MADE EASY

Leading Institute for ESE, GATE & PSUs

Detailed Solutions

ESE-2026 Mains Test Series

Electrical Engineering Test No : 4

Section A : Electrical Machines

Q.1 (a) Solution:

(i) Speed of rotor field with respect to stator structures

$$= \frac{120 f_1}{P} = \frac{120 \times 50}{4} = 1500 \text{ rpm}$$

Speed of rotor field with respect to rotor structure

$$= \frac{120 f_2}{P} = \frac{120 \times 20}{4} = 600 \text{ rpm}$$

In a 3-phase induction motor, rotor speed (N_r) ± speed of rotor field w.r.t. rotor

= speed of stator field w.r.t. stator (N_s)

$$N_r \pm 600 = 1500 \text{ rpm}$$

For positive sign, rotor must be driven in the direction of stator field at a speed,

$$N_r = 1500 - 600 = 900 \text{ rpm}$$

For negative sign, rotor must be driven against the direction of stator field at a speed,

$$N_r = 1500 + 600 = 2100 \text{ rpm}$$

(ii) Rotor emf at any slip 's' is given by,

$$E_{2s} = \sqrt{2}\pi(sf_1)N_2\phi k_{w2}$$

For, $N_r = 900$ rpm

Slip, $$s_1 = \frac{1500 - 900}{1500} = 0.4$$

$$E'_{2s} = \sqrt{2}\pi(0.4 f_1)\, N_2\, \phi k_{w2}$$

For, $N_r = 2100$ rpm

Slip, $$s_2 = \frac{1500-2100}{1500} = -0.4$$

$$E''_{2s} = \sqrt{2}\pi\,(-0.4 f_1)\, N_2\, \phi k_{w2}$$

$\therefore$ $$\frac{E'_{2s}}{E''_{2s}} = \frac{\sqrt{2}\pi(+0.4 f_1) N_2\, \phi k_{w2}}{\sqrt{2}\pi(-0.4 f_1) N_2\, \phi k_{w2}} = -1$$

Q.1 (b) Solution:

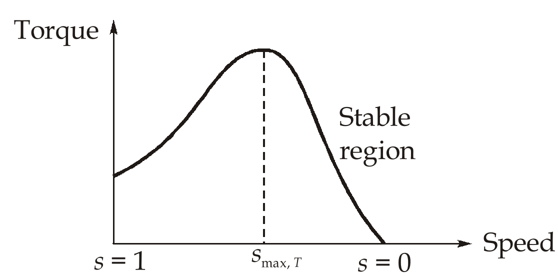
$$N_{s_1} = \frac{120 f_1}{P} = \frac{120\times 50}{4} = 1500 \text{ rpm}$$

$$s_1 = \frac{N_{s_1} - N_{R_1}}{N_{s_1}} = \frac{1500-1440}{1500} = 0.04$$

As $$\frac{V}{f} = \text{Constant}$$

$$\frac{V_1}{f_1} = \frac{V_2}{f_2}$$

$\Rightarrow$ $$V_2 = V_1\left(\frac{f_2}{f_1}\right) = 400\times\frac{30}{50} = 240 \text{ V}$$



Torque developed in induction motor

$$T = \frac{3}{\omega_s}\frac{V^2 R'_2/s}{(R'_2/s)^2 + X_2'^2}$$

in stable region, slip is very low,

so $$\frac{R'_2}{s} >> X'_2$$

So, T can be approximated as

$$T = \frac{3}{\omega_s}\frac{V^2R_2'/s}{(R_2'/s)^2} = \frac{3}{\omega_s}\frac{s\,V^2}{R_2'}$$

$$T \propto \frac{sV^2}{f}$$

$$\frac{T_1}{T_2} = \frac{s_1}{s_2}\left(\frac{V_1}{V_2}\right)^2 \times \left(\frac{f_2}{f_1}\right)$$

as load torque is constant, $T_1 = T_2$

$$s_2 = s_1\left(\frac{V_1}{V_2}\right)^2 \times \left(\frac{f_2}{f_1}\right) = 0.04 \times \left(\frac{400}{240}\right)^2 \times \left(\frac{30}{50}\right) = 0.067$$

$$N_{s2} = \frac{120\,f_2}{P} = \frac{120 \times 30}{4} = 900\,\text{rpm}$$

Rotor speed, $N_{r2} = N_{s2}(1 - s_2) = 900\,(1 - 0.067) \approx 840$ rpm

Q.1 (c) Solution:

Turns ratio, $N_1 : N_2 : N_3$ is 4 : 2 : 1

Induced emf in winding 1 $= E_1 \approx V_1 = 400\angle 0°$V

As we know,

$$\frac{E_1}{E_2} = \frac{N_1}{N_2}$$

$$\Rightarrow \quad E_2 = \frac{N_2}{N_1}E_1 = \left(\frac{2}{4}\right)400\angle 0° = 200\angle 0°\text{ V}$$

and

$$\frac{E_1}{E_3} = \frac{N_1}{N_3}$$

$$\Rightarrow \quad E_3 = \left(\frac{N_3}{N_1}\right)E_1 = \left(\frac{1}{4}\right)400\angle 0° = 100\angle 0°\text{ V}$$

Current in secondary winding, $I_2 = \dfrac{E_2}{R} = \dfrac{200\angle 0°}{10} = 20\angle 0°$ A

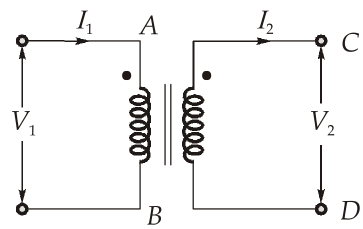
Current in tertiary winding, $I_3 = \dfrac{E_3}{-jX_C} = \dfrac{100\angle 0°}{-j2.5} = 40\angle 90°$ A

I_2 referred to primary side, $I_2' = \left(\dfrac{N_2}{N_1}\right)I_2 = \left(\dfrac{2}{4}\right)\times(20\angle 0°) = 10\angle 0°$A

I_3 reffered to primary side, $I_3' = \left(\frac{N_3}{N_1}\right) I_3 = \left(\frac{1}{4}\right)(40\angle 90^\circ) = 10\angle 90^\circ$

The supply current, $I_1 = I_2' + I_3' = 10\angle 0^\circ + 10\angle 90^\circ = (10 + j10)$ A

Q.1 (d) Solution:



In two winding transformer, $V_1 = 500$ V;

$V_2 = 250$ V

$$I_1 = \frac{50\times 10^3}{500} = 100\,A$$

and $$I_2 = \frac{50\times 10^3}{250} = 200\,A$$

$$\eta = \frac{xS\cos\phi}{xS\cos\phi + \text{losses}}$$

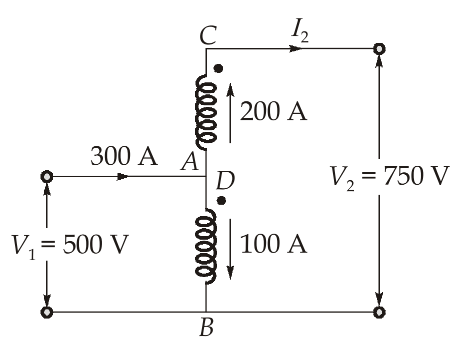
Full load, $x = 1$, upf, $\cos\phi = 1$, $S = 50$ kVA

$$0.95 = \frac{1\times 50\times 1}{1\times 50\times 1 + \text{losses}}$$

Losses = 2.63 kW

Losses = Iron loss + Copper loss

When two winding transformer is connected as step up autotransformer



$I_2 = 200$; $V_2 = 750$

kVA rating of auto transformer

$$S_{auto} = V_2 I_2 = 750 \times 200 = 150 \text{ kVA}$$

As current through windings and voltage across windings are equal in two-winding transformer and autotransformer. Losses remain same at full load

efficiency at upf and full load,

$$\%\eta = \frac{x S_{auto} \cos\phi}{x S_{auto} \cos\phi + \text{losses}} \times 100$$

$$= \frac{1 \times 150 \times 1}{1 \times 150 \times 1 + 2.63} \times 100 = 98.276\%$$

Q.1 (e) Solution:

As generator

$$P_e = \sqrt{3} \times 400 I_a \times 0.8 = 4 \times 10^3$$

$$I_a = 7.22 \text{ A}$$

$$\phi = \cos^{-1} 0.8 = 36.9° \text{ lagging}$$

$$\overline{I_a} = 7.22 \angle -36.9°$$

$$\overline{V_t} = \frac{400}{\sqrt{3}} \angle 0° = 231 \angle 0° \text{ V}$$

$$\overline{E_f} = 230 \angle 0° + j7.22 \angle -36.9° \times 25$$

$$= 231 + 180.5 \angle 53.1°$$

$$= 368.8 \angle 23°$$

$$= 339.4 + j144.3$$

$$E_f = 368.6 \text{ V}, \delta = +23° \; E_f \text{ leads } V_t$$

As motor

Excitation emf (constant,), $E_f = 368.8$

$$P_e(\text{in}) = \frac{V_t E_f}{X_s} \sin\delta$$

$$\frac{1}{3} \times 4000 = \frac{231 \times 368.8}{23} \sin\delta$$

$$\delta = 23°, \; E_f \text{ lags } V_t$$

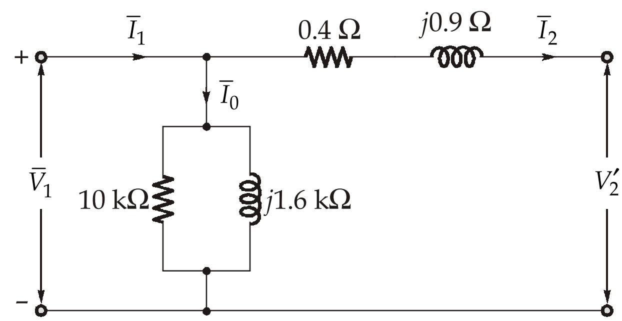
Total change in power angle = 23° + 23° = 46°.

