Q1 (a) Universal motor : $P = 2$

$\llcorner$ AC series motor. $Z = 960$

$P_{input} = 300\,W$

$R_a = 3.5\,\Omega$; $V_t = 100\,V$ $N = 5000$ rpm ; $I_a = 4.6\,A$.

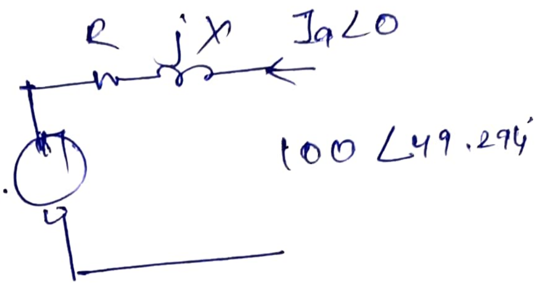
Back emf. $E_b = \dfrac{PN\phi Z}{60A} \Rightarrow \phi = \dfrac{E_b \times 60}{N \times Z}$ — (1)

$[P = 2 = A]$.

$P_{i/p} = VI\cos\phi$

$300 = 100 \times 4.6 \times \cos\phi$

$\phi = 49.294^\circ$



$100\angle 49.294 = I_a\angle 0\,(R + jX) + E_b\angle 0$.

$65.217 + j75.8 = 4.6 \times (3.5 + jX) + E_b$.

$65.217 + j75.8 = 16.1 + E_b + j4.6X$.

Comparing real & imaginary part.

$E_b = 65.217 - 16.1 = \underline{\underline{49.117\,V}}$.

& $X = \dfrac{75.8}{4.6} = \underline{\underline{16.478\,\Omega}}$ Ans

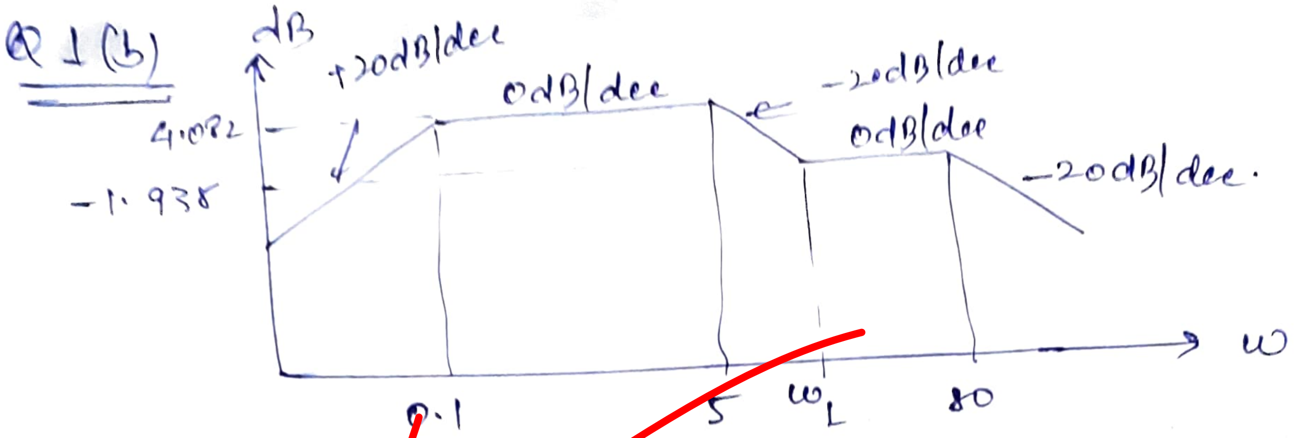
Rms value of emf is:

$E = \dfrac{1}{\sqrt{2}} \dfrac{\phi N Z}{60}$

$\phi = \dfrac{\sqrt{2} \times 49.117 \times 60}{5000 \times 960}$

$\boxed{\phi = 0.868\,mWb}$ Ans

Q 1 (b)



zero at : origin, ω_1

poles at : 0.1, 5, 80.

∴ Let the transfer function be T.F = $\dfrac{K s\left(\frac{s}{\omega_1}+1\right)}{\left(\frac{s}{0.1}+1\right)\left(\frac{s}{5}+1\right)\left(\frac{s}{80}+1\right)}$ —(1)

Eqn of line is given as:-

$y = mx + c.$

$y = 20\log\omega + 20\log K.$

at $\omega = 0.1$ $y = 4.082$ dB.

$4.082 = 20\log 0.1 + 20\log K.$

$24.082 = 20\log K.$

$K = 15.9992 \simeq 16.$ $\boxed{K=16}$ —(2)

How to find ω_1

$$\text{slope} = \frac{y_2 - y_1}{x_2 - x_1}$$

between $\omega = 5$ & $\omega = \omega_1$ slope = −20dB/dec

$$-20 = \frac{-1.938 - 4.082}{\log\omega_1 - \log 5}.$$

$\log \omega_1 - \log 5 = 0.301$

$\omega_1 = 9.9993$

$\boxed{\omega_1 \simeq 10 \text{ r/s}}$ —(3)

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

$$T.F = \frac{16 s \left(\frac{s}{10}+1\right)}{\left(\frac{s}{0.1}+1\right)\left(\frac{s}{5}+1\right)\left(\frac{s}{80}+1\right)}$$

$$= \frac{16 s \frac{(s+10)}{10}}{\frac{1}{0.1\times5\times80}(s+0.1)(s+5)(s+80)}$$

$$\boxed{T.F. = \frac{64 s (s+10)}{(s+0.1)(s+5)(s+80)}}$$

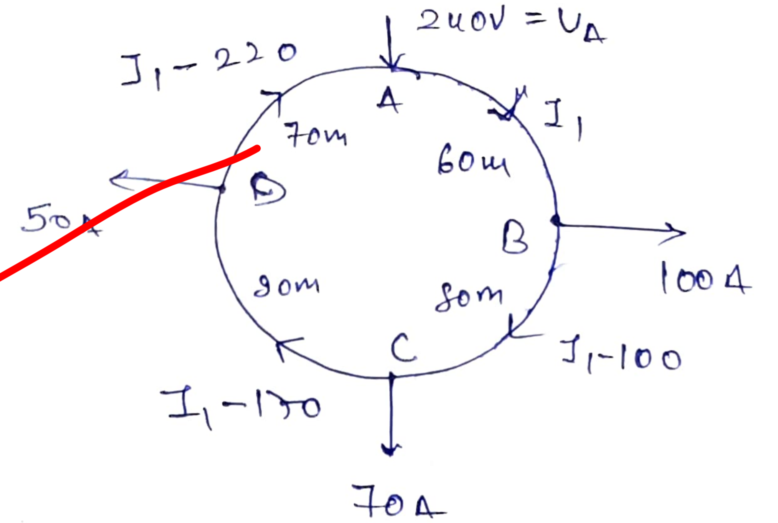
Ans

Q.1 (c) conductor resistance

$= 0.1 \Omega/km$

$= 0.1\Omega/10^3 m.$

$= 10^{-4} \Omega/m.$



$\therefore r_{AB} = 60 m \times 10^{-4} \frac{\Omega}{m}$

$= 6\times10^{-3}\Omega$

$r_{BC} = 80\times10^{-4} = 8\times10^{-3}\Omega$; $r_{CD} = 90\times10^{-4} = 9\times10^{-3}\Omega$

$r_{DA} = 70\times10^{4} = 7\times10^{-3}\Omega$

Applying KVL in loop circuit

$0 = I_1 . r_{AB} + (I_1 - 100)\times r_{BC} + (I_1 - 170)\times r_{CD} + (I_1 - 220)\times r_{DA}$

$= I_1\times 6\times10^{-3} + (I_1 - 100)\times 8\times10^{-3} + (I_1 - 170)\times 9\times10^{-3}$
$+ (I_1 - 220)\times 7\times10^{-3}$

$0 = 6I_1 + 8I_1 - 800 + 9I_1 - 1530 + 7I_1 - 1540.$

$\boxed{I_1 = 129 A}$

(i). voltage at B $\quad V_B = V_A - I_1 \times r_{AB}$

$= 240 - 129\times 6\times10^{-3}$

$\boxed{V_B = 239.226 V}$

voltage at C $\quad V_C = V_B - (I_1 - 100)\times r_{BC}$

$= 239.226 - 29\times 8\times10^{-3}$

$\boxed{V_C = 238.994 V}$

Voltage at D : $V_D = V_C - (I_1 - 170) \times r_{CD}$

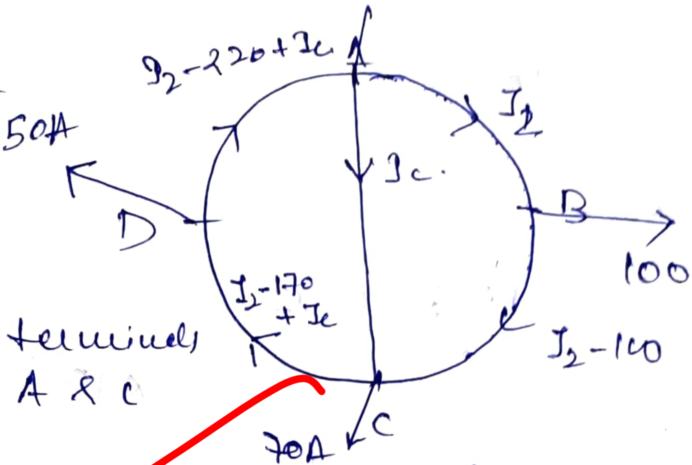
$= 238.994 + 41 \times 9 \times 10^{-3}$

