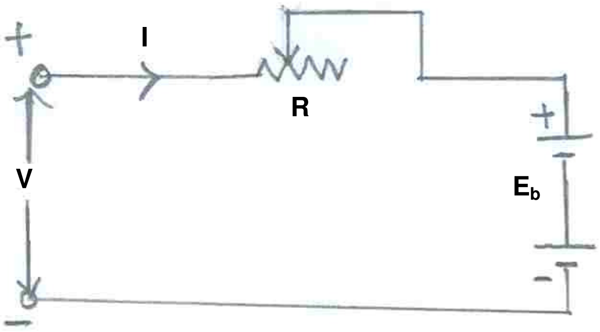
(ii) Different **methods of charging a battery:** The two general methods are employed for charging are constant current system and constant voltage system.

Constant current system: - In this method, the charging current is kept constant by varying the supply voltage to overcome the increased back emf of cells. If a charging booster is used, the current supplied by it can be kept constant by adjusting its excitation. If charged on d.c. supply, the current is controlled by varying the rheostat connected in the circuit. The value of charging current should be so chosen that there would be no excessive gassing during final stages of charging and, also, the cell temperature does not exceed 45^{0}C. This method takes a comparatively longer time.



Constant Current System

Constant voltage system: In this method voltage is kept constant but results in very large charging current in the beginning when the back emf of the cells is low and a small current when their back emf increases on being charged. With this method, time of charging is almost reduced to half. It increases the capacity by approximately 20% but reduces the efficiency by 10% or so.



Constant Voltage System

Detailed Solutions D-05 December 2004

Q1 a) D A series of RLC circuit will have unity power factor is operated at a frequency of

$$\frac{1}{2\pi\sqrt{LC}}$$

(Since $X_L = X_C$ or $\omega L = 1/\omega C$)

$$2\pi f L = \frac{1}{2\pi f C}$$

$$f^2 = \frac{1}{4\pi^2 L C}$$

$$f = \frac{1}{2\pi\sqrt{LC}}$$

b) C The difference between synchronous speed and the actual speed of an induction motor is known as slip speed.

c) A The efficiency of a transformer is given as
Output / (Output + Losses)
(Since, Efficiency = Output / Input = Output / (Output + Losses))

d) A Speed of a motor is given by 120 f/p

e) A Load factor is defined as
average demand / maximum demand

f) A Like a resonant R-L-C circuit, a parallel resonance circuit is also has a power factor of unity

g) C Slip rings for an induction motors are made of Phosphor Bronze.

h) D The motor which has the least noise is the hysteresis motor

PART-I

Q2 a) (i) Node: The junction point of two or more branches is known as a node.
(ii) Branch: Group of network element connected in series, parallel or any complex manner but having only two terminals.
(iii) Loop : Any close path, formed by the branches in network is known as a loop.
$[m = b - n + 1]$
(iv) Path : This is the route followed by current from one point of source to other point of source.

b)

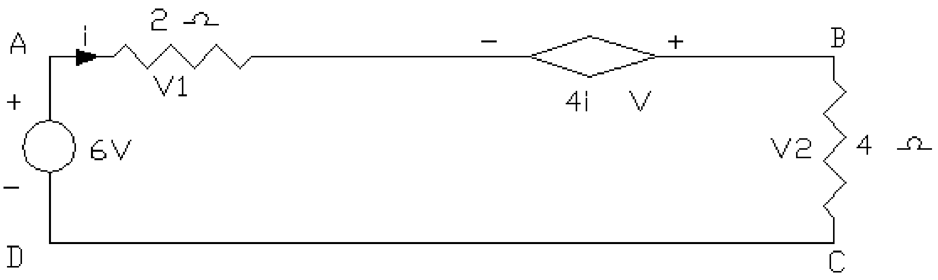


FIG 2b

$2i - 4i + 4i - 6 = 0$
$2i = 6$
Since $i = 3$ Amp
$V_1 = 2 \times 3 = 6V$
$V_{\text{dep. source}} = 4\,i$
$= 4 \times 3 = 12V$

Q3 a) (i) Series combination of Resistances

FIG 5(a)