Q.2 (a) (i) Solution:

$$R(HV) = 0.2 + 2 \times 10^{-3} \times (10)^2 = 0.4\ \Omega$$

$$X(HV) = 0.45 + 4.5 \times 10^{-3} \times (10)^2 = 0.9\ \Omega$$

The circuit model is



$$I_2(fl) = \frac{150 \times 1000}{240} = 625\text{ A},\ 0.8 \text{ power factor lagging}$$

$$V_2 = 240\text{ V}$$

$$I_2 = \frac{625}{10} = 62.5\text{ A},\ 0.8 \text{ power factor lagging}$$

$$V_2' = 2400\text{ V}$$

$$\text{Voltage drop} = 62.5\,(0.4 \times 0.8 + 0.9 \times 0.6)$$

$$= 53.75\text{ V}$$

$$\text{Voltage regulation} = \frac{53.75}{2400} \times 100 = 2.24\%$$

$$V_1 = 2400 + 53.75 \approx 2454\text{ V}$$

$$P_{(out)} = 150 \times 0.8 = 120\text{ kW}$$

$$P_{c(\text{Copper loss})} = (62.5)^2 \times 0.4$$

$$= 1.56\text{ kW}$$

$$P_{i(\text{Core loss})} = \frac{(2454)^2}{10 \times 1000} = 0.60\text{ kW}$$

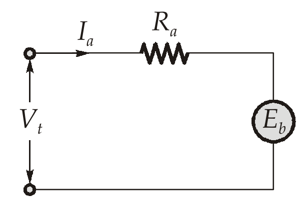
$$P_L = P_i + P_c = 0.60 + 1.56 = 2.16\text{ kW}$$

$$n = \frac{120}{120 + 2.16} = 98.2\%$$

$$\overline{I_0} = \frac{2454\angle 0^\circ}{10 \times 1000} - \frac{j2454\angle 0^\circ}{1.6 \times 1000} = 0.245 - j1.53\text{ A}$$

$$I_2' = 62.5(0.8 - j0.6)$$
$$= (50 - j37.5)\text{A}$$
$$\overline{I_1} = \overline{I_0} + \overline{I_2}$$
$$= 50.25 - j39.03$$
$$= 63.63 \angle{-37.8°}\ \text{A}$$
$$I_1 = 63.63\ \text{A and power factor} = 0.79\ \text{lagging}$$

Q.2 (a) (ii) Solution:



At no load, $I_{a0} = 1.5$ A

Supply voltage $= V_t = 250$ V

Back emf at no load, $E_{bo} = V_t - I_{a0}R_a$

$= 25 - 1.5 \times 0.8 = 23.8$ V

Power developed by the motor,

$$P_0 = E_{b0}\, I_{a0} = 23.8 \times 1.5 = 35.7 \text{ W}$$

As the motor is working at no load, power P_0 supplies no load losses.

When the motor is on load, $I_{a1} = 3.5$ A

$$E_{a1} = V_t - I_{a1}R_a = 25 - 3.5 \times 0.8 = 22.2 \text{ V}$$

Power developed by the motor,

$$P_1 = E_{a1}\, I_{a1} = 22.2 \times 3.5 = 77.7 \text{ W}$$

Power available at shaft, $P_s = P_1 -$ no load losses $= 77.7 - 35.7 = 42$ W

$$\text{Efficiency} = \frac{\text{Output power}}{\text{Input Power}} \times 100$$

$$= \frac{P_0}{V_t I_{a_1}} \times 100 = \frac{42}{25 \times 3.5} \times 100 = 48\%$$

Q.2 (b) Solution:

(i) At a field current of 2.20 A, the line to line voltage on the air-gap line is

$$V_{a,ag} = \frac{202}{\sqrt{3}} = 116.70 \text{ V}$$

and for the same field current, the armature current on short circuit is

$$I_{a,sc} = 118 \text{ A}$$

Unsaturated synchronous reactance,

$$X_{\text{s.u.}} = \frac{116.70}{118} = 0.987 \ \Omega/\text{phase}$$

Note that armature current is

$$I_{a,\text{rated}} = \frac{45000}{\sqrt{3} \times 220} = 118 \text{ A}$$

Therefore, $I_{a,sc}$ = 1.00 pu. The corresponding air-gap line voltage is

$$V_{a,ag} = \frac{202}{220} = 0.92 \text{ p.u.}$$

Now, $$X_{\text{s.u.}} = \frac{0.92}{1.00} = 0.92 \text{ p.u.}$$

The saturated synchronous reactance can be found from open and short-circuit characteristics,

$$X_s = \frac{V_{a,\text{rated}}}{I'_a} = \frac{\left(\frac{220}{\sqrt{3}}\right)}{152} = 0.836 \ \Omega/\text{phase}$$

In per unit, $$I'_a = \frac{152}{118} = 1.29$$

$$X_s = \frac{1.00}{1.29} = 0.775 \text{ p.u.}$$

Finally, from open and short-circuit characteristics, the short circuit ratio is given by

$$\text{SCR} = \frac{2.84}{2.20} = 1.29$$

As we know, the inverse of short-circuit ratio is equal to the per-unit saturated synchronous reactance,

$$X_s = \frac{1}{\text{SCR}} = \frac{1}{1.29} = 0.775 \text{ p.u.}$$

(ii) Let Base MVA = 325 MVA

Base voltage = 26 kV

Therefore, $$V_t = 1.0 \text{ pu}$$

$$P = \frac{250}{325} = 0.7692 \text{ pu}$$

Therefore, $I_{a(\text{pu})} = \dfrac{0.7692}{1 \times 0.89} = 0.8642\angle{-\cos^{-1} 10.89}$

$= 0.8642\angle{-27.12°}$ pu

Now, $E' = \sqrt{(V_t \cos\phi + I_a R_a)^2 + (V_t \sin\phi + I_a X_q)^2}$

$= \sqrt{(0.89)^2 + (0.456 + 0.8642 \times 1.18)^2}$

$E' = 1.723$ pu

Now, $\tan\psi = \dfrac{V_t \sin\phi + I_a X_q}{V_t \cos\phi + I_a R_a} = \dfrac{0.456 + 0.8642 \times 1.18}{0.89}$

$\psi = \tan^{-1}(1.658) = 58.90°$

Now, load angle, $\delta = \psi - \phi = 58.90 - 27.12$

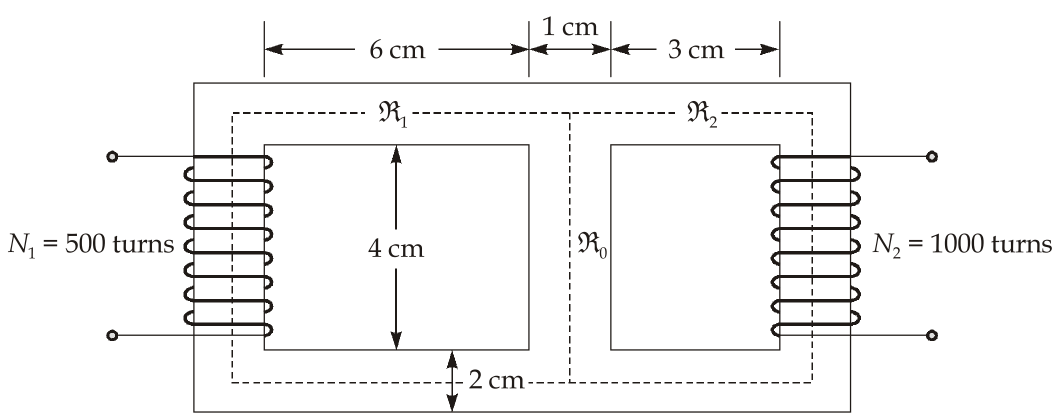
$\delta = 31.786°$

Now, excitation emf, $E_f = E' + I_d(X_d - X_q)$

$= 1.723 + 0.74 \times 0.77 = 2.29$ pu

$E_f = 2.29 \times 26 \text{ kV} = 59.62 \text{ kV (L–L)}$

Q.2 (c) Solution:



$l_1 = (6 + 0.5 + 1) \times 2 + (4 + 2) = 21$ cm

$l_2 = (3 + 0.5 + 1) \times 2 + (4 + 2) = 15$ cm

$l_0 = 4 + 2 = 6$ cm

Reluctance, $\mathfrak{R} = \dfrac{l}{\mu_0 \cdot \mu_r \cdot A}$

$\mathfrak{R}_1 = \dfrac{21 \times 10^{-2}}{4\pi \times 10^{-7} \times 1600 \times 2 \times 2 \times 10^{-4}} = 0.261 \times 10^6$ AT/Wb

$$\Re_2 = \frac{15\times10^{-2}}{4\pi\times10^{-7}\times1600\times2\times2\times10^{-4}} = 0.187\times10^6 \text{ AT/Wb}$$

$$\Re_0 = \frac{6\times10^{-2}}{4\pi\times10^{-7}\times1600\times1\times2\times10^{-4}} = 0.149\times10^6 \text{ AT/Wb}$$

Coil-1 excited with 1 A:

$$\Re = \Re_1 + (\Re_0 || \Re_2)$$

$$= 0.261 + (0.1871 || 0.149)$$

$$\Re = 0.344 \times 10^6 \text{ AT/Wb}$$

Flux, $$\phi = \frac{\text{mmf}}{\text{reluctance}} = \frac{N \cdot I}{\text{reluctance}}$$

i.e., $$\phi_1 = \frac{500\times1}{0.344\times10^6} = 1.453 \text{ mWb}$$

Flux in coil 2 due to 1 i.e.,

$$\phi_{21} = 1.453\times\frac{0.149}{0.149+0.187} = 0.64 \text{ mWb}$$

Self inductance of coil 1,

$$L_{11} = N_1\phi_1 = 500 \times 1.453 \times 10^{-3} = 0.7265 \text{ H}$$

Mutual inductance, $$M_{21} = N_2\phi_{21} = 1000 \times 0.649 \times 10^{-3} = 0.65 \text{ H}$$

Coil-2 excited with 1 A:

$$\Re = \Re_2 + \frac{\Re_0\Re_1}{\Re_0 + \Re_1}$$

$$\phi_2 = \frac{1000\times1}{0.284\times10^6} = 3.52 \text{ mWb}$$

Self inductance of coil 2,

$$L_{22} = N_2\phi_2 = 1000 \times 3.52 \times 10^{-3} = 3.52 \text{ H}$$

$$M_{12} = M_{21} = 0.65 \text{ H}$$

Q.3 (a) (i) Solution:

$$E_a = \frac{3.75\times10^{-3} I_a \times n \times 180}{60} \times 1$$

$$= 11.25 \times 10^{-3} n I_a \quad \text{...(i)}$$

$$T = \frac{1}{2\pi} \times 3.75 \times 10^{-3} I_a \times 180 \times I_a$$

$$= 107.4 \times 10^{-3} I_a^2 \quad \text{...(ii)}$$

$$\frac{250 - E_a}{1} = I_a \quad \text{...(iii)}$$

Under steady condition,

$$T = T_L$$

$$107.4 \times 10^{-3} I_a^2 = 10^{-4} n^2$$

$$I_a = \frac{n}{32.77} \quad \text{...(iv)}$$

Substituting (iii) and (iv) in eqn. (i)

$$250 - \frac{n}{32.77} = 11.25 \times 10^{-3} \times \frac{n^2}{32.77}$$

$$n^2 + \frac{10^3}{11.25} n - \frac{250 \times 32.77 \times 1000}{11.25} = 0$$

$$n^2 + 88.9n - 72.8 \times 10^4 = 0$$

$$n = \frac{-89 \pm \sqrt{0.79 \times 10^4 + 291.2 \times 10^4}}{2}$$

$$n = 810 \text{ rpm}$$

$$I_a = \frac{810}{32.77} = 24.7 \text{ A}$$

Q.3 (a) (ii) Solution:

$$A = 2,$$

Separately excited DC machine

$$R_a \approx 0, 230 \text{ V}, 5 \text{ kW}$$

$$N = 1200 \text{ rpm}$$

For wave winding,
$$230 = \frac{\phi \times 4 \times 1200 \times Z_1}{60 \times 2} \quad \text{...(i)}$$

For lap winding,
$$V = \frac{\phi \times 4 \times 1200 \times Z_1}{60 \times 4} \quad \text{...(ii)}$$