$\boxed{V_D = 239.363\,V}$

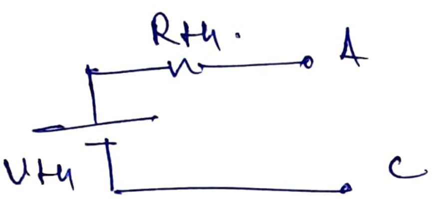
(ii). Interconnector resistance

$= 100 \times 10^{-4}\ \Omega$

$R_C = 10^{-2}\ \Omega$



Thevenin Equivalent at terminals A & C



$R_{th} = (r_{AB} + r_{BC}) \,||\, (r_{CD} + r_{DA})$

$R_{th} = (14 \times 10^{-3}) \,||\, (16 \times 10^{-3})$

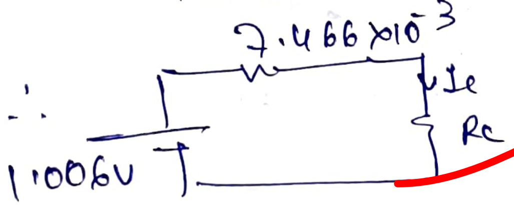
$R_{th} = 7.466 \times 10^{-3}\ \Omega$

$V_{th} = V_A - V_C$

$= 240 - 238.994$

$= 1.006\,V.$

∴



$I_c = \frac{V_{th}}{R_{th} + R_c} = \frac{1.006}{7.466 \times 10^{-3} + 10^{-2}}$

$I_c = 57.597\ A.$

∴ ~~Voltage at B V_B =~~

Apply KVL in loop

$0 = I_2 \times 6m + (I_2 - 100) \times 8m + (I_2 - 112.403) \times 9m + (I_2 - 162.403) \times 7m.$

$= 6I_2 + 8I_2 - 800 + 9I_2 - 1011.627 + 7I_2 - 1136.821$

$\boxed{I_2 = 98.2816\ A}$

$\therefore$ voltage at B $\quad V_B = 240 - 98.2816 \times 6\times10^{-3}$

$$\boxed{V_B' = 239.4103\ V}$$

voltage at C $\quad V_C = V_B - (I_2 - 100) \times 8\times10^{-3}$

$$\boxed{V_C' = 239.424\ V}$$

voltage at D $\quad V_D = V_C - (I_2 - 170 + 10) \times 9\times10^{-3}$

$$\boxed{V_D' = 239.5511\ V}$$

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(iii). Losses without inter connector

$= (129^2 \times 6\times10^{-3}) + (29^2 \times 8\times10^{-3}) + (41^2 \times 9\times10^{-3})$
$+ (91^2 \times 7\times10^{-3})$

$= 179.67$ W.

Losses with inter connector

$= (98.2816^2 \times 6\times10^{-3}) + (1.7184^2 \times 8\times10^{-3}) + (14.1214^2 \times 9\times10^{-3})$
$+ (64.1214^2 \times 7\times10^{-3})$

$= 88.554$ W.

efficiency $(\eta) = \dfrac{o/p}{i/p} = \dfrac{i/p - loss}{i/p} = 1 - \dfrac{loss}{i/p}.$

$$\boxed{\eta \propto losses}$$

$\therefore$ change in efficiency $= |\Delta\eta| = \left|\dfrac{88.554 - 179.67}{179.67}\right| \times 100$

$$\boxed{\Delta\eta = 50.71\ \%.}$$

ie. 'η' improves by 50.71 % Ans

Q.1 (d) NBFM $\phi_{FM}(t)$

i) Avg power = $8W = \frac{A_c^2}{2}$ $\Rightarrow$ $A_c = \sqrt{16}$

$\boxed{A_c = 4\,V}$

$f_c = 100\text{ kHz} = 10^5\text{ Hz}$

(ii). $\beta = 0.5$ (iii). i/p $m(t) = 6\cos(300\pi t)$

$f_m = \frac{300\pi}{2\pi} = 150\text{ Hz}$.

NBFM is given as :-

$$\phi_{FM}(t) = A_c\cos\left[2\pi f_c t + 2\pi k_f\int_0^t m(\tau)\,d\tau\right]$$

$$= A_c\cos\left[2\pi f_c t + 2\pi k_f\int_0^t 6\cos 300\pi t\,dt\right]$$

$$= A_c\cos\left[2\pi f_c t + 2\pi k_f\cdot\frac{6\sin 300\pi t}{300\pi}\right]$$

$$= A_c\cos\left[2\pi f_c t + \underbrace{0.04k_f}_{\beta = 0.5}\sin 300\pi t\right].$$

$\therefore\ k_f = \frac{0.5}{0.04} = 12.5$ Hz/volt.

$$= A_c\cos\left[2\pi f_c t + \beta\sin 300\pi t\right].$$

$$= A_c\cos(2\pi f_c t)\cdot\cos(\underbrace{\beta\sin 300\pi t}_{\theta}) - A_c\sin(2\pi f_c t)\cdot\sin(\underbrace{\beta\sin 300\pi t}_{\theta})$$

for NBFM $\beta < 1$.

for small θ ; $\cos\theta \simeq 1$

$\sin\theta \simeq \theta$

$\therefore \phi_{FM}(t) = A_c \cos(2\pi f_c t) - A_c \sin(2\pi f_c t)(\beta \sin 300\pi t)$

$$= A_c \cos(2\pi f_c t) - \frac{A_c\beta}{2} \cdot \cos 2\pi (f_c - f_m) t + \frac{A_c\beta}{2} \cdot \cos 2\pi (f_c + f_m) t.$$

Substituting values of A_c, f_c, β, f_m in above eq^n.

$$\phi_{FM}(t) = 4 \cos(2\pi \times 10^5 t) - \cos 2\pi (99850\, t) + \cos 2\pi (100150\, t)$$

= Ans

Q1 (e) Two 6 pulse converter Bipolar HVDC transmission 1000 MW ± 200 kV.

$P = V.I$

crt in transmission line $\Rightarrow I = \dfrac{1000 \times 10^6}{400 \times 10^3} = 2500$ A.

$= 2.5$ KA.

$I_{T\,rms} = \dfrac{2500}{\sqrt{3}} = \cancel{1767.767\ A}$

$= 1443.375$ A.

~~I_T peak = I~~

for PIV rating, $PIV = \dfrac{V_{ml}}{2}$.

for $\alpha = 0$.

$\dfrac{3V_{ml}}{\pi} \cos\alpha = 200 \times 10^3$

$V_{ml} = \dfrac{200 \times 10^3 \times \pi}{3} = 209.44$ kV.

∵ Two thyristor values are connected.

∴ ~~PIV~~ PIV of each thyristor value $= \dfrac{V_{ml}}{2}$

$= 104.719$ kV

= Ans

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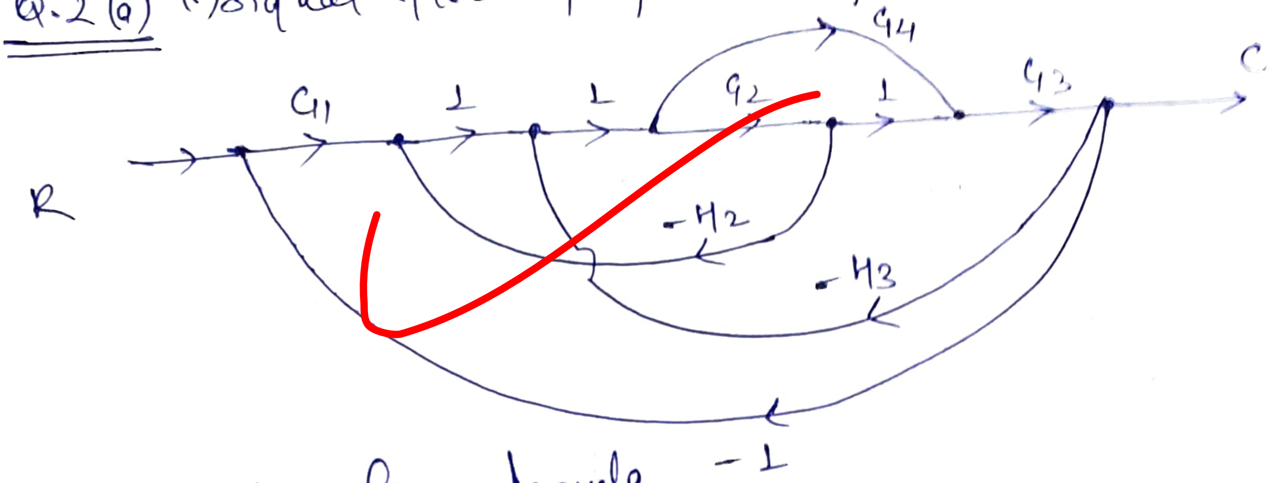
Q.2 (a) (i) Signal flow graph is given as:



By Mason's Gain formula.

$$T.F = \frac{\sum P_K \cdot \Delta_K}{\Delta}$$

$P_1 = G_1 G_2 G_3$; $P_2 = G_1 G_3 G_4$

$L_1 = -G_1 G_2 G_3$; $L_2 = -G_2 H_2$; $L_3 = -G_2 G_3 H_3$

$L_4 = -G_3 G_4 H_3$; $L_5 = -G_1 G_3 G_4$

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$\therefore \Delta = 1 - (L_1 + L_2 + L_3 + L_4 + L_5)$