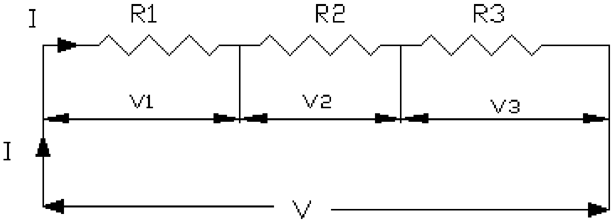


FIG 3a (I)

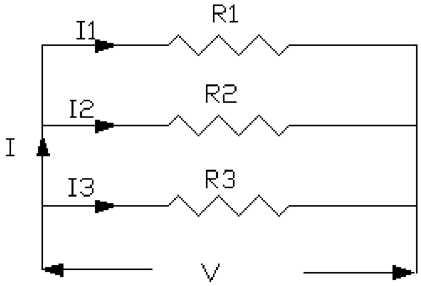


FIG 3a (ii)

In the above figure three resistance R_1 , R_2, R_3 are connected in series across a voltage source of V volts. The total voltage is the sum of voltage drop across R_1 , R_2 & R_3 . So if the voltage drop across R_1 , R_2 & R_3 is V_1 ,V_2 & V_3 respectively. Then
$V = V_1 + V_2 + V_3$
$V_1 = IR_1$, $V_2 = IR_2$ & $V_3 = IR_3$
Where I is the current in the circuit
$V = IR_1 + IR_2 + IR_3$
$V = I(R_1 + R_2 + R_3)$

$V/I = R_1 + R_2 + R_3$ Where $V/I = R$

i.e. $$\frac{\text{Total Voltage}}{\text{Total Current}} = \text{Total Resistance}$$

Or $R = R_1 + R_2 + R_3$

Hence if n components or devices with resistance R_1, R_2,….$R_n$are connected in series
$R = R_1 + R_2 + \ldots\ldots.. + R_n$

Parallel combination of resistance:

When resistance are connected in parallel then the equivalent resistance of the circuit ca be calculated by using the relation

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots\ldots\ldots \text{n times}$$

where R is the equivalent resistance ad R_1 and R_2 are the resistance connected in parallel .
The relation can be explained with the help of above fig 3 a(ii)

From fig:

$$I = I_1 + I_2 + I_3$$

$$\frac{V}{R} = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3} \qquad (I = \frac{V}{R})$$

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

b)

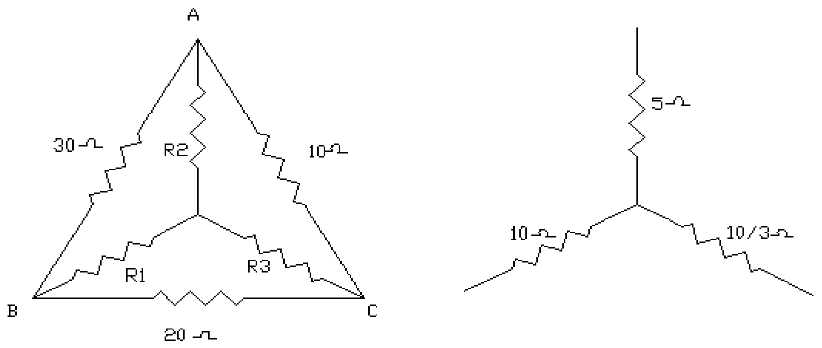


FIG 3 (b)

$$R_1 = \frac{30 \times 20}{30 + 20 + 10} = \frac{600}{60} = 10\,\Omega$$

$$R_2 = \frac{30 \times 10}{60} = 5\,\Omega$$

$$R_3 = \frac{20 \times 10}{60} = \frac{10}{3}\,\Omega$$

Q4 a) Commutation : The current induced in armature of DC generator is alternating. To make their flow unidirectional in external circuit, we need a commutator. As conductor pass out from influence of N-pole and enter to S-pole, the current in them is reversed. This reversal of current takes place along magnetic neutral axis or brush axis. A process by which current in short-circuited coil is reversed while it crosses MNA (Magnetic Neutral Axis) is called commutation. The brief period during which coil remains short-circuited is known as commutation period T_C.

b) Voltage Regulation of transformer : As Transformer is loaded, the secondary terminal voltage falls (for a lagging p.f.), hence to keep the output voltage constant, the primary voltage must be increased. The rise in primary voltage required to maintain rated output voltage from no load to full load at a given p.f. expressed as % of rated primary voltage gives regulation of transformer

$$\% \text{ reg} = \frac{V_1^1 - V_1}{V_1} \times 100$$

C)

