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UPSC ENGINEERING SERVICES EXAMINATION

Electrical Engineering

Test-8 : Full Syllabus Test (Paper-II)

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Instructions for Candidates

1. Do furnish the appropriate details in the answer sheet (viz. Name & Roll No).
2. There are Eight questions divided in TWO sections.
3. Candidate has to attempt FIVE questions in all in English only.
4. Question no. 1 and 5 are compulsory and out of the remaining THREE are to be attempted choosing at least ONE question from each section.
5. Use only black/blue pen.
6. 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.
7. Any page or portion of the page left blank in the Question Cum Answer Booklet must be clearly struck off.
8. There are few rough work sheets at the end of this booklet. Strike off these pages after completion of the examination.

FOR OFFICE USE

Question No.	Marks Obtained
Section-A	
Q.1	40
Q.2	42
Q.3	34
Q.4	
Section-B	
Q.5	32
Q.6	49
Q.7	
Q.8	
Total Marks Obtained	197

Signature of Evaluator: Sourabh kumar

Cross Checked by: ....

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IMPORTANT INSTRUCTIONS

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DONT'S

1. Do not write your name or registration number anywhere inside this Question-cum-Answer Booklet (QCAB).
2. Do not write anything other than the actual answers to the questions anywhere inside your QCAB.
3. Do not tear off any leaves from your QCAB, if you find any page missing do not fail to notify the supervisor/invigilator.
4. Do not leave behind your QCAB on your table unattended, it should be handed over to the invigilator after conclusion of the exam.

DO'S

1. Read the Instructions on the cover page and strictly follow them.
2. Write your registration number and other particulars, in the space provided on the cover of QCAB.
3. Write legibly and neatly.
4. For rough notes or calculation, the last two blank pages of this booklet should be used. The rough notes should be crossed through afterwards.
5. If you wish to cancel any work, draw your pen through it or write "Cancelled" across it, otherwise it may be evaluated.
6. Handover your QCAB personally to the invigilator before leaving the examination hall.

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Section-A

(a) A hydro-electric station is to be designed for a catchment area of 500 km^2, rainfall for which is 130 cm/annum. The head available is 30 m. Assume that 80% of the total rainfall is available, rest is lost to evaporation. Penstock efficiency is 97%, turbine efficiency is 87%, generator efficiency is 92% and the load factor is 60%. Determine the electricity generation capacity of the station.

[12 marks]

Given:- area = 500 km^2

Rainfall = 130 cm/annum

H = 30 m

Total efficiency of hydro-electric station

$\eta = 0.8 \times 0.97 \times 0.87 \times 0.92$

$= 0.621$

$= 62.1\%$

Total power output

$= \frac{0.98}{\cancel{0.736}} \eta Q H . d$ (kWh)

$= 0.98 \times 0.621 \times Q \times 30 \times 1000$

discharge

$Q = 500 \times 10^6 \times 130 \times 10^{-2}$

$= 6.5 \times 10^8$ m^3

$= 0.98 \times 0.621 \times 6.5 \times 10^8 \times 30 \times 1000$

$= 1186.7$ MWh

Load factor $= 0.6$

electricity ~~generated~~
generated by hydro-electric
station —

$W = 1186.7 \times 0.6$

$= 712.02$ MWh

5

(b) A 3-phase long line has constants $A = 0.98\angle 3°$ and $B = 110\angle 75°$ ohm per phase.

(i) If the load is 50 MVA, 0.8 pf lagging, find the capacity of shunt compensation equipment if voltages at the two ends of the line are 132 kV each.

(ii) Find the capacity of shunt compensation equipment if the voltage at the two ends are to be maintained at 132 kV under no load condition.

