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ESE 2020 : Mains Test Series

UPSC ENGINEERING SERVICES EXAMINATION

Electrical Engineering

Test-11: Full Syllabus Test

Paper-II

Name : ....

Roll No : ☐☐☐☐☐☐☐☐☐☐☐☐

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Instructions for Candidates

1. Do furnish the appropriate details in the answer sheet (viz. Name & Roll No).
2. Answer must be written in English only.
3. Use only black/blue pen.
4. The space limit for every part of the question is specified in this Question Cum Answer Booklet. Candidate should write the answer in the space provided.
5. Any page or portion of the page left blank in the Question Cum Answer Booklet must be clearly struck off.
6. Last two pages of this booklet are provided for rough work. Strike off these two pages after completion of the examination.

FOR OFFICE USE

Question No.	Marks Obtained
Section-A	
Q.1	
Q.2	
Q.3	
Q.4	
Section-B	
Q.5	
Q.6	
Q.7	
Q.8	
Total Marks Obtained	

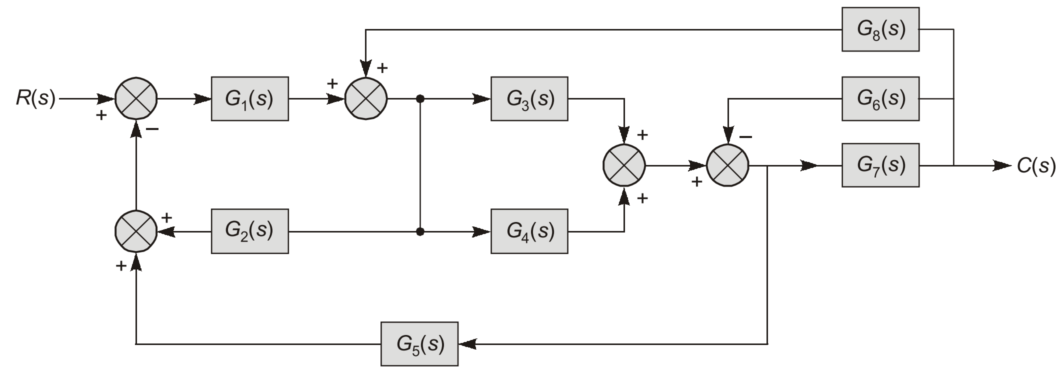
Signature of Evaluator ....

Cross Checked by ....

Do not write in this margin

Section A

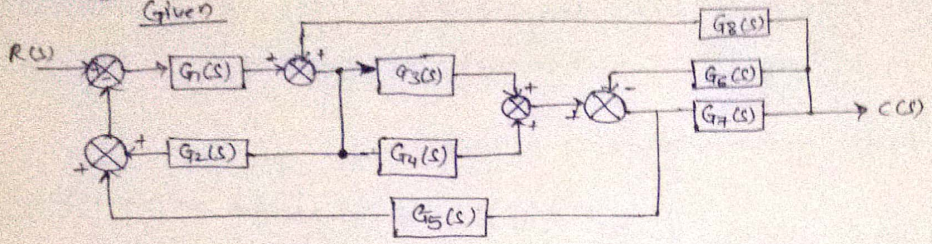
Q.1 (a) Obtain the signal flow graph and thus obtain the transfer function $C(s)/R(s)$ using Mason's gain formula for the following system:



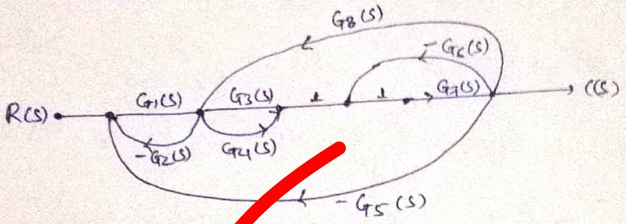
[12 marks]

Ans 1 ⓐ

Given



Signal flowgraph :-



Forward path : $F_1 = G_1 G_3 G_7$, $F_2 = G_1 G_4 G_7$

Loop : Invidual loop

$L_1 = -G_1G_2$, $L_2 = -G_1 G_3 G_5 G_7$, $L_3 = -G_6 G_7$

$L_4 = G_3 G_7 G_8$, $L_5 = G_4 G_7 G_8$, $L_6 = -G_1 G_4 G_5 G_7$

Two Non touching loop :-

$L_{11} = G_1 G_2 G_6 G_7$,

From Mason gain formula, T.F. $= \dfrac{F_1\Delta_1 + F_2\Delta_2}{\Delta}$

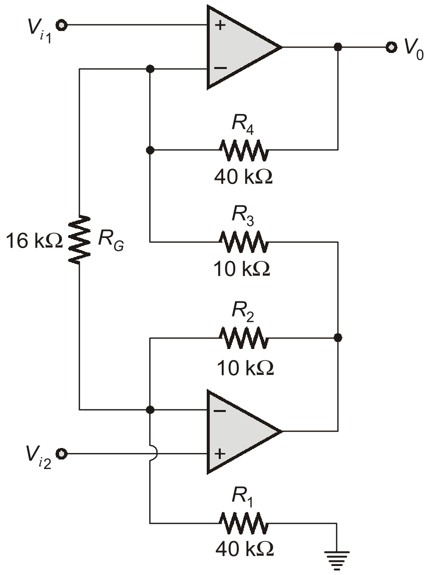
10

Here $\Delta_1 = 1$, $\Delta_2 = 1$

So T.F. $= \dfrac{G_1 G_3 G_7 + G_1 G_4 G_7}{1 + G_1G_2 + G_1 G_3 G_5 G_7 + G_6 G_7 + G_1 G_4 G_5 G_7 - G_3 G_7 G_8 - G_4 G_7 G_8 + G_1 G_2 G_6 G_7}$

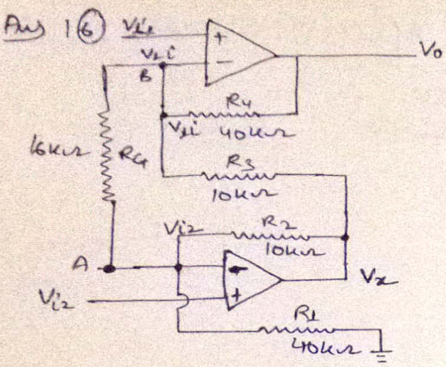
Hence Transfer function $= \dfrac{C(s)}{R(s)} = \dfrac{G_1 G_7 (G_3 + G_4)}{1 + G_1(G_2 + G_3 G_5 G_7) + G_6 G_7 (1 + G_1 G_2) + G_4 G_7 (G_1 G_5 - G_8) - G_3 G_7 G_8}$

Q.1 (b) Determine the value of overall differential voltage gain A_d of the following op-amp circuit.



[12 marks]

Ans 1(b)



∴ since negative feedback is used from virtual ground concept $V_+ = V_-$

Apply KCL at Node A we get

$$\frac{V_{i2} - V_{i1}}{16k} + \frac{V_{i2} - V_x}{10k} + \frac{V_{i2}}{40k} = 0$$

$$V_{i2}\left[\frac{1}{16k} + \frac{1}{10k} + \frac{1}{40k}\right] = \frac{1}{16k}V_{i1} + \frac{V_x}{10k}$$

$$\Rightarrow V_{i2} = \frac{1}{3}V_{i1} + \frac{8}{15}V_x \quad \text{—}①$$

Apply KCL at Node B

$$\frac{V_{i1} - V_{i2}}{16k} + \frac{V_{i1} - V_o}{40k} + \frac{V_{i1} - V_x}{10k} = 0$$

$$\Rightarrow V_{i1}\left[\frac{1}{16k} + \frac{1}{40k} + \frac{1}{10k}\right] = V_{i2}\left[\frac{1}{16k}\right] + V_o\left[\frac{1}{40k}\right] + V_x\left[\frac{1}{10k}\right] \quad \text{—}②$$

from Eq ① put value of Vx in eq ② we get

$$V_{i1} = \frac{1}{3}V_{i2} + \frac{2}{15}V_o + \frac{8}{15}\left[V_{i2} - \frac{1}{3}V_{i1}\right] \times \frac{15}{8}$$

$$\Rightarrow V_{i1} = \frac{1}{3}V_{i2} + \frac{2}{15}V_o + V_{i2} - \frac{1}{3}V_{i1}$$

$$\Rightarrow \frac{4}{3}V_{i1} = \frac{4}{3}V_{i2} + \frac{2}{15}V_o \Rightarrow \frac{4}{3}\left[V_{i1} - V_{i2}\right] = \frac{2}{15}V_o$$

So Differential gain $= \dfrac{V_o}{(V_{i1} - V_{i2})} = \left(\dfrac{2}{15}\right)^{-1} \times \dfrac{4}{3} = 10$

Hence differential gain of amplifier is 10.

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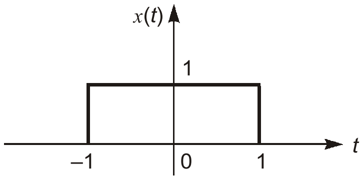
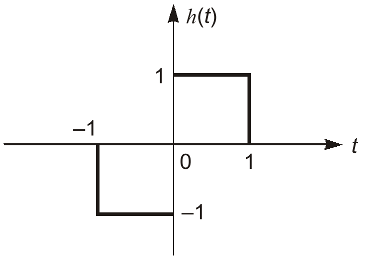
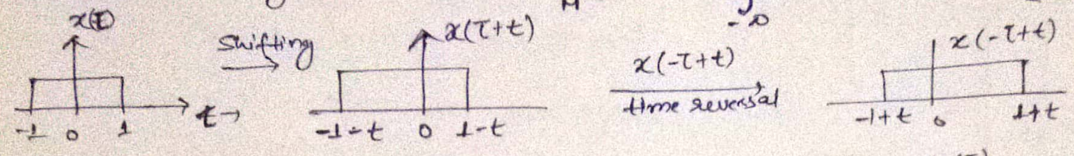
Q.1 (c) Use the convolution integral to find the response $y(t)$ of the LTI system with the following impulse response $h(t)$ to the given input $x(t)$. Also sketch the response $y(t)$.



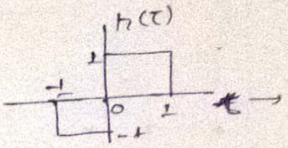


[12 marks]

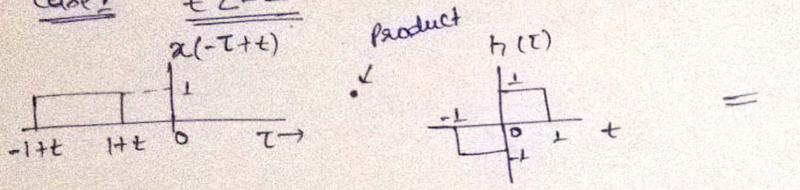
Ans ① ⓒ $\therefore\ y(t) = x(t) * h(t) = \int_{-\infty}^{\infty} x(t-\tau)\, h(\tau)\, d\tau$ —— ①



Let $1+t < -1 \Rightarrow \boxed{t < -2}$



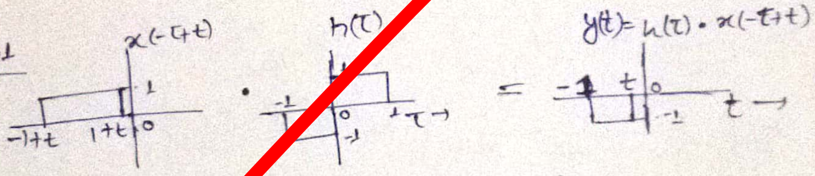
Case 1 $t < -2$



= 0

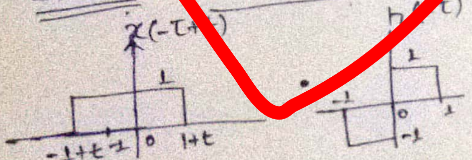
So, $y(t) = 0 \quad \forall \ t < -2$

Case 2 $-2 \leq t \leq -01$



$y(t) = -1 \quad \forall -1 < \tau < t$ and $-2 < t \leq -1$

Case 3 $-1 < t < 0$



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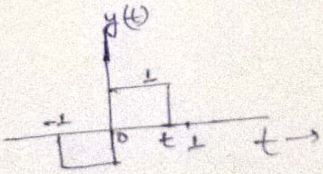
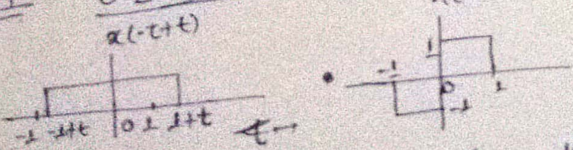


So $y(t) = -1 \quad \forall -1 < t < 0$

$= 1 \quad \forall\ 0 < \tau < t$

Case 4 $0 < t < 1$



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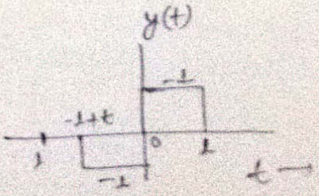
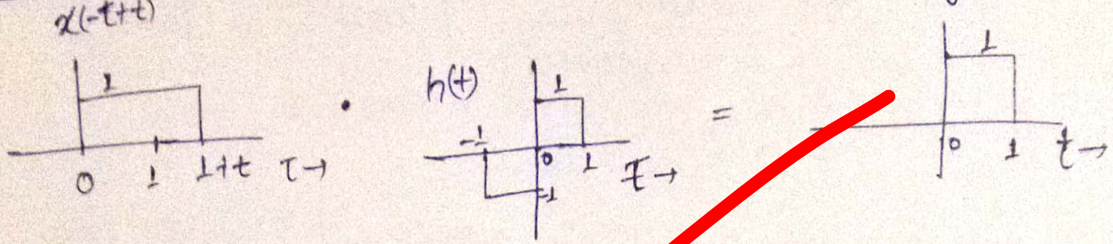


So $y(t) = -1 \quad \forall\ -1 < \tau < 0$

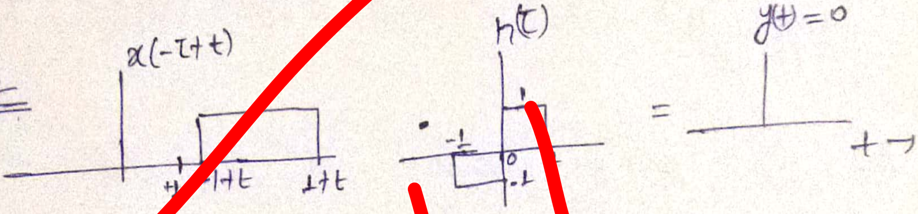
$= 1 \quad \forall\ 0 < \tau \leq 1$

Case 5 $\quad 1 < t < 2$



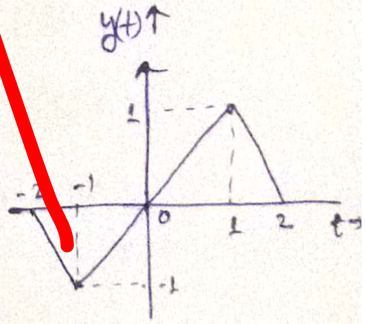
$y(t) = 1 \quad \forall \quad 1 < t < 2$

Case 6 $\quad t > 2$



$y(t) = 0$

Hence $\quad y(t) = \begin{cases} 0 & t < -2 \\ -(t+2) & -2 \leq t \leq -1 \\ +t & -1 \leq t \leq 0 \\ t & 0 \leq t \leq 1 \\ 0 & t > 2 \end{cases}$



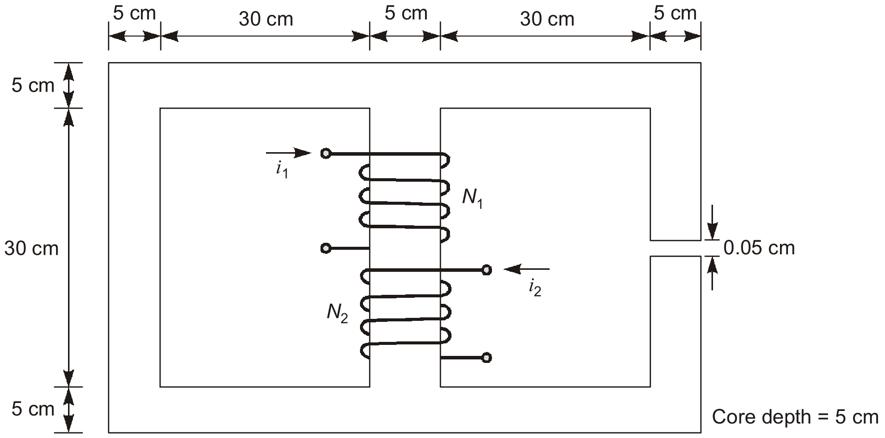
Q.1 (d) A ferromagnetic core as shown:

Relative permeability = 2000

$N_1 = 400$ turns, $N_2 = 500$ turns

$i_1 = 1$ A, $i_2 = 0.5$ A

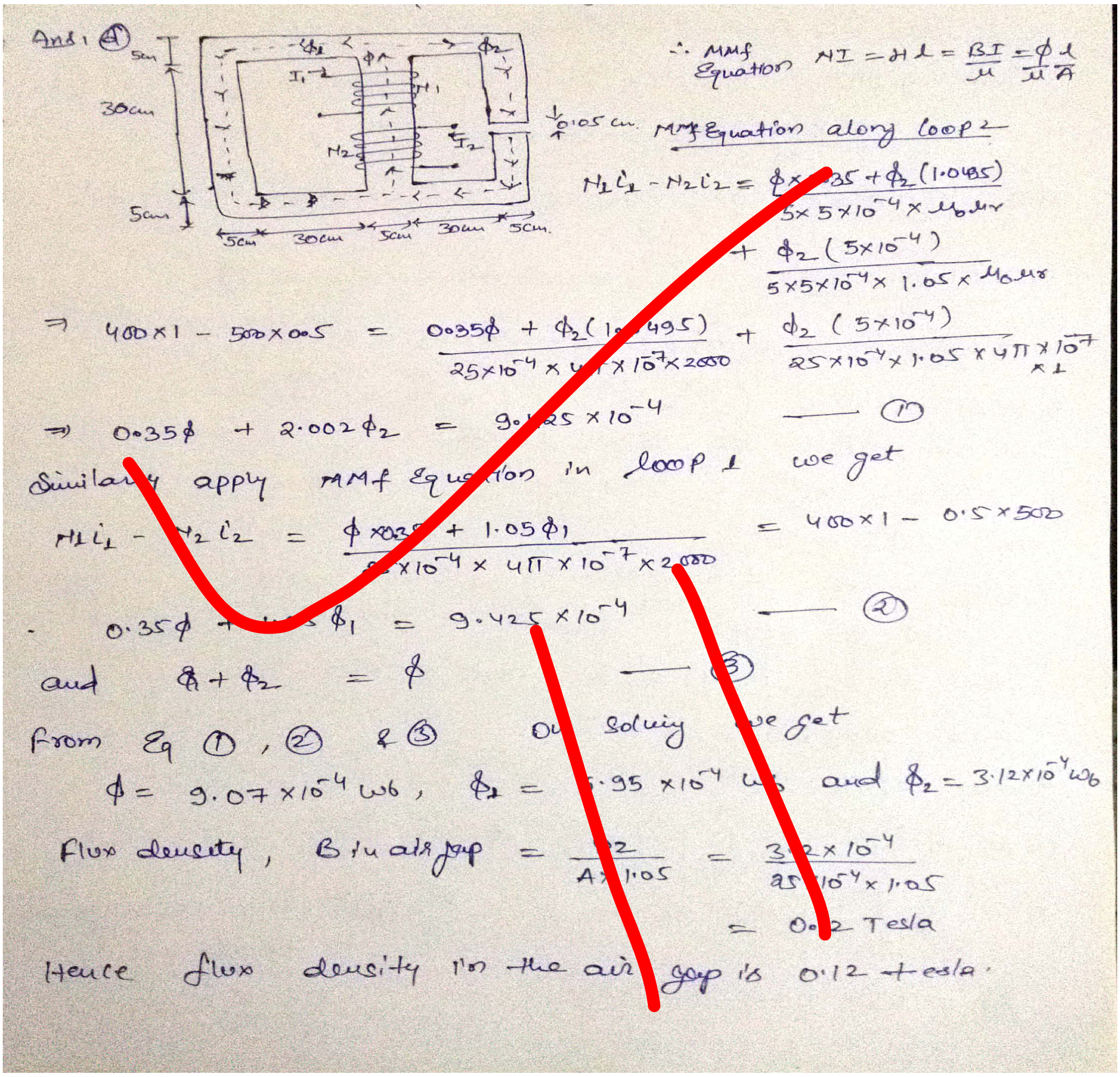
Assume due to fringing effect, the effective area of air gap is 5% larger then their physical size.



What is the flux in each of the left, center and right legs of the core?

What is the flux density in the air gap?

[12 marks]



Ans: ⓓ

∴ MMf Equation $NI = Hl = \frac{Bl}{\mu} = \frac{\phi l}{\mu A}$

MMf Equation along loop 2

$$N_1 i_1 - N_2 i_2 = \frac{\phi \times 0.35 + \phi_2(1.0495)}{5\times 5\times 10^{-4}\times \mu_0\mu_r} + \frac{\phi_2(5\times 10^{-4})}{5\times 5\times 10^{-4}\times 1.05\times \mu_0\mu_r}$$

$$\Rightarrow 400\times 1 - 500\times 0.5 = \frac{0.35\phi + \phi_2(1.0495)}{25\times 10^{-4}\times 4\pi\times 10^{-7}\times 2000} + \frac{\phi_2(5\times 10^{-4})}{25\times 10^{-4}\times 1.05\times 4\pi\times 10^{-7}\times 1}$$

$\Rightarrow 0.35\phi + 2.002\phi_2 = 9.425\times 10^{-4}$ —— ①

Similarly apply MMf Equation in loop 1 we get

$$N_1 i_1 - N_2 i_2 = \frac{\phi\times 0.35 + 1.05\phi_1}{25\times 10^{-4}\times 4\pi\times 10^{-7}\times 2000} = 400\times 1 - 0.5\times 500$$

$0.35\phi + 1.05\phi_1 = 9.425\times 10^{-4}$ —— ②

and $\phi_1 + \phi_2 = \phi$ —— ③

from Eq ①, ② & ③ on solving we get

$\phi = 9.07\times 10^{-4}$ wb, $\phi_1 = 5.95\times 10^{-4}$ wb and $\phi_2 = 3.12\times 10^{-4}$ wb

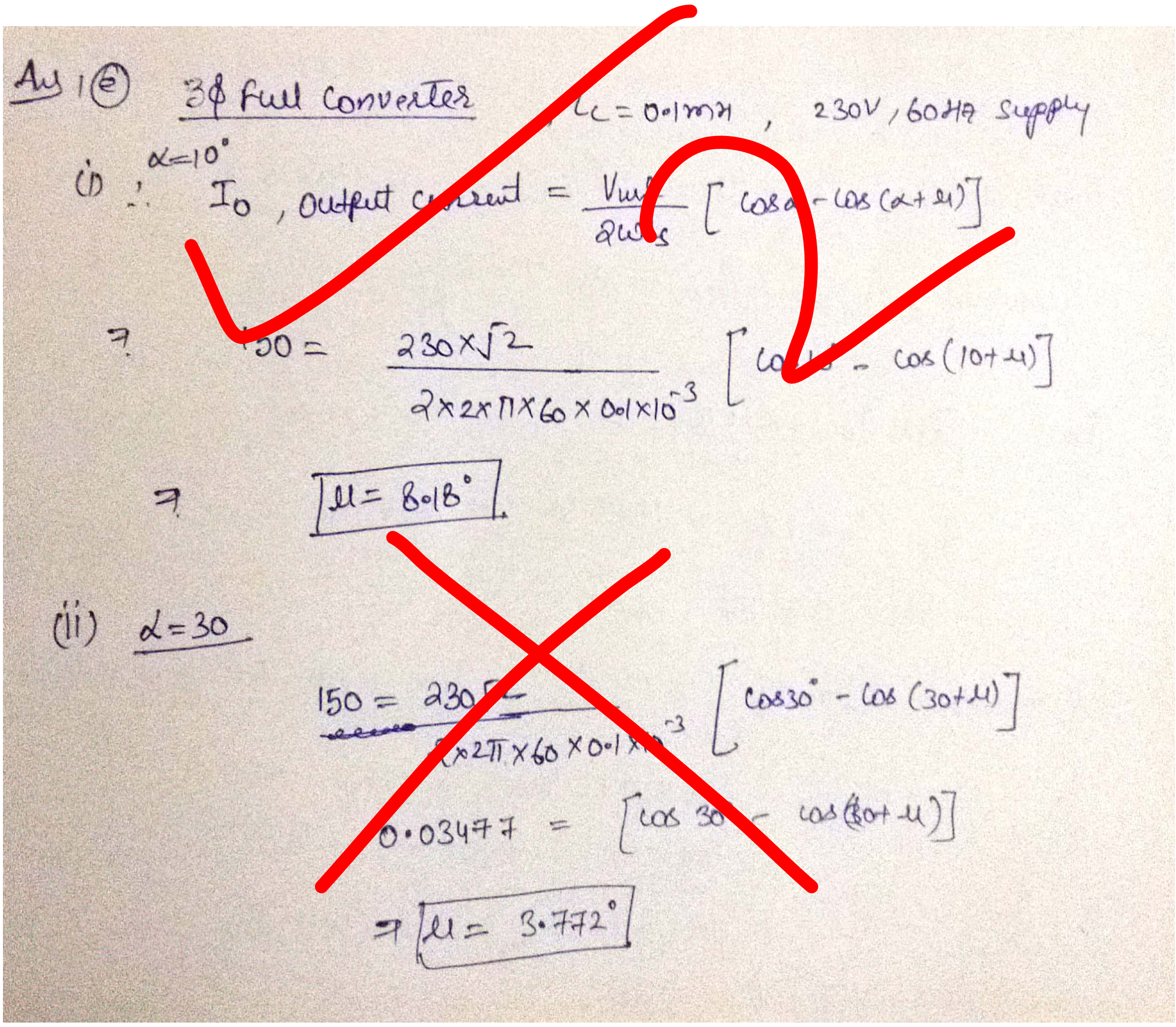
Flux density, B in air gap $= \frac{\phi_2}{A\times 1.05} = \frac{3.12\times 10^{-4}}{25\times 10^{-4}\times 1.05}$

$= 0.12$ Tesla

Hence flux density in the air gap is 0.12 tesla.

Q.1 (e) A three-phase full converter is supplied from a three-phase 230 V, 60 Hz supply. The load current is constant, 150 A and has negligible ripple. If the commutating inductances L_C = 0.1 mH, determine the overlap angle when: (i) α = 10° (ii) α = 30° (iii) α = 60°

[12 marks]



Ans 1 ⓔ 3ϕ Full Converter , $L_C = 0.1 mH$, 230V, 60Hz supply

(i) ∴ $\alpha = 10°$

I_0 , output current $= \frac{V_{ml}}{2\omega L_s}[\cos\alpha - \cos(\alpha+\mu)]$

2

$\Rightarrow 150 = \frac{230\times\sqrt{2}}{2\times2\times\pi\times60\times0.1\times10^{-3}}[\cos10 - \cos(10+\mu)]$

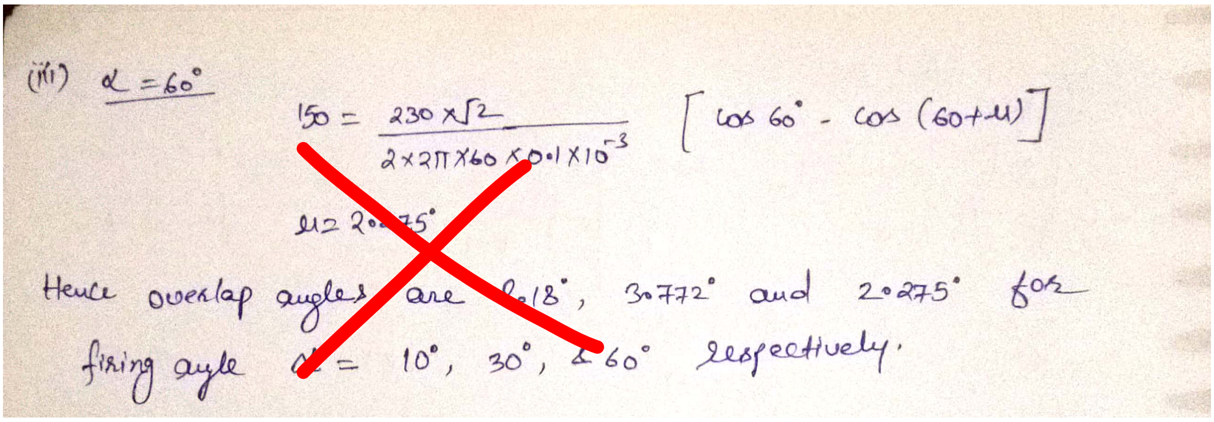
$\Rightarrow \boxed{\mu = 8.18°}$

(ii) $\alpha = 30$

$150 = \frac{230\sqrt{2}}{2\times2\pi\times60\times0.1\times10^{-3}}[\cos30° - \cos(30+\mu)]$

$0.03477 = [\cos30° - \cos(30+\mu)]$

$\Rightarrow \boxed{\mu = 3.772°}$



(iii) $\alpha = 60°$

$150 = \frac{230\times\sqrt{2}}{2\times2\pi\times60\times0.1\times10^{-3}}[\cos60° - \cos(60+\mu)]$

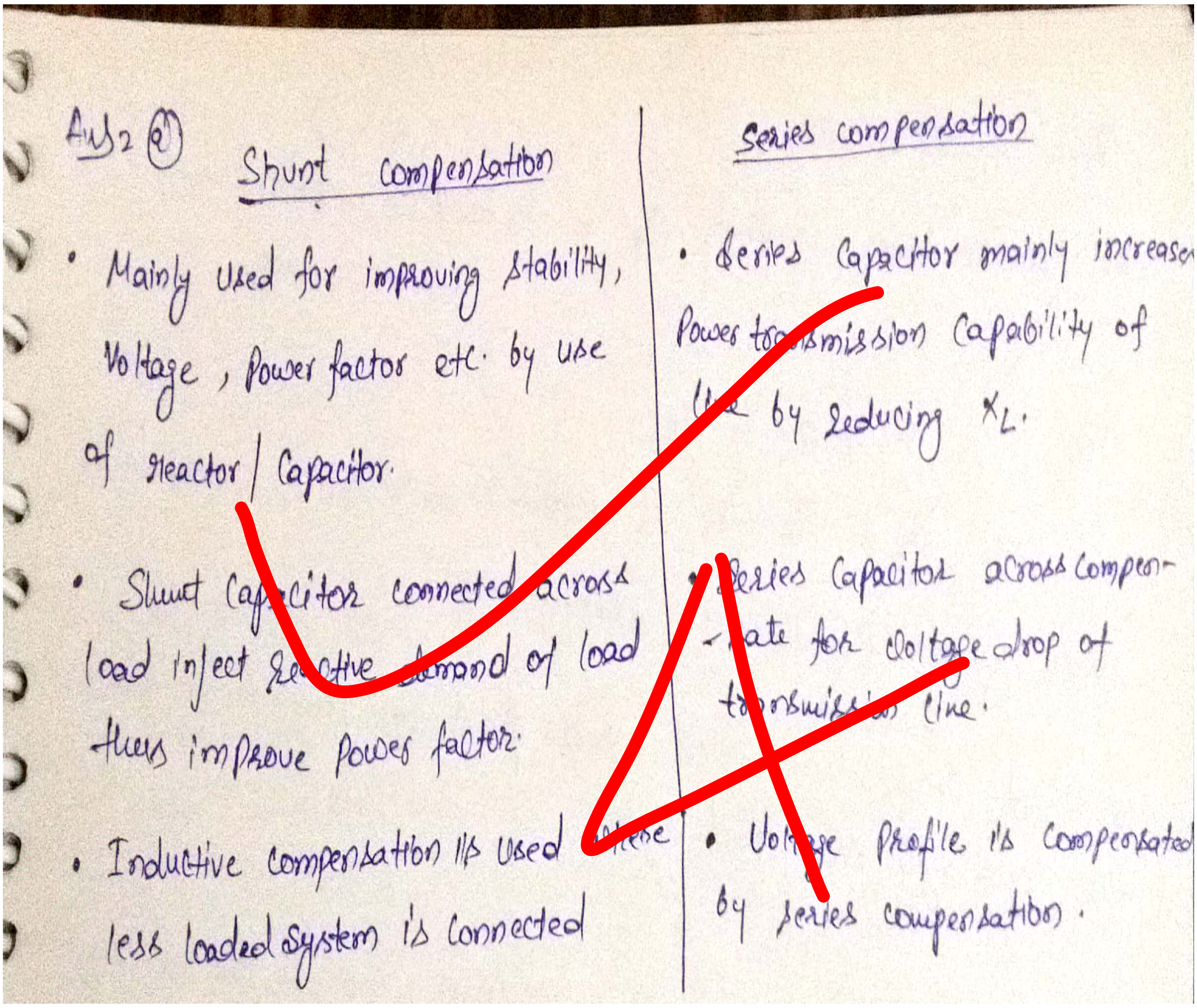
$\mu = 2.275°$

Hence overlap angles are 8.18°, 3.772° and 2.275° for firing angle α = 10°, 30°, & 60° respectively.

Q.2 (a) (i) Compare the shunt and series methods of compensation in the improvement of power system performance.

(ii) A 3-phase overhead line has per phase resistance and reactance of 6 Ω and 20 Ω respectively. The sending end voltage is 66 kV while receiving end voltage is maintained at 66 kV by a synchronous phase modifier. Determine the kVAr of the modifier when the load at the receiving end is 75 MW at p.f. of 0.8 lagging. Also determine the maximum load that can be transmitted.

[5 + 15 = 20 marks]



Ans 2 ⓐ

Shunt compensation	Series compensation
• Mainly used for improving stability, Voltage, Power factor etc. by use of reactor / Capacitor.	• Series Capacitor mainly increases Power transmission Capability of line by reducing X_L.
• Shunt Capacitor connected across load inject reactive demand of load thus improve Power factor.	• Series Capacitor across compen-sate for voltage drop of transmission line.
• Inductive compensation is used where less loaded system is connected	• Voltage Profile is Compensated by series compensation.