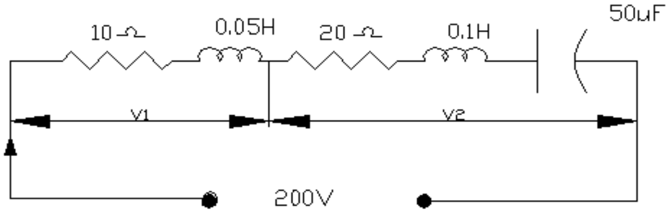


FIG 4c

$R = 30\ \Omega$

$X_L = 2\pi f L = 2\pi \times 50 \times 0.15 = 41.12\ \Omega$

$$X_C = \frac{1}{2\pi f C} = 6.366 \times 10 = 63.66\ \Omega$$

$Z = 30 + j(X_L - X_C)$

$= 30 + j(-22.54)$

$= 30 - j\,22.54$

$$I = \frac{|V|}{|Z|} \quad ; \quad |Z| = 37.52\ \Omega$$

$$= \frac{200}{37.52}$$

= 5.33 A

$V_1 = I.Z_1$
$= 5.33 \times 18.62$
$= 99.25$ V

$V_2 = I.Z_2$
$= 5.33 \times 37.94$
$= 202$ V

$$\cos\phi = \frac{R}{Z} = \frac{30}{37.52} = 0.799 \cong 0.8$$

Q5 a)

The purpose of this test is to determine no load loss or core loss and no load current I_0 is helpful for finding X_0 & R_0. One winding of transformer usually HV winding is left open and other connected to supply with wattmeter (W), ammeter (A), & voltmeter (V).

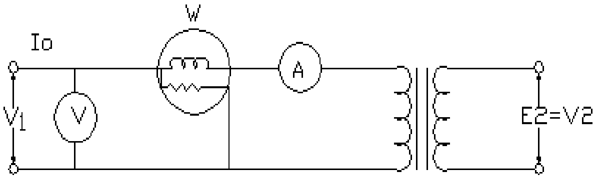


FIG 5(a)

With the normal voltage applied to primary, normal flux will be setup in core, hence normal iron loss will occur and recorded by wattmeter. As primary no load current I_0 measured by Ammeter is small i.e. 2-10% of rated load current, cu loss is negligible in primary and nil in secondary.

$W_0 = V_1 I_0 \cos\phi_o$

$$\cos\phi_o = \frac{W_0}{V_1 I_0}$$

$I_0 \cong I_\mu$

Since current is practically exciting current when a transformer is at no load i.e. $I_0 \cong I_\mu$

b) P = 50 KVA
$V_1 = 6600$V

$V_2 = 254V$
$N_2 = 32$
$N_1 = ?$
$I_2 = ?$
Primary Current (I_1) = 50 x 10^3 / 6600 = 7.575 A

$$\frac{V_2}{V_1} = \frac{N_2}{N_1} = \frac{I_1}{I_2}$$

$$\frac{N_2}{N_1} = \frac{254}{6600}$$

$$N_1 = \frac{6600}{254} \times 32 = 831$$

$$I_2 = \frac{I_1 \times V_1}{V_2}$$

$$= \frac{50 \times 10^3 \times 6600}{6600 \times 254} = 196.85 \text{ A}$$

Q6 (a) **Speed – Torque characteristics of various types of DC motors.**

Speed – torque i.e. N/T_a it is known as mechanical characteristics deduce from Ta/Ia and N/Ia characteristics

$T_a \ \alpha \ \phi I_a$
$N \ \alpha \ E_b / \phi$

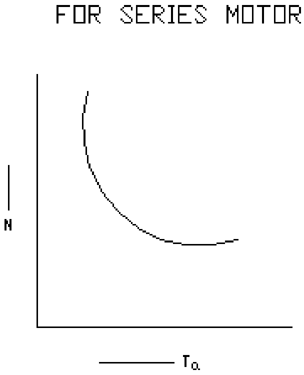


FIG-6a(i)