[12 marks]

Given :- $A = 0.98\angle 3°$ $\quad B = 110\angle 75°\ \Omega$

(i) Load 50 MVA, 0.8 pf

$P_L = 40\text{MW}, \quad Q_L = 30\text{MVAR}$

$V_R = V_S = 132\text{kV}$

Active power eqn -

$$P = \frac{V_R V_S}{B}\cos(\beta - \delta) - \frac{A V_R^2}{B}\cos(\beta - \alpha)$$

$$\Rightarrow 40 \times 10^6 = \frac{(132 \times 10^3)(132 \times 10^3)}{110}\cos(75 - \delta) - \frac{0.98 \times (132 \times 10^3)^2}{110}\cos(75 - 3°)$$

$$\boxed{\delta = 18.73°}$$

Reactive power

$$Q = \frac{V_R V_S}{B}\sin(\beta - \delta) - \frac{A V_R^2}{B}\sin(\beta - \alpha)$$

$$= \frac{(132 \times 10^3)(132 \times 10^3)}{110}\sin(75 - 18.73°) - \frac{0.98 \times (132 \times 10^3)^2}{110}\sin(75 - 3°)$$

$Q = -15.89\text{MVAR}$

Shunt compensation capacity

$Q_{sh} = 30 + 15.89$

$\boxed{Q_{sh} = 45.89\text{MVAR}}$ (Ans)

(11)

At No load $P_L = Q_L = 0$

$V_R = V_S = 132\ kV$

$$P_L = \frac{V_S V_R}{B} \cos(\theta - \delta) - \frac{A V_R^2}{B} \cos(\alpha - \delta)$$

$$0 = \frac{(132 \times 10^3)^2}{110} \cos(75 - \delta) - \frac{0.98 \times (132 \times 10^3)^2}{110} \cos(75 - 3)$$

$$\cos(75 - \delta) = 0.98 \times \cos 72$$

$$\boxed{\delta = 2.63^\circ}$$

$$Q = \frac{V_S V_R}{B} \sin(\theta - \delta) - \frac{A V_R^2}{B} \sin(\alpha - \delta)$$

$$= \frac{(132 \times 10^3)^2}{110} \sin(75 - 2.63) - \frac{0.98 \times (132 \times 10^3)^2}{110} \sin(75 - 3)$$

$$= 3.325\ MVAR$$

∴ Shunt capacity required at no load

$$\boxed{Q_{sh} = Q = 3.325\ MVAR}$$ Ans

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Good Approach

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(c) A DC motor has an armature resistance of 0.5 Ω and $K\phi$ of 3 V-sec. The motor is driven by a single-phase thyristorized full converter. The input to the converter is an AC source of 230 V, 50 Hz. The motor is used as a prime mover of a forklift. In the upward direction, the mechanical load is 69 Nm and the triggering angle is $\alpha = 15°$. In the downward direction, the load torque is 180 Nm. Calculate the triggering angle required to keep the downward speed equal in magnitude to upward speed. Assume continuous motor current for all operation. Also calculate the triggering angle to keep the motor at holding position while it was moving upward.

[12 marks]

Given:- $r_a = 0.5\,\Omega$ $\quad K\phi = 3$ V-sec

1 ϕ full converter $\quad V_s = 230$ V, 50 Hz

upward

$T_L = 69$ Nm $\quad \alpha = 15°$

downward

$T_L = 180$ Nm

$T_L = T_{em} = K\phi I_a$

$\Rightarrow 180 = 3 \times I_{a_2} \Rightarrow \boxed{I_{a_2} = 60\text{ A}}$

upward

$T_L = K\phi I_{a_1}$

$69 = 3 \times I_{a_1} \quad I_{a_1} = 13$ A

$V_0 = E_{b_1} + I_{a_1} r$

$\Rightarrow \frac{2 \times 230 \times \sqrt{2}}{\pi} \cos 15° = E_{b_1} + 13 \times 0.5$

$E_{b_1} = 193.51$ V

$E_{b_2} = E_{b_1} = 193.51$ V

$\therefore V_{0_2} = E_{b_2} + I_{a_2} r_a$

$\frac{2 \times 230\sqrt{2}}{\pi} \cos\alpha_2 = 193.51 + 60 \times 0.5$

$\boxed{\alpha_2 = 142.15°}$

Firing angle in downward is $\boxed{\alpha = 142.15°}$

To keep motor at holding position

$E_b = 0$

$V_0 = I_0 r_a$

$\Rightarrow \frac{2 \times 230\sqrt{2}}{\pi} \cos\alpha_3 = 13 \times 0.5$

$$\boxed{\alpha_3 = 88.2^\circ}$$

Hence, firing angle to keep motor holding position in upward direction is $\alpha_3 = 88.2^\circ$

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Good Approach

(d) Find the z-transform of the discrete time signal, $x(n) = \sin(2\omega_0 n)\, u[n]$.