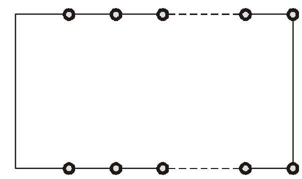
Dividing equation (i) by equation (ii),

$$\frac{230}{V} = \frac{4}{2}$$

$\Rightarrow$
$$V = 115 \text{ V}$$

For power:

Wave:

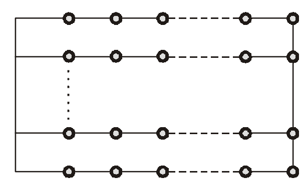


Total conductor in single path $= \frac{Z}{2}$

Let, resistance of $\left(\frac{Z}{2}\right)$ conductor $= R$

Total resistance, $$P_1 = \frac{V_1^2}{R_1} = \frac{V_1^2}{(R/2)} \quad ...(i)$$

Lap:



Total conductor in single path $= \frac{Z}{4}$

Let, resistance of single path $= \frac{R}{2}$

Total resistance $= \frac{R/2}{4} = \frac{R}{8}$

$$P_2 = \frac{V_2^2}{R_2} = \frac{V_2^2}{(R/8)} \quad ...(ii)$$

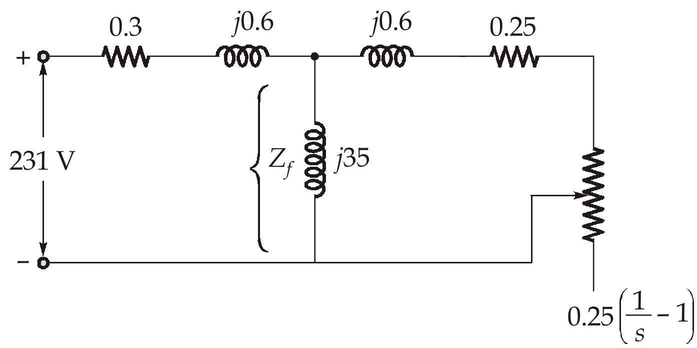
By equation (i) and (ii), we get

$$\frac{P_1}{P_2} = \frac{V_1^2/(R/2)}{V_2^2/(R/8)}$$

$$= \frac{(230)^2}{R/2} \times \frac{R/8}{(715)^2} = 1$$

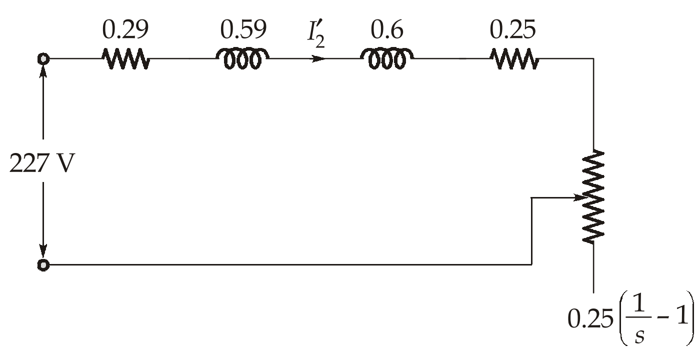
Q.3 (b) Solution:

The motor circuit model is drawn in figure



Its Thevenin equivalent is

$$\overline{Z_{Th}} = \frac{j35(0.3+j0.6)}{0.3+j35.60} = 0.29 + j0.59\ \Omega$$



$$\overline{V_{Th}} = \frac{231\angle 0°\times j35}{0.3\times j35.60} = 227\angle 0.5°\text{V}$$

$$N_s = 1500 \text{ rpm}, \omega_s = 157.1 \text{ rad/sec}$$

(i) Starting on full voltage ($s = 1$)

$$\overline{Z_f} = \frac{j35(0.25+j0.6)}{0.25+j35.6} = (0.29+j0.59)\ \Omega$$

$$R_f = 0.24\ \Omega$$

$$\overline{Z_{in}} = (0.3 + j0.6) + (0.29 + j0.59)$$

$$= 1.328\angle 63.62°\ \Omega$$

$$I_1\text{ (start)} = \frac{227}{1.32} = 171.96 \text{ A}$$

$$T\text{ (start)} = \frac{3I_1^2 R_f}{\omega_s}$$

$$\frac{3\times(171.96)^2\times 0.25}{157.1} = 141.18 \text{ Nm}$$

$$S_{fl} = \frac{1500-1450}{1500} = \frac{1}{30}$$

(ii)

$$R_2'/S_{fl} = 0.25 \times 30 = 7.5\ \Omega$$

$$\overline{Z_f} = \frac{j35(7.5+j0.6)}{7.5+j35.6} = (6.94+j2.05)\ \Omega$$

$$R_f = 6.94\ \Omega$$

$$\overline{Z_{in}} = (0.3 + j0.6) + (6.94 + j2.05)$$

$$= 7.71\ \angle 20.1°\ \Omega$$

$$I_1 = \frac{231}{7.71} = 30 \text{ A}$$

$$\text{Power factor} = \cos 20.1° = 0.94 \text{ lagging}$$

$$P_G = 3 \times (30)^2 \times 6.94 = 18.74 \text{ kW}$$

$$\text{Power output (gross)} = (1 - s)P_G$$

$$\left(1-\frac{1}{30}\right)\times 18.74 = 18.12 \text{ kW}$$

$$\text{Rotational loss} = 1.5 \text{ kW}$$

$$\text{Power output (net)} = 18.12 - 1.5 = 16.62 \text{ kW}$$

$$\text{Torque (net)} = \frac{16.62\times 1000}{157.1\left(1-\frac{1}{30}\right)} = 109.4 \text{ Nm}$$

$$\text{Power input} = \sqrt{3}\times 400\times 30\times 0.94 = 19.54 \text{ kW}$$

$$n = \frac{16.62}{19.54}\times 100 = 85.06\%$$

$$\text{Internal efficiency} = \frac{P_G(1-s)}{P_{in}}$$

$$= \frac{18.74\left(1-\frac{1}{30}\right)}{19.54} = 92.71\%$$

We shall use the Thevenin equivalent circuit.

For maximum torque

$$\frac{0.25}{s_{max,T}} = \sqrt{(0.29)^2 + (0.59+0.6)^2}$$

$$s_{max,\ T} = 0.204$$

$$R_2' / s_{max,T} = \frac{0.25}{0.204} = 1.225$$

$$\bar{Z}(\text{total}) = (0.29 + j0.59) + (1.225 + j0.6)$$

$$= 1.93 \angle 38.1°$$

$$I_2' = \frac{227}{1.93} = 117.6$$

$$T_{max} = 3 \times \frac{(117.6)^2 \times 1.225}{157.1} = 323.5 \text{ Nm}$$

Q.3 (c) Solution:

(i) As we know,

$$e = N\frac{d\phi}{dt}$$

$$N.d\phi = edt$$

$$N.\Delta\phi = E\Delta t$$

Flux linkage change = Volt-time product

Flux linkage during the each half cycle is

$$\Delta\phi = \frac{1}{500}\left[45 \times \frac{1}{360} + 90 \times \frac{1}{360} + 45 \times \frac{1}{360}\right]$$

$$\Delta\phi = 1 \times 10^{-3} \text{ Wb}$$

$\because$ $V_{av} = 0, \quad \therefore \quad \phi_{av} = 0$

$\therefore$ During positive half cycle of the input voltage, the flux varies from -0.5×10^{-3} Wb to 0.5×10^{-3} Wb.

From $0 < t < \frac{1}{360}$

$$\phi(t) = -0.5 \times 10^{-3} + \frac{45}{500}t$$

$$\phi(t)\Big|_{t=\frac{1}{360}} = -0.5 \times 10^{-3} + \frac{45}{500} \times \frac{1}{360} = -0.25 \times 10^{-3} \text{ Wb}$$

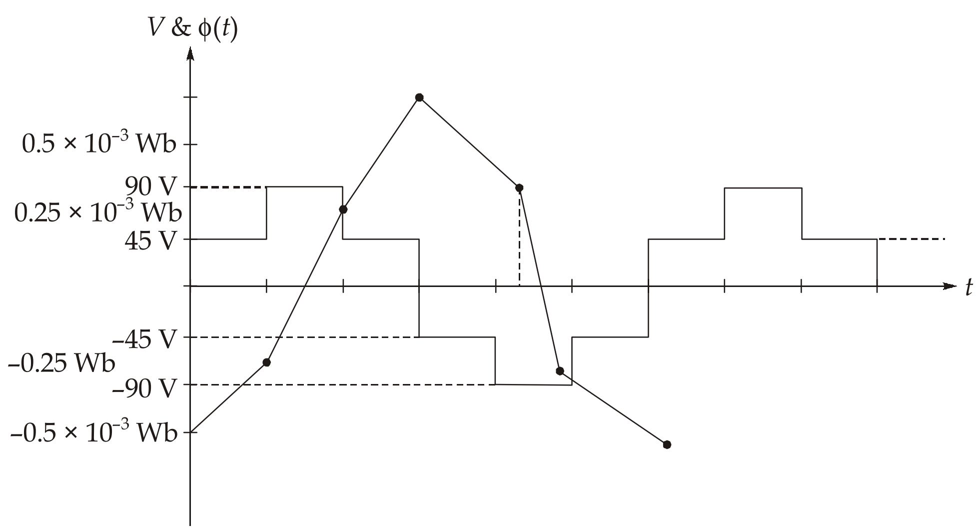
From $\frac{1}{180} < t < \frac{1}{120}$

$$\phi(t) = 0.25 \times 10^{-3} + \frac{45}{500}\left(t - \frac{1}{180}\right)$$

$$\phi(t)\Big|_{t=\frac{1}{120}} = 0.25 \times 10^{-3} + \frac{45}{500}\left(\frac{1}{120} - \frac{1}{180}\right)$$

$$= 0.5 \times 10^{-3} \text{ Wb}$$

Now, since waveform is symmetrical about $t = \frac{1}{120}$, therefore, waveform in negative half cycle will symmetrical about $t = \frac{1}{120}$.