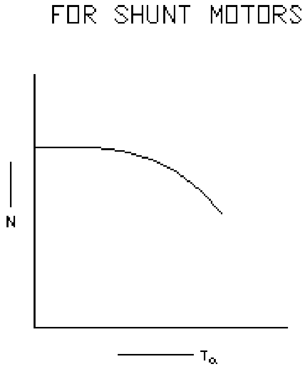
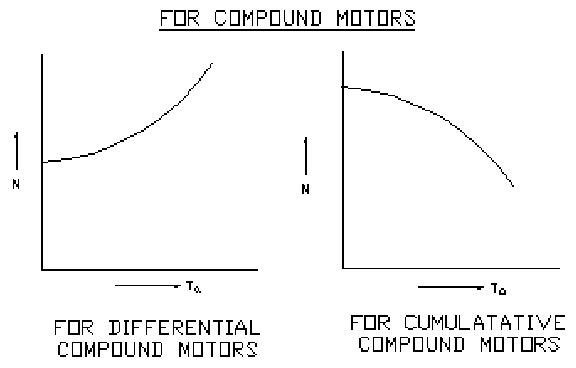


FIG-6a(ii)



FOR DIFFERENTIAL COMPOUND MOTORS

FOR CUMULATATIVE COMPOUND MOTORS

FIG–6a(iii)

Q6b)

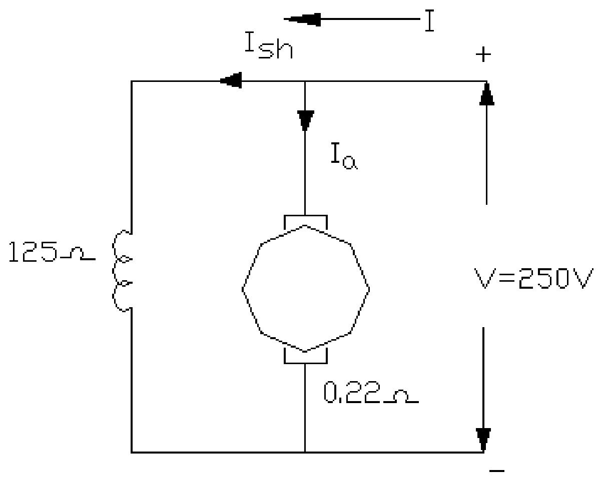


FIG 6b

$P_i = 50$ KW
$V = 250$ V
$I_L = 200$ A
$N = 1250$ rpm
$R_a = 0.22\ \Omega$
$T_{sh} = ?$
$\eta = ?$
$W_i = 600$ (Driving power out put – E_bI_a)
$R_{sh} = 125\ \Omega$

$$T_{sh} = 9.55 \frac{(O/p)}{N}$$

(as $T_{sh}\ W_m = O/p$; where $W_m = 2\pi N/60$

$$:.\ T_{sh} = (60/2\pi)\frac{(O/p)}{N}$$

$$= 9.55 \frac{(O/p)}{N} \quad)$$

$$= 9.55 \frac{(50 \times 10^3 - 600)}{1250}$$

$= 3.77.416$ N-m

$W_I = 600$ W

$I_{sh} = 250/125 = 2A$

$Ia = 200 - 2 = 198A$

Field ‘Cu’ loss $= I_{sh} R_{sh} = 125 \times 2 = 250$ W

Armature ‘Cu’ loss $= Ia^2 R_a = (198)^2 \times 0.22 = 8624.88$ W

Efficency (η) $= \frac{\text{output}}{\text{input}} \times 100$

$= \frac{100 \times 50{,}000 - (600 + 250 + 8624.88)}{50{,}000}$

$= 81.05\%$

PART-II

Q7 a) **Comparison of Shunt & Series motors**

S.no.	Features	Shunt Motor	Series motor
1.	Definition	The motor field winding is in **parallel** with the armature. $I_L = I_a + I_{Shunt}$	The motor field winding is in **series** with the armature. $I_L = I_a = I_{Series}$
2.	Application	Constant speed application drive. e.g. Lift, Escalator	Variable speed application and load is connected. e.g. Traction
3.	Torque	Torque remains constant, very, less variation	Starting torque is very high.
4.	Speed	Constant speed characteristics	variable speed characteristics

Q7 (b) In a 3-phase induction motor

Voltage $V = 400V$

No. of Pole $p = 6$

Line current $I_L = 80$ A

Power Factor $\cos \phi = 0.75$

Slip $(s) = 4\%$

Efficiency $(\eta) = 85\%$

Find

Shaft output (P_o) & Shaft torque (T_{sh})