[12 marks]

$$\sin(2w_0 n)\,u(n) = \left[\frac{e^{j2w_0 n} - e^{-j2w_0 n}}{2j}\right] u(n)$$

$$\sin(2w_0 n)\,u(n) = \frac{e^{j2w_0 n}\cdot u(n)}{2j} - \frac{e^{-j2w_0 n}\, u(n)}{2j}$$

$$u(n) \xleftrightarrow{ZT} \frac{1}{1-z^{-1}}$$

$$e^{j(2w_0 n)}\, u(n) \xleftrightarrow{ZT} \frac{1}{1-(e^{-jw_0} z)^{-1}}$$

$$e^{j2w_0 n}\, u(n) \Longleftrightarrow \frac{1}{1-e^{2jw_0} z^{-1}}$$

Similarly, $e^{-j2w_0 n}\, u(n) \longleftrightarrow \dfrac{1}{1-e^{-j2w_0} z^{-1}}$

$$\sin(2w_0 n)\, u(n) = \frac{1}{2j}\left[\frac{1}{1-e^{2jw_0} z^{-1}} - \frac{1}{1-e^{-j2w_0} z^{-1}}\right]$$

$$= \frac{1}{2j}\left[\frac{1-e^{-j2w_0} z^{-1} - 1 + e^{2jw_0} z^{-1}}{1-(e^{2jw_0}+e^{-j2w_0}) z^{-1} + z^{-2}}\right]$$

$$= \frac{1}{2j}\left[\frac{(e^{+j2w_0} - e^{2jw_0}) z^{-1}}{1 - 2\cos(2w_0)\, z^{-1} + z^{-2}}\right]$$

$$= \frac{\sin(2w_0)\, z^{-1}}{1 - 2z^{-1}\cos(2w_0) + z^{-2}}$$

Hence, z - transform of

$$x(n) = \sin(2w_0 n)\, u(n) \longleftrightarrow \frac{\sin(2w_0)\, z^{-1}}{1 - 2z^{-1}\cos(2w_0) + z^{-2}}$$

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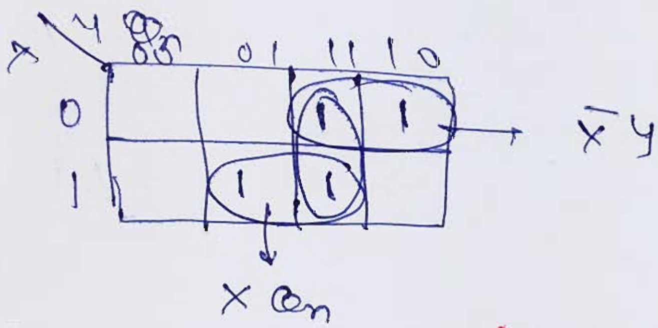
(e) The truth table of XY flip flop is shown below. Design this flip flop using T-flip flops and additional logic gates.