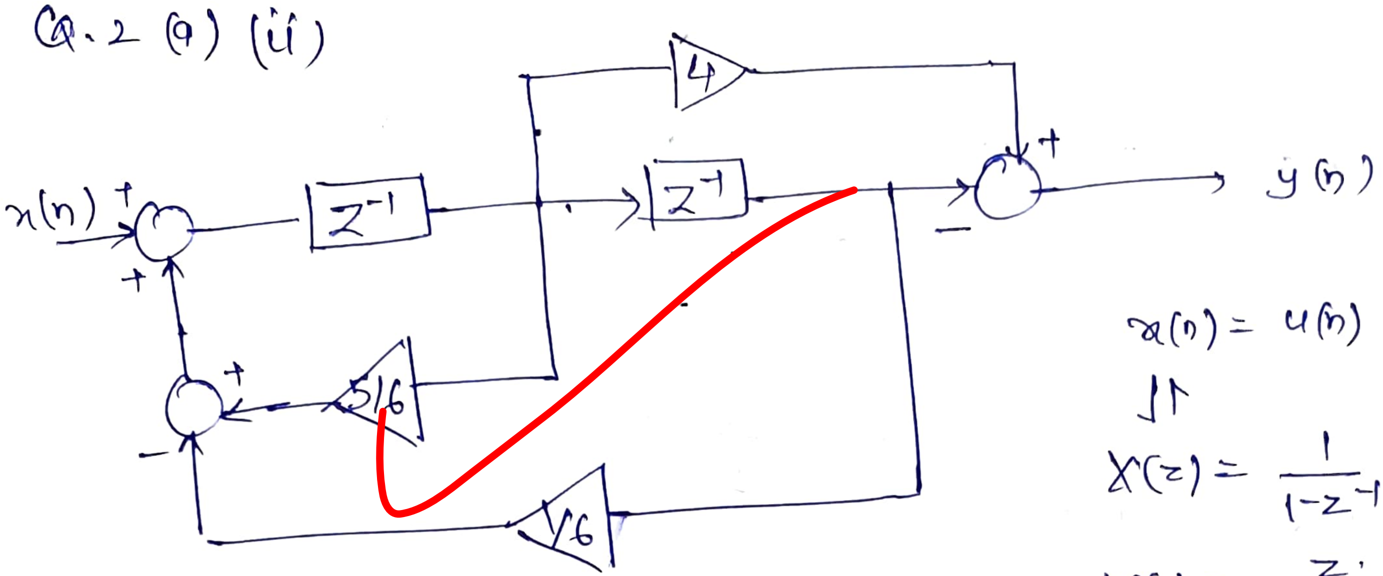
$\Delta_1 = 1$; $\Delta_2 = 1$.

$$\therefore T.F = \frac{G_1 G_2 G_3 + G_1 G_3 G_4}{1 + G_1 G_2 G_3 + G_2 H_2 + G_2 G_3 H_3 + G_3 G_4 H_3 + G_1 G_3 G_4}$$

$$= \frac{G_1 G_3 (G_2 + G_4)}{1 + G_1 G_2 G_3 + G_2 H_2 + G_2 G_3 H_3 + G_3 G_4 H_3 + G_1 G_3 G_4}$$

= Ans

Q. 2 (a) (ii)



$x(n) = u(n)$

$\Downarrow\Uparrow$

$X(z) = \frac{1}{1-z^{-1}}$.

$X(z) = \frac{z}{z-1}$

To obtain $\frac{Y(z)}{X(z)} = ?$

Using Mason's Gain Formula,

$P_1 = 4z^{-1}$ $\quad P_2 = z^{-2}$

$L_1 = \frac{5}{6}z^{-1}$; $L_2 = -\frac{1}{6}z^{-2}$

$$\therefore \frac{Y(z)}{X(z)} = \frac{4z^{-1} + z^{-2}}{1 - \left(\frac{5}{6}z^{-1} - \frac{1}{6}z^{-2}\right)} = \frac{4z^{-1} + z^{-2}}{1 - \frac{5}{6}z^{-1} + \frac{1}{6}z^{-2}}$$

$$\frac{Y(z)}{X(z)} = \frac{6(4z+1)}{6z^2 - 5z + 1}$$

$$Y(z) = \frac{6(4z+1)}{6z^2 - 5z + 1} \cdot \frac{z}{(z-1)}$$

$$\frac{Y(z)}{z} = \frac{24z + 6}{(z-1)(z-\frac{1}{2})(z-\frac{1}{3})} \quad -(1)$$

Using partial fraction

$$\frac{Y(z)}{z} = \frac{A}{z-1} + \frac{B}{z-1/2} + \frac{C}{z-1/3}.$$

$$(24z+6) = A(z-1/2)(z-1/3) + B(z-1)(z-1/3) + C(z-1)(z-1/2).$$

Put $z=1$.	Put $z=1/2$.	Put $z=1/3$.
$30 = \frac{A}{3}$	$18 = -\frac{1}{12}B$	$14 = \frac{1}{9}C$.
$A = 90$	$B = -216$	$C = 126$.

$$\therefore Y(z) = 90\frac{z}{z-1} - 216\frac{z}{z-1/2} + 126\frac{z}{z-1/3}.$$

|| Inverse Z transform.

$$y(n) = 90(1)^n u(n) - 216\left(\frac{1}{2}\right)^n u(n) + 126\left(\frac{1}{3}\right)^n u(n). \quad -(1)$$

Put $n=0$

$y(0) = 90 - 216 + 126. = 0$ Ans

Put $n=\infty$

$y(\infty) = 90 - \cancel{216(1/2)^\infty + 126(1/3)^\infty}$ $\cancel{90 - 0 + 0 = 90}$. $= \cancel{153} + 90$ Ans

Initial value theorem is given as -

$$y(n)\Big|_{n=0} = \lim_{z\to\infty} [Y(z)] = \lim_{z\to\infty} \frac{6(4z+1)\cdot z}{(6z^2-5z+1)(z-1)}$$

$$\boxed{y(0) = 0} \text{ Ans.}$$

Final value theorem is given as -

$$y(n)\Big|_{n=\infty} = \lim_{z\to 1} (1-z^{-1})\, Y(z) = \cancel{\frac{(1-z^{-1})\,6(4z+1)}{6z^2-5z+1}} \cdot \frac{1}{(1-z^{-1})}$$

$y(\infty) = \cancel{90}$

$$= \lim_{z \to 1} \frac{\cancel{z-1}}{z} \cdot \frac{(24z+6)z}{\cancel{(z-1)}(z-1/2)(z-1/3)}$$

$$= \frac{24+6}{\frac{1}{2} \times \frac{2}{3}} = \underline{\underline{90}}. \text{ Ans}$$

$$\boxed{y(\infty) = 90} \text{ = Ans}$$

Q 2(b) PMDC motor

$R_a = 4.2\,\Omega$

for $V = 6V$; $N = 12125$ rpm ; $I_{a0} = 14.5\,mA$.

no load i/p $= V \times I_{a0} = 6 \times 14.5 \times 10^{-3} = 0.087\ W$. —(1)

or no load rotation loss

$E_b = V - I_{a0} \times R_a = 6 - 14.5 \times 10^{-3} \times 4.2$

$E_b = 5.9391\,V$

$E_b = K\phi\,\omega_m$.

$$K\phi = \frac{5.9391}{2\pi \times \frac{12125}{60}} = 4.677 \times 10^{-3}\ \frac{V}{r/sec} \quad -(2)$$

Stalled condition i.e. $\omega_m = 0 \Rightarrow E_b = 0$.

$$\therefore I_a = \frac{V}{R_a} = \frac{6}{4.2} = 1.42857\ A.$$

Torque $T = K\phi . I_a$.

$= 4.677 \times 10^{-3} \times 1.42857$

Stalled torque $T = 6.6814 \times 10^{-3}$ N-m. Ans.

Stalled current $I_a = 1.42857\ A$ Ans

for Given o/p $= 1.6\ W = E_b . I_a$.

$\boxed{\cancel{\text{rot loss} \propto N^2}}$

~~Let N_2 be new speed~~

~~I_{a2} be new current.~~

~~new rot. loss $= P_{R2} = P_{R1} \times \left(\frac{N_2}{N_1}\right)^2$.~~

$$P_{R_2} = 0.087 \times \left(\frac{N_2}{12125}\right)^2 \quad -(3)$$

$$\cancel{\text{motor o/p} = \frac{1.6}{1.6 + 0.087 \times \left(\frac{N_2}{12125}\right)^2}}$$

~~Also motor o/p ⇒ $E_b \cdot I_a$~~

$$1.6 = E_b \cdot I_a \Rightarrow 1.6 = (6 - 4.2 I_a) \cdot I_a$$

$$1.6 = 6 I_a - 4.2 I_a^2$$

on solving, $I_a = 1.073\,A$ (rejected) ; $I_a = 0.354\,A$

$\boxed{I_a = 0.354\,A}$ Ans.

$\therefore E = 6 - 0.354 \times 4.2 = 4.5132\,V$

$$\therefore \omega_2 = \frac{4.5132}{K\phi} = \frac{4.5132}{4.678 \times 10^{-3}} = 964.77\ r/s.$$

$\therefore \boxed{N_2 = 9212.88\ rpm}$ Ans.

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$\therefore$ From eqn (3)

$$P_{R_2} = 0.087 \times \left(\frac{9212.88}{12125}\right)^2$$

$$P_{R_2} = 0.05\,W$$

$$\eta = \frac{o/p}{i/p} = \frac{1.6 - 0.05}{6 \times 0.354} \times 100$$

$\boxed{\eta = 72.995\,\%}$ Ans.