4

Ans 2 ⓐ Given $R_{ph} = 6\Omega$, $X_{ph} = 20\Omega$, $V_s = V_R = 66\,kV$

load = 75 MW at 0.8 pf lag

So $\cos\phi = 0.8 \Rightarrow \phi = \cos^{-1}(0.8) = 36.86^\circ$ lag.

$Z_{ph} = R_{ph} + j X_{ph} = 6 + 20j = 20.88 \angle 73.30^\circ\ \Omega$

$\beta = 73.3^\circ$

Now

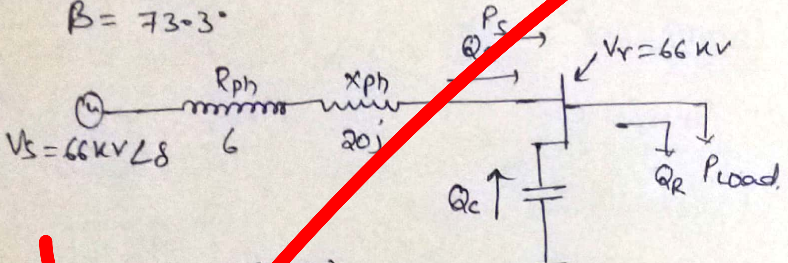


fig 2(a)

Power Supplied by source $P_s = \frac{V_s V_r}{|Z|}\cos(\beta-\delta) - \frac{V_r^2}{|Z|}\cos\beta$ —①

$$75 = \frac{66^2}{20.88}\left[\cos(73.3-\delta) - \cos(73.3)\right]$$

$$\boxed{\delta = 23.60^\circ}$$

So reactive power, $Q_s = \frac{|V_s V_r|}{|Z|}\sin(\beta-\delta) - \frac{|V_r|^2}{|Z|}\sin\beta$

$\Rightarrow Q_s = \frac{66^2}{20.88}\sin(73.3-23.6) - \frac{66^2}{20.88}\sin 73.3$

$\Rightarrow Q_s = -40.713$ MVAR

Now, load reactor power demand $Q_R = P_R \tan\phi$

$= 75 \tan 36.86$

$= 56.23$ MVAR

∴ As per fig 2a, $Q_s + Q_c = Q_R$

$\Rightarrow Q_c = Q_R - Q_s = 56.23 - (-40.713)$

$= 96.943$ MVAR

Hence reactive power supplied by synchronous modifier is 96.943 MVAR or 96943 KVAR.

for maximum Power transfer $\delta = \beta$ i.e. $\delta = 73.3$ put this in Eq ① we get

$P_{supplied/transmitted} = \frac{66^2}{20.88}\left[\cos(73.3-73.3) - \cos 73.3\right]$

$= 148.67$ MW

∴ Hence maximum power transmitted is 148.67 at $\delta = 73.3^\circ$

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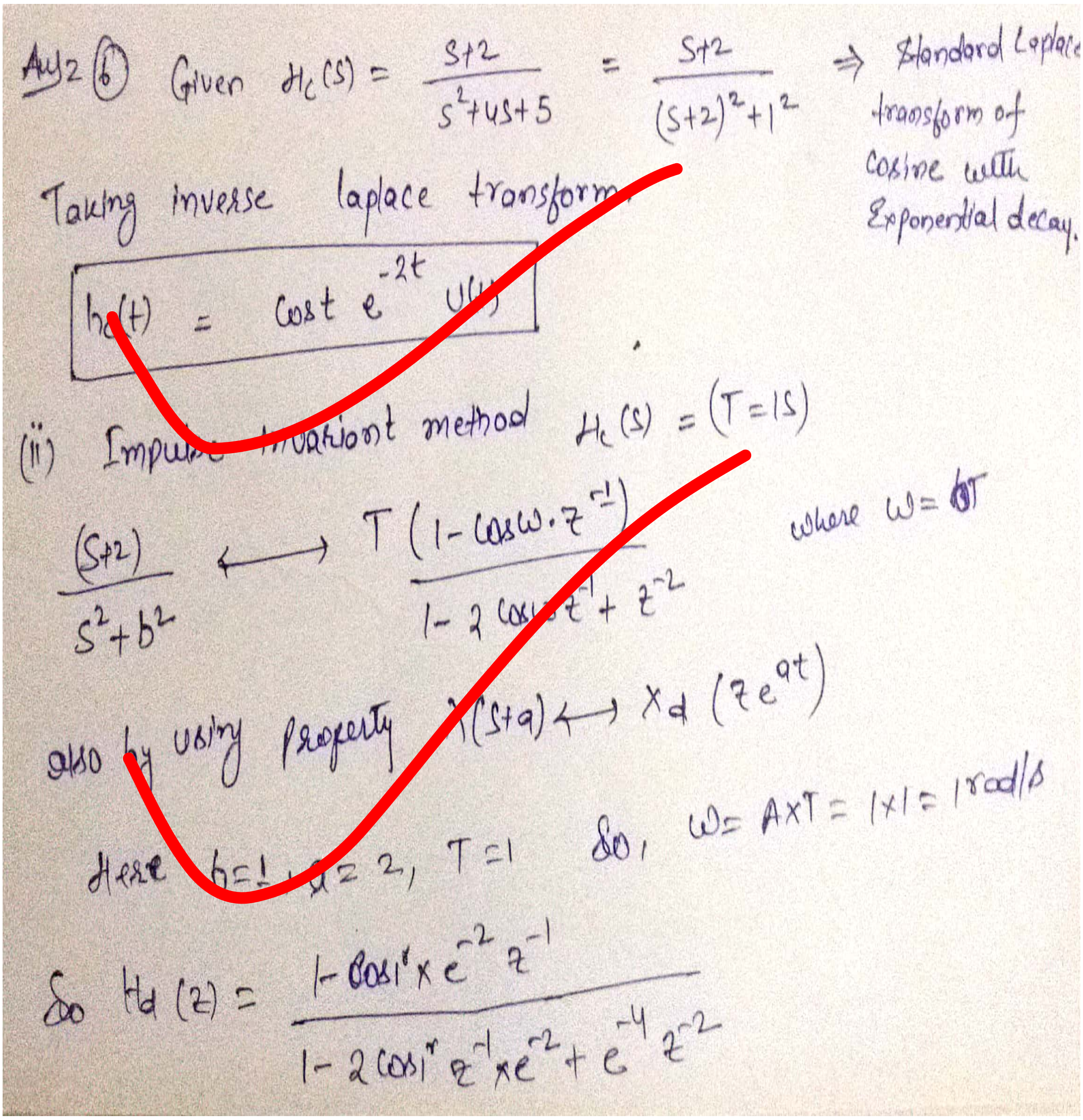
Q.2 (b) Consider a causal continuous-time system with system function: $H_c(s) = \dfrac{s+2}{s^2+4s+5}$.

(i) Using properties of Inverse-Laplace transform find impulse response $h_c(t)$.

(ii) Using impulse invariant method, determine the discrete time equivalent $H_d(z)$ of the given continuous-time system $H_c(s)$ $\{T = 1s\}$.

(iii) Using properties of inverse Z-transform find discrete impulse response $h_d[n]$. Verify $h_c(t = nT) = h_d[n]$.

[4 + 8 + 8 = 20 marks]



Ans 2 ⓑ Given $H_c(S) = \dfrac{S+2}{S^2+4S+5} = \dfrac{S+2}{(S+2)^2+1^2}$ ⇒ Standard Laplace transform of Cosine with Exponential decay.

Taking inverse laplace transform

$$\boxed{h_c(t) = \cos t\, e^{-2t}\, u(t)}$$

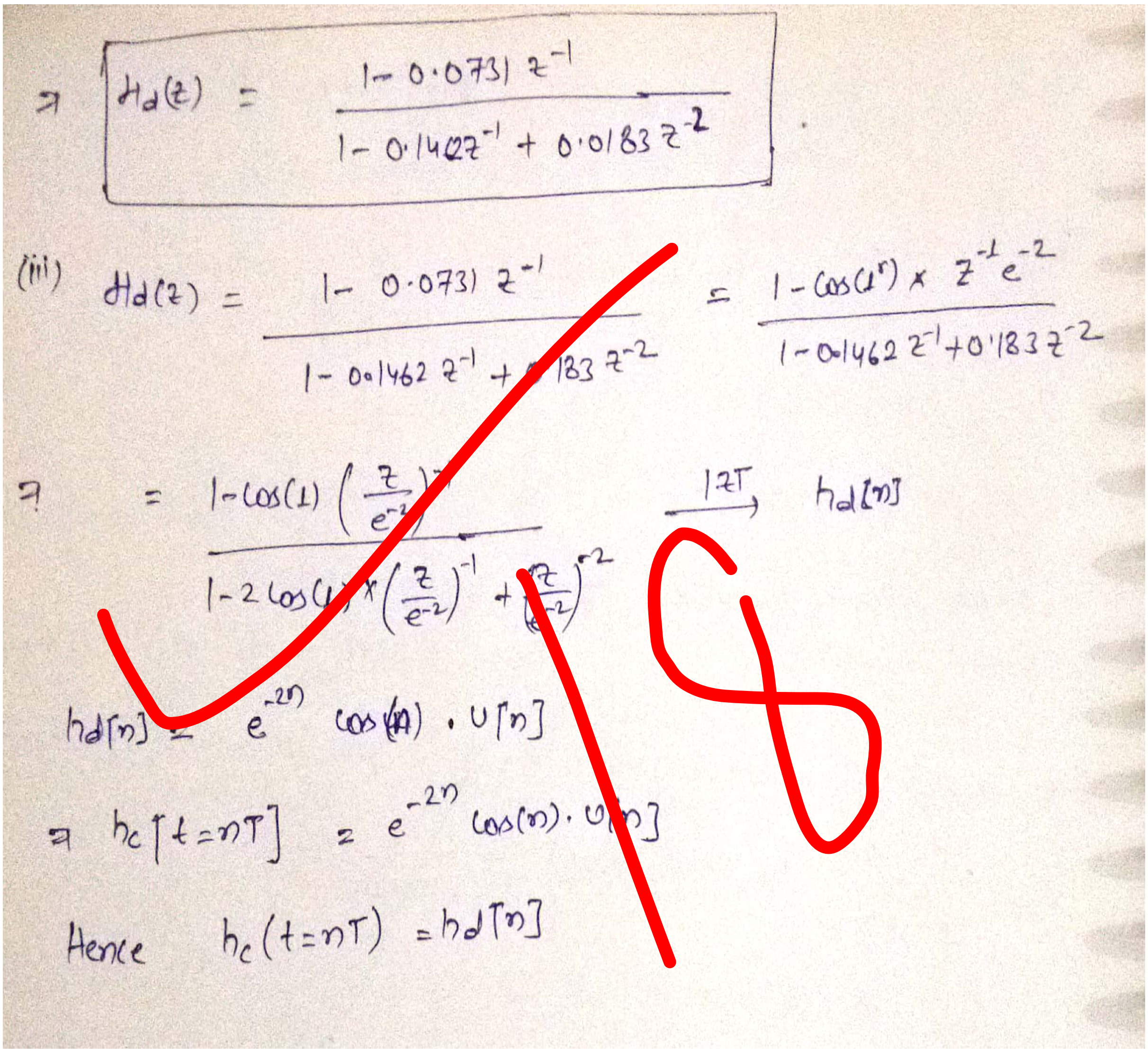
(ii) Impulse invariant method $H_c(S) = (T = 1S)$

$$\frac{(S+2)}{S^2+b^2} \longleftrightarrow T\frac{(1-\cos\omega\cdot z^{-1})}{1-2\cos\omega z^{-1}+z^{-2}}$$ where $\omega = bT$

also by using property $X(S+a) \longleftrightarrow X_d(ze^{at})$

Here $b=1$, $a=2$, $T=1$ So, $\omega = A\times T = 1\times 1 = 1$ rad/s

So $$H_d(z) = \frac{1-\cos 1^r \times e^{-2} z^{-1}}{1-2\cos 1^r z^{-1}\times e^{-2}+e^{-4} z^{-2}}$$



$$\Rightarrow \boxed{H_d(z) = \frac{1 - 0.0731 z^{-1}}{1 - 0.1462 z^{-1} + 0.0183 z^{-2}}}.$$

(iii) $$H_d(z) = \frac{1 - 0.0731 z^{-1}}{1 - 0.1462 z^{-1} + 0.183 z^{-2}} = \frac{1 - \cos(1^r) \times z^{-1} e^{-2}}{1 - 0.1462 z^{-1} + 0.183 z^{-2}}$$

$$\Rightarrow \quad = \frac{1 - \cos(1)\left(\frac{z}{e^{-2}}\right)^{-1}}{1 - 2\cos(1) \times \left(\frac{z}{e^{-2}}\right)^{-1} + \left(\frac{z}{e^{-2}}\right)^{-2}} \xrightarrow{IZT} h_d[n]$$

$$h_d[n] = e^{-2n} \cos(n) \cdot u[n]$$

$$\Rightarrow h_c[t = nT] = e^{-2n} \cos(n) \cdot u[n]$$

Hence $h_c(t = nT) = h_d[n]$

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Q.2 (c) Consider the state equation:

$$\begin{bmatrix} \dfrac{dx_1(t)}{dt} \\ \dfrac{dx_2(t)}{dt} \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ -2 & -3 \end{bmatrix} \begin{bmatrix} x_1(t) \\ x_2(t) \end{bmatrix} + \begin{bmatrix} 0 \\ 1 \end{bmatrix} u(t)$$

Determine the state-transition matrix $\phi(t)$ and the state vector $x(t)$ when the initial state is $x(0) = [1 \quad 1]^T$ and input $u(t) = 1$ for $t \geq 0$.

[20 marks]

Ans 2 ⓒ Given $\begin{bmatrix} \dfrac{dx_1(t)}{dt} \\ \dfrac{dx_2(t)}{dt} \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ -2 & -3 \end{bmatrix} \begin{bmatrix} x_1(t) \\ x_2(t) \end{bmatrix} + \begin{bmatrix} 0 \\ 1 \end{bmatrix} u(t)$

$A = \begin{bmatrix} 0 & 1 \\ -2 & -3 \end{bmatrix}$, $B \begin{bmatrix} 0 \\ 1 \end{bmatrix}$

So $SI - A = \begin{bmatrix} S & 0 \\ 0 & S \end{bmatrix} - \begin{bmatrix} 0 & 1 \\ -2 & -3 \end{bmatrix} = \begin{bmatrix} S & -1 \\ 2 & S+3 \end{bmatrix}$