Truth table

X	Y	Q_{n+1}
0	0	Q_n
0	1	$\bar{Q}_n$
1	0	0
1	1	1

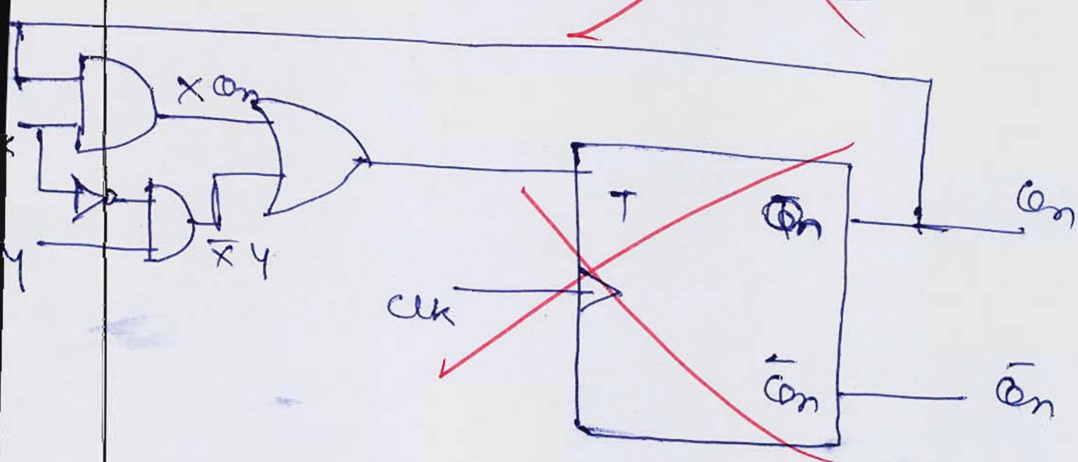
[12 marks]

X	Y	Q_n	Q_{n+1}	T
0	0	0	0	0
0	0	1	1	0
0	1	0	1	1
0	1	1	0	1
1	0	0	0	0
1	0	1	0	1
1	1	0	1	φ
1	1	1	1	0



3

$$\therefore \boxed{\cancel{T = XQ_n + \bar{X}Y}}$$



(a) The ohmic, hysteresis and eddy current losses in a transformer at 50 Hz are 1.6%, 0.9% and 0.6% respectively. For a steinmetz's coefficient of 1.6,

Find:

(i) The losses at 60 Hz, for the same system voltage and current.

(ii) The output at 60 Hz, for the total losses to remain the same as on 50 Hz.

[20 marks]

Given at 50 Hz

$W_{cu} = 1.6\%$

$W_h = 0.9\%$

$W_e = 0.6\%$

$\eta = 1.6$

① losses at 60 Hz

$B \propto \frac{V}{f}$

Since voltage and current are same hence, ohmic losses remain constant

$W_{cu_2} = \boxed{W_{cu_1} = 1.6\%}$

$\frac{V}{f} \neq$ const

$W_h \propto \left(\frac{V}{f}\right)^{1.6} \cdot f$

$W_h \propto \frac{V^{1.6}}{f^{0.6}} \propto \frac{1}{f^{0.6}}$

$\frac{W_{h_2}}{W_{h_1}} = \left(\frac{50}{60}\right)^{0.6}$

$W_{h_2} = W_{h_1} \times \left(\frac{50}{60}\right)^{0.6}$

$= 0.9 \times \left(\frac{50}{60}\right)^{0.6}$

$\boxed{W_{h_2} = 0.806\%}$

$$w_e \propto \left(\frac{V}{f}\right)^2 \cdot f^2$$

$$w_e \propto V^2$$

$$w_e = \text{constant}$$

$$\boxed{w_{e_2} = w_{e_1} = 0.6\%}$$

(ii) At 50 Hz

Total losses $= w_{cu_1} + w_{h_1} + w_{e_1}$

$= 1.6 + 0.9 + 0.6$

$= 3.1\%$

output 1 $= (1 - 0.031)$ KVA $= (0.969)$ KVA

At 60 Hz

Total losses $= w_{cu_2} + w_{h_2} + w_{e_2}$

$= 1.6 + 0.806 + 0.6$

$= 3.006\%$

output 2 $= (0.9699)(\text{KVA})_2$

~~Total losses to be~~ remain same

~~(3.1)(KVA) o/p, = (3.00069% (KVA)~~

~~(3.1)~~

Total losses to be remain same

$$\frac{(3.1)}{100}(\text{KVA})_1 = \left(\frac{3.006}{100}\right) \text{KVA}_2$$

$$\boxed{(\text{KVA})_2 = (1.0312)\,\text{KVA}_1}$$

Do not write in this margin

Hence, output at 60Hz is (1.0312) times the at output at 50Hz

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Do not write in this

Q.2 (b) A three phase, 50 Hz transmission line of length 80 km is having resistance and inductive reactance of 3.75 mΩ/km and 15.92 μH/km respectively. The line is delivering a load of 375 kVA per phase at 0.8 p.f. lagging while the sending end line to line voltage is maintained at 3300 V.