(ii) Slot/pole/phase,

$$m = \frac{90}{3 \times 10} = 3$$

$$\gamma = \frac{180°}{\text{slot/pole}} = \frac{180° \times 10}{90} = 20°$$

Distribution factor,

$$K_d = \frac{\sin\left(\frac{m\gamma}{2}\right)}{m\sin\left(\frac{\gamma}{2}\right)} = \frac{\sin(30°)}{3\sin(10°)} = 0.9597$$

Winding is assumed to be full-pitched, then

$$E_p = 4.44 \times \phi_m \times f \times N_{Ph} \times K_d$$

$$\frac{11000}{\sqrt{3}} = 4.44 \times 0.9597 \times 50 \times 0.16 \times N_{ph}$$

$$N_{ph} = 186.30 \simeq 187 \text{ turns}$$

Q.4 (a) (i) Solution:

$$P_{fan} = P_{dev} = P; \text{ no rotational loss}$$

$$P = E_a I_a$$

$$T_{dev} = K'_a K_f I_{se} I_a = K'_a K_f I_a^2; I_{se} = I_a$$

Linear magnetization

$$T_{fan} = K_F n^2$$

But $T_{dev} = T_{fan} = T$

$\therefore$ $I_a \propto n$

Operation at 400 rpm (R_{ext} = 0)

1. $E_a = 220 - (0.6 + 0.4) \times 30 = 190$ V

$$I_a = 30 \text{ A}$$

$$P = 190 \times 30 = 5.7 \text{ kW}$$

$$T\omega = E_a I_a$$

$$T = \frac{5700}{\frac{2\pi \times 400}{60}} = 136 \text{ Nm}$$

2. Operation at 200 rpm (R_{ext} = ?)

$$T = 136 \times \left(\frac{200}{400}\right)^2 = 34 \text{ Nm}$$

$$I_a = 30 \times \left(\frac{200}{400}\right) = 15\text{A}$$

$$T\omega = E_a I_a$$

$$T = \frac{5700}{\frac{2\pi \times 400}{60}} = 136 \text{ Nm}$$

$$34 \times \left(\frac{2\pi \times 200}{60}\right) = [220 - (0.6 + 0.4 + R_{ext}) \times 15] \times 15$$

Solving we get

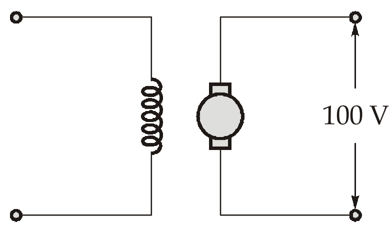
$$R_{ext} = 10.5\ \Omega$$

$$P = T\omega = 34\times\left(\frac{2\pi\times 200}{60}\right) = 0.721\ \text{kW}$$

Q.4 (a) (ii) Solution:

Given, separately initiated DC motor.

Field excitation is constant,



Producing a torque of 500 N-m

At zero speed,

$\because$ $N = 0,$

$$E_b = 0$$

$$E_b = V - I_a R_a$$

$\therefore$ $0 = 100 - I_a(0.05)$

$\therefore$ $I_{a1} = \frac{100}{0.05} = 2000\ \text{A}$

$$T = \frac{60}{2\pi N} E_b I_a = \frac{60}{2\pi N}\frac{\phi ZNP}{60\ A}\cdot I_a$$

Let, $T_1 = \frac{1}{2\pi}\frac{ZP}{A}\phi I_{a1}$ N-m

Let, $T_1 = kI_{a1}$

where, $k = \frac{1}{2\pi}\frac{ZP\phi}{A}$

$$T_1 = 500\ \text{N-m},$$

$$I_{a1} = 2000\ \text{A}$$

$$k = \frac{500}{2000} = 0.25$$

When motor runs on no-load given all mechanical losses neglected. No-load current is negligible and the voltage drop at no-load can be neglegible.

$\therefore$ $E_b \simeq V = 150$ V

$$E_b = \frac{\phi Z N P}{60 A}$$

Already solved,

$$k = \frac{1}{2\pi}\left(\frac{ZP\phi}{A}\right)$$

$$\therefore \quad \frac{ZP\phi}{A} = 2\pi\,(k)$$

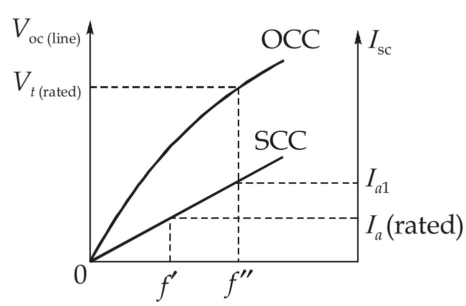
$$\therefore \quad E_b = 2\pi(k)\cdot\frac{N}{60}$$

$$\therefore \quad E_b = k \times \omega \qquad (\omega : \text{No-load speed in rad/sec.})$$

$$\therefore \quad \omega = \frac{E_b}{k}$$

$$\therefore \quad \omega = \frac{150}{0.25} = 600 \text{ rad/sec.}$$

Q.4 (b) (i) Solution:



Rated open circuit voltage is obtained at

$$of' = 15 \text{ A}$$

$$\text{Rated armature current} = \frac{100 \times 1000}{\sqrt{3} \times 415} = 139.12 \text{ A}$$

Short-circuit characteristics is linear.
Short-circuit armature current at field current 15 A

$$I_{a_1} = I_a \times \frac{of''}{of'} = 139.12 \times \frac{15}{10} = 208.68 \text{ A}$$

Phase voltage, $$V_p = \frac{V_{oc(\text{line})}}{\sqrt{3}} = \frac{415}{\sqrt{3}}$$

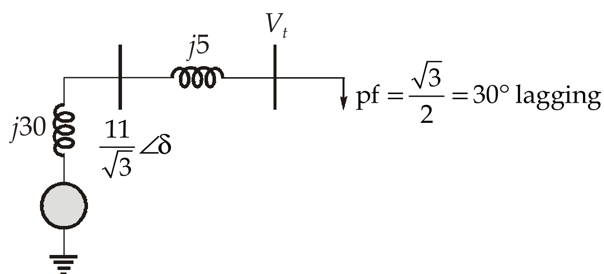
$$\text{Saturated synchronous reactance} = X_s = \frac{V_p}{I_{a_1}} = \frac{415/\sqrt{3}}{208.68} = 1.148\ \Omega$$

Base impedance, $$Z_B = \frac{415^2}{100\times10^3} = 1.722\ \Omega$$

Per unit saturated synchronous reactance

$$= \frac{X_s}{Z_B} = \frac{1.148}{1.722} = 0.666\,\text{pu}$$

Q.4 (b) (ii) Solution:



$$\text{pf} = \frac{\sqrt{3}}{2} = 30^\circ \text{ lagging},$$

$$I_{\text{rated}} = \frac{10\times10^6}{\sqrt{3}\times11\times10^3} = 524.86\ \text{A}$$

$$E = \sqrt{(V\cos30 + IR)^2 + (V\sin30^\circ + IX)^2}$$

$$\frac{11\text{K}}{\sqrt{3}} = \sqrt{\left(V\cdot\frac{\sqrt{3}}{2}\right)^2 + \left(\frac{V}{2} + 524.86(5)\right)^2}$$

$$\left(\frac{11\text{K}}{\sqrt{3}}\right)^2 = V^2\cdot\frac{3}{4} + \left(\frac{V}{2} + 2624.319\right)^2$$

$$\left(\frac{11\text{K}}{\sqrt{3}}\right)^2 = \frac{3}{4}V^2 + \frac{V^2}{4} + 2624.319\,\text{V} + 2624.319^2$$

$$V_t = 4618.105\ \text{V}$$

$$E\angle\delta = V\angle0^\circ + I_{\text{rated}} \times Z$$

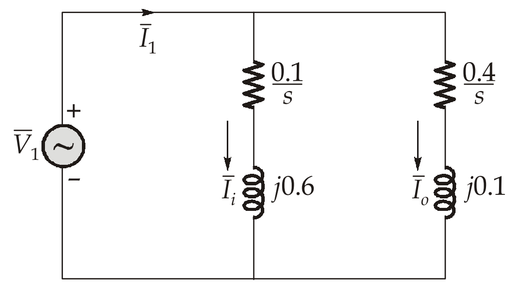
$$= 4618.105 + 524.86\angle{-30^\circ} \times (j5)$$

$$E\angle\delta = 6350.84\angle20.97$$

$$\phi_{\text{net}} = 20.97 - (-30)$$

$$\cos\phi_{\text{net}} = 0.629 \text{ lagging}$$

Q.4 (c) Solution:



The rotor currents in the inner and the outer cage are

$$\bar{I}_i = \frac{\bar{V}_1}{\left(\frac{0.1}{s} + j0.6\right)}$$

$$\bar{I}_o = \frac{\bar{V}_1}{\left(\frac{0.4}{s} + j0.1\right)}$$

The torque developed by a 3-phase induction motor is

$$T_d = \frac{3I_2^2 R_2}{s\omega_s}$$

Thus, the ratio of the torque developed by the outer and inner ages is

$$\frac{T_o}{T_i} = \frac{I_o^2 R_o}{I_i^2 R_i}$$

$$\frac{T_o}{T_i} = \frac{\left(\frac{0.1}{s}\right)^2 + 0.6^2}{\left(\frac{0.4}{s}\right)^2 + 0.1^2} \times \frac{0.4}{0.1} \qquad ...(1)$$

Substituting $s = 1$ in equation (1)

$$\frac{T_o}{T_i} = \frac{(0.1)^2 + 0.6^2}{(0.4)^2 + 0.1^2} \times \frac{0.4}{0.1} = 8.71$$

For slip $s = 0.05$, putting s = 0.05 in equation (1)

$$\frac{T_o}{T_i} = \frac{\left(\frac{0.1}{0.05}\right)^2 + 0.6^2}{\left(\frac{0.4}{0.05}\right)^2 + 0.1^2} \times \frac{0.4}{0.1} = 0.272$$

The inner cage is most effective at a slip of 5% because it develops nearly 3.67 times as much torque as the outer cage for both torque to be equal.

$$\frac{T_o}{T_i} = 1 = \frac{\left(\frac{0.1}{s}\right)^2 + 0.6^2}{\left(\frac{0.4}{s}\right)^2 + 0.1^2} \times 4$$

Let $$x = \frac{1}{s}$$

So, $$1 = \frac{x^2 + 36}{16x^2 + 1} \times 4$$

$$16x^2 + 1 = 4x^2 + 144$$

$$(16 - 4)x^2 = 144 - 1 = 143$$

$$x = \sqrt{\frac{143}{12}} = 3.452$$

So, Slip $$s = \frac{1}{x} = 0.2896$$

So, torque developed by the two cages is the same at slip of 28.96%.

Section B : Power Systems-1 + Digital Electronics-2 + Microprocessors -2

Q.5 (a) Solution:

(i) In the given sequential circuit,
the input logic functions of each flip-flop is

$$D_1 = Q_3$$
$$D_2 = Q_1 \oplus X$$
$$D_3 = Q_2 \oplus Y$$

Since for the D-flip-flop, the next state is $Q^+ = D$.

$\therefore$
$$Q_1^+ = Q_3$$
$$Q_2^+ = Q_1 \oplus X$$
$$Q_3^+ = Q_2 \oplus Y$$

(a) For the given outputs $Q_1 = 0$; $Q_2 = 0$; $Q_3 = 0$ and inputs to XOR gate $X = 0$; $Y = 1$.

$$Q_1^+ = Q_3 = 0$$
$$Q_2^+ = Q_1 \oplus X = 0 \oplus 0 = 0$$
$$Q_3^+ = Q_2 \oplus Y = 0 \oplus 1 = 1$$

(b) For the given outputs $Q_1 = 1; Q_2 = 1; Q_3 = 0$, and inputs to XOR gate $X = 1; Y = 1$

$$Q_1^+ = Q_3 = 0$$
$$Q_2^+ = Q_1 \oplus X = 1 \oplus 1 = 0$$
$$Q_3^+ = Q_2 \oplus Y = 1 \oplus 1 = 0$$

(c) For the given outputs $Q_1 = 0; Q_2 = 0; Q_3 = 1$ and inputs to XOR gate $X = 1; Y = 0$

$$Q_1^+ = Q_3 = 1$$
$$Q_2^+ = Q_1 \oplus X = 0 \oplus 1 = 1$$
$$Q_3^+ = Q_2 \oplus Y = 0 \oplus 0 = 0$$

∴ The complete table is

Q_1	Q_2	Q_3	X	Y	Q_1^+	Q_2^+	Q_3^+
0	0	0	0	1	0	0	1
1	1	0	1	1	0	0	0
0	0	1	1	0	1	1	0

(ii) From the given timing diagram, just before the negative edge of clock before the dashed line, $X = 0; Y = 1$.