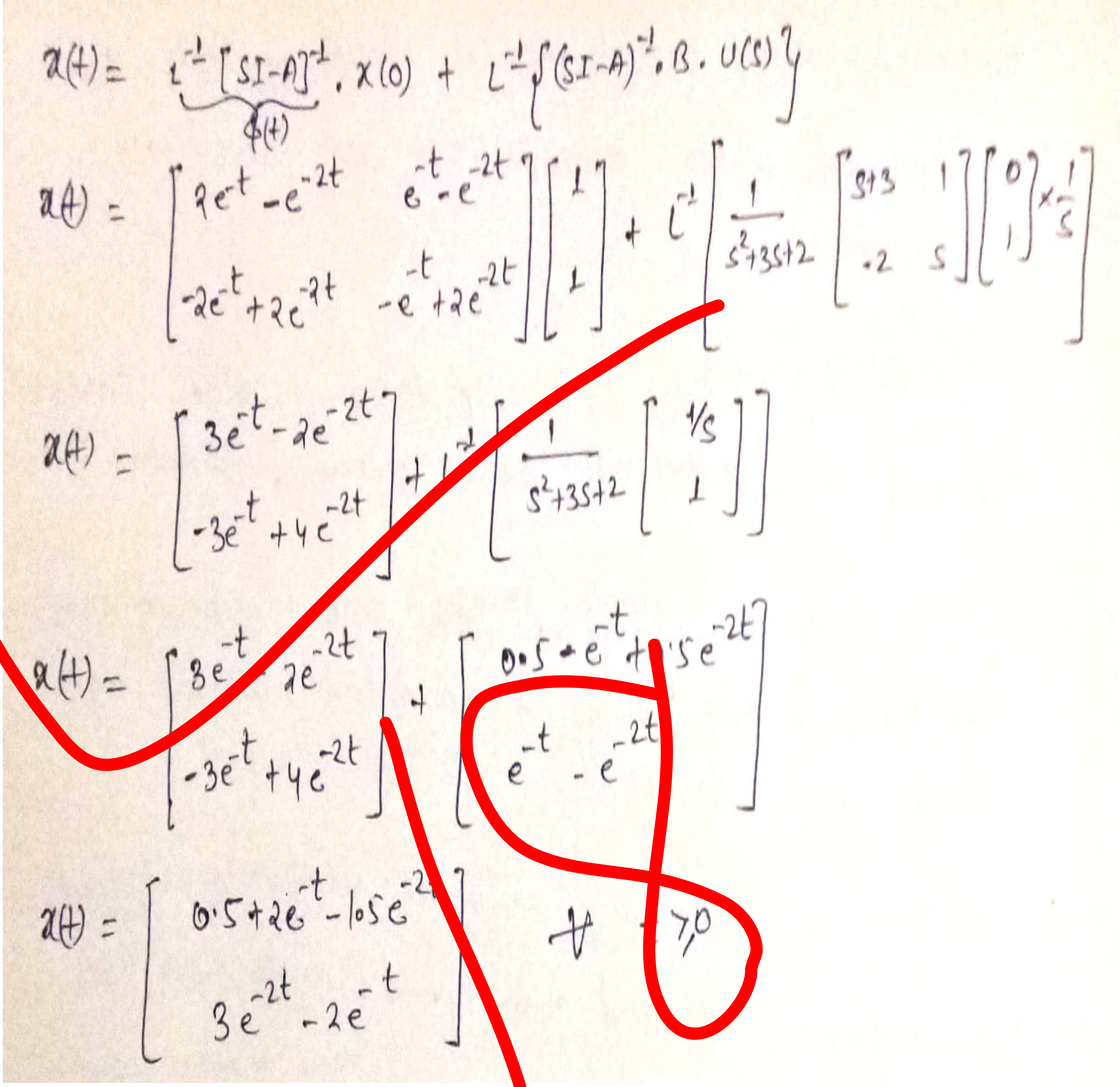
So, State transition Matrix $\phi(t) = L^{-1}\left[[SI-A]^{-1} \right]$

$$\phi(t) = L^{-1}\left[\frac{1}{s^2+3s+2} \begin{bmatrix} S+3 & 1 \\ -2 & s \end{bmatrix} \right] = L^{-1} \underbrace{\begin{bmatrix} \dfrac{S+3}{(S+2)(S+1)} & \dfrac{1}{(S+2)(S+1)} \\ \dfrac{-2}{(S+2)(S+1)} & \dfrac{s}{(S+2)(S+1)} \end{bmatrix}}_{[SI-A]^{-1}} \quad —①$$

$$\Rightarrow \phi(t) = L^{-1}\begin{bmatrix} \dfrac{2}{S+1} - \dfrac{1}{S+2} & \dfrac{1}{(S+1)} - \dfrac{1}{(S+2)} \\ -2\left(\dfrac{1}{S+1} - \dfrac{1}{S+2}\right) & \dfrac{2}{S+2} - \dfrac{1}{S+1} \end{bmatrix}$$

$$\Rightarrow \phi(t) = \begin{bmatrix} 2e^{-t} - e^{-2t} & e^{-t} - e^{-2t} \\ -2e^{-t} + 2e^{-2t} & 2e^{-2t} - e^{-t} \end{bmatrix} \Rightarrow \text{State transition matrix.}$$

Now, $X(0) = [1 \quad 1]^T$



$$x(t) = \underbrace{L^{-1}[SI-A]^{-1}}_{\phi(t)} . x(0) + L^{-1}\left\{(SI-A)^{-1} . B . U(S)\right\}$$

$$x(t) = \begin{bmatrix} 2e^{-t} - e^{-2t} & e^{-t} - e^{-2t} \\ -2e^{-t} + 2e^{-2t} & -e^{-t} + 2e^{-2t} \end{bmatrix} \begin{bmatrix} 1 \\ 1 \end{bmatrix} + L^{-1}\left[\frac{1}{s^2+3s+2}\begin{bmatrix} s+3 & 1 \\ -2 & s \end{bmatrix}\begin{bmatrix} 0 \\ 1 \end{bmatrix} \times \frac{1}{s}\right]$$

$$x(t) = \begin{bmatrix} 3e^{-t} - 2e^{-2t} \\ -3e^{-t} + 4e^{-2t} \end{bmatrix} + L^{-1}\left[\frac{1}{s^2+3s+2}\begin{bmatrix} 1/s \\ 1 \end{bmatrix}\right]$$

$$x(t) = \begin{bmatrix} 3e^{-t} - 2e^{-2t} \\ -3e^{-t} + 4e^{-2t} \end{bmatrix} + \begin{bmatrix} 0.5 - e^{-t} + 0.5e^{-2t} \\ e^{-t} - e^{-2t} \end{bmatrix}$$

$$x(t) = \begin{bmatrix} 0.5 + 2e^{-t} - 1.5e^{-2t} \\ 3e^{-2t} - 2e^{-t} \end{bmatrix} \quad \forall \; t \geq 0$$

✓ 18

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Q.3 (a) (i) Briefly discuss the methods of power factor improvement in phase controlled rectifier.

(ii) A single-phase full converter in operated with symmetrical angle control, conduction angle $\beta = \frac{\pi}{3}$.

If the load current, I_a is constant and ripple is negligible. Determine the Fourier series expression of input current, the harmonic factor HF, the displacement factor DF and the input power factor.

[8 + 12 = 20 marks]

Ans 3 ⓐ For power factor improvement three schemes are used:→

- Extinction angle control:→ Circuit diagram of 1ϕ full wave half controlled force commutated converter is shown below:→

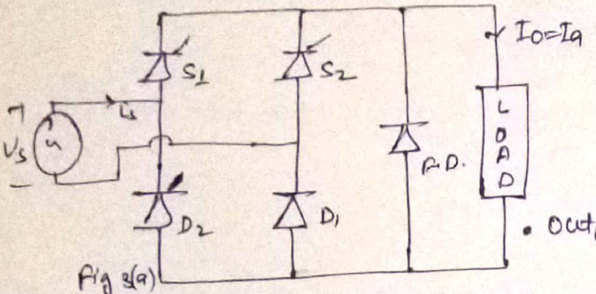


Fig 3(a)

Here S_1 turned on at $\omega t = 0$ and forced turned off at $\omega t = \pi - \beta$

The S_2 switch turned on at $\omega t = \pi$ and force turned off at $\omega t = 2\pi - \beta$

- output voltage varied by varying β.

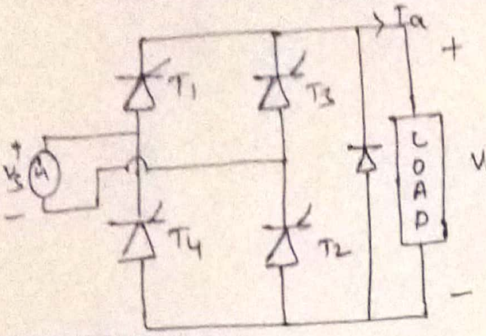
The fundamental component of current lead the input voltage and displacement power factor is leading feature may be used to simulate a capacitive load. Thus compensate line voltage drop.

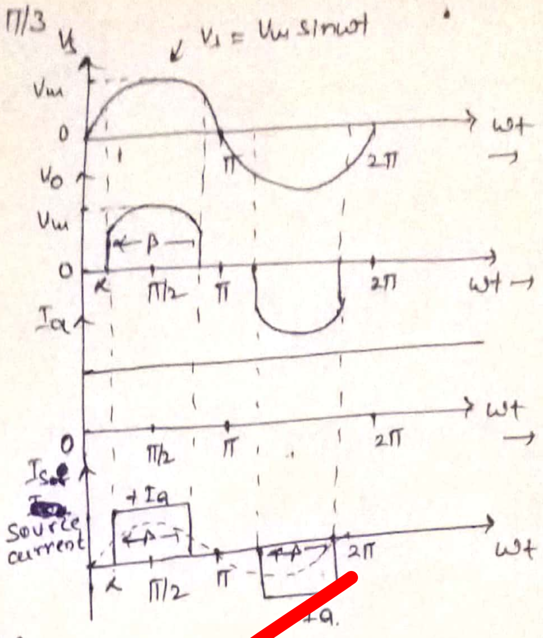
- Symmetrical angle control:→ Refer same fig 3(a) here switch S_1 is turned on at $\omega t = (\pi - \beta)/2$ and turned off at $\omega t = (\pi + \beta)/2$. The other switch S_2 turned on at $\omega t = \frac{(3\pi - \beta)}{2}$ and turned off at $\omega t = \frac{(3\pi + \beta)}{2}$. Here fundamental component of current in phase with voltage so displacement factor is unity 1.0. Therefore power factor is improved.

- Pulse width modulation (PWM) control:→
  - If output voltage is controlled by delay angle extinction angle or symmetrical angle, there is only one pulse per half cycle as a result lower order harmonic in the input current is third.
  - It is difficult to filter out lower order harmonics. So here switches are turned on & off several times per half cycle.
  - By selective elimination technique lower harmonics can be eliminated and high harmonics can be filtered out easily.

✓ 8

(ii) Symmetrical angle control :- $\beta = \pi/3$





Conduction starts

$\alpha = \omega t = \left(\frac{\pi - \beta}{2}\right) = \frac{(\pi - \pi/3)}{2}$

$\boxed{\alpha = \pi/3}$

So, and conduction end at $= \omega t = \alpha + \beta$

$= \frac{\pi}{3} + \pi/3 = \frac{2\pi}{3} = 120°$

Fourier series of source current $I_s = a_0 + \sum_{n=1,3,5} a_n \cos n\omega t + b_n \sin n\omega t$

∴ since source current is odd wave so $a_n = 0$ and Half wave Symmetrical or $a_0 = 0$

$b_n = \frac{2}{T_0} \int_0^T f(t) \sin n\omega t = \frac{2}{2\pi} \left[\underbrace{\int_{\alpha}^{\alpha+\beta} I_s(t) \sin n\omega t \, d\omega t} + \underbrace{\int_{\pi+\alpha}^{\pi+\alpha+\beta} I_s(t) \sin n\omega t \, d\omega t} \right]$

Both are Equal.

$b_n = \frac{2}{\pi} \left[\int_{\pi/3}^{2\pi/3} I_a \sin n\omega t \, d\omega t \right]$

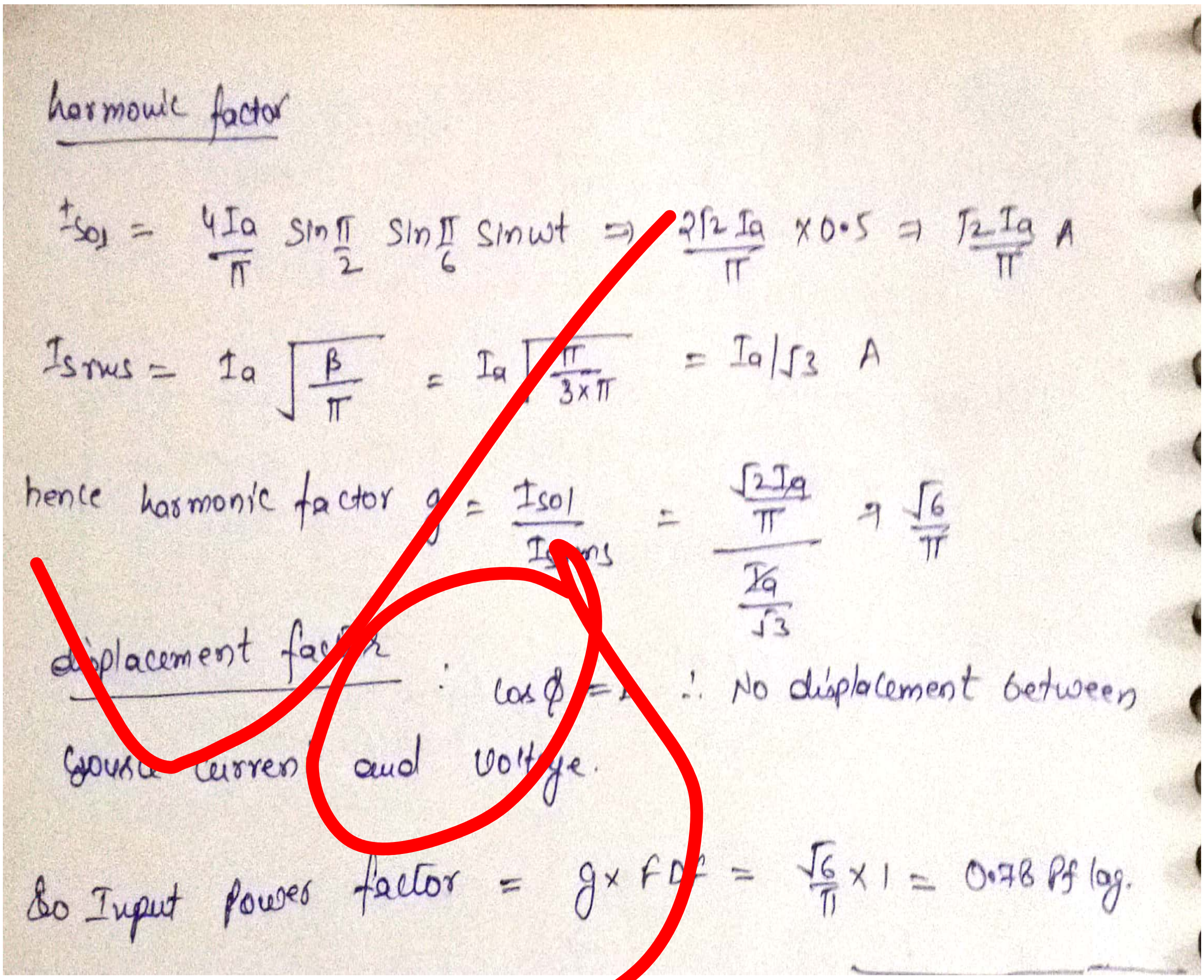
$b_n = \frac{2}{\pi} \frac{I_a}{n} \left[-\cos n\omega t \right]_{\pi/3}^{2\pi/3} = \frac{2}{\pi} I_a \left[\cos n\frac{\pi}{3} - \cos n\frac{2\pi}{3} \right]$

$b_n = \frac{2}{\pi} I_a \left[2 \sin \frac{n\pi}{2} \right] \sin \left[\frac{n\pi}{6} \right]$ ∴ $\sin \frac{n\pi}{2} = (+1)$ or -1 or 0

∴ $\boxed{\cos C - \cos D = 2 \sin \frac{C+D}{2} \sin \frac{D-C}{2}}$

So $I_s = \frac{4 I_a}{n\pi} \sum_{n=1,3,5--}^{\infty} \left(\sin \frac{n\pi}{2} \sin \frac{n\pi}{6} \sin n\omega t \right)$

Hence input current $\boxed{I_s = \frac{4 I_a}{n\pi} \sum_{1,3,5}^{\infty} \sin \frac{n\pi}{2} \sin \frac{n\pi}{6} \sin n\omega t}$



harmonic factor

$$I_{s01} = \frac{4I_a}{\pi} \sin\frac{\pi}{2} \sin\frac{\pi}{6} \sin\omega t \Rightarrow \frac{2\sqrt{2}\, I_a}{\pi} \times 0.5 \Rightarrow \frac{\sqrt{2}\, I_a}{\pi} \text{ A}$$

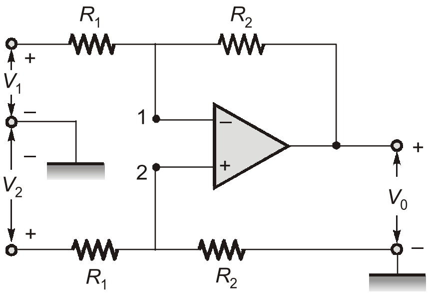
$$I_{s\,rms} = I_a \sqrt{\frac{\beta}{\pi}} = I_a \sqrt{\frac{\pi}{3\times\pi}} = I_a/\sqrt{3} \text{ A}$$

hence harmonic factor $g = \frac{I_{s01}}{I_{s\,rms}} = \frac{\frac{\sqrt{2} I_a}{\pi}}{\frac{I_a}{\sqrt{3}}} \Rightarrow \frac{\sqrt{6}}{\pi}$

displacement factor : $\cos\phi = 1$ ∴ No displacement between source current and voltage.

So Input power factor = $g \times FDF = \frac{\sqrt{6}}{\pi} \times 1 = 0.78$ pf lag.

Q.3 (b) (i) The differential input operational amplifier shown below consists of a base amplifier of infinite gain. Derive an expression for its output voltage, V_0.



(ii) Draw the pin diagram of the 555 timer.

A 555 timer is connected for Astable operation with $V_{CC} =$ 12 V. The component values are selected as R_A = 10 kΩ, R_B = 2.3 kΩ and C = 0.1 μF.

Calculate:

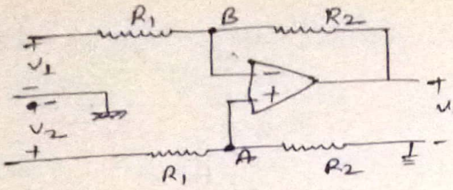
(a) Output frequency

(b) Duty cycle

(c) Average power dissipated if 1 kΩ resistive load is connected between source and the output pin.