$P_i = \sqrt{3}\, VI \cos\phi$

$= \sqrt{3} \times 400 \times 80 \times 0.75$

$= 41.569$ kW

$(\eta) = P_o / P_i$

$P_o = \eta \times P_i$

$= 0.85 \times 41.569$

$= 35.33$ kW

$N = N_S - (1 - s)$

$= \frac{120 f}{p} (1-s)$

$= 960$ rpm

$P_o = 2 \pi N T_{sh}$

$T_{sh} = \frac{35.333 \times 10^3}{2 \pi \times 960}$

$= 5.857$ N-m

Q8 Construction: Shaded pole motor is constructed with salient poles in stator. Each pole has its own exciting coil as shown in figure below. A

1/3rd portion of each pole core is surrounded by a copper strip forming a closed loop called the shading band. Rotor is usually squirrel cage type.

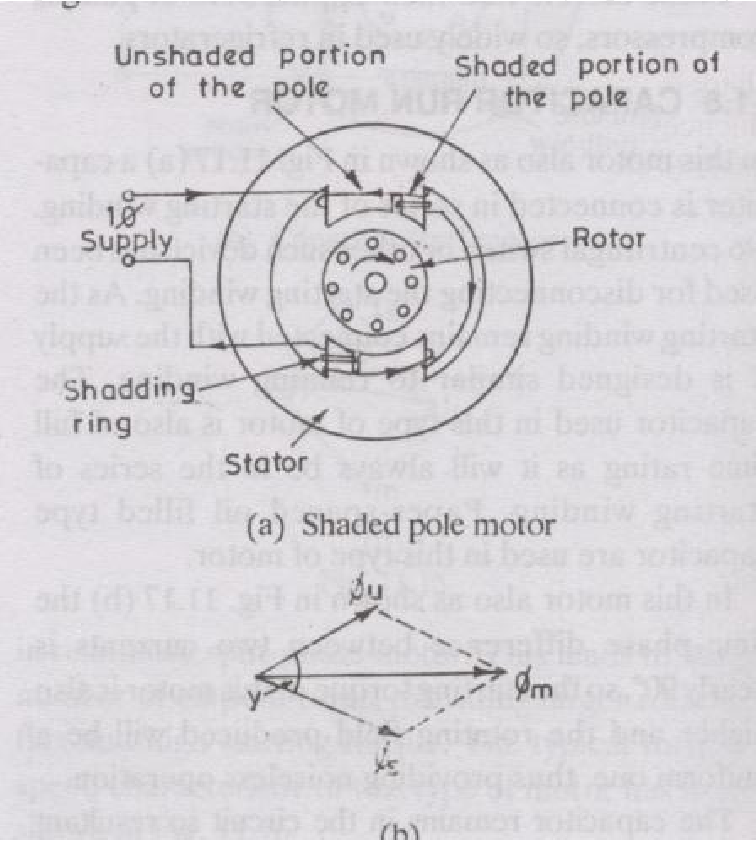


Fig (8)

Working A single-phase supply produces alternating flux. When flux is increasing in pole, a portion of flux attempts to pass through the shaded portion of the pole. This flux induces voltages and hence current in copper ring. In beginning the greater portion of flux passes through unshaded side of each pole and resultant lies on unshaded side of pole. When flux reaches max. Value, its rate of change is zero, Thereby e.m.f and hence current in shading coil becomes zero. Flux is uniformly distributed over the pole phase and the resultant field lies at center of pole. After that main flux tends to decrease, the current induced in the shading coil now tends to increase the flux on shaded portion of the pole and resultant lies on shaded portion of the pole.

Hence revolving field is set up which rotates from unshaded portion of pole to shaded portion. Thus by electromagnetic induction a starting torque is developed in rotor and rotor starts rotating.

Application: Starting torque is very small about 50% of full load torque. Efficiency is low because of continuous power loss in shading coil. These motors are used for small fans, electric clocks, gramophones etc.

Q9 (a) Advantages of HVDC system:

- Continuous transmission losses are absent in HVDC lines
- Cost of HVDC transmission line per km is lesser than EHV AC line for same power/insulation level.
- HVDC transmission line having only two conductors.
- HVDC submarine cables do not take charging current (except initially)
- Frequency disturbance are not transferred to neighboring grid.
- The fault levels of both interconnected grids do not get added.

(b) Disadvantages of HVDC system.