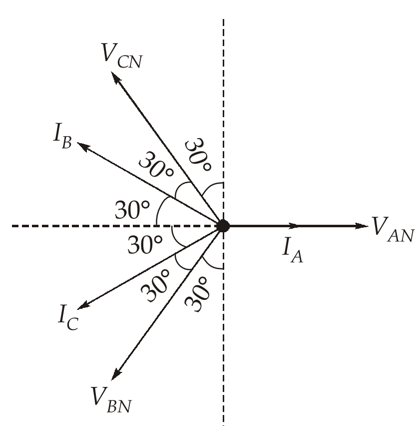
∴ For given, $Q_1Q_2Q_3 = 001$

the next state $Q_1^+Q_2^+Q_3^+$ is obtained as below:

$$Q_1^+ = Q_3 = 1$$
$$Q_2^+ = Q_1 \oplus X = 0 \oplus 0 = 0$$
$$Q_3^+ = Q_2 \oplus Y = 0 \oplus 1 = 1$$

∴ The next state is $Q_1^+ Q_2^+ Q_3^+ = 101$.

Q.5 (b) Solution:



Taking V_{AN} as the reference, phase voltage

$$V_{AN} = 230 \angle 0° V$$
$$V_{BN} = 230 \angle -120° V$$
$$V_{CN} = 230 \angle 120° V$$
$$I_A = \frac{P}{V_{AN} \cos\phi} = \frac{4 \times 10^3}{230 \times 1} = 17.4\angle 0°$$

- If a pure inductor is present in phase B, then I_B lags V_{BN} by 90°.
- If a pure capacitor is present in phase C, then I_C leads V_{CN} by 90°.

  If current through neutral is to be zero.

$$I_B \sin 30° = I_C \sin 30°$$
$$\Rightarrow \quad I_B = I_C = I$$
$$I_A = I_B \cos 30° + I_C \cos 30°$$
$$= 2I \cos 30° = \sqrt{3}\, I$$
$$|I_B| = |I_C| = |I|$$
$$= \frac{|I_A|}{\sqrt{3}} = \frac{17.04}{\sqrt{3}} = 10.05 \text{ A}$$
$$|I_B| = \frac{|V_{BN}|}{\omega L}$$
$$\Rightarrow \quad 10.05 = \frac{230}{2\pi \times 50 \times L}$$
$$L = 72.847 \text{ mH}$$
$$|I_C| = |V_{CN}| \cdot \omega C$$
$$\Rightarrow \quad 10.05 = 230 \times 2 \times \pi \times 50 \times C$$
$$C = 139.087\ \mu F$$

Q.5 (c) Solution:

Given : Conductor diameter, $d = 10$ mm

Radius, $r = 0.5d = 5 \times 10^{-3}$ m

Air density factor, $$\delta = \frac{3.92b}{273 + T} = \frac{3.92 \times 750 \times 10^{-1}}{273 + 30} = 0.9703$$

where b is barometric atmospheric pressure in cm of Hg.

Distance between conductor, $D = 2.5$ m

Surface of irregularity factor, $m_o = 0.85$

Critical distruptive voltage, $$V_c = g m_o r \delta \ln \frac{D}{r} \text{ V/phase}$$

$$= \frac{30\times10^3}{\sqrt{2}\times10^{-2}}\times0.85\times5\times10^{-3}\times0.9703\ln\left(\frac{25}{5\times10^{-3}}\right)$$

$$= 54.364 \text{ kV/ph}$$

$$V_{ph} = \frac{110}{\sqrt{3}} = 63.508 \text{ kV/phase}$$

According to Peek's formula, corona power loss under fair weather conditions is given by,

$$P_L = 241\times10^{-5}\left(\frac{f+25}{\delta}\right)\sqrt{\frac{r}{d}}(V_{ph}-V_c)^2 \text{ kW/km/phase}$$

$$= \frac{241\times10^{-5}}{0.9703}(50+25)(63.508-54.364)^2\sqrt{\frac{5\times10^{-3}}{2.5}}\times150 \text{ kW/phase}$$

$$= 104.48 \text{ kW/phase}$$

Total corona loss $= 3P_c = 3 \times 104.48$

$= 313.44$ kW

Q.5 (d) Solution:

$\rightarrow$ MVIA, 07H, move the data immediately to accumulator

[A] $\leftarrow$ 07H

$\rightarrow$ RLC

Rotate the content of accumulator to left by 1-bit without carry,

A $\rightarrow$ 0000 0111 $\Rightarrow$ 0000 1110

[A] 0EH (Data is multiplied by 2)

$\rightarrow$ MOV B, A

[B] $\leftarrow$ [A], Move the contents of A to B

[B] $\leftarrow$ 0EH

$\rightarrow$ RLC

Rotate contents of accumulator to left without carry

$$00001110 \Rightarrow \underbrace{0001}_{1}\ \underbrace{1100}_{C}$$

[A] $\leftarrow$ 1CH (Multiplication by 2)

$\rightarrow$ RLC

$$00011100 \Rightarrow \underbrace{0011}_{3}\ \underbrace{1000}_{8}$$

[A] $\leftarrow$ 38H (Multiplication by 2)

→ ADD B

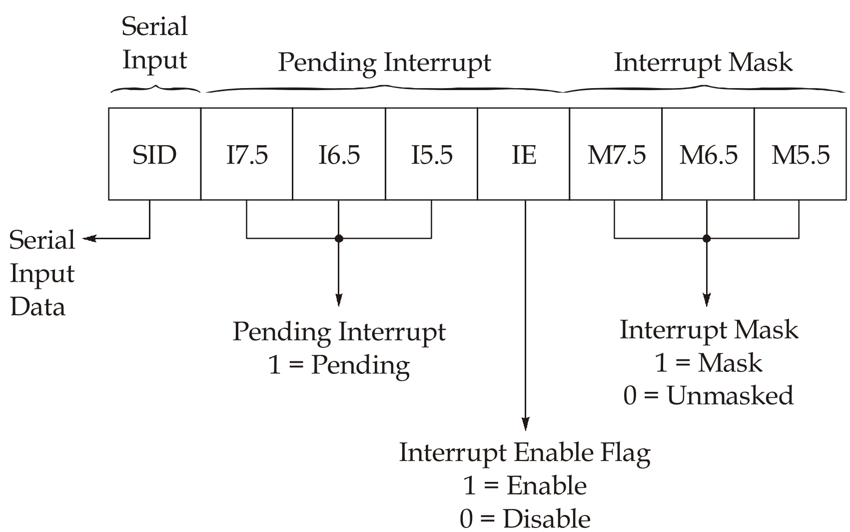
$[A] \leftarrow [A] + [B],\quad \begin{array}{r} 38 \\ 0E \\ \hline 46 \end{array}$

$[A] \leftarrow 46H$

At last we can see that the decimal value of [A] is almost 70 which is 10 times the initial value. Hence, we can say that multiplication by 10 is performed in above instructions.

Q.5 (e) Solution:

RIM stands for 'Read Interrupt Mask' and its format is as follows :



When RIM instruction is executed in software, the status SID, pending interrupts and interrupt mask are loaded into the accumulator. Their status can be monitored.

It may so happen that when interrupt is being serviced, other interrupts may occur. The status of these pending interrupts can be monitored by the RIM instruction.

None of the flags are affected by RIM instruction.

Q.6 (a) (i) Solution:

By KCL at Bus (3) :

$$\vec{I}_3 = \vec{I}_1 + \vec{I}_2$$

$$\vec{I}_3 = 0.75\angle 0° + 0.8\angle 0°$$

$$\vec{I}_3 = 1.55\angle 0° \text{ pu}$$

Power loss in the transmission system is given by :

$$P_L = P_{L1} + P_{L2} + P_{L3}$$

$$= |I_1|^2 R_1 + |I_2|^2 R_2 + |I_3|^2 R_3$$

$$= (0.75^2 \times 0.07) + (0.8^2 \times 0.06) + (1.55^2 \times 0.05)$$

$$P_L = 0.039375 + 0.0384 + 0.120125$$

$$P_L = 0.1979 \text{ pu}$$

Q.6 (a) (ii) Solution:

$$\vec{V}_R = 33 \times 10^3 \angle 0° \text{ V}$$

$$\vec{I}_R = \frac{S}{V_{RL}} \angle -\cos^{-1} 0.85$$

$$\Rightarrow \quad \vec{I}_R = \frac{10 \times 10^6}{33 \times 10^3} \angle -31.79° \text{A}$$

$$\Rightarrow \quad \vec{I}_R = 303.03 \angle -31.79° \text{ A}$$

$$\therefore \quad \vec{V}_S = A\bar{V}_R + B\bar{I}_R$$

$$= (1\angle 0°)(33 \times 10^3 \angle 0°) + (12.12\angle 64.64°) \times (303.03\angle -31.79°)$$

$$\vec{V}_S = 36140.384\angle 3.16° \text{ Volts}$$

$$P_S = \left|\frac{D}{B}\right| |V_S|^2 \cos(\beta - \alpha) - \frac{|V_S||V_R|}{|\beta|}\cos(\beta + \delta)$$

$$= \frac{1}{12.12} \times (36.14 \times 10^3)^2 \cos(64.64 - 0°) - \frac{36.14 \times 10^3 \times 33 \times 10^3}{12.12}\cos(64.64° + 3.16°)$$

$$= 8.976 \text{ MW}$$

$$Q_S = \frac{|D||V_S|^2}{|B|}\sin(\beta - \alpha) - \frac{|V_S||V_R|}{|B|}\sin(\beta + \alpha)$$

$$= \frac{1 \times (36.14 \times 10^3)^2}{12.12}\sin(64.64° - 0°) - \frac{36.14 \times 10^3 \times 33 \times 10^3}{12.12} \times \sin(64.64° + 16°)$$

$$= 6.273 \text{ MVAR}$$

Q.6 (b) Solution:

(i) **1.** From the given circuit,

Output of flip-flops,

$$F1 = X_1 = Q_1$$

$$F2 = X_2 = Q_2$$

$$F3 = X_3 = Q_3$$

$\therefore$ The input logic X is transferred to the output of the next stage flip-flop on the active edge of the clock pulse as

$X \rightarrow X_1 \rightarrow X_2 \rightarrow X_3$

$\therefore$ It is a shift register behaviour.

The output logic, $Z = Y \cdot X_3$

where, $Y = X_1 + X_2$

$\therefore$ $Z = (X_1 + X_2) \cdot X_3$

2.