[10 + 10 = 20 marks]

Ans ③ ⓑ (i)



Applying KCL at Node A

$$\frac{V_A - V_2}{R_1} + \frac{V_A - 0}{R_2} = 0$$

$$V_A\left[\frac{1}{R_1} + \frac{1}{R_2}\right] = \frac{V_2}{R_1} + \frac{0}{R_2}$$

$$\Rightarrow V_A\left[\frac{R_2 + R_1}{R_1 R_2}\right] = \frac{V_2}{R_1} + \frac{0}{R_2} \quad —— ①$$

∴ Negative feedback is used so from virtual ground concept $V_+ = V_-$ ⇒ so $V_B = V_A$

Applying KCL at Node B

$$\frac{V_B - V_o}{R_2} + \frac{V_B - V_1}{R_1} = 0 \Rightarrow V_B\left[\frac{1}{R_2} + \frac{1}{R_1}\right] = \frac{V_1}{R_1} + \frac{V_o}{R_2}$$

∴ $V_B = V_A$ so $V_A\left[\frac{R_2 + R_1}{R_1 R_2}\right] = \frac{V_1}{R_1} + \frac{V_o}{R_2}$ —— ②

From eq ① & ②

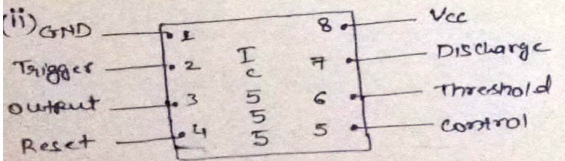
$$\frac{V_2}{R_1} + 0 = \frac{V_1}{R_1} + \frac{V_o}{R_2}$$

$$\Rightarrow \frac{(V_2 - V_1)}{R_1} = \frac{V_o}{R_2} \Rightarrow \boxed{V_o = -(V_1 - V_2) \times \frac{R_2}{R_1}}$$

Hence output voltage $\boxed{V_o = \frac{-R_2}{R_1}(V_1 - V_2)}$ Volts.

9

(ii)



IC 555 Pin diagram

Pin1 = Ground
Pin2 = Trigger
Pin3 = output
Pin4 = Reset
Pin5 = control
Pin6 = threshold
Pin7 = Discharge
Pin8 = Vcc (supply)

It is a 8 pin device/I.C.

Given, $V_{CC} = 12V$, $R_A = 10k\Omega$, $R_B = 2.3k\Omega$, $C = 0.1\mu f$

$t_1 = 0.693(R_A + R_B)C$ ⇒ charging time | $t_2 = 0.693 \times R_B \times C$ ⇒ Discharge time

So $t_1 = 0.693(10 + 2.3) \times 10^3 \times 0.1 \times 10^{-6}$ | $t_2 = 0.693 \times 2.3 \times 10^3 \times 0.1 \times 10^{-6}$

$t_1 = 0.852\ ms$ | $t_2 = 0.16\ ms$

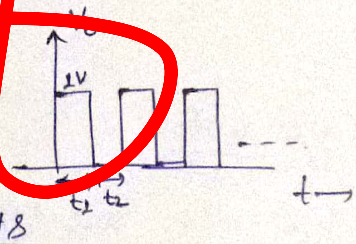
So T, total time $= t_1 + t_2 = 0.852 + 0.16 = 1.012\ ms$

Hence frequency $= \frac{1}{T} = \frac{1}{1.012 \times 10^{-3}} = 988.14\ Hz$

Hence output frequency $= 988.14\ Hz$.

⑥ Duty cycle $= \frac{T_{ON}}{T} = \frac{t_1}{T} = \frac{0.852}{1.012} = 0.842$

© Output Voltage of Astable operation



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So $V_{O\,Avg} = \frac{1 \times t_1 + 0 \times t_2}{T}$ ⇒ $\underline{\underline{0.842\ Volts}}$

So, Average Power loss if 1kΩ connected b/w source and output $= ~~\left(\frac{V_s - V_o}{R}\right)^2 \times R = \left(\frac{12 - 0.842}{1 \times 10^3}\right)^2 \times 1 \times 10^3~~$

~~$= 11.1$[illegible]mw.~~

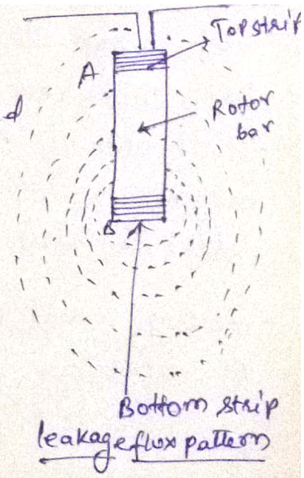
Q.3 (c) (i) Explain with the help of diagram the advantages of deep-bar and double-cage rotor. Also draw the torque slip characteristics of deep bar rotor and double cage rotor.

(ii) The impedances at standstill of the inner and outer cages of a double-cage rotor are $(0.01 + j0.5)\ \Omega$ and $(0.05 + j0.1)\ \Omega$ respectively. The stator impedance may be neglected. Calculate the ratio of the torques due to the two cages at starting as well as while running with a slip of 5%.

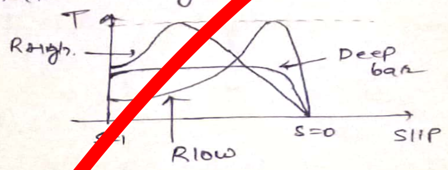
[10 + 10 = 20 marks]

Ans ③ ⓒ

Deep bar rotor :→



- Bar of narrow width laid down in semi enclosed slot.
- Bar imagined to be composed of elimentary parallel strips
- much larger flux linkage to bottom so $x_B >> x_A$. So $I_A >> I_B$ and current I_A lead to I_B because low x_A.
- Non uniform current distribution in the strip and current increases as we go up from B to A. and resistance a.c. increases
- As speed approaches to synchronous speed N_s i.e. $N_r \rightarrow N_s$ So $f_r = sf_s$ is low so reactance of all strips become nearly equal.
- thereby current uniform in all the strip from top to bottom and $R_{ac} \simeq R_{dc}$.
- In deep bar starting torque is greater than running torque and starting current is low.
- X_{net} i.e. reactance at standstill is high so T_{max} is low compared to normal bar motor



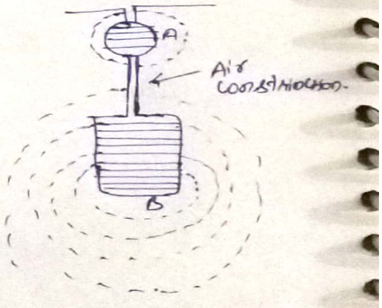
Double Cage motor

Double Cage rotor are expensive but better starting and running performance.

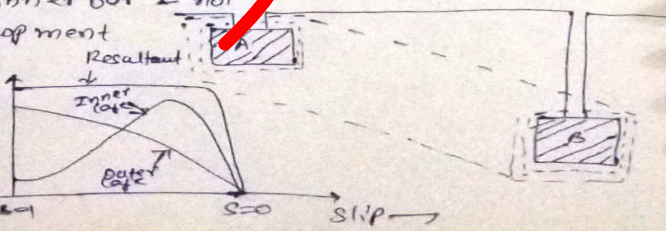
Here Area of cage A is greater than that of B.

So resistance of cage A less than that B.

- Bar A has low leakage flux linkage so $x_A << x_B$.



- self linkage flux in upper bar or lower bar controlled by Air constriction dimension.
- It its absence main flux link with Iron path between 2 slots missing the Inner bar & not contribute the torque development
- starting current mainly confined to outer cage only.



Ans 3 ⓒ(ii) $\therefore\ T_s = \frac{3}{\omega_s} \frac{V'^2 R_2^2}{R_2^2 + X_2^2}$ where V' = rotor induced emf

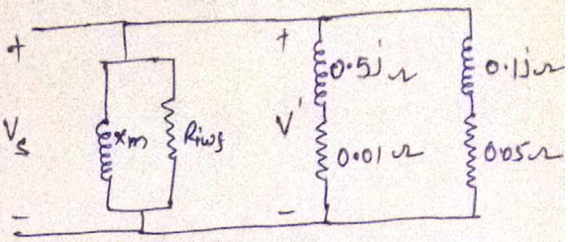
Starting torque ↗ $s=1$.

Given, $Z_i = 0{\cdot}01 + j\,0{\cdot}5\Omega$, $Z_o = 0{\cdot}05 + j\,0{\cdot}1\Omega$

So substituting values

$$T_{so} = \frac{3}{\omega_s} \times \frac{V'^2 \times 0{\cdot}05}{0{\cdot}05^2 + 0{\cdot}1^2}$$

and $$T_{si} = \frac{3}{\omega_s} \times \frac{V'^2 \times 0{\cdot}01}{0{\cdot}01^2 + 0{\cdot}5^2}$$



Approx. circuit model of double cage induction motor.

So $$\frac{T_{so}}{T_{s1}} = \frac{(0{\cdot}01^2 + 0{\cdot}5^2)}{(0{\cdot}05^2 + 0{\cdot}1^2)} \times \frac{(0{\cdot}05)}{(0{\cdot}01)} = 100$$

Torque with slip at running condition,

$$T = \frac{3}{\omega_s} \frac{V'^2 (R_2/s)}{\left(\frac{R_2}{s}\right)^2 + X_2^2}$$

$$T_o = \frac{3}{\omega_s} \cdot \frac{V'^2 (0{\cdot}05/0{\cdot}05)}{(0{\cdot}05/0{\cdot}05)^2 + 0{\cdot}1}$$

$$T_i = \frac{3}{\omega_s} V'^2 \frac{(0{\cdot}01/0{\cdot}05)}{\left(\frac{0{\cdot}01}{0{\cdot}05}\right)^2 + 0{\cdot}3^2}$$

So $$\frac{T_o}{T_i} = \frac{\left(\frac{0{\cdot}01}{0{\cdot}05}\right)^2 + 0{\cdot}5^2}{\left(\frac{0{\cdot}05}{0{\cdot}05}\right)^2 + 0{\cdot}1^2} \times \frac{0{\cdot}05}{0{\cdot}01} = 1{\cdot}436$$

Hence outer cage contribute 100 times than inner cage at starting while it contributes only 1.436 times during running.

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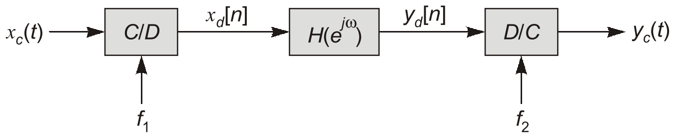
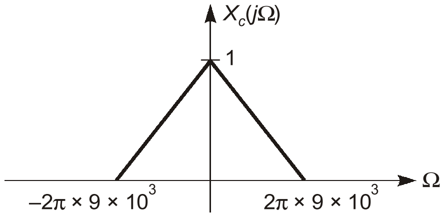
Q.4 (a)

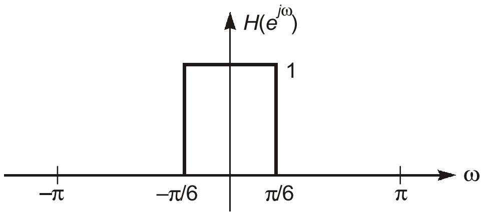
(i) State the sampling theorem. What is Nyquist rate?

(ii) In the system below, $X_c(j\Omega)$ and $H(e^{j\omega})$ are shown, f_1 = 30 kHz, f_2 = 10 kHz. Sketch and label the Fourier transform of $y_d[n]$ and $y_c(t)$. Also calculate the value of $\sum_{n=-\infty}^{\infty} y_d[n]$.



where, *C*/*D* is ideal continuous to discrete time converter and *D*/*C* is ideal discrete to continuous time converter.





[2 + 18 marks]

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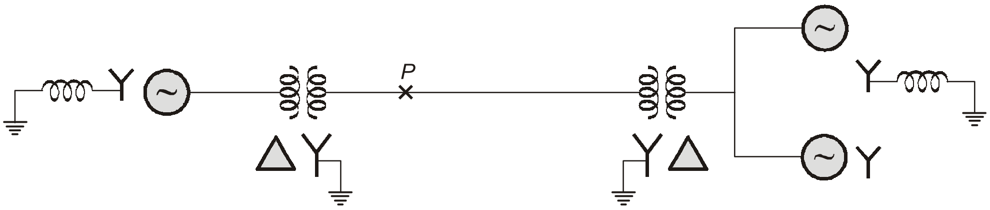
Q.4 (b) A 30 MVA, 13.8 kV, 3-phase alternator has a subtransient reactance of 15% and negative and zero sequence reactances of 15% and 5% respectively. The alternator supplies two motors over a transmission line having transformer at both ends as shown on the one-line diagram. The motors have rated inputs of 20 MVA and 10 MVA both 12.5 kV with 20% subtransient reactance and negative and zero sequence reactances are 20% and 5% respectively. Current limiting reactors of 2 Ω each are in the neutral of the alternator and the larger motor. The 3-phase transformer are both rated 35 MVA, 13.2 Δ-115 Y kV with leakage reactance of 10%. Series reactance of line is 80 Ω. The zero sequence reactance of the line is 200 Ω. Determine the fault current when a line-to-ground (L-G) fault occurs at point *P*. (Assume $V_f = 120$ kV)

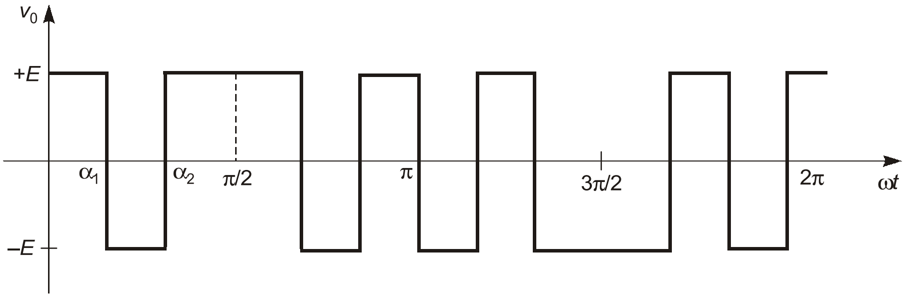


[20 marks]

Q.4 (c) (i) A two-notch PWM inverter output voltage waveform is shown in figure. Prove that the Fourier series representation is given by

$$v_0(t) = \sum_{n=1,3,5}^{\infty} A_n \sin n\omega t$$

where, $$A_n = \frac{4E}{n\pi}(1-2\cos n\alpha_1 + 2\cos n\alpha_2)$$



(ii) Find the values of α_1 and α_2 to eliminate 3rd and 5th harmonics from output.

[10 + 10 = 20 marks]

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Section-B

Q.5 (a) The following assembly language program of an 8085 microprocessor, working with a clock frequency of 3 MHz is used to set up a delay of 10 ms:

```
        MVI B,  wx H
        MVI C,  yz H
L1:     DCX B
        JNZ L1
```

What is the minimum value of $(wxyz)_H$ in hexadecimal to obtain required delay?

[12 marks]

Ans5 ⓐ

MVI B , wx H → 07T States

MVIC , yz H → 07 T states

L1 DCXB → 06T States

JNZ L1 → 10T / 07 States

$\swarrow$ True $\searrow$ False

HLT

Total T States = $07T + 7T + 6[16\times w + x]T + 10T[16w+x]$

$+ 7T = 10\times10^{-3}\,s$

total time = $[21 + (16w+x)[16]]T = 10\times10^{-3}$

∴ frequency = 3MHz (given) so $T = \frac{1}{f} = \frac{1}{3\times106}$

5

So $[21 + (16w+x)\times16] = 10\times10^{-3} \times 3\times10^{6}$

$\Rightarrow 16w + x = 1873.68 \approx 1874$

$\Rightarrow w = 117,\ x=2$

for minimum value of $(wxyz)$, $yz = 00$ i.e. $y=0,\ z=0$

So $(wxyz)_{10} = 1000\times w + 100\times x + 10\times y + z$

$= 1000\times117 + 100\times2 + 0 + 0$

$= (117200)_{10} = (1C9D0)_{H}$

Hence minimum value of $(wxyz)_{10} = (1C9D0)_H$

Q.5 (b) A generating station has a maximum demand of 20 MW, a load factor of 60%, plant capacity factor of 48% and plant use factor of 80%. Find:

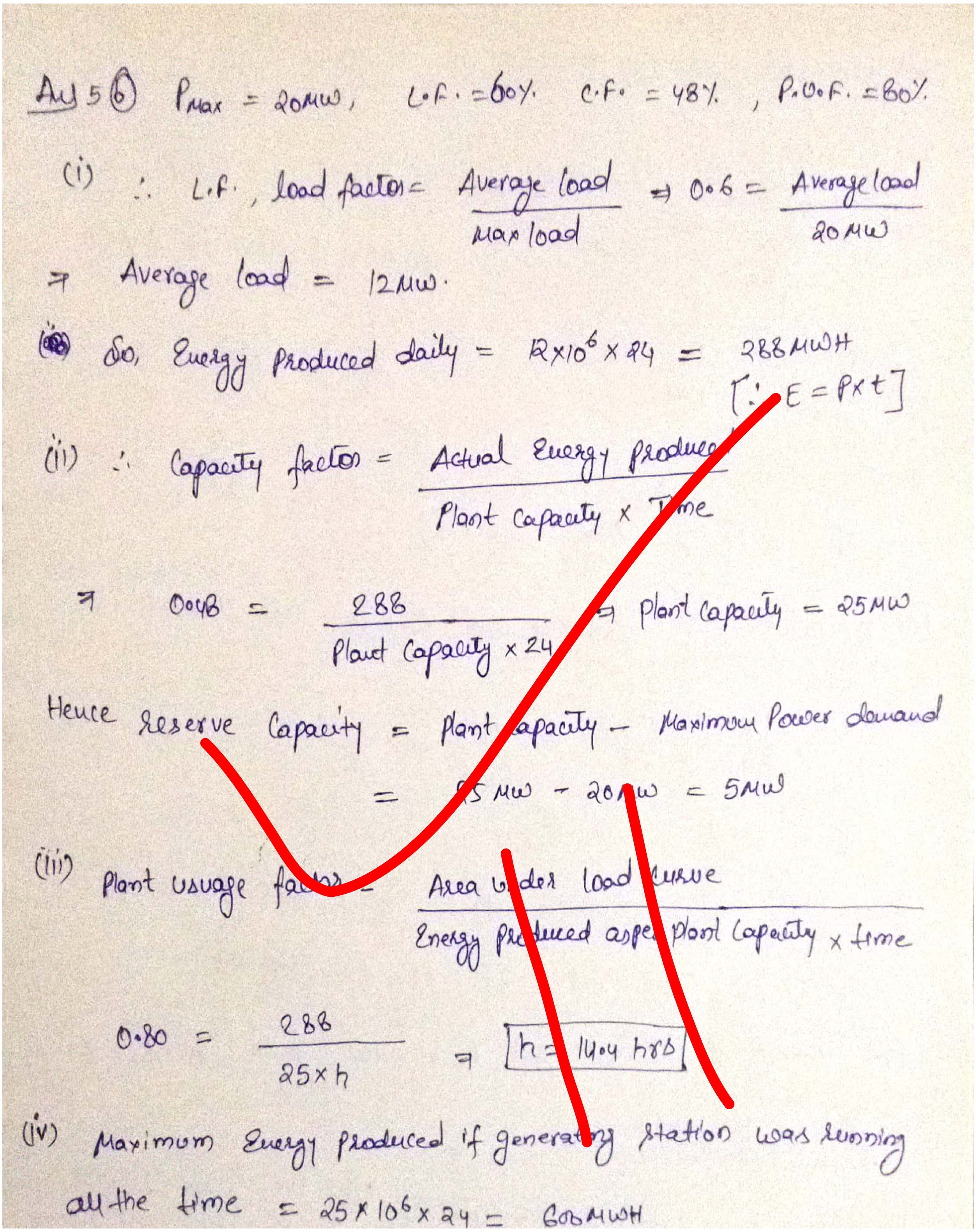
(i) The daily energy produced

(ii) The reverse capacity

(iii) The number of operating hours per day

(iv) The maximum energy that could be produced daily if the generation station was running all the time.