Determine:

(i) The receiving end voltage and receiving end line current.

(ii) Sending end power and power factor.

(iii) Voltage regulation of the line.

[20 marks]

Given :-
$$l = 80\text{ km}$$
$$r = 3.75\text{ m}\Omega/\text{km}$$
$$l = 15.92\ \mu H/\text{km}$$

Total resistance, $R = 3.75 \times 10^{-3} \times 80$
$$R = 0.3\,\Omega$$

Total reactance, $X_L = 2\pi \times 50 \times 15.92 \times 10^{-6} \times 80$
$$X_L = 0.4\,\Omega$$

$$Z = (0.3 + j0.4)\,\Omega$$

let V_R and I_R are receiving end per phase voltage and current -

$$3 \cdot V_R I_R = 375 \times 10^3$$
$$I_R = \frac{125000}{V_R}$$

$$V_S = \frac{3300}{\sqrt{3}} = 1905.25\,V$$

$$V_S^2 = \cancel{V_R + eI_R}\ (V_R \cos\phi + I_R \cdot R)^2 + (V_R \sin\phi + I_R \cdot X)^2$$

Do not write in this margin

$$(1905.25)^2 = \left[V_R \times 0.8 + \frac{125000}{V_R} \times 0.3\right]^2 + \left[V_R \times 0.6^2 + \frac{125000}{V_R} \times 0.4\right]^2$$

$$\Rightarrow 3.62 \times 10^6 = V_R^2 + \frac{1.4 \times 10^9}{V_R^2} + 60000 + \frac{2.5 \times 10^9}{V_R^2} + 60000$$