Inputs			Output
X_3	X_2	X_1	$Z = (X_1 + X_2) \cdot X_3$
0	0	0	0
0	0	1	0
0	1	0	0
0	1	1	0
1	0	0	0
1	0	1	1
1	1	0	1
1	1	1	1

Since, output logic, $Z = 1$ only for certain 3-bit input patterns which are 101, 110 and 111.

$\therefore$ The functionality of the given circuit is 3-bit serial-in shift register with combinational detection logic.

(ii) For the given logic circuit,

inputs are: X, Y

output, $Q = A$

input of FF,

$$D = (X + Y) \oplus A$$

$$D = \bar{A}(X+Y) + A(\overline{X+Y})$$

$\therefore$ For D-FF, Next state, $A^+ = D$

$\therefore$ $A^+ = \bar{A}(X+Y) + A(\overline{X+Y})$

if $A = 1$ $\Rightarrow$ $A^+ = \bar{1}(X+Y) + 1 \cdot (\overline{X+Y})$

$\therefore$ $A^+ = 0(X+Y) + (\overline{X+Y})$

$\therefore$ $A^+ = \overline{X+Y}$

if $A = 0$ $\Rightarrow$ $A^+ = \bar{0}(X+Y) + 0 \cdot (\overline{X+Y})$

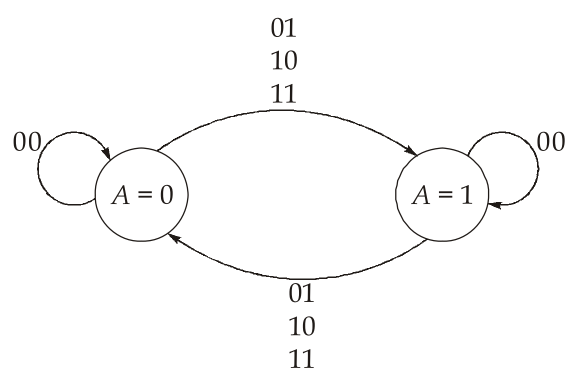
$\therefore$ $A^+ = (X + Y)$

State table of the given circuit;

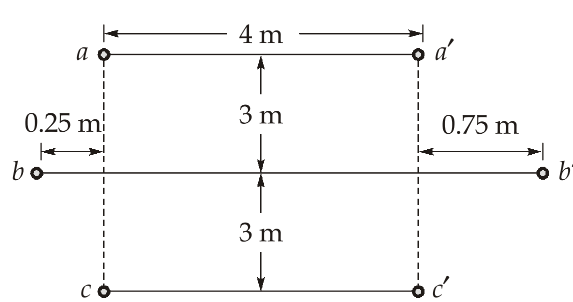
Present state (A)	Inputs X	Y	Next state (A^+)
0	0	0	0
0	0	1	1
0	1	0	1
0	1	1	1
1	0	0	1
1	0	1	0
1	1	0	0
1	1	1	0

State diagram:

There are only two states, $A = 0$ and $A = 1$. State transition happens only when inputs XY are 01, 10, 11 and the state is not changed when input $XY = 00$.



Q.6 (c) (i) Solution:



Self GMD for phase ***a***:

$$D_{Sa} = \sqrt[2]{0.7788 \times r \times D_{aa'}}$$

$$= \sqrt{0.7788 \times 0.75 \times 10^{-2} \times 4} = 15.28 \text{ cm}$$

Self GMD for phase ***b***:

$$D_{Sb} = \sqrt[2]{0.7788 \times r \times D_{bb'}} = \sqrt[2]{0.7788 \times 0.75 \times 10^{-2} \times 5.5}$$

$$= 17.92 \text{ cm}$$

$\because$

$$D_{Sa} = D_{sc}$$

Threfore self GMD:

$$D_s = \sqrt[3]{D_{Sa} \cdot D_{Sb} \cdot D_{Sc}} = \sqrt[3]{15.28 \times 17.92 \times 15.28}$$

$$D_s = 16.11 \text{ cm}$$

Mutual GMD calculation:

$$D_a = D_{bc} = D_{a'b'} = D_{c'b'} = \sqrt{3^2 + 0.75^2} = 3.092\,\text{m}$$

$$D_{ab'} = D_{a'b} = D_{cb'} = D_{c'b'} = \sqrt{4.75^2 + 3^2} = 5.61\,\text{m}$$

$$D_{ac'} = D_{a'c} = \sqrt{6^2 + 4^2} = 7.21\,\text{m}$$

Mutual GMD for phase ***a*** and phase ***c***:

$$D_{ma} = D_{mc} = \sqrt[4]{D_{ab} \cdot D_{ac} \cdot D_{ab'} \cdot D_{ac'}}$$

$$= \sqrt[4]{3.092 \times 6 \times 7.21 \times 5.61} = 5.233 \text{ m}$$

Mutual GMD for phase ***b***:

$$D_{mb} = \sqrt[4]{D_{ba} \cdot D_{ba'} \cdot D_{bc} D_{bc'}}$$

$$= \sqrt[4]{3.092 \times 5.61 \times 3.092 \times 5.61} = 4.16 \text{ m}$$

Equivalent mutual GMD:

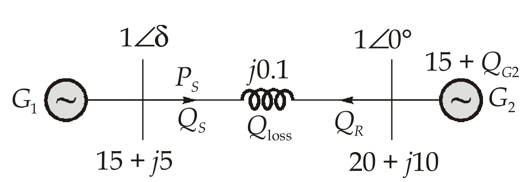
$$D_m = \sqrt[3]{D_{ma} \cdot D_{mb} \cdot D_{mc}}$$

$$= \sqrt[3]{5.233 \times 4.16 \times 5.233} = 4.847 \text{ m}$$

$$\text{Inductance of line } (L) = 0.2 \ln\left(\frac{D_m}{D_s}\right) \text{mH/km/phase}$$

$$L = 0.2 \ln\left(\frac{4.847}{16.11 \times 10^{-2}}\right) = 0.68 \text{ mH/km/phase}$$

Q.6 (c) (ii) Solution:



At G_2 load demand is 20 pu, G_2 supplies only 15 pu. Remaining supplied by G_1 through transmission line.

Real power,
$$P_s = \left|\frac{V_S V_R}{X_L}\right| \sin\delta$$

$$5 = \frac{1\times 1}{0.1}\sin\delta$$

$$\delta = 30°$$

$$Q_S = \frac{V_S^2}{X_L} - \frac{V_S V_R}{X_L}\cos\delta = \frac{1^2}{0.1} - \frac{1\times 1}{0.1}\cos 30° = 1.34 \text{ p.u.}$$

$$Q_R = \left|\frac{V_S V_R}{X_L}\right|\cos\delta - \left|\frac{V_R^2}{X_L}\right|$$

$$= \left|\frac{1\times 1}{0.1}\right|\cos 30° - \frac{1^2}{0.1} = -1.34 \text{ p.u.}$$

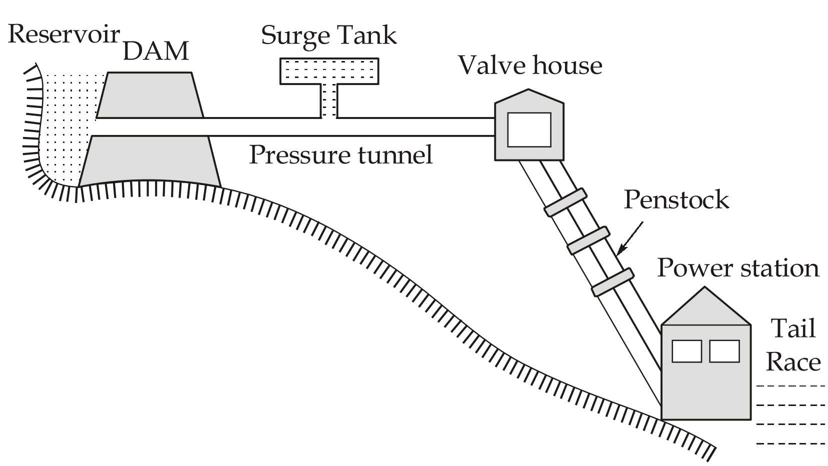
$$Q_{\text{loss}} = Q_S - Q_R$$
$$= 1.34 - (-1.34) = 2.68 \text{ p.u.}$$

At G_1:
$$Q_{G1} = Q_{\text{load}} + Q_S$$
$$= 5 + 1.34 = 6.34 \text{ p.u.}$$

At G_2:
$$Q_{G2} = Q_{\text{load}} + (-Q_R)$$
$$= 10 - (-1.34) = 11.34 \text{ p.u.}$$

Q.7 (a) (i) Solution:

Schematic arrangement of a Hydroelectric plant



The chief requirements for hydroelectric power plant is the availability of water in huge quantity at sufficient head and this requirement can be met by constructing a dam across a river or a lake.

An artificial storage reservoir is formed by constructing a dam across a river (or) a lake and a pressure tunnel is taken off from the reservoir to the valve house at the start of the penstock. The valve house contains mains sluice valves for controlling water flow to the power station and automatic isolating valves for cutting off water supply in case the penstock bursts. A surge tank is also provided just before the valve house for better regulation of water pressure in the system.

From the reservoir the water is carried to valve house through pressure tunnel and from valve house to the water turbine through pipes of large diameter made of steel or reinforcement concrete, called the penstock.

The water turbine converts hydraulic energy into mechanical energy and the alternator coupled to the water turbine converts mechanical energy into electrical energy.

Water after doing useful work is discharged to the tail race.

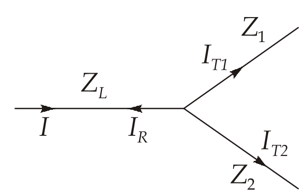
Q.7 (a) (ii) Solution:

Incident voltage, $E = 100$ kV

Surge impedance of overhead line, $Z_c = 500\ \Omega$

Surge impedance of branched lines, $Z_1 = 40\ \Omega$

and $Z_2 = 60\ \Omega$



Transmitted voltage,
$$E_T = \frac{2E}{Z_C + \frac{Z_1 \times Z_2}{(Z_1 + Z_2)}} \times \left(\frac{Z_1 \times Z_2}{Z_1 + Z_2}\right)$$

$$= \frac{2 \times 100}{500 + \left(\frac{40 \times 60}{40 + 60}\right)} \times \left(\frac{40 \times 60}{40 + 60}\right) = 9.16 \text{ kV}$$

Transmitted current,
$$I_{T1} = \frac{E_T}{Z_1} = \frac{9.16 \times 1000}{40} = 229 \text{ A}$$

$$I_{T2} = \frac{E_T}{Z_2} = \frac{9.16 \times 1000}{60} = 152.67 \text{ A}$$

Reflected voltage, $E_R = E_T - E = 9.16 - 100$

$= -90.84$ kV

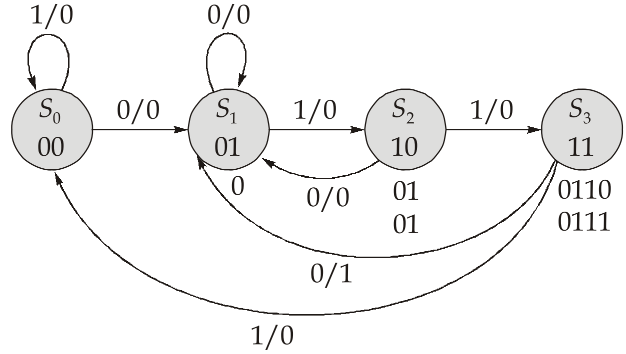
Incident current,
$$I = \frac{E}{Z_C} = \frac{100 \times 1000}{500} = 200 \text{ A}$$

$$\text{Reflected current, } I_R = I_{T1} + I_{T2} - I$$
$$= 229 + 152.67 - 200$$
$$= 181.67 \text{ A}$$

Q.7 (b) Solution:

Serial input X : 00110101101, Output Y : 00001000010

Detected sequence = 0110



For the above sequence detector, the non-overlapping sequence has been given.