Q.2 (c) (i). Universal Relay Torque Equation is given as:

$$T_d = K_1 I^2 + K_2 V^2 + K_3 VI \cos(\theta - \tau) - K_4$$

$K_1 I^2 \rightarrow$ overcurrent ; $K_3 VI \cos(\theta - \tau) \rightarrow$ directional

$K_2 V^2 \rightarrow$ over voltage ; $K_4 \rightarrow$ spring restraining torque

$T_d \rightarrow$ deflecting torque

3 distance relays are :

1. Impedance Relay: (Voltage Restraint Overcurrent Relay).

$$T_d = K_1 I^2 - K_2 V^2$$

(i) for trip condition $T_d > 0$

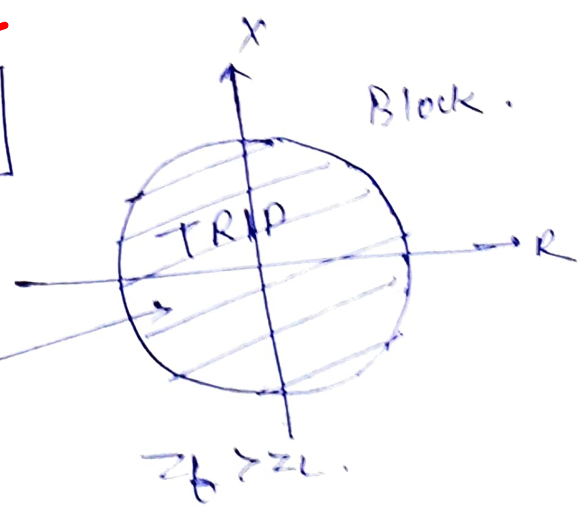
i.e. $K_1 I^2 - K_2 V^2 > 0$.

$$\sqrt{\frac{K_1}{K_2}} > \frac{V}{I}$$

Here $\frac{V}{I} = Z_f$ (fault impedance)

& $\sqrt{\frac{K_1}{K_2}} = Z_L$ (line impedance).

$\therefore$ trip condition. $\boxed{Z_f < Z_L}$



2. Mho / Admittance Relay : (Voltage restraint directional relay)

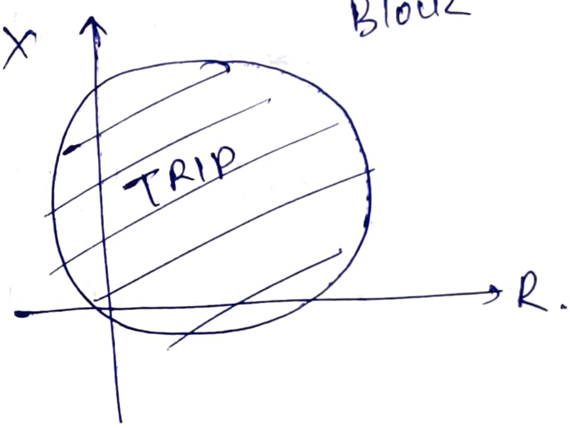
$T_d = K_3 VI \cos(\theta - \tau) - K_2 V^2$

for trip condition: $T_d > 0$.

$K_3 VI \cos(\theta - \tau) - K_2 V^2 > 0$.

$\frac{K_3}{K_2} \cos(\theta - \tau) > \frac{V}{I}$.

$\frac{V}{I} = Z_f$; $\frac{K_3}{Z_2} \cos(\theta - \tau) = Z_f$.



3. Reactance Relay:

(Directional restraint overcurrent relay.)

$T_d = K_1 I^2 - K_3 VI \cos(\theta - \tau)$

for trip condition $T_d > 0$.

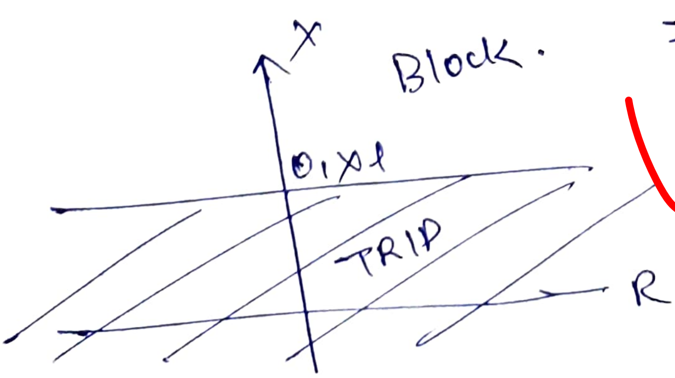
i.e. $K_1 I^2 - K_3 VI \cos(\theta - \tau) > 0$

$\frac{K_1}{K_3} > \frac{V}{I} \cos(\theta - \tau)$

for $\tau = 90°$ $\Rightarrow$ $\frac{K_1}{K_3} > Z \sin\theta$

$\Rightarrow \frac{K_1}{K_2} > X_f$.

$\frac{K_1}{K_3} = X_f$.



Q.2C (ii). $V = 10KV$; $R_n = 10\Omega$

out of balance current $= 1.8$ A

1. % of winding unprotected $\% W_u = \frac{I_N R_H}{V_{ph}} \times 100$

$$\% W_u = \frac{\frac{1.8 \times 5000}{5} \times 10}{\frac{10 \times 10^3}{\sqrt{3}}} \times 100 = 62.3538\%$$

1. ∴ % of winding protected $= 100 - \% W_u$

$= 37.6461\%$ Ans.

2. Let R_x be the value of resistance required to protect 80% of winding.

∴ % of winding unprotected = 20%.

$$\therefore \quad 20\% = \frac{\frac{1.8 \times 1000}{5} \times R_x}{\frac{10 \times 10^3}{\sqrt{3}}} \times 100$$

on solving $\boxed{R_x = 3.2075\,\Omega}$ Ans.

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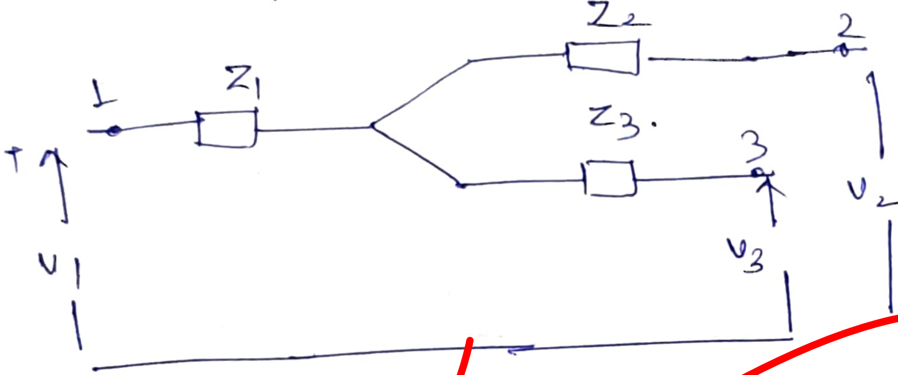
Q3(a) (b). 1° : 6.35 kV, 5 MVA

2° : 1.91 kV, 2.5 MVA

3° : 400 V, 2.5 MVA.

Eq. ckt. of 3 wdg. xmer can be represented as:



$$\left.\begin{aligned} Z_{12} &= Z_1 + Z_2 \\ Z_{13} &= Z_1 + Z_3 \\ Z_{23} &= Z_2 + Z_3 \end{aligned}\right\} \text{(A)}$$

Z_{12} = SC impedance of wdg 1° & 2° with 3° open.

Z_{23} = SC impedance of wdg 2° & 3° with 1° open

Z_{13} = SC impedance of wdg 1° & 3° with 2° open

& (B)
$$\left\{\begin{aligned} Z_1 &= \frac{1}{2}(Z_{12} + Z_{13} - Z_{23}) \\ Z_2 &= \frac{1}{2}(Z_{12} + Z_{23} - Z_{13}) \\ Z_3 &= \frac{1}{2}(Z_{13} + Z_{23} - Z_{12}) \end{aligned}\right.$$

Let $S_B = 5$ MVA

$$\therefore Z_{12} = \frac{500}{393.7} = 1.27\ \Omega.$$

$$Z_{12}(pu) = 1.27 \times \frac{5}{(6.35)^2} = 0.15748\ pu.$$

$$\boxed{Z_{12}(pu) = 0.15748\ pu}$$

$$Z_{13} = \frac{900}{393.7} \times \frac{2.5}{6.35^2} = 0.14173\ pu \text{ on own base}$$

on 5 MVA base $Z_{13} = 0.14173 \times \frac{5}{2.5}$

$$\boxed{Z_{13(pu)} = 0.2834\ pu}$$

$$Z_{23} = \frac{231}{1308.9} \times \frac{2.5}{1.91^2} \times \frac{5}{2.5} = 0.24083\ pu$$

$$\boxed{Z_{23} = 0.24083}\ pu.$$

(i). $Z_{12} = 0.15748$; $Z_{13} = 0.2834$ pu ; $Z_{23} = 0.2418$ pu

Using eqn's (B)

$\therefore Z_1 = \frac{1}{2}(0.15748 + 0.2834 - 0.2418) = 0.09954$ pu

$Z_2 = \frac{1}{2}(0.15748 + 0.2418 - 0.2834) = 0.05794$ pu

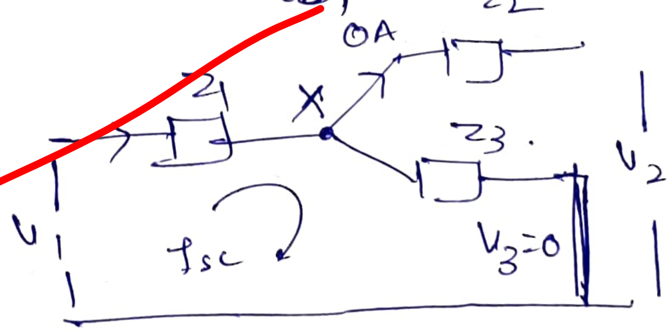
$Z_3 = \frac{1}{2}(0.2834 + 0.2418 - 0.15748) = 0.18386$ pu.