$$\Rightarrow V_R^2 + \frac{3.9 \times 10^9}{V_R^2} - 3.5 \times 10^6 = 0$$

$$V_R^4 - 3.5 \times 10^6 V_R^2 + 3.9 \times 10^9 = 0$$

$$V_R^2 = 3.5 \times 10^6, \ 1114.64$$

$$\boxed{V_R = 1870.82 V}$$

$$\therefore I_R = \frac{125000}{1870.82} = 66.82 A$$

$\therefore$ receiving end voltage, $V_R = 3240.3 V$

receiving end current, $I_R = 66.82 A$

(ii) $I_S = I_R$

$$I_S = 66.82 \angle -\cos^{-1}(0.8)$$

$$= 66.82 \angle -36.87^\circ$$

sending end power

$$P_S = 3 V_S I_S \cos\phi$$

Do not write in this

$P_s = P_R + 3 I_R^2 R$

$= 375 \times 10^3 \times 0.8 + 3 \times (66.82)^2 \times 0.4$

$\boxed{P_s = 305.35}$ KW

sending end power facter

$\cos\phi_s = \dfrac{305.35 \times 10^3}{\sqrt{3} \times 3300 \times 66.82}$

$\boxed{\cos\phi_s = 0.7995 \text{ lag}}$

(iii) voltage regulation

$= \dfrac{(V_R)_{Nl} - (V_R)_{Fl}}{(V_R)_{Fl}} \times 100$

$= \dfrac{1905.25 - 1870.82}{1870.82} \times 100$

$= 1.84$ %

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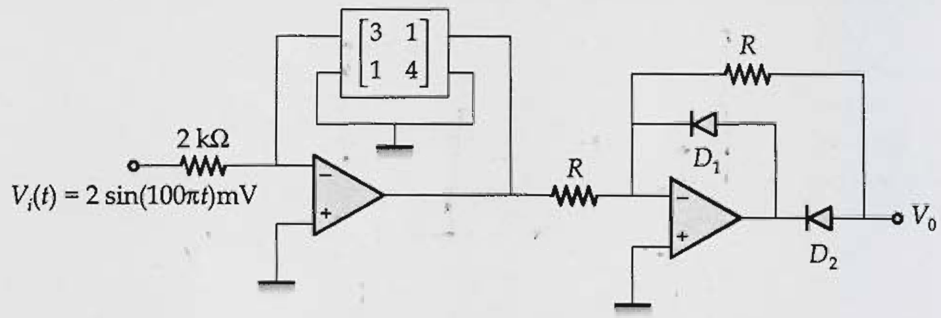
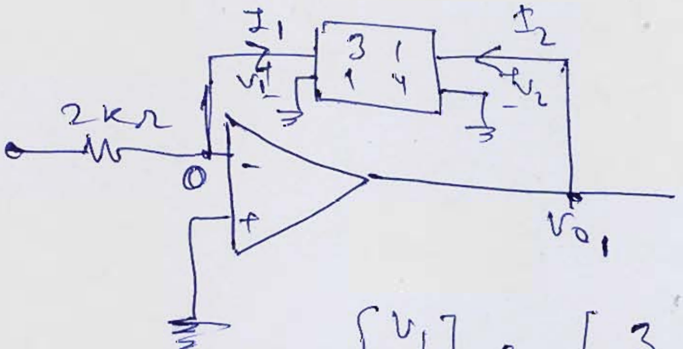
2 (c) In the circuit shown in figure below, all the op-amps and diodes are ideal.



The two port network is characterized by the z-parameters (kΩ). Draw the output voltage (V_o) waveform. Also, calculate the average value of V_o.

[20 marks]

v_i



$$\begin{bmatrix} V_1 \\ V_2 \end{bmatrix} = \begin{bmatrix} 3 & 1 \\ 1 & 4 \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \end{bmatrix}$$