Table from State Diagram :

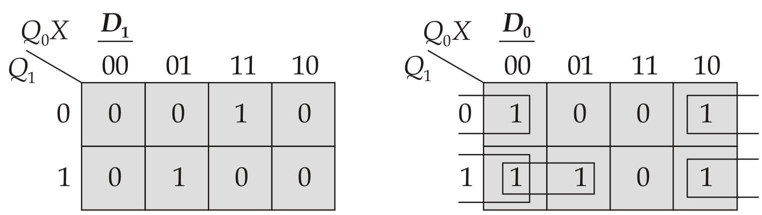
State	Next state		Output (y)	
	$X = 0$	$X = 1$	$X = 0$	$X = 1$
s_0	s_1	s_0	0	0
s_1	s_1	s_2	0	0
s_2	s_1	s_3	0	0
s_3	s_1	s_0	1	0

A simple state assignment can be assuming the outputs of flip flops or Q_1 and Q_0 as given below :

State	Q_1	Q_0
S_0	0	0
S_1	0	1
S_2	1	0
S_3	1	1

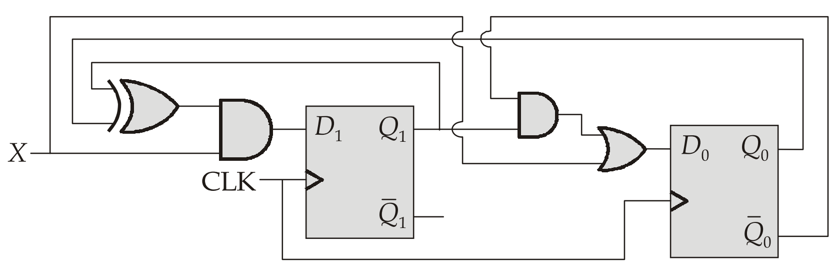
Excitation Table :

Present state Q_1	Q_0	X	Next State Q_1^+	Q_0^+	Output (Y)	D_1	D_0
0	0	0	0	1	0	0	1
0	0	1	0	0	0	0	0
0	1	0	0	1	0	0	1
0	1	1	1	0	0	1	0
1	0	0	0	1	0	0	1
1	0	1	1	1	0	1	1
1	1	0	0	1	1	0	1
1	1	1	1	0	0	0	0



$$D_0 = \bar{X} + Q_1\bar{Q}_0$$

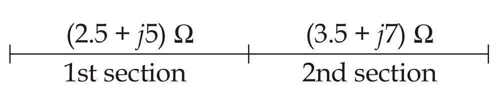
$$D_1 = Q_1\bar{Q}_0X + \bar{Q}_1Q_0X = (Q_1 \oplus Q_0)X$$



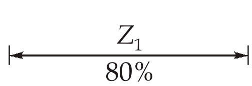
Q.7 (c) Solution:

CT Ratio : 400/1 A

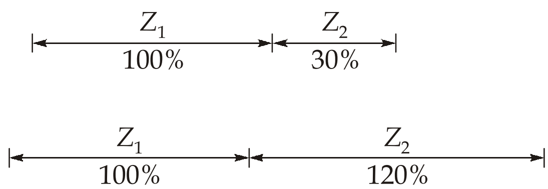
PT Ratio : 132 kV/110 V



For Zone (1) :



For Zone (2) :



(i) Reactance Relay :

For Zone (1) : 80% of section 1,

$$Z_1 = (2 + j4)\ \Omega$$

Reactance, $X = 4\ \Omega \rightarrow$ Primary side

$$X_1\text{ (secondary)} = \left(\frac{\text{CTR}}{\text{PTR}}\right) \times X_1(\text{Primary})$$

$$= \frac{\left(\frac{400}{1}\right)}{\left(\frac{132000}{110}\right)} \times 4 = \frac{4}{3}\ \Omega$$

Therefore, setting of reactance relay for zone 1 = 1.33 Ω

For Zone (2) : 100% of section 1 + 30% of section 2

$$Z_2 = 1 \times (2.5 + j5) + 0.3 \times (3.5 + j7)$$

$$= (3.55 + j7.10)\ \Omega$$

Reactance, $X_2 = 7.10\ \Omega$

$$X_2\text{ (secondary)} = \left(\frac{\text{CTR}}{\text{PTR}}\right) \times X_2(\text{Primary})$$

$$= \frac{400 \times 110}{132000} \times 7.10 = 2.367\ \Omega$$

Therefore, setting of reactance relay for zone 2 = 2.367 Ω

For Zone (3) : 100% of section 1 + 120% of section 2

$$Z_3 = (2.5 + j5) + 1.2 \times (3.5 + j7)$$

$$= (6.7 + j13.4)\ \Omega$$

$$X_3 = 13.4\ \Omega$$

$$X_3\text{ (secondary)} = \left(\frac{\text{CTR}}{\text{PTR}}\right) \times X_3(\text{Primary})$$

$$= \frac{400 \times 110}{132000} \times 13.4 = 4.467\ \Omega$$

Therefore, setting of reactance relay for zone 3 = 4.467 Ω

(ii) Mho relay : $\alpha = 60°$

For Zone 1 : Z_1 = 80% of section (1)

$$Z_1 = (2 + j4)\ \Omega$$

$$Z_1\text{ (Secondary)} = \left(\frac{\text{CTR}}{\text{PTR}}\right) \times Z_1(\text{Primary})$$

$$= \frac{400 \times 110}{132000} \times (2 + j4) = (0.67 + j1.33)\ \Omega$$

$$Z_1 = 1.49\angle 63.43° \Rightarrow \phi = 63.43$$

Therefore, setting of Mho relay for zone (1),

$$K_1 = \frac{Z_1}{\cos(\phi - \alpha)} = \frac{1.49}{\cos(63.43° - 60°)} = 1.4926\ \Omega$$

For Zone 2 : Z_2 = 100% of section (1) + 30% of section (2)

$$Z_2 = (2.5 + j5) + 0.3 \times (3.5 + j7)$$

$$= (3.55 + j7.1)\ \Omega$$

$$Z_2 = 7.94\angle 63.43°\ \Omega$$

$$Z_2\text{ (Secondary)} = \left(\frac{\text{CTR}}{\text{PTR}}\right) \times Z_1(\text{Primary})$$

$$= \frac{400 \times 110}{132000} \times 7.94\angle 63.43° = 2.646\angle 63.43°\ \Omega$$

Therefore, setting of Mho relay for zone (2),

$$K_2 = \frac{Z_2}{\cos(\phi - \alpha)} = 2.65\ \Omega$$

For Zone 2 : Z_3 = 100% of section (1) + 120% of section (2)

$$= (2.5 + j5) + 1.2 \times (3.5 + j7) = (6.7 + j13.4)\ \Omega$$

$$Z_3 = 14.98\angle 63.43°\ \Omega$$

$$Z_3\text{ (Secondary)} = \left(\frac{\text{CTR}}{\text{PTR}}\right) \times Z(\text{Primary})$$

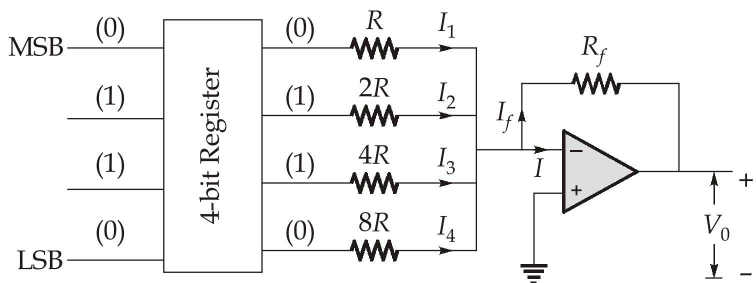
$$= \frac{400 \times 110}{132000} \times 14.98\angle 63.43° = 5\angle 63.43°\ \Omega$$

Therefore, setting of Mho relay for zone (3),

$$K_3 = \frac{Z_3}{\cos(\phi - \alpha)} = \frac{5}{\cos(63.43 - 60°)} = 5\ \Omega$$

Q.8 (a) (i) Solution:

Given, input code is 0110.



Using the concept of virtual short, $V^- = V^+ = 0$.

$$\therefore \quad I_1 = \frac{V_R}{R}(0) = 0\text{ A}$$

$$I_2 = \frac{V_R}{2R}(1) = \frac{10}{2 \times 1\text{ k}}(1) = 5\text{ mA}$$

$$I_3 = \frac{V_R}{4R}(1) = \frac{10}{4 \times 1\text{ k}}(1) = 2.5\text{ mA}$$

$$I_4 = \frac{V_R}{8R}(0) = 0\text{ A}$$

Output voltage, $V_0 = -I_f \times R_f$

where, $I_f = I_1 + I_2 + I_3 + I_4 = 7.5\text{ mA}$

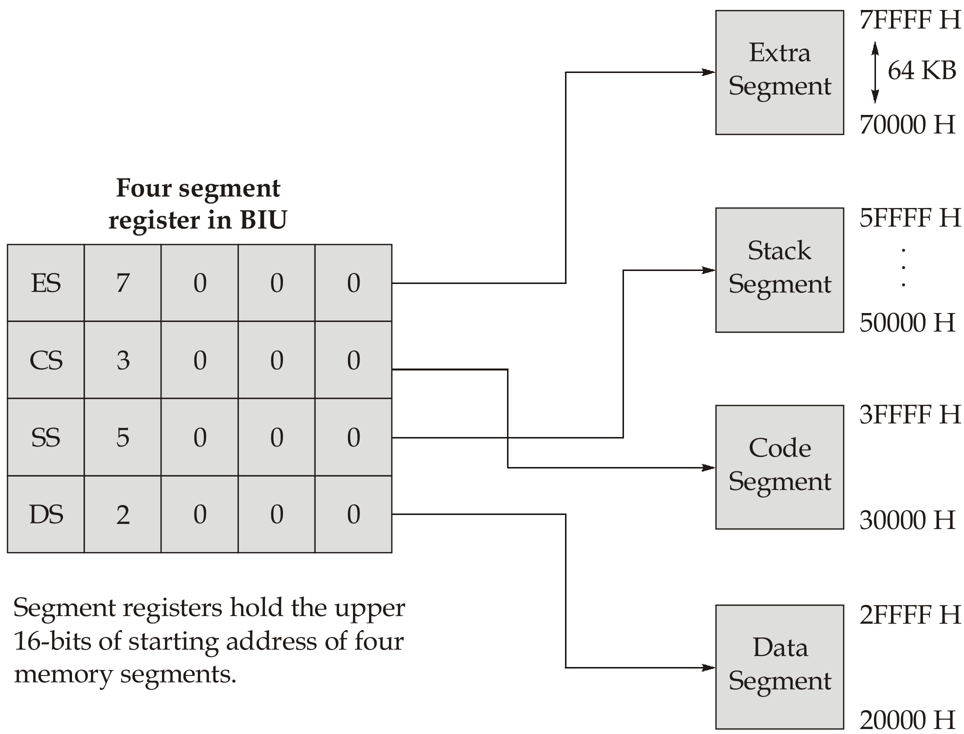
$\therefore \quad V_0 = -7.5 \times 10^{-3} \times 10^3$

$\therefore \quad V_0 = -7.5\text{ V}$

Q.8 (a) (ii) Solution:

Segmentation is a process in which the main memory of the computer is logically divided into different segments and each segment has its base address. It is basically used to enhance the speed of execution of the computer system, so that the processor is able to fetch and execute the data from the memory easily and fast.