(ii) 3φ short circuit of 3° terminals. i.e. $V_3 = 0$.

$\therefore I_{sc} = \frac{V_1}{Z_1 + Z_3} = \frac{1}{Z_{13}} = \frac{1}{.2834} = 3.5285$ pu

1° short ckt current

$I_{sc_{1°}} = 3.5285 \times \frac{5 \times 10^6}{6.35 \times 10^3}$



$I_{sc_{1°}} \simeq 2778.41$ A

3° short ckt current

$I_{sc_{3°}} = 3.5285 \times \frac{5 \times 10^6}{400/\sqrt{3}} = 76.394$ KA.

Voltage at 2° terminal $= I_{sc} \times Z_3$

$= 3.5285 \times 0.18386$

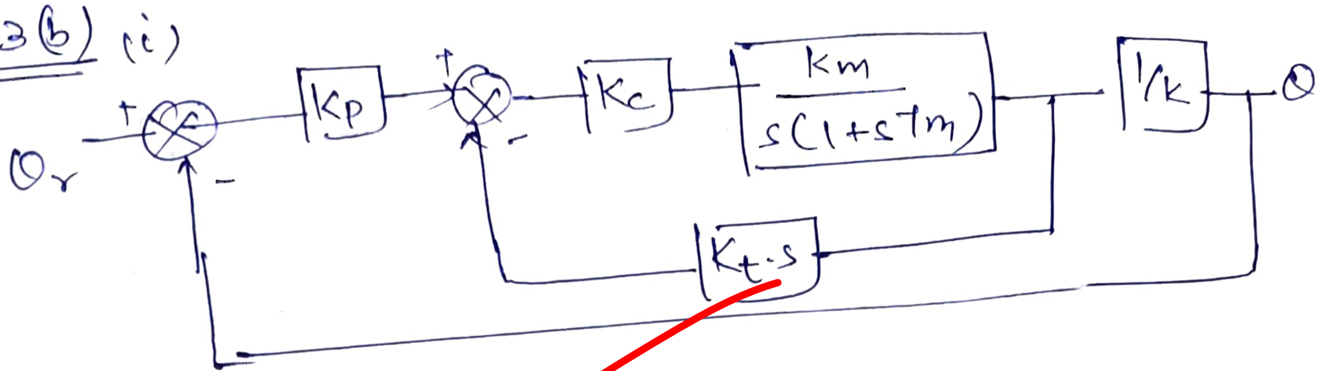
$\simeq 0.64875$ pu.

$= 0.64875 \times \frac{1.91 \times 10^3}{\sqrt{3}}$

$\simeq 2.146$ KV

= Ans

Q.3 (b) (i)



Using Mason gain formula to find T.F.

$$T.F = \frac{\sum P_k \Delta_k}{\Delta} \qquad P_1 = \frac{K_p \cdot K_c K_m}{Ks(1+sT_m)}$$

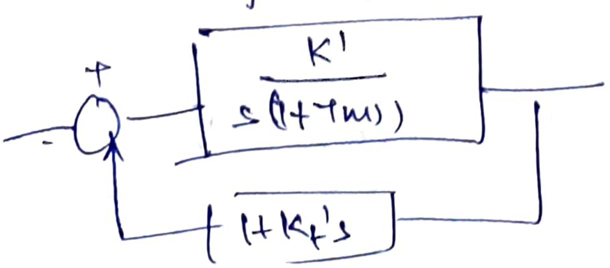
$$L_1 = -\frac{K_c K_m \cdot K_t \cdot s}{s(1+sT_m)} = -\frac{K_c K_m K_t}{(1+sT_m)}$$

$$L_2 = -\frac{K_p \cdot K_c \cdot K_m}{Ks(1+sT_m)}$$

$$\therefore TF = \frac{\dfrac{K_p K_c K_m}{Ks(1+sT_m)}}{1 + \dfrac{K_c K_m K_t}{1+sT_m} + \dfrac{K_p K_c K_m}{Ks(1+sT_m)}}$$

$$TF_1 = \frac{\dfrac{K_p K_c K_m}{K} \cdot \dfrac{1}{s(1+sT_m)}}{1 + \left[\dfrac{K_c K_m K_t}{(1+sT_m)} + \dfrac{K_p K_c K_m}{Ks(1+sT_m)}\right]} \quad -(1)$$

On comparing with 2nd T.F. ie —



$$\Rightarrow T.F._2 = \frac{\dfrac{K'}{s(1+T_m s)}}{1 + \dfrac{K' K_t'}{(1+T_m s)} + \dfrac{K'}{s(1+T_m s)}} \quad -(2)$$

On comparing eqn (1) & (2)

1. $\boxed{K' = \dfrac{K_p K_c K_m}{K}}$ = Ans

&. $K_c K_m K_t = K' K_t'$

$K_c K_m K_t = \dfrac{K_p K_c K_m}{K} \cdot K_t'$

$\boxed{K_t' = K \cdot K_t}$ = Ans

2. ~~OLTF = num~~ / denom num.

$$OLTF = \frac{\dfrac{K'}{s(1+T_m s)}}{1 + \dfrac{K' \cdot K_t'}{(1+T_m s)}} = \frac{K'}{s\left[1 + T_m s + K' K_t'\right]}.$$

It is Type 1 system

$$\therefore K_v = \lim_{s \to 0} s\, G(s)H(s) = \lim_{s \to 0} s \cdot \frac{K'}{s\left(1 + T_m s + K' K_t'\right)}$$

$$\boxed{K_v = \frac{K'}{1 + K' K_t'}} = \text{Ans}$$

3. ess with feedback = $e_{ss} = \dfrac{1}{K_v}$.

$$\boxed{e_{ss} = \frac{1 + K' K_t'}{K'}}$$

for without feedback put $K_t' = 0$.

$$\therefore OLTF = \frac{K'}{s(1+T_m s)}$$

$$e_{ss} = \frac{1}{K_v} = \frac{1}{\lim_{s \to 0} \dfrac{s\, K'}{s(1+T_m s)}} = \frac{1}{K'}$$

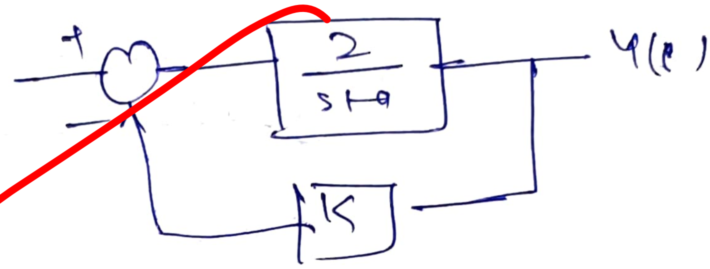
$$\boxed{e_{ss} = 1/K'}$$

With the addition of feedback e_{ss} has increased

e_{ss} with feedback = $\frac{1}{K'} + Kf'$

e_{ss} without feedback = $\frac{1}{K'}$ = Ans

Q.3 (b) (ii)



K=2

a=6.

Sensitivity is given as : $S^T_K = \frac{\partial T/T}{\partial K/K}$

$$T = T.F. = \frac{\frac{2}{s+a}}{1+\frac{2K}{s+a}} = \frac{2}{s+a+2K}$$

Sensitivity w.r.t. 'a' is $S^T_a = \frac{\partial T/T}{\partial a/a} = \frac{a}{T}\cdot\frac{\partial T}{\partial a}$

$$S^T_a = \frac{a}{\frac{2}{(s+a+2K)}} \cdot \frac{0-2.1}{(s+a+2K)^2} = \frac{-a}{(s+a+2K)}$$

put $s=j\omega$

$s = 2j$

$$S^T_a\Big|_{\omega=2} = \frac{-6}{2j+-6+2\times 2}$$

$$|S^T_a| = 2.121 = \text{Ans}$$

Sensitivity wrt K is $S^T_K = \dfrac{\partial T/T}{\partial K/K} = \dfrac{K}{T} \cdot \dfrac{\partial T}{\partial K}$

$$= \frac{K}{\frac{2}{s+a+2K}} \times \frac{0 - 2 \cdot 2}{(s+a+2K)^2} = \frac{-2K}{(s+a+2K)}$$

$$S^T_K \Big|_{\omega = 2} = \frac{-2 \times 2}{j2 + 6 + 2 \times 2}$$

$$\left| S^T_K \right| = 0.3922 \text{ Ans}$$

18

Q. 3 (a)

	Q_2	Q_1	Q_0	Q_2^+	Q_1^+	Q_0^+	D_2	D_1	D_0
1	0	0	1	0	1	1	0	1	1
3	0	1	1	1	0	0	1	0	0
4	1	0	0	1	1	1	1	1	1
7	1	1	1	1	1	0	1	1	0
6	1	1	0	1	0	1	1	0	1
5	1	0	1	0	1	0	0	1	0
2	0	1	0	0	0	0	0	0	0
0	0	0	0	0	0	1	0	0	1

Excitation table of D f/f ui

Q	Q^+	D
0	0	0
0	1	1
1	0	0
1	1	1

$D_2 = \Sigma m(3, 4, 6, 7)$

$D_1 = \Sigma m(1, 4, 5, 7)$

$D_0 = \Sigma m(0, 1, 4, 6)$

K-map for D_2

$Q_2 \backslash Q_1 Q_0$	$\overline{Q_1}\,\overline{Q_0}$	$\overline{Q_1} Q_0$	$Q_1 Q_0$	$Q_1 \overline{Q_0}$
$\overline{Q_2}$			1	
Q_2	1		1	1

$$D_2 = Q_1 Q_0 + Q_2 \overline{Q_0}$$

K-map for D_1

$Q_2 \backslash Q_1 Q_0$	$\overline{Q_1}\,\overline{Q_0}$	$\overline{Q_1} Q_0$	$Q_1 Q_0$	$Q_1 \overline{Q_0}$
$\overline{Q_2}$		1		
Q_2	1	1	1	