- DC generator have a limitation of rating due to commutator problems and it is not economical to use DC generator for large power generation.
- For transmission & distribution DC can not easily step up & step down according to requirement.
- AC induction motors are robust & economical than DC
- HVDC (± 500 kV) is used for long distance (above 800 km) high power (above 1000 MW) transmission system.

Q9 (b) Given:

Max. Demand = 100MW
Load factor = 40%
Find
Energy generated in a year

$$\text{Load factor} = \frac{\text{Energy generated into given period}}{\text{Max. demand x hours of operation in a given period.}}$$

$$0.4 = \frac{\text{Energy generated}}{100 \times 365 \times 24} \qquad (\text{ time} = 365 \times 24 \text{ hrs.})$$

Therefore, Energy generated = 0.4 x 100 x 8760
= 350400 MWh

Q10 (a) PV Cell

A photovoltaic cell or solar cell is a PN junction which converts solar radiated energy into electrical form by photovoltaic action. When light strikes p-surface, p-surface gets deficiency of electrons. These are released from n surface via electrical load. Electrical power flows through the external circuit.

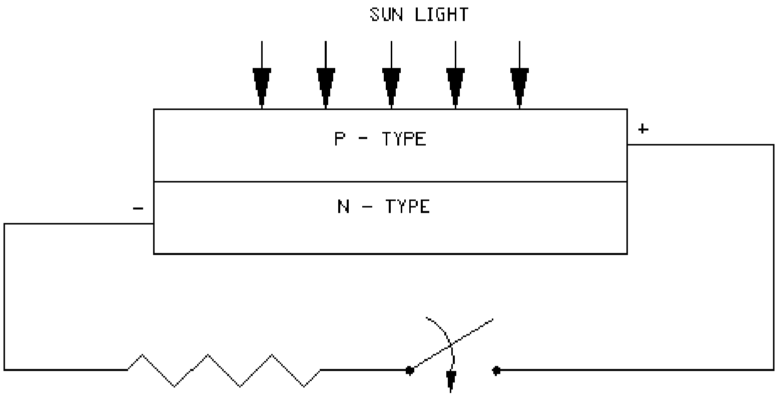


FIG-10a

PV cells developed after 1980's have silicon wafer treated with thin layer of cadmium sulphide, gallium sulphide, indium phosphate, gallium arsenide etc. Packaged cells are mounted on either flat plate collectors or with fresnel lenses or infront of a paraboloid reflector.

(b) (i) $\text{Diversity factor} = \frac{\text{Max. demand of installation}}{\text{Sum of individual max. demand}}$

$$= \frac{2500\text{ kW}}{1500+750+100+450}$$

$$= \frac{2500}{2800}$$

$$= \frac{25}{28}$$

(ii) Annual load factor $= \frac{\text{Average demand}}{\text{Max. demand}}$

$$= \frac{\text{Energy generated into given period}}{\text{Max demand x hrs of operation}}$$

$$= \frac{45 \times 10^5 \text{ kWh}}{2500 \times 365 \times 24 \text{ kWh}}$$

$$= \frac{9.0}{43.8}$$

Annual load factor = 9/44

Q11 **i) Selection of motors for different Engg. application**

1. For Cement industry:
   - Several types of motors for pumps, fans, conveyors ,crushers, kilns an mills
   - Main mill motor may be synchronous motor.
   - Motors should be dust protected, highly reliable automatically controlled.

10. Chemical, Rubber, Petrochemical Industry
    - Needs all types of motors, all size of motors
    - Needs non sparking, flame proof, increased safety
    - Variable frequency synchronous motors supplied by static frequency converters.
    - Direct coupled induction motors needs for compressor drive

11. Material handling applications.
    - Squirrel cage motors with high starting torque are used for conveyor applications.

12. Machine tools application
    - Generally fixed speed motors with gear selection are employed
    - Special purpose synchronous motors with direct drive supplied at appropriate high frequency are used for high speed
    - Complex duty cycle drives require special high accuracy servo system

13. Marine Application
    - Suitably designed single or double speed squirrel cage induction motors are used.

14. Metallurgical Industry
    - Variable speed DC drives are being use traditionally now variable frequency AC drives using squirrel cage motors

15. Mines
    - Flame proof squirrel cage induction motors are used in coal mines

16. Printing Paper Industry:
    - Synchronous motors are used in grinders.
    - DC drives are used for pumping pulp and refining it.