The Bus Interface Unit (BIU) contains four 16 bit special purpose registers (mentioned below) called as Segment Registers.



Code Segment Register : It is used for addressing memory location in the code segment of the memory where executable program is stored.

Data Segment Register : Points to the data segment of the memory where the data is stored.

Extra Segment Register : Also refers to a segment in the memory where the data is stored.

Stack Segment Register : It is used for addressing stack segment of the memory.

The number of address lines in 8086 is 20, 8086 BIU will send 20 bit address, so as to access one of the 1 MB memory locations. The four segment registers actually contain the upper 16-bits of the starting addresses of the four memory segments of 64 kB each.

In memory segmentation, each segment consists of two main components which are—

- **Segment Address** — It is a 16-bit address which points to the first location of the segment.
- **Offset Address** — It is also a 16-bit address which specifies the location within the memory segment, with respect to its starting address.

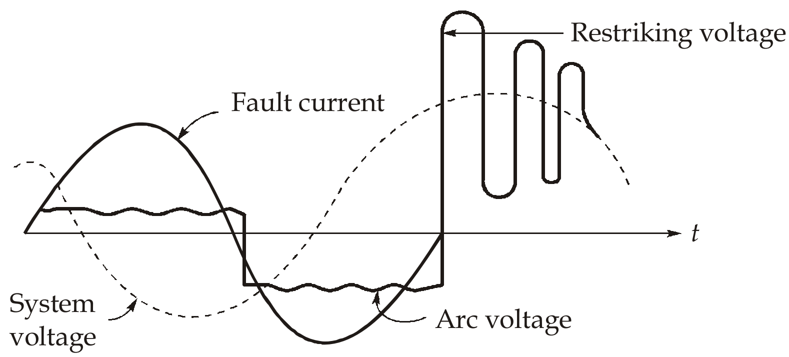
When the microprocessor accesses the memory, it combines the segment and offset addresses to calculate the physical address of the memory location. It is done by using the following formula:

$$\text{Physical Address} = (\text{Segment Address} * 10\text{H}) + \text{Offset Address}$$

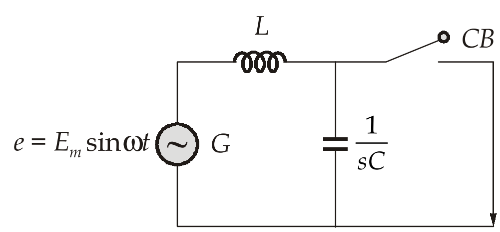
8086 does not work the whole 1 MB memory at any given time. However it works only with four 64 kB segments within the whole 1 MB memory.

Q.8 (b) Solution:

(i) **Restriking voltage:** At the instant of arc extinction, an LC transient occurs including the generator inductance and stray capacitance causing high frequency damped oscillations. This voltage appearing across the circuit-breaker is known as restriking voltage.



RRRV: It is the rate of rise of restriking voltage which appears across the circuit breaker.



For an instant $e = E_m \sin\omega t$,

$$V_B(s) = \frac{\frac{1}{sC}}{\left(\frac{1}{sC}+sL\right)} \times \left(\frac{E_m}{s}\right) = \frac{E_m}{s(s^2LC+1)}$$

$$V_B(s) = E_m\left[\frac{1}{s} - \frac{s}{s^2+1/LC}\right]$$

Take inverse L.T,
$$V_B(t) = E_m\left(1-\cos\frac{1}{\sqrt{LC}}\right)\text{kV}$$

$$= E_m(1-\cos\omega t)\ \text{kV}$$

Maximum restriking voltage occurs at,

$$\omega t = \pi$$

$$V_{B\max} = 2E_m$$

$$\text{RRRV} = \frac{dV_B}{dt} = E_m\left(\frac{1}{\sqrt{LC}}\sin\omega t\right)$$

$$\text{RRRV} = \frac{E_m}{\sqrt{LC}}\sin\omega t \text{ kV/sec}$$

$$\text{RRRV}_{\max} = \frac{E_m}{\sqrt{LC}} \text{ kV/sec}$$

(ii) SF_6 circuit breaker is preferred for voltages 132 kV and above because of the following reasons.

(a) **High dielectric strength:** SF_6 has high electronegativity so it absorbs the free e^- in space avoids the possibility of electron avalanche and therefore give rise the high dielectric strength.

(b) **Effective arc quenching:** SF_6 has unique property of after the source emerging the spark is removed. This makes SF_6 100 times effective as air in arc quarching.

(c) **High RRRV rating:** Due to lower thermal time constant of SF_6, for the same operating voltage frequency of mains is 100 times as to air, and RRRV ∝ Natural frequency (f_n), therefore it can withstand severe RRRV. Thus most suitable for short line faults without suitabling resistors and can interrupt capacitive current without restriking.

(d) **Excellent heat transfer capability:** Because of its high ‘molecular weight with its low gaseous viscosity enables it transfer heat by convection more effectively.

(e) It requires low pressure at which SF_6 is stored and used.

(iii)
$$E_m = \frac{132\sqrt{2}}{\sqrt{3}} = 107.78 \text{ kV/phase}$$

Max restriking voltage,

$$TR\ V_{\max} = 2\,E_m = 2 \times 107.78 = 215.56 \text{ kV}$$

$$L = \left(\frac{X_L}{\omega}\right) = \frac{5}{100\pi} = 15.915 \text{ mH}$$

$$RRR\ V_{\max} = \frac{Em}{\sqrt{LC}}$$

$$RRR\ V_{\max} = \frac{107.78}{\sqrt{15.915\times10^{-3}\times0.03\times10^{-6}}} = 4932.581 \text{ kV/sec}$$

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

$$f_n = \frac{1}{2\pi\sqrt{15.915\times10^{-3}\times0.03\times10^{-6}}}$$

$$= 7283.769 \text{ Hz} = 7.283 \text{ kHz}$$

Q.8 (c) (i) Solution:

From the given sequential circuit

$$S_1 = Q_2(\overline{RQ_2 \oplus \overline{R}T}) + \overline{Q}_2(RQ_2 \oplus \overline{R}T)$$

$$= Q_2(RQ_2 \odot \overline{R}T) + \overline{Q}_2(RQ_2 \oplus \overline{R}T)$$

$$= Q_2(RQ_2\overline{R}T + \overline{RQ_2}\,\overline{\overline{R}T}) + \overline{Q}_2(\overline{RQ_2}\,\overline{R}T + RQ_2\,\overline{\overline{R}T})$$

$$= Q_2[RQ_2\overline{R}T + (\overline{R}+\overline{Q}_2)(R+\overline{T})] + \overline{Q}_2((\overline{R}+\overline{Q}_2)\overline{R}T + RQ_2(R+\overline{T})]$$

$$= Q_2[0 + \overline{R}\,\overline{T} + RQ_2 + \overline{T}\,\overline{Q}_2] + \overline{Q}_2[\overline{R}T + \overline{Q}_2\overline{R}T + RQ_2 + RQ_2\overline{T}]$$

$$= \overline{R}\,\overline{T}Q_2 + \overline{Q}_2\overline{R}T$$

$$\Rightarrow \quad S_1 = Q_2\overline{R}\,\overline{T} + \overline{Q}_2\overline{R}T$$

$$R_1 = \overline{Q}_2(\overline{RQ_2 \oplus \overline{R}T}) + Q_2(RQ_2 \oplus \overline{R}T)$$

$$= \overline{Q}_2(RQ_2 \odot \overline{R}T) + Q_2(RQ_2 \oplus \overline{R}T)$$

$$= \overline{Q}_2[RQ_2\overline{R}T + \overline{RQ_2}\,\overline{\overline{R}T}] + Q_2[(\overline{RQ_2}\,\overline{R}T + RQ_2\,\overline{\overline{R}T}]$$

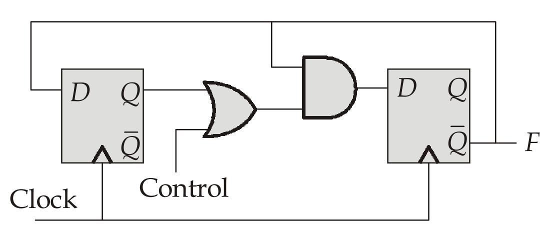
$$= \overline{Q}_2(\overline{R}+\overline{Q}_2)(R+\overline{T}) + Q_2(\overline{R}+\overline{Q}_2)\overline{R}T + RQ_2(R+\overline{T})]$$

$$= \overline{R}\,\overline{T}\,\overline{Q}_2 + R\overline{Q}_2 + \overline{Q}_2\overline{T} + \overline{R}TQ_2 + RQ_2 + RQ_2\overline{T} + \overline{T}\,\overline{Q}_2(R+1)$$

$$+R + \overline{R}TQ_2 + RQ_2\overline{T}\;\overline{T}\,\overline{Q}_2 + R(1+Q_2\overline{T}) + \overline{R}TQ_2$$

$$= \overline{T}\,\overline{Q}_2 + R + \overline{R}TQ_2$$

Q.8 (c) (ii) Solution:



We have, $D_1 = \begin{cases} \overline{Q}_1 \cdot Q_0; \text{ when control} = 0 \\ \overline{Q}_1; \text{ when control} = 1 \end{cases}$

and $D_0 = F = \overline{Q_1}$

Assume the initial state as $Q_1Q_0 = 00$.

State Table [when control = 0]:

D_0	D_1	Q_0	Q_1	F
		0	0	1
1	0	1	0	1
1	1	1	1	0
0	0	0	0	0

Hence, after 3 clock cycles, the output repeats.

$$\therefore \qquad f_{\text{out}} = \frac{f_{clk}}{3} = \frac{12\text{ MHz}}{3} = 4\text{ MHz}$$

State table [when control = 1]

D_0	D_1	Q_0	Q_1	F
		0	0	1
1	1	1	1	0
0	0	0	0	1

Hence, the output repeats after 2 clock cycles.

$$\therefore \qquad f_{\text{out}} = \frac{f_{clk}}{2} = \frac{12\text{ MHz}}{2} = 6\text{ MHz}$$

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