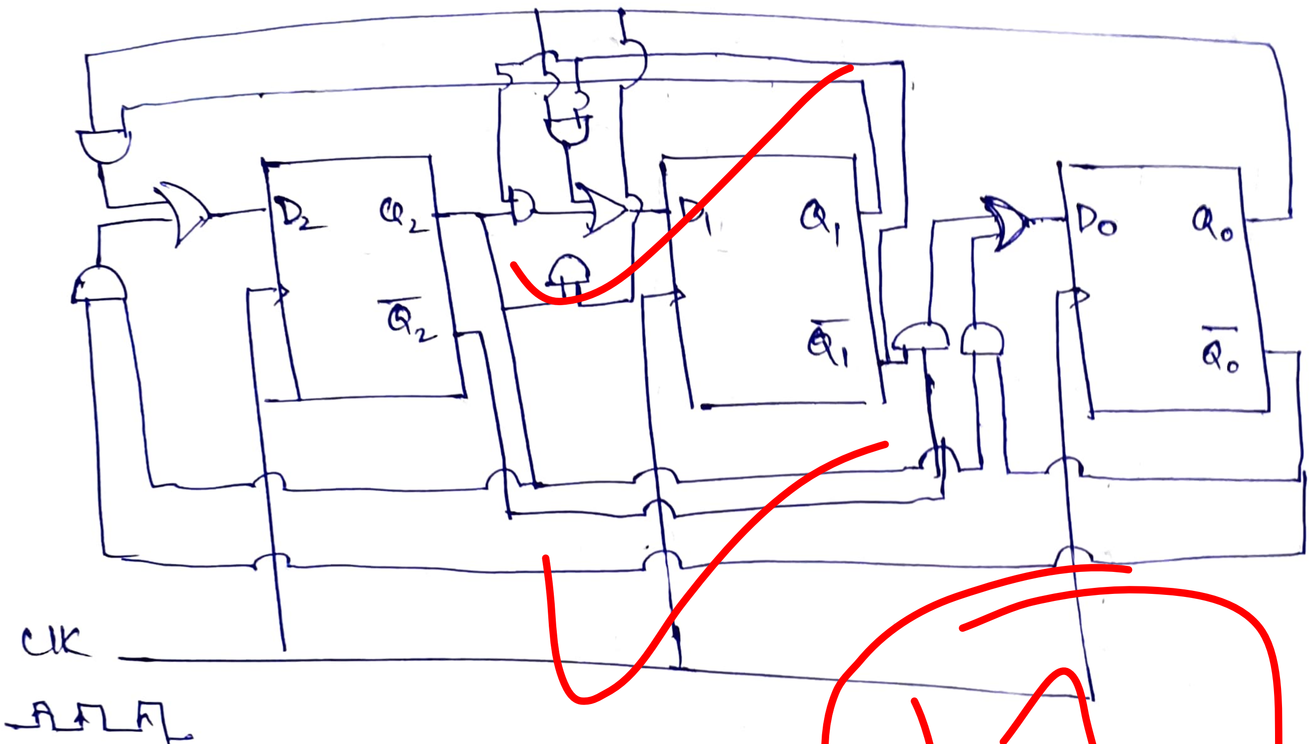
$$D_1 = \overline{Q_1} Q_0 + Q_2 \overline{Q_1} + Q_2 Q_0 .$$

K-maps for D_0

$Q_2 \backslash Q_1Q_0$	$\overline{Q_1}\,\overline{Q_0}$	$\overline{Q_1}\,Q_0$	Q_1Q_0	$Q_1\overline{Q_0}$
$\overline{Q_2}$	1	1		
Q_2	1			1

$$D_0 = \overline{Q_2}\,\overline{Q_1} + Q_2\overline{Q_0}$$

Circuit implementation.



17

Q4.(a) (i). 132 kV, 50 Hz, $X_L = 4\Omega$; $C = 0.031\,\mu F$.

$pf = 0.5$ $\quad L = \frac{4}{2\pi \times 50}$

1. freq. $f_n = \frac{1}{2\pi\sqrt{LC}} = \frac{1}{2\pi\sqrt{\frac{4}{2\pi \times 50} \times 0.031 \times 10^{-6}}}$

$$\boxed{f_n = 8010.953\ Hz}$$

2. Restriking voltage is given as -

$TRV = K_1 K_2 K_3 V_m \left(1 - \cos\frac{t}{\sqrt{LC}}\right)$

$K_1 = 1$ (grounded fault)

$K_2 = 0.95$ (given)

$K_3 = \sin\theta$ (power factor).

$= \sin(\cos^{-1} 0.5) = \sqrt{3}/2$.

$max^m\ TRV = K_1 K_2 K_3 \times 2V_m$

$= 1 \times 0.95 \times \frac{\sqrt{3}}{2} \times 2 \times \frac{132 \times 10^3}{\sqrt{3}} \times \sqrt{2}$

$= 177.342\ kV$ Ans.

3. max value of RRRV

$= K_1 K_2 K_3 \cdot \frac{V_m}{\sqrt{LC}}$

$= 1 \times 0.95 \times \frac{\sqrt{3}}{2} \times \frac{1}{\sqrt{\frac{4}{2\pi \times 50} \times 0.031 \times 10^{-6}}} \times \frac{132 \times 10^3}{\sqrt{3}} \times \sqrt{2}$

$RRRV|_{max.} = 4.463\ kV/\mu sec.$

4. Avg. RRRV $= \dfrac{2 K_1 K_2 K_3 V_m}{\pi \sqrt{LC}}$

$= \dfrac{2 \times 1 \times 0.95 \times \frac{\sqrt{3}}{2} \times \frac{132 \times 10^3}{\sqrt{3}} \times \sqrt{2}}{\pi \times \sqrt{\frac{4}{2\pi \times 50} \times 0.031 \times 10^{-6}}}$

$= 2.841\ kV/\mu sec.$ Ans

Q.4 (a). (ii) Given CB rating: 1200A, 2000 MVA, 33kV,

1. Rated normal current $I_N = 1500\,A$

2. Breaking current $I_{BK\,rms} = \dfrac{2000 \times 10^6}{\sqrt{3} \times 33 \times 10^3}$

$I_{BK(rms)} = 34.99\ kA.$

3. Making current $I_{MK} = 2.55 \times I_{BK\,(rms)}$

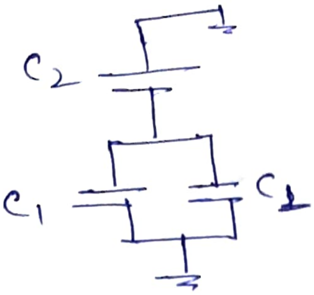
$= 89.226\ kA.$

4. Short time rating current.

Here $\dfrac{I_{BK}}{I_N} = \dfrac{34.99 \times 10^3}{1500}$ ~~89.226×10^3~~ $= 23.32 < 40$

$\therefore$ Short time rating current $= 3$ sec. Ans

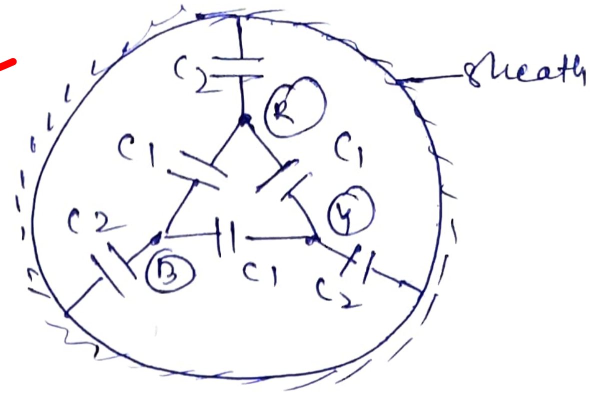
Q.4 (a). (iii) 3φ 3 core cable.