[4 × 3 = 12 marks]



Ans 5 (b) $P_{Max} = 20MW$, $L.F. = 60\%$ $C.F. = 48\%$, $P.U.F. = 80\%$

(i) ∴ L.F., load factor $= \frac{\text{Average load}}{\text{Max load}} \Rightarrow 0.6 = \frac{\text{Average load}}{20MW}$

$\Rightarrow$ Average load $= 12MW$.

(i) So, Energy produced daily $= 12\times10^6 \times 24 = 288MWH$

$[\because E = P\times t]$

(ii) ∴ Capacity factor $= \frac{\text{Actual Energy produced}}{\text{Plant capacity} \times \text{Time}}$

$\Rightarrow 0.48 = \frac{288}{\text{Plant Capacity} \times 24} \Rightarrow$ Plant capacity $= 25MW$

Hence reserve capacity = plant capacity − Maximum Power demand

$= 25MW - 20MW = 5MW$

(iii) Plant usage factor $= \frac{\text{Area under load curve}}{\text{Energy produced as per plant capacity} \times \text{time}}$

$0.80 = \frac{288}{25\times h} \Rightarrow \boxed{h = 14.04 \text{ hrs}}$

(iv) Maximum Energy produced if generating station was running all the time $= 25\times10^6\times24 = 600MWH$

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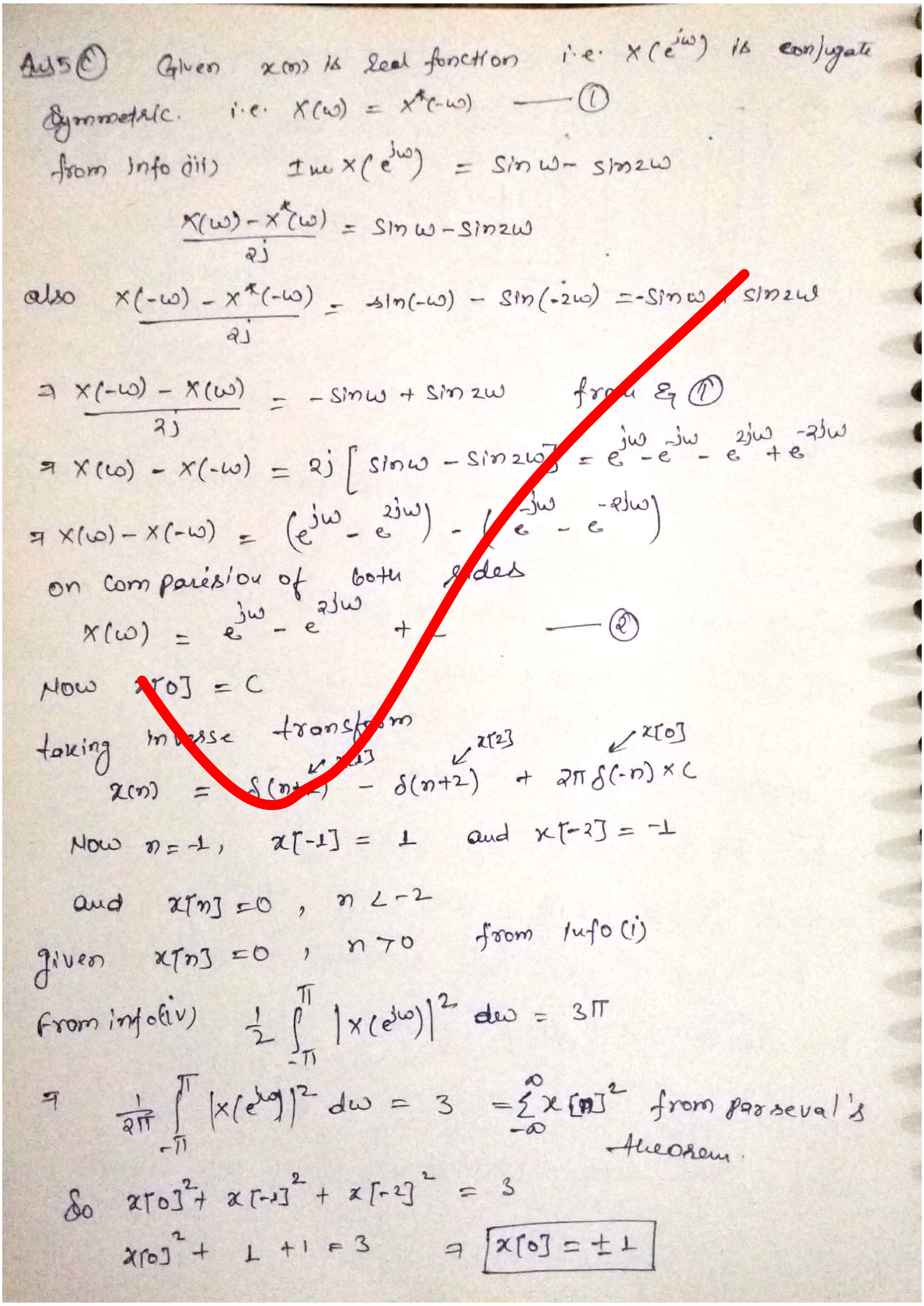
Q.5 (c) A real signal $x[n]$ with Fourier transform $X(e^{j\omega})$ has following properties:

(i) $x[n] = 0$ for $n > 0$ (ii) $x[0] > 0$

(iii) $\text{Im}(X(e^{j\omega})) = \sin\omega - \sin 2\omega$ (iv) $\frac{1}{2}\int_{-\pi}^{\pi}\left|X(e^{j\omega})\right|^2 d\omega = 3\pi$

Determine $x[n]$

[12 marks]



Ans 5 ⓒ Given $x(n)$ is Leal fonction i.e. $X(e^{jw})$ is conjugate Symmetric. i.e. $X(\omega) = X^*(-\omega)$ —— ①

from Info (iii) $\text{Im}\, X(e^{jw}) = \sin w - \sin 2w$

$$\frac{X(\omega) - X^*(\omega)}{2j} = \sin\omega - \sin 2\omega$$

also $\frac{X(-\omega) - X^*(-\omega)}{2j} = \sin(-\omega) - \sin(-2\omega) = -\sin\omega + \sin 2\omega$

$\Rightarrow \frac{X(-\omega) - X(\omega)}{2j} = -\sin w + \sin 2w$ from Eq ①

$\Rightarrow X(\omega) - X(-\omega) = 2j\left[\sin w - \sin 2w\right] = e^{jw} - e^{-jw} - e^{2jw} + e^{-2jw}$

$\Rightarrow X(\omega) - X(-\omega) = \left(e^{jw} - e^{2jw}\right) - \left(e^{-jw} - e^{-2jw}\right)$

on comparesiou of both sides

$X(\omega) = e^{jw} - e^{2jw} + c$ —— ②

Now $x[0] = c$

taking inverse transform

$x(n) = \overset{x[1]}{\delta(n+1)} - \overset{x[2]}{\delta(n+2)} + \overset{x[0]}{2\pi\delta(-n) \times c}$

Now $n = -1$, $x[-1] = 1$ and $x[-2] = -1$

and $x[n] = 0$, $n < -2$

given $x[n] = 0$, $n > 0$ from Info (i)

From info (iv) $\frac{1}{2}\int_{-\pi}^{\pi}|X(e^{jw})|^2 dw = 3\pi$

$\Rightarrow \frac{1}{2\pi}\int_{-\pi}^{\pi}|X(e^{jw})|^2 dw = 3 = \sum_{-\infty}^{\infty} x[n]^2$ from Parseval's theorem.

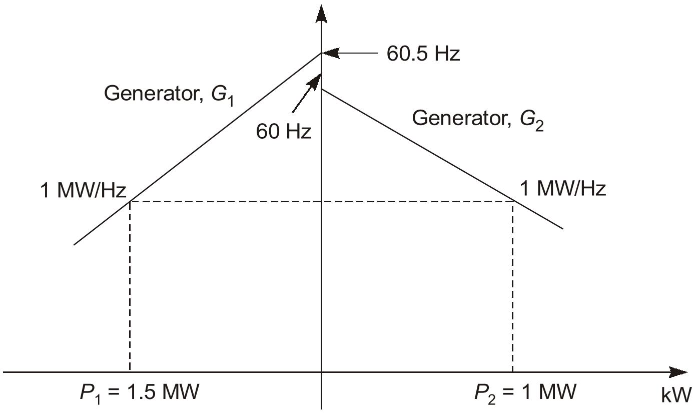
So $x[0]^2 + x[-1]^2 + x[-2]^2 = 3$

$x[0]^2 + 1 + 1 = 3 \Rightarrow \boxed{x[0] = \pm 1}$

But $x[0] > 0$ So $x[0] = 1$ is accepted

Hence $x[n] = \{-1, 1, \underset{\uparrow}{1}\} = \delta[n] + \delta[n+1] - \delta[n+2]$

Q.5 (d) Two generators G_1 and G_2 share a total load of 2.5 MW at 0.8 p.f. lagging.

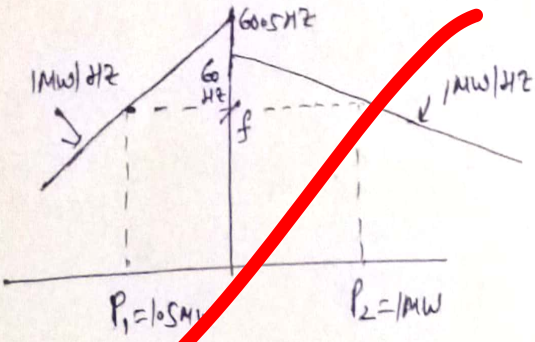


(i) If an additional 1 MW load is added to the system, what would be the system operating frequency and power supplied by each generator?

(ii) If the governor set point on G_2 is increased by 0.5 Hz, what will be the system frequency and generator powers?

[12 marks]

Ans 5(d)



for generator 1

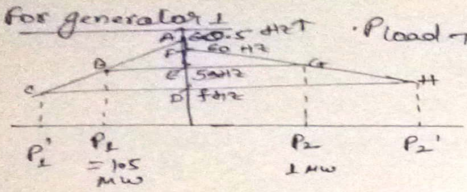
$$\frac{1 MW}{HZ} = \frac{1.5-0 \quad MW}{(60.5-f) HZ} \Rightarrow$$

$$60.5 - f = 1.5$$

$$\boxed{f = 59 HZ}$$

Both generator currently operating at 59 HZ

For generator 1



· Pload Total now = 2.5 + 1 = 3.5 MW

Δ ABE similar to Δ ACD

So $\frac{CD}{AD} = \frac{BE}{AE}$

$\Rightarrow \frac{P_1'}{(60.5-f)} = \frac{1.5}{1.5}$

$\Rightarrow P_1' = (60.5 - f)$ MW ——— ①

For generator 2 Δ FEG and Δ FDH are similar

Hence $\frac{DH}{AD} = \frac{EG}{FE} \Rightarrow \frac{P_2'}{60-f} = \frac{1}{1}$

$\Rightarrow P_2' = 60 - f$ ——— ②

Given $P_T = 3.5MW = P_1' + P_2' = 60.5 - f + 60 - f$

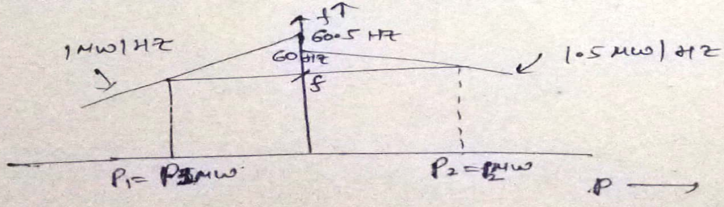
$\Rightarrow 120.5 - 3.5 = 2f \Rightarrow f = 58.5$ HZ

Put this in Eq ① we get $P_1 = 2MW$ and so $P_2' = 3.5 - P_1'$

So, $\boxed{P_2' = 1.5 \text{ MW}}$

Hence both generator operate at 58.5 HZ and Power supplied by generator 1 and 2 is 2MW and 1.5 MW respectively.

(ii)



For generator 1 Same condition as before so $P_1 = 60.5 - f$ — ①

For generator 2 : Frequency increased by 0.5HZ

i.e. drop is now $\frac{1MW}{1.5HZ} = \frac{P_2}{60-f}$

So $P_2 = 40 - \frac{f}{1.5}$ ——— ②

So $P_1 + P_2 = P_T \Rightarrow 60.5 - f + 40 - \frac{f}{1.5} = 2.5$

$\Rightarrow f = 58.8$ HZ

Put this in Eq ① we get $P_1 = 60.5 - 58.8 = 1.07$ MW

So $P_2 = P_T - P_1 = 2.5 - 1.07 = 0.8$MW

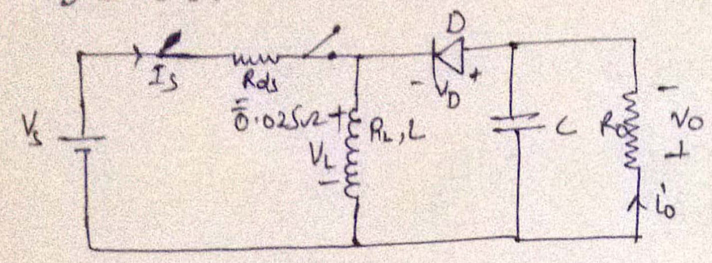
Hence both generator now operate at 58.8 HZ and Power supplied by generator 1 and 2 is $P_1 = 1.07$ MW and $P_2 = 0.8$MW.

Q.5 (e) A 1.5 V battery is to drive a load at 5 V. The load resistance is 5 Ω. A buck-boost converter is considered for this application. The MOSFET switch selected has an on-state resistance of 0.025 Ω. The schottky diode to be used for the converter has a forward voltage drop = 0.5 V, it's on-state resistance may be neglected. If it is desired to operate the converter with 70% efficiency. How large can the resistance R_L of the inductor be?

[12 marks]

Ans 5ⓔ Given $V_s = 1.5\,V$ and $V_o = 5V$, $R_o = 5\Omega$, $R_{ds} = 0.025\Omega$

$V_D = 0.5V$, $\eta = 70\%$.