$$V_1 = 3I_1 + I_2$$

$V_1 = 0 \quad \Rightarrow \quad I_2 = -3I_1$

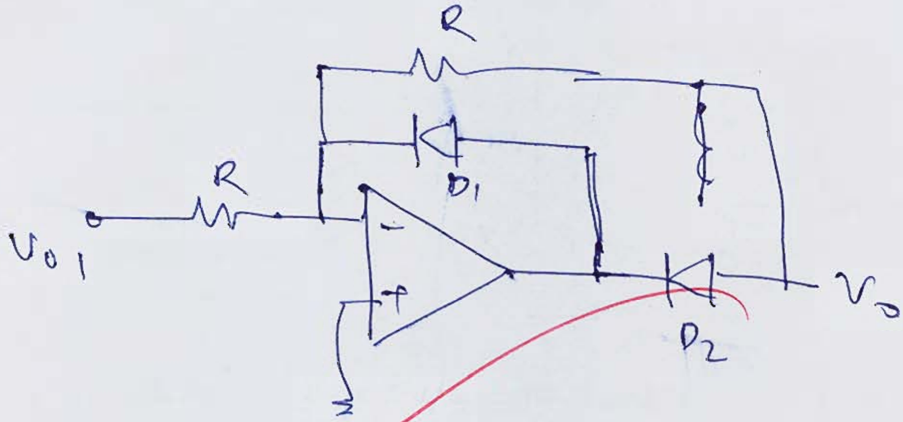
$$I_2 = -3 \times \frac{v_i}{2}$$

$$I_2 = -1.5 v_i$$

and $\quad V_2 = V_{o1} = I_1 + 4I_2$

$$V_{o1} = \frac{v_i}{2} + 4 \times (-1.5 v_i)$$

$$\boxed{V_{o1} = -5.5 v_i}$$

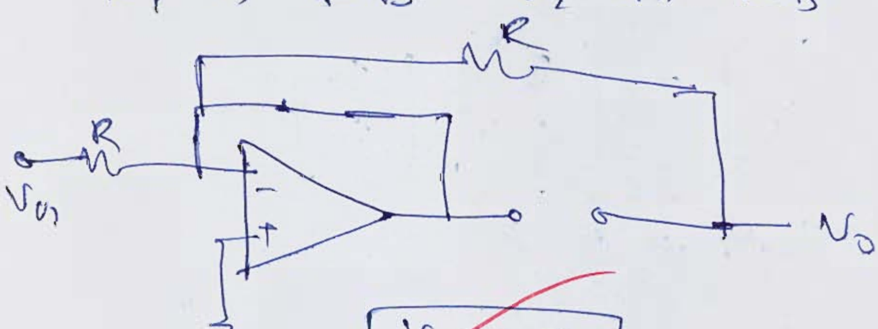


~~when ei~~ During +ve half cycle

$V_i = +ve$

$V_{o1} = -ve$

D_1 is FB D_2 is R.B



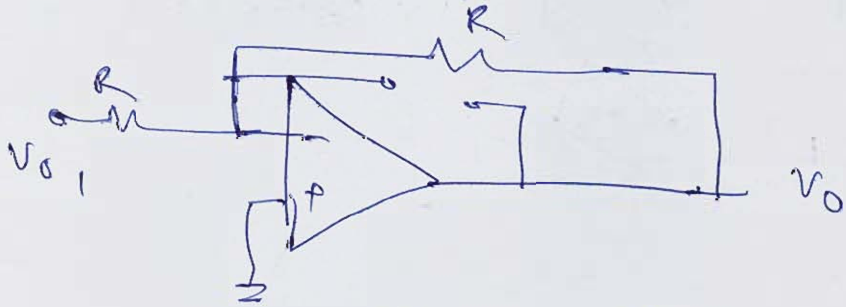
$$\boxed{V_0 = 0}$$

During -ve half cycle

$V_i = -ve$

$V_{o1} = +ve$

D_1 is RB D_2 is FB



$$V_0 = -\frac{R}{R} V_{o1}$$

$$V_0 = -V_{01}$$

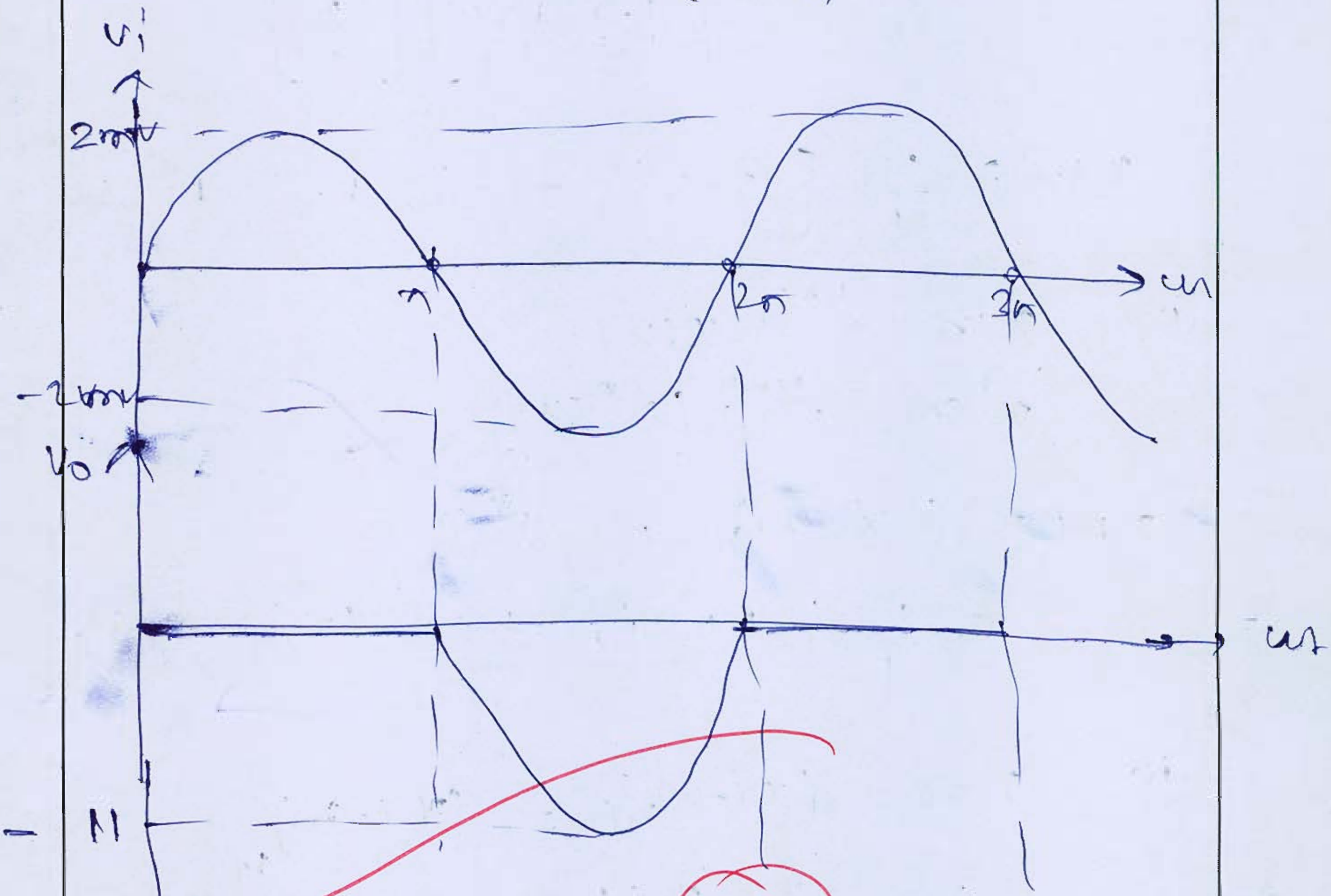
$$= -(-5.5 v_i)$$

$$\boxed{V_0 = 5.5 v_i} \quad = 5.5 \times 2 \sin(100\pi t)$$

$$= 11 \sin(100\pi t) \text{ mV}$$

Hence output voltage

$$V_0 = \begin{cases} 0 & v_i \text{ is } +ve \\ 5.5 v_i & v_i \text{ is } -ve \\ = 11 \sin(100\pi t) & \end{cases}$$