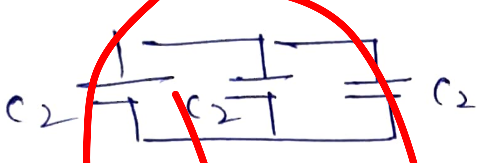


$C_b = C_2 + 2C_1$ — (1)

$C_b = 0.4\ \mu F/km.$

$0.4 = C_2 + 2C_1.$





$C_a = 3C_2$ — (2)

$C_a = 0.625\ \mu F/km$

$\Rightarrow C_2 = \frac{C_a}{3}$

$C_2 = \frac{0.625}{3}$

$= 0.20833\ \mu F$

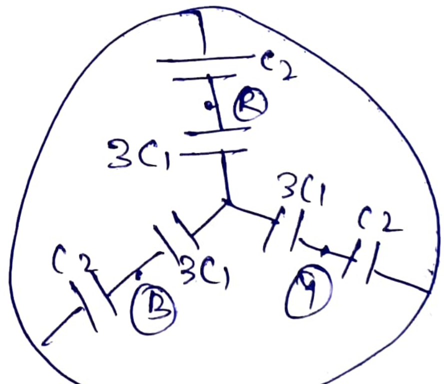
from (1). $C_b = \frac{C_a}{3} + 2C_1$

$C_1 = \frac{3C_b - C_a}{2} = 0.2875\ \mu F$

1. capacitance btwn three conductors. ci

$C_{ph} = 3C_1 + C_2$

$= 3\ \frac{3C_b - C_a}{2} + \frac{C_a}{3}.$

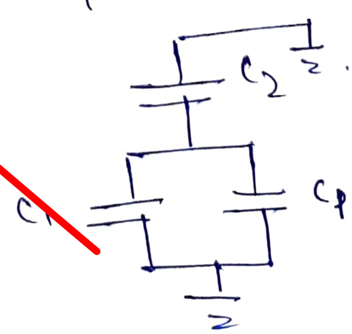


$C_{ph} = \frac{9C_b - C_a}{6}$

$= \frac{9 \times 0.4 - 0.625}{6}$

$C_{ph} = 0.49583\ \mu F$

2. Capacitance between two bunched conductors & third conductor



$C = 2C_1 + C_2$

$= 2 \times 0.2875 + 0.20833$

$\boxed{C = 0.7833\ \mu F}$ — Ans

3. $I_c = \frac{V_{ph}}{X_c}$

$I_c = V_{ph} \cdot \omega C_{ph}$

$I_c = \frac{10 \times 10^3}{\sqrt{3}} \times 2\pi \times 50 \times 0.49583 \times 10^{-6}$

$\boxed{I_c = 0.899\,A}$ = Ans

2

Q. 4(b) Analog filter. $H_a(s) = \frac{5}{s^2+6s+5}$

(i). digital filter using Bilinear z-transform

put $s = \frac{2}{T}\left(\frac{1-z^{-1}}{1+z^{-1}}\right)$

$$T = \frac{1}{f_s} = \frac{1}{12}$$

$$H_a(s) = \frac{5}{s^2+6s+5} = \frac{5}{(s+1)(s+5)}$$

$$\frac{1}{T} = 12$$

$$\| \quad s = \frac{2}{T}\left(\frac{1-z^{-1}}{1+z^{-1}}\right)$$

$$H_a(z) = \frac{5}{\left[24\left(\frac{1-z^{-1}}{1+z^{-1}}\right)+1\right]\left[24\left(\frac{1-z^{-1}}{1+z^{-1}}\right)+5\right]}$$

$$= \frac{5(1+z^{-1})^2}{(24-24z^{-1}+1+z^{-1})(24-24z^{-1}+5+5z^{-1})}$$

$$= \frac{5(z^{-2}+2z^{-1}+1)}{(25-23z^{-1})(29-21z^{-1})}$$

$$H_a(z) = \frac{5z^{-2}+10z^{-1}+5}{725-1192z^{-1}+483z^{-2}}$$

Ans

12

Q. 4. (c) (i) 3ϕ VSI. $V_s = 450V$

$R = 10\Omega$

Case 1 180° mode

o/p voltage is given as. $V_L = V_s\sqrt{2/3}$

per phase o/p voltage = $V_L/\sqrt{3}$. = $\frac{V_s\sqrt{2}}{3}$

∴ 1. Rms value of load current = $\frac{\frac{V_s\sqrt{2}}{3}}{R}$

$= \frac{450 \times \frac{\sqrt{2}}{3}}{10} = 21.2132\ A.$

2. Rms value of thyristor current = $I_{Trms} = \frac{21.2132}{\sqrt{2}}$

$= 15A$. Ans

3. Load power = $3 \times I_{or}^2 R$

$= 3 \times 21.2132^2 \times 10 = 13.5kW$ Ans

Case 2: 120° mode

o/p voltage is given as $V_L = V_s/\sqrt{2}$

per phase o/p voltage = $V_L/\sqrt{3} = V_s/\sqrt{6}$.

1. Rms value of load current = $\frac{V_s/\sqrt{6}}{R} = \frac{450/\sqrt{6}}{10}$

$= 18.371\ A.$

2. Rms value of thyristor current = $\frac{18.371}{\sqrt{2}}$

$= 12.99\ A.$

Load power $P = 3 \times I_{or}^2 \times R$

$= 3 \times 18.3711^2 \times 10$

$= 10.125$ kW

$=$ Ans.

10

Q. 4. (c) ii 3ϕ, 3 pulse M-3 converter

3ϕ supply: 230 V, 50 Hz $R = 10\,\Omega$.

$V_o = \frac{1}{2} V_{om}$.

for R load for $\alpha \leq \cancel{60}\,30^\circ$ (assumed)

$V_o = \frac{3V_{mL}}{2\pi} \cos\alpha$.

$\frac{1}{2} V_{om} = V_{om} \cdot \cos\alpha$.

$\cos\alpha = 1/2 \Rightarrow \underline{\alpha = 60^\circ}$ ← This makes our assumption wrong.

∴ α must be greater than 30°

∴ for $\alpha > 30^\circ$ $V_o = \frac{3V_{mp}}{2\pi}\left[1 + \cos\left(\alpha + \frac{\pi}{6}\right)\right]$

$\frac{0.5 \times 3V_{mL}}{\cancel{2\pi}} = \frac{3V_{mph}}{\cancel{2\pi}}\left(1 + \cos(\alpha + 30^\circ)\right)$

$0.5 \times \cancel{3} \times 230\sqrt{2} = \cancel{3} \times \frac{230\sqrt{2}}{\sqrt{3}}\left[1 + \cos(\alpha + 30^\circ)\right]$.

$\boxed{\alpha = 67.6993^\circ}$

avg. load current $I_o = \frac{V_o}{R} = \frac{\frac{0.5 \times 3 V_{mL}}{2\pi}}{10}$

$$= \frac{0.5 \times 3 \times 230\sqrt{2}}{2\pi \times 10}$$

$$\boxed{I_o = 7.765 A}$$

rms value of load current $I_{or} = \frac{V_{orm}}{R}$.

$$V_{orm} = \frac{V_{ml}}{2\sqrt{\pi}}\left[\left(\frac{5\pi}{6} - \alpha\right) + \frac{1}{2}\sin\left(2\alpha + \frac{\pi}{3}\right)\right]^{1/2}$$

$$= \frac{230\sqrt{2}}{2\sqrt{\pi}}\left[\left(\frac{5\pi}{6} - \frac{67.7 \times \pi}{180}\right) + \frac{1}{2}\sin\left(2 \times 67.7 + 60\right)\right]^{1/2}$$

$$V_{orm} = 104.764 V$$

$$\therefore I_{orm} = \frac{104.764}{10} = 10.4764 A.$$

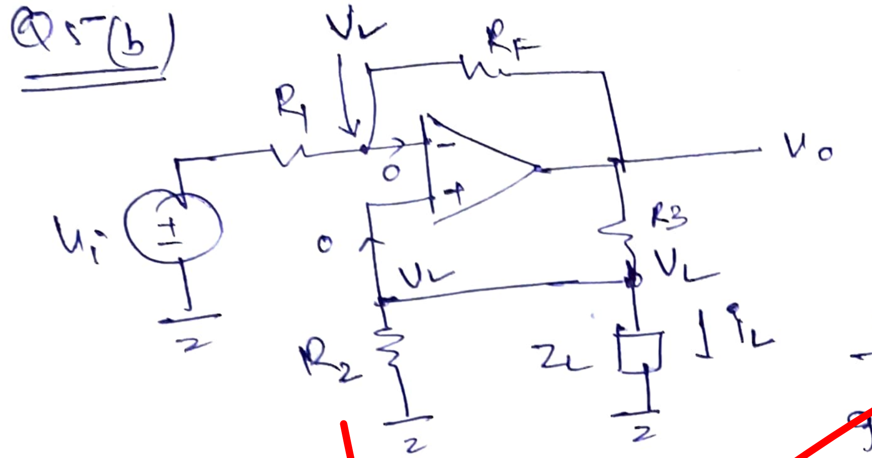
$$\therefore \eta = \frac{o/p}{i/p} = \frac{V_o . I_o}{V_{or} . I_{or}} = \frac{77.765 \times 7.765}{104.764 \times 10.4764} \times 100$$

$$= 54.93 \%$$

Ans

10

Q5 (b)



from ckt

$$i_L = \frac{V_L}{Z_L}$$

from concept of virtual ground.

$$V^- = V^+ = V_L.$$

KCL at inverting terminal.

$$\frac{V_L - V_i}{R_1} + \frac{V_L - V_o}{R_F} = 0.$$

$$V_L\left(\frac{1}{R_1} + \frac{1}{R_F}\right) - \frac{V_i}{R_1} - \frac{V_o}{R_F} = 0.$$

Also $V_L = \frac{R_2 \| Z_L}{R_2 \| Z_L + R_3} \cdot V_o = \frac{\frac{R_2 Z_L}{R_2 + Z_L}}{\frac{R_2 Z_L}{R_2 + Z_L} + R_3} \times V_o.$

$$V_L = \frac{R_2 Z_L}{R_2 Z_L + R_2 R_3 + R_3 Z_L} \times V_o$$

$$V_L = \frac{R_2 Z_L}{Z_L(R_2 + R_3) + R_2 R_3.} \times V_o \quad -(1)$$

KCL at node V_L.

$$\frac{V_o - V_L}{R_3} = \frac{V_L}{Z_L} + \frac{V_L}{R_2}$$

$$\frac{V_o}{R_3} = V_L\left(\frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{Z_L}\right)$$

$$V_o = V_L \cdot R_3 \left[\frac{(R_3 + R_2) Z_L + R_2 R_3}{R_2 R_3 Z_L} \right] \quad -(2)$$

Put eq^n (2) in (1)

$$V_L = \frac{R_2 Z_L}{(R_2 + R_3) Z_L + R_2 R_3} \times V_L .$$

8

Q.5 (c) (i). $T[x(t)] = y(t) = [x(t) + 2]^2$

System is causal $\because$ it doesn't depend on any future value.

$$x(t) \longrightarrow \boxed{\text{system}} \xrightarrow{(x(t)+2)^2} \boxed{K} \longrightarrow \text{o/p} = y_1(t)$$

$$= K[x(t)+2]^2$$

$$x(t) \longrightarrow \boxed{K} \xrightarrow{Kx(t)} \boxed{\text{system}} \longrightarrow \text{o/p} = y_2(t)$$

$$= [Kx(t)+2]^2$$

$y_1(t) \neq y_2(t)$.