17. Textile industry:
    - High speed drives are necessary with wide range of control, small & medium motors are employed.
    - Commutator motors and synchronous motors are used.

10. Traction application
    - Specially developed traction motors with high mechanical and thermal stresses, axle drive are used.
    - For 16.67 Hz AC commutator motors are used with 25kV , single phase AC supply (in Europe)
    - 25 kV, single phase, 50Hz voltage stepped down and rectified. DC series motors are used in India.
    - DC or AC motors with special design feature and with variable voltage, variable frequency thyristor converters are use in today traction applications.

11. Battery powered vehicles
    - Used DC series motors is the first choice. Recently AC motors with frequency converters are being considered.

(ii) **Disadvantage of low Power Factor**

We know that

$P = VI\cos\phi$, for certain amount of power at constant voltage, Power P and voltage V in the above expression of power are constant, so

$I \propto 1/\cos\phi$

From the above relation it is clear that current is inversely proportional to the power factor of the load. Therefore low power factor results in higher current, more losses, more voltage drop, greater size of conductor and high rating of the equipments used in the power system.

In brief poor power factor results uneconomical power system.

Now with the help of power triangle low power factor means $\cos\phi < 1$

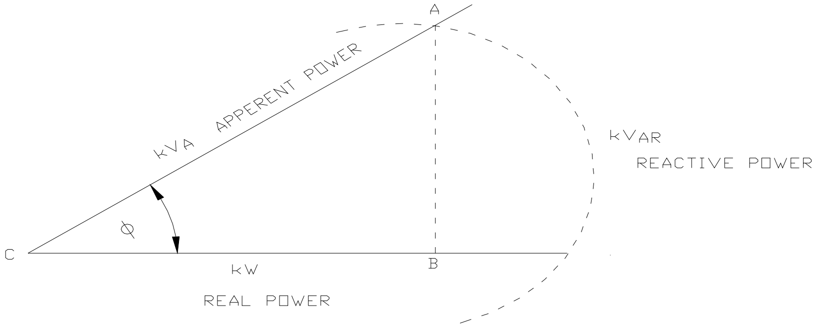


Fig -11(ii)

Therefore, kVAR or reactive power will be more, so user machine will require more kVA power for desired kW load, therefore

$kVA = \sqrt{(kVAR^2 + kW^2)}$

$kW^2 = kVA^2 - kVAR^2$

if $kVAR = 0$

$kW = kVA$

it means

- Wastage of power in reactive component
- More kVA input power is required to real (kW) load.
- Loss of energy.

Causes of Low power factor

The main causes of low power factor in the electric supply system are as follows.

- Due to reactive load
  Most of the AC motors used in industry or with domestic appliances are of induction type which works at low power factor.
- Low R/Z ratio:
  Arc lamp, arc furnaces, induction furnaces etc. used in industry operates at poor power factors.
- Low kW/kVA ratio
  Modern alternator, transformers, certain protective devices and even AC transmission and distribution lines are of inductive nature and further decreases the power factor of the electrical power system.

Step to improve Power Factor

i) By using static capacitor:

Static capacitor is generally used to improve the power factor of the power system. Since the capacitor draws leading current which partly or completely neutralizes the lagging wattless component of the least current, thus increasing the over all power factor of the load. For improving the power factor , capacitor is connected in parallel with the load.

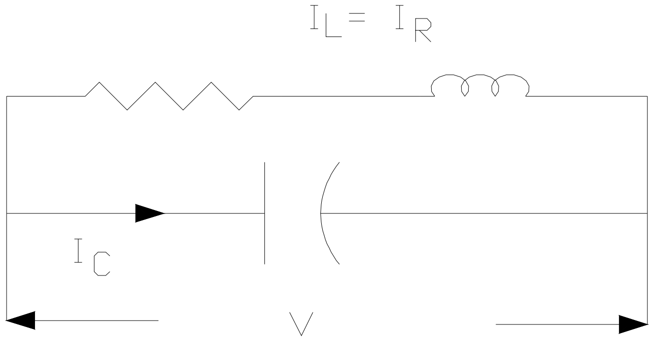


Fig-11(ii)

iii) Another way of improving the power factor is the use of synchronous motor with the load. Synchronous motor can operate at any power factor i.e. lagging , unity or at leading power factor. Synchronous motor when used to improve the power factor only is called as " Synchronous Condenser".