$V_L = L\frac{di_L}{dt}$

During Ton :- $V_s = R_L i_L + L\frac{di_L}{dt} + R_{ds} \times i_L$

So $L\frac{di_L}{dt} = V_s - R_L i_L - R_{ds} \times i_L$ —①

During Toff :- $L\frac{di_L}{dt} = -\left[V_o + V_D + R_L i_L\right]$ —②

∴ I_s, source current $= D i_L \Rightarrow i_L = \frac{I_s}{D}$ —③

and $i_o = i_L(1-D)$ —④

So $i_L = \frac{i_o}{1-D} = \frac{V_o}{R_o(1-D)}$

Now $L\frac{di_L}{dt} \times T_{on} + L\frac{di_L}{dt} \times T_{off} = 0$

$\Rightarrow D V_s - D R_L i_L - D R_{ds} \times i_L + (1-D)\left[-V_o + V_D + R_L \times i_L\right] = 0$ —⑤

put $i_L = \frac{V_o}{R_o(1-D)}$ in Eq ⑤ we get

$$V_o = \frac{D V_s - (1-D) V_D}{(1-D)\left[1 + \frac{R_L}{(1-D)^2 R_o} + \frac{D R_{ds}}{(1-D)^2 R_o}\right]}$$

$$\Rightarrow 5 = \frac{(2D - 0.5)(1-D)}{0.05D + 0.2R_L + (1-D)^2}$$

$7D^2 - 12.475D + R_L + 5.5 = 0$

for real roots of quadratic Equation $b^2 - 4ac \geq 0$

So $(12.475)^2 - 4 \times (7) \times (R_L + 5.5) > 0$

$\Rightarrow \boxed{R_L < 0.058\ \Omega}$ ⟵ ⑥

Now, $P_{loss} = i_L^2 D R_{ds} + i_L^2 \times R_L + I_o V_D$

$= \frac{I_o^2 \times D R_{ds}}{(1-D)^2} + \frac{I_o^2 R_L}{(1-D)^2} + I_o V_D$

and $P_{out} = V_o I_o = I_o^2 \times R_o$

$\therefore \eta = \frac{P_{out}}{P_{out} + P_{loss}} \Rightarrow \frac{1}{1 + \frac{P_{loss}}{P_{out}}} = 0.7$

$\Rightarrow \frac{1}{1 + \frac{D R_{ds}}{R_o (1-D)^2} + \frac{R_L}{(1-D)^2 R_o} + \frac{V_D}{V_o}} = 0.7$

Put values: $\Rightarrow 0.7 = \frac{(1-D)^2}{1.(1-D) + 0.005D + 0.2R_L}$

$\Rightarrow 0.23D^2 - 0.4[illegible]35D + 0.23 - 0.14R_L = 0$

For real root $b^2 - 4ac > 0$

$0.[illegible]35^2 - 4(0.23)(0.[illegible]3 - 0.14R) > 0$

$\Rightarrow \boxed{R_L > -0.025\ \Omega}$ ⟵ ⑦

Hence from Eq ⑥ & ⑦

$R_{L\,max} = 0.058\ \Omega$

Q.6 (a) (i) A 220 V, 6-pole, 50 Hz, single-winding, single-phase induction motor has the following equivalent circuit parameters as referred to the stator:

$$R_{1m} = 3\,\Omega, \quad X_{1m} = 5\,\Omega$$
$$R_2 = 1.5\,\Omega, \quad X_2 = 2\,\Omega$$

Neglect the magnetizing current.

When the motor runs at 97% of synchronous speed, compute the torque produced by both the fields and also determine the resultant torque.

(ii) A compound DC motor has the following specifications:

$$R_A = 0.8\,\Omega, \quad R_{f,\text{ser}} = 0.6\,\Omega, \quad R_{f,\text{shunt}} = 100\,\Omega$$

No external (adjustable) resistance is connected.

When a mechanical load of 111 Nm is connected to its shaft, it rotates at 800 rpm and operates with 67.3%, efficiency. It is given that shunt field winding copper losses is equal to 11% of output power. Find:

(a) Shunt field current I_{sh}

(b) Supply (Terminal) voltage V_s

(c) Supply (Line) current I_s

(d) Rotational + core losses ($P_{rot + \text{core}}$)

[12 + 8 = 20 marks]

Q.6 (b) (i) Signal $x(t)$ with period $T = 1$ and with Fourier coefficients $a_k = \frac{jk}{1+k^4}$.

$x(t)$ is input to an LTI system with frequency response,

$$H(j\omega) = \begin{cases} 1 & |\omega| < 7 \\ 0 & \text{otherwise} \end{cases}$$

What is the power of the output signal $y(t)$?

(ii) Consider a continuous time signal $x(t) + t^2 = |t|$. Find the expression of Fourier transform of signal $X(\omega)$.

[10 + 10 = 20 marks]

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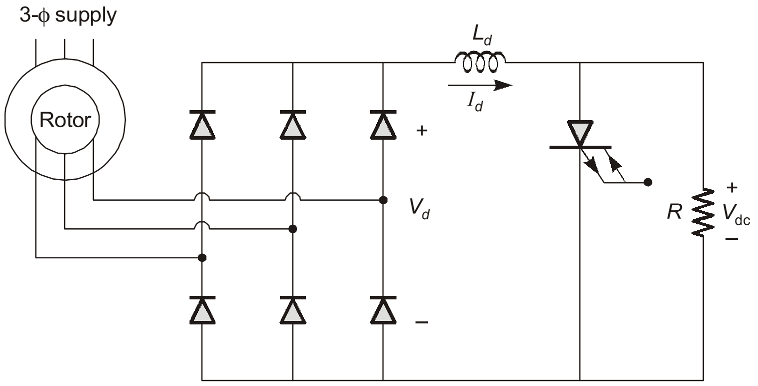
Q.6 (c) A three-phase 460 V, 60 Hz, 6-pole, Y-connected would rotor induction motor whose speed is controlled by slip power is shown in figure. The parameters are:

$$R_s = 0.041\ \Omega,\ R_r = 0.044\ \Omega,\ X_s = 0.29\ \Omega,\ X_r = 0.44\ \Omega \text{ and } X_m = 6.1\ \Omega$$

The turns ratio of rotor to stator windings is $n_m = \dfrac{N_r}{N_s} = 0.9$.

The inductance L_d is very large (as compared to R_s, R_r, X_s, X_r) and its current I_d has negligible ripple. (No-load losses of motor is negligible).



The load torque is proportional to speed squared, is 750 N-m at 1175 rpm. If the motor has to operate with a minimum speed of 800 rpm, determine resistance R.

[20 marks]

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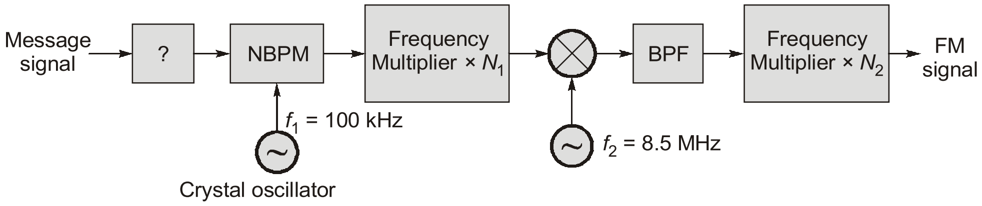
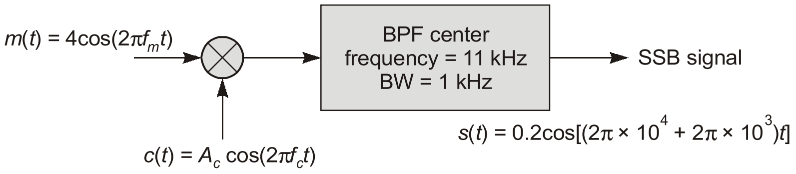
Q.7 (a) (i) For the FM modulator using Armstrong's indirect method, the desired FM signal has a carrier frequency of 100 MHz and frequency deviation of Δf = 75 kHz.



1. Complete the missing block.
2. Calculate the frequency multiplication factors N_1 and N_2 and the center frequency of the BPF.
3. Find the frequency deviation Δf_1, at the input of the first frequency multiplier.

(ii) For the SSB modulator shown:



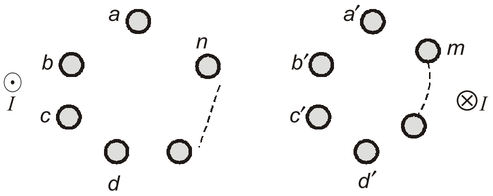
(a) What are the value of f_m, f_c and A_c?

(b) Sketch the spectrum of $s(t)$.

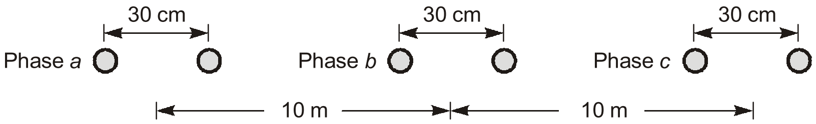
(c) Can we use envelope detector to recover the message signal $m(t)$? Explain

[10 + 10 = 20 marks]

Q.7 (b) (i) Derive an expression for the total inductance of single-phase composite conductor line composed of two conductors (x, y). Each conductor arrangement consists of n and m conductors respectively and both conductors share the same current equally. The arrangement is shown below:



(ii) A 200 km completely transposed three-phase overhead transmission line with bundled phase conductors is given in figure. All conductors have a radius of 0.74 cm with 30 cm bundle spacing. Determine the inductance per phase and inductive line reactance per phase at 50 Hz.



[12 + 8 = 20 marks]

Q.7 (c) The open-loop transfer function is $G(s) = \dfrac{2}{s^2 + s}$.

Design requirements:

Damping ratio, $\xi = 0.5$

Undamped natural frequency, $\omega_n = 2$ rad/s

(i) Find the desired dominant poles that meet desired requirements.

(ii) Find the angle deficiency.

(iii) Design a lead compensator if the zero of compensator is at (–2, 0).

[20 marks]

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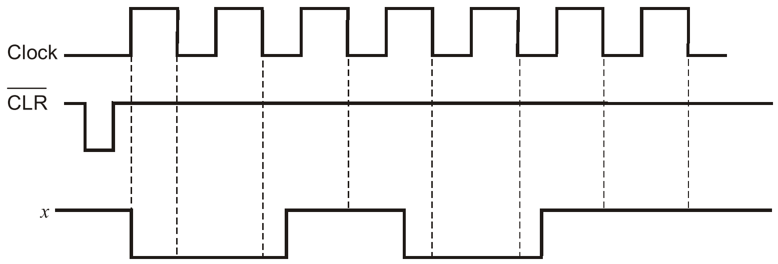
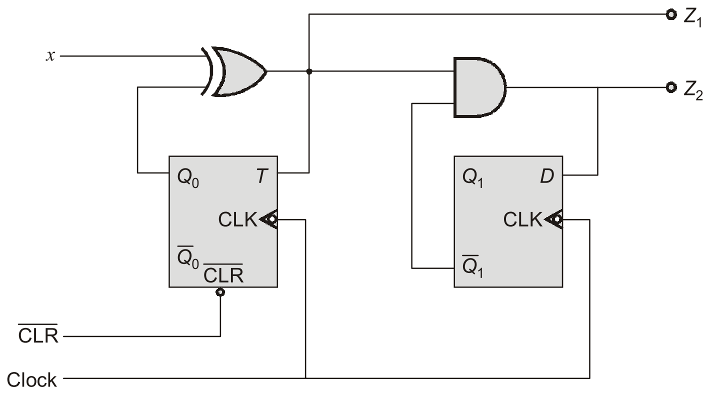
Q.8 (a) (i) Using the timing diagram with inputs below, draw output of the circuit. Assume initial states to be zero.





(ii) Construct a JK flip-flop using D-flip-flop.

[12 + 8 = 20 marks]

Ans 8 ⓐ (i) Initially $Q_0 = 0$, $Q_1 = 0$

$Z_1 = x \oplus Q_0$ and $[x \oplus Q_0] \cdot \overline{Q_1} = Z_2 = Z_1 \cdot \overline{Q_1}$

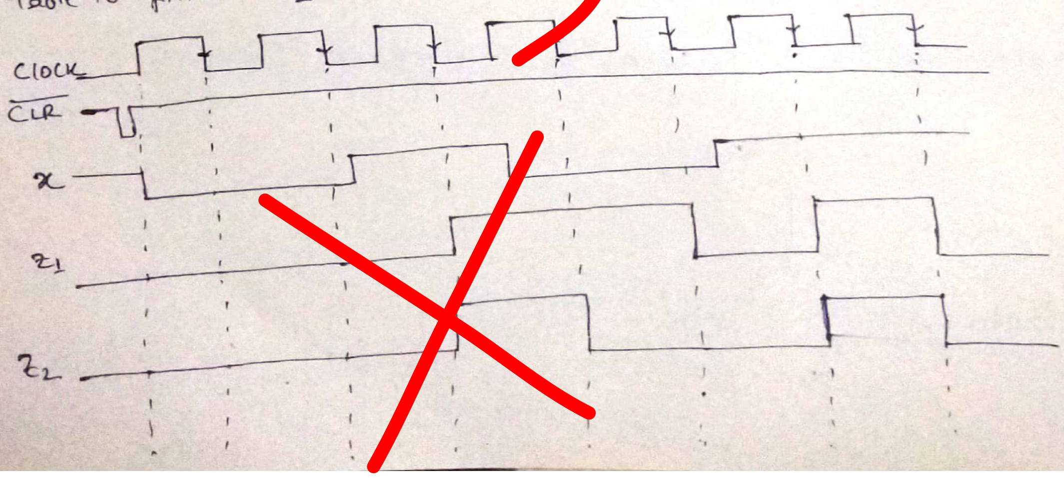
clk	x_n	Q_{0n}	Z_1	Q_{n+1}
1	0	0	0	0
2	0	0	0	0
3	1	0	1	1
4	0	1	1	0
5	0	0	0	0
6	1	0	1	1
7	1	1	0	1

Table to find Z_1

CLK	Z_1	$\overline{Q_{1n}}$	Z_2	$\overline{Q_{1,n+1}}$
1	0	1	0	1
2	0	1	0	1
3	1	1	1	0
4	1	0	0	1
5	0	1	0	1
6	1	1	1	0
7	0	0	0	1

Table to find Z_2

5



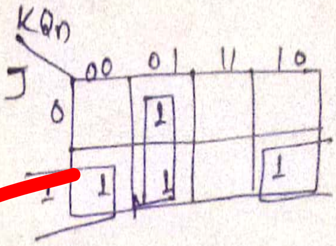
(ii) Construct JK flip flop using D flip flop

J	K	Q_n	Q_{n+1}	D
0	0	0	0	0
0	0	1	1	1
0	1	0	0	0
0	1	1	0	0
1	0	0	1	1
1	0	1	1	1
1	1	0	1	1
1	1	1	0	0

Truth table of JK

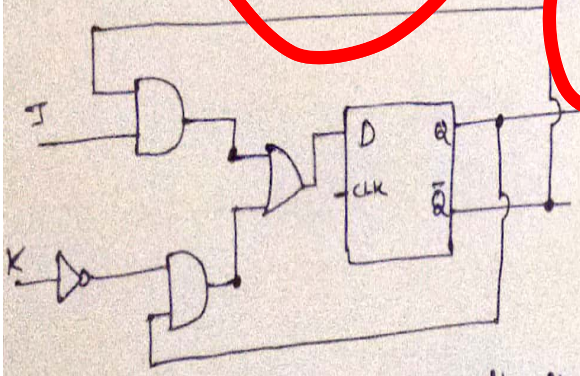
excitation table of D flip flop

So, using Kmap technique for D flip flop



$D = J\bar{Q}_n + \bar{K}Q_n$

So a logical diagram can be developed on the above relationship



JK flip flop using D flip flop

Q.8 (b) A separately excited dc motor has following ratings:

J_m (Motor inertia) = 6.2×10^{-4} Nm s^2/rad

K (Motor constant) = 0.06 Nm/A

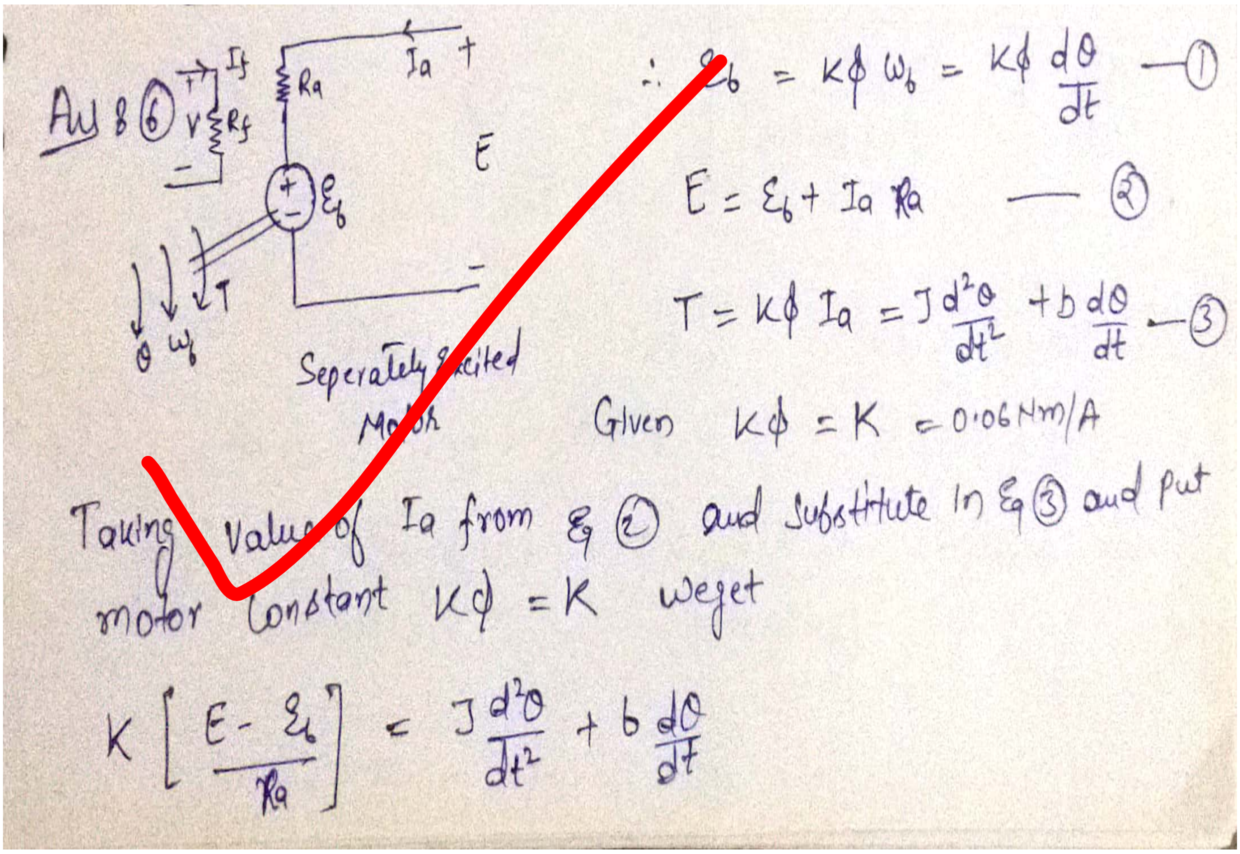
b (Viscosity coefficient): 1.0×10^{-4} Nm-s/rad

R_a (Armature resistance): 1.2 Ω

(i) Find the transfer function $\theta_m(s)/E(s)$, where θ_m is shaft angular displacement (rad) and E is supply terminal voltage.