$\therefore$ non-linear.

$$x(t) \longrightarrow \boxed{\text{delay}} \xrightarrow{x(t-t_0)} \boxed{\text{system}} \longrightarrow \text{o/p} = y_1(t) = [x(t-t_0)+2]^2$$

$$x(t) \longrightarrow \boxed{\text{system}} \xrightarrow{[x(t)+2]^2} \boxed{\text{delay}} \longrightarrow \text{o/p} = y_2(t)$$

$$= [x(t-t_0)+2]^2$$

$y_1(t) = y_2(t)$

$\therefore$ System is Time invariant.

Hence system is Casual, non-linear & Time invariant.

= Ans.

(ii). $y(t) = x(t^2 + t) + 2.$

Put $t = -2$ (say)

$y(-2) = x[(-2)^2 - 2] + 2$

$y(-2) = x(2) + 2$

Here o/p depend on future value of i/p

$\therefore$ non casual

$$x(t) \rightarrow \boxed{\text{System}} \xrightarrow{x(t^2+t)+2} \boxed{K} \rightarrow \text{o/p} = y_1(t) = K[x(t^2+t)+2]$$

$$x(t) \rightarrow \boxed{K} \xrightarrow{Kx(t)} \boxed{\text{System}} \rightarrow \text{o/p} = y_2(t) = Kx(t^2+t)+2$$

$y_1(t) \neq y_2(t)$

Hence system is non-linear.

$$x(t) \rightarrow \boxed{\text{System}} \xrightarrow{x(t^2+t)+2} \boxed{\text{delay } t_0} \rightarrow y_1(t) = x[(t-t_0)^2 + t - t_0] + 2$$

$$x(t) \rightarrow \boxed{\text{delay } t_0} \xrightarrow{x(t-t_0)} \boxed{\text{System}} \rightarrow y_2(t) = x[(t-t_0)^2 + t - t_0] + 2$$

$y_1(t) = y_2(t)$

System is time invariant.

Hence system is: Non-casual, non-linear, time invariant.

Q 5 (a) 3ϕ, 400 kVA, 50Hz Y sync gen.

$N = 300$ rpm $V_t = 3300V$ $300 = \frac{120 \times 50}{P}$

Slots = 180. $\boxed{P = 20}$

Total no of conductor = $180 \times 8 = 1440$ conductor

Peak mmf for a P pole mlc m -

$F_m = \frac{4\sqrt{2}}{\pi} \times \frac{I}{P} \times K_w \cdot N$ ATs/pole.

$I = \frac{400 \times 10^3}{\sqrt{3} \times 3300} = 69.981$ A.

$N =$ no of turn/ph $= \frac{1440}{2 \times 3} = 240$ turn/ph.

$K_d = \frac{\sin \frac{m\beta}{2}}{m \sin \beta/2}$ $m = \frac{180}{20 \times 3} = 3.$

$\beta = \frac{180°}{180/20} = 20°$

$= \frac{\sin \frac{3 \times 20}{2}}{3 \times \sin \frac{20}{2}} = 0.9598$

$\therefore F_m = \frac{4\sqrt{2}}{\pi} \times \frac{69.981}{20} \times 0.9598 \times 240$

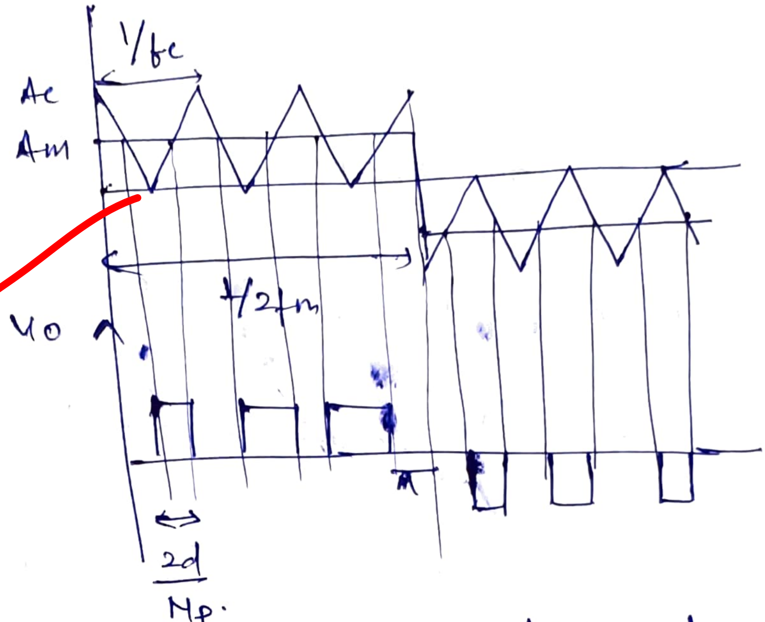
$F_m = 1451.333$ ATs/pole

Resulting mmf $= 1.5 \times F_m$

$= 2177..$ ATs/pole

Q.5 (e) Multiple pulse modulation:

In MPM PWM, multiple pulses are obtained in the o/p voltage waveform.

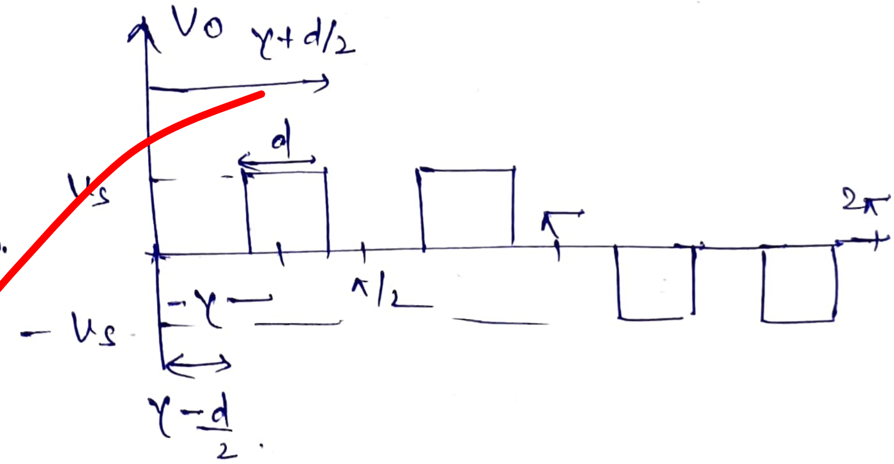


$$V_{or} = V_s \sqrt{\frac{2d}{\pi}}$$

$N_c = \frac{f_c}{2f_m}$ ← This gives no. of pulses obtained.

$$\boxed{\frac{2d}{N_p} = \frac{A_m}{A_c} \cdot \frac{\pi}{N_p}}$$ ← This gives pulse width.

The o/p voltage waveform is Odd Half Wave Symmetry.



∴ $a_0 = 0$

$a_n = 0$.

$$b_n = \frac{2}{\pi/2} \int_{\gamma-d/2}^{\gamma+d/2} V_s \cdot \sin n\omega t \, d\omega t$$

$$= \frac{4}{\pi} V_s \cdot \left[-\frac{\cos n\omega t}{n} \right]_{\gamma-d/2}^{\gamma+d/2}$$

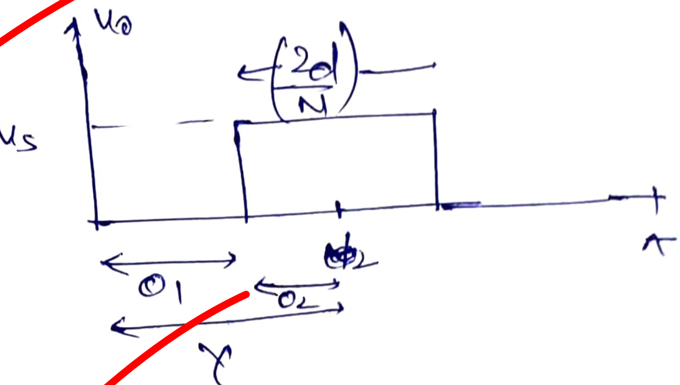
$$= \frac{4V_s}{n\pi}\left[\cos n(\gamma - d/2) - \cos n(\gamma + d/2)\right].$$

$$b_n = \frac{8V_s}{n\pi} \sin n\gamma \cdot \sin \frac{nd}{2}$$

$\therefore$ o/p voltage $v_0 = \sum_{n=1,3,5}^{\infty} b_n \sin n\omega t$

$$v_0 = \sum_{n=1,3,5}^{\infty} \frac{8V_s}{n\pi} \sin n\gamma \cdot \sin \frac{nd}{2} \sin n\omega t.$$

$\gamma = \theta_1 + \theta_2$



Let 'N' be no of pulses.

$\therefore \quad (N+1)\,\theta_1 = \pi - 2d.$

$\theta_1 = \frac{\pi - 2d}{N+1}.$ & $\theta_2 = \frac{2d/N}{2}$

$\theta_2 = \frac{d}{N}.$

$$\therefore \quad \boxed{\gamma = \theta_1 + \theta_2 = \frac{\pi - 2d}{N+1} + \frac{d}{N}}$$

Ans