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Q.3 (a) Let $x[n]$ = IDFT $[X(k)]$ for n, K = 0, 1, ... Apply below all properties to the sequence, $X(k)$ = DFT$\{1, -j2, j, -j4\}$ by deriving the relationship between $x[n]$ and the IDFT's.

(i) IDFT$\{X^*(k)\}$.

(ii) IDFT$\{X(-k)_N\}$.

(iii) IDFT$\{\text{Re}[X(k)]\}$.

(iv) IDFT$\{\text{Im}[X(k)]\}$.

(Note : Use the result directly)

[20 marks]

$$X(k) = \text{DFT}\{1, -j2, j, -j4\}$$

for 4 point DFT

$$[x(n)] = \frac{1}{4}\begin{bmatrix} 1 & 1 & 1 & 1 \\ 1 & j & -1 & -j \\ 1 & -1 & 1 & -1 \\ 1 & -j & -1 & j \end{bmatrix}\begin{bmatrix} 1 \\ -j2 \\ j \\ -j4 \end{bmatrix}$$

$$x(n) = \frac{1}{4}\left[1-5i,\ -1-i,\ 1-i,\ 1-3i\right]$$

(i) $x(n) \xleftrightarrow{\text{DFT}} X(k)$

$x^*(n) \xleftrightarrow{\text{DFT}} [X^*(k)]$

$$\text{IDFT}\{X^*(k)\} = x^*(n)$$

$$= \frac{1}{4}\{1+5i,\ -1+i,\ 1+i,\ 1+3i\}$$

(ii) $$\text{IDFT}\{