(ii) Find the shaft angular velocity $\omega_m(t)$ rad/s for 10 V supply.

[20 marks]



Ans 8 ⑥

Seperately Excited Motor

$$\therefore \mathcal{E}_b = K\phi\,\omega_b = K\phi \frac{d\theta}{dt} \quad — ①$$

$$E = \mathcal{E}_b + I_a R_a \quad — ②$$

$$T = K\phi\, I_a = J\frac{d^2\theta}{dt^2} + b\frac{d\theta}{dt} \quad — ③$$

Given $K\phi = K = 0.06$ Nm/A

Taking value of I_a from Eq ② and Substitute In Eq ③ and put motor constant $K\phi = K$ weget

$$K\left[\frac{E - \mathcal{E}_b}{R_a}\right] = J\frac{d^2\theta}{dt^2} + b\frac{d\theta}{dt}$$

$$\Rightarrow \frac{KE}{R_a} - \frac{KE_b}{R_a} = \frac{J d^2\theta}{dt} + b\frac{d\theta}{dt} \quad — ④$$

Now put the value of E_b from Eq ① in Eq ④

$$\frac{KE}{R_a} - \frac{K}{R_a}\left[K\frac{d\theta}{dt}\right] = \frac{J d^2\theta}{dt} + b\frac{d\theta}{dt}$$

Taking laplace transform both sides

$$\frac{K}{R_a}E(s) - \frac{KS}{R_a}\theta(s) = Js^2\theta(s) + bs\,\theta(s)$$

$$\Rightarrow \frac{K}{R_a}E(s) = \theta(s)\left[Js^2 + bs + \frac{KS}{R_a}\right]$$

$$\Rightarrow \frac{K}{\cancel{R_a}}E(s) = \theta(s)\left[\frac{JR_as^2 + bR_as + KS}{\cancel{R_a}}\right]$$

$$\Rightarrow \frac{\theta(s)}{E(s)} = \frac{K}{S[JR_aS + bR_a + K]} = \frac{0.06}{S[6.2\times10^{-4}\times1.2S + 10^{-4}\times1.2 + 0.06]}$$

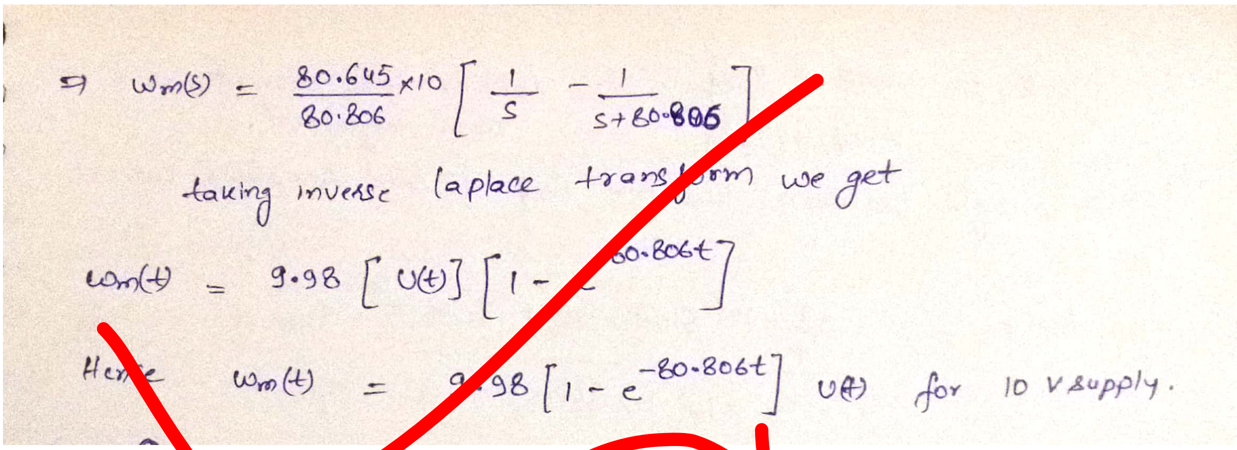
$$\Rightarrow \cancel{\frac{\theta(s)}{E(s)} = \frac{0.06\times10^4}{S[7.44S + \text{[illegible]}]}} = \cancel{\frac{600}{S[7.44S + 1.26]}}$$

$$\frac{\theta(s)}{E(s)} = \frac{0.06\times10^4}{S[7.44S + 1.2 + 600]} = \frac{600}{S[7.44S + 601.2]}$$

$$\boxed{\frac{\theta(s)}{E(s)} = \frac{80.645}{S[S + 80.806]}} \quad — ⑤$$

(ii) Now $\frac{S\,\theta(s)}{E(s)} = \frac{80.645}{(S + 80.806)} = \frac{\omega_m(s)}{E(s)}$

So $\omega_m(S) = \frac{80.645}{(S + 80.806)} \times E(S) = \frac{80.645\times10}{S(S + 80.806)}$ [Given $E(s) = 10/s$ or $E = 10V$]



$$\Rightarrow \omega_m(s) = \frac{80.645}{80.806}\times 10\left[\frac{1}{s} - \frac{1}{s+80.806}\right]$$

taking inverse laplace transform we get

$$\omega_m(t) = 9.98\,[u(t)]\left[1 - e^{-80.806t}\right]$$

Hence $\omega_m(t) = 9.98\left[1 - e^{-80.806t}\right] u(t)$ for 10 V supply.

✓

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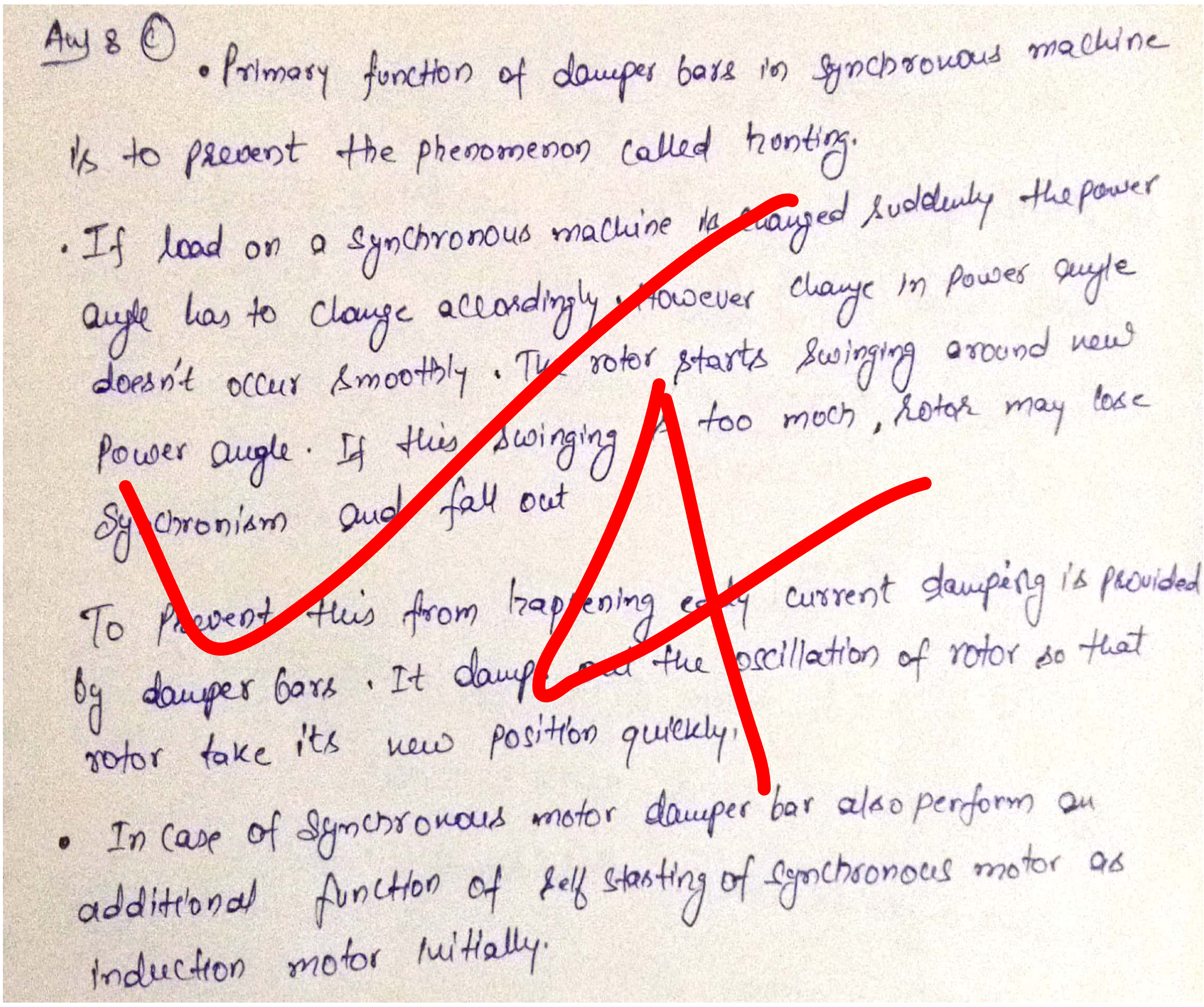
Q.8 (c)

(i) What are damper bars? Elucidate its significance with respect to synchronous machines.

(ii) A 300 MVA,22 kV, three phase salient-pole generator is operating at 250 MW power output at a lagging power factor of 0.85 synchronized to 22 kV bus. The generator reactances are $X_d = 1.93$ p.u. and $X_q = 1.16$ p.u. The generator gives rated open-circuit voltage at a field current of 338 A. Calculate the power angle, excitation emf and the field current.

[5 + 15 = 20 marks]



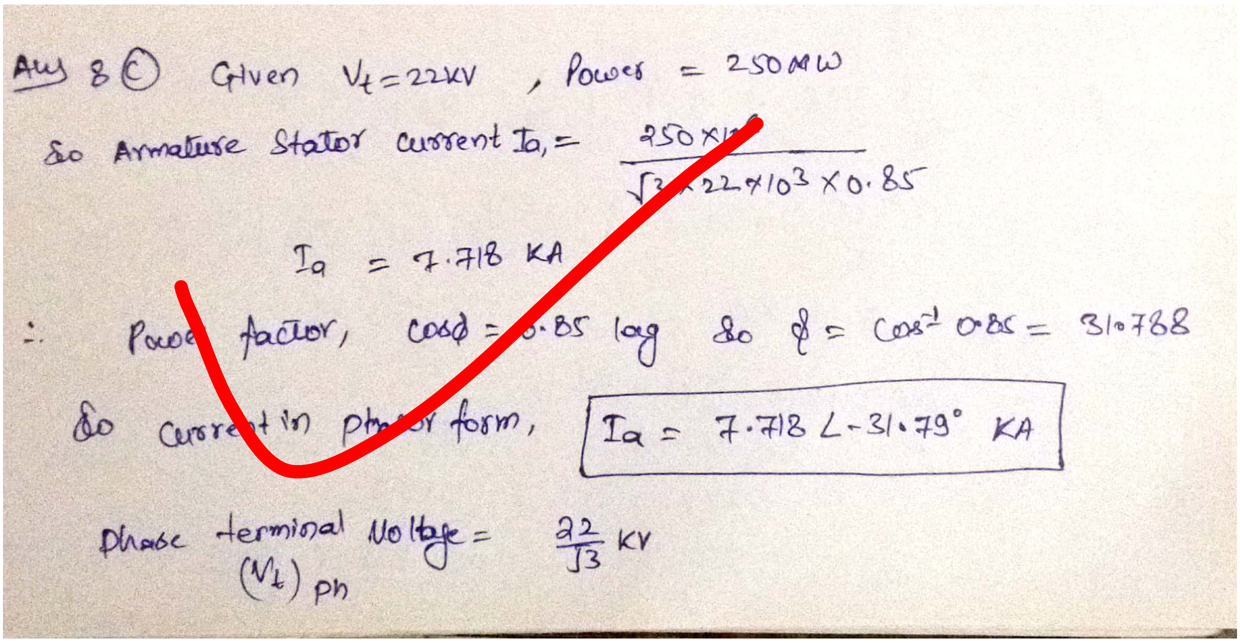
Ans 8 ⓒ

- Primary function of damper bars in synchronous machine is to prevent the phenomenon called hunting.
- If load on a synchronous machine is changed suddenly the power angle has to change accordingly. However change in power angle doesn't occur smoothly. The rotor starts swinging around new power angle. If this swinging is too much, rotor may lose synchronism and fall out

To prevent this from happening eddy current damping is provided by damper bars. It damps out the oscillation of rotor so that rotor take its new position quickly.

- In case of synchronous motor damper bar also perform an additional function of self starting of synchronous motor as induction motor initially.

4



Ans 8 ⓒ Given $V_t = 22KV$, Power = 250 MW

So Armature Stator current I_a, = $\frac{250\times10^6}{\sqrt{3}\times22\times10^3\times0.85}$

$I_a = 7.718$ KA

∴ Power factor, $\cos\phi = 0.85$ lag so $\phi = \cos^{-1}0.85 = 31.788$

So current in phasor form, $\boxed{I_a = 7.718\angle-31.79°\ KA}$

Phase terminal Voltage $(V_t)_{ph}$ = $\frac{22}{\sqrt{3}}$ KV

$\therefore \tan\psi = \dfrac{V\sin\phi + I_a x_q}{V\cos\phi + I_a r_a}$ Let armature resistance r_a is neglected so $r_a = 0\Omega$

where ψ: Angle between induced Emf E and current I_a

So $\tan\psi = \dfrac{\frac{22}{\sqrt{3}} \times 10^3 \sin 31.79' + 7.718 \times 10^3 \, X_{q\,actual}}{\frac{22}{\sqrt{3}} \times 10^3 \cos 31.79'}$ —— ①

Base impedance, $Z_b = \dfrac{V^2}{S} = \dfrac{22^2}{300} = 1.613\Omega$

So X_q actual $= X_q\,p.u. \times X_{base} = 1.16 \times 1.613 = 1.871\,\Omega$

and X_d actual $= X_d\,p.u. \times X_{base} = 1.93 \times 1.613 = 3.113\,\Omega$

So from Eq ① $\tan\psi = \dfrac{6.69 + 7.718 \times 1.871}{10.796}$

10

$\Rightarrow \psi = 61.783°$

$\therefore \psi = \phi + \delta$ where δ is load angle

$\delta = \psi - \phi = 61.783 - 31.79 = 29.993 \simeq 30°$

So Power angle, $\delta = 30°$

Using Power Equation to find Line Emf E

$$P = \frac{V_t E_f}{x_d} \sin\delta + \frac{1}{2} V_t^2 \left[\frac{1}{x_q} - \frac{1}{x_d}\right] \sin 2\delta$$

$$250 = \frac{22 \times E_f}{3.113} \sin 30 + \frac{1}{2} \times 22^2 \left[\frac{1}{1.871} - \frac{1}{3.113}\right] \sin 60$$

Line Voltage, $E_f = 58.10$ KV

At open circuit $|E_f| = |V_t|$

$\therefore$ O.C. Voltage I_f

22 KV 338 A

So 58.10 KV $\rightarrow$ 338 $\times \dfrac{58.10}{22}$ = 892.627 A

Hence field current required to generated Emf is 892.627 Amps.

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Space for Rough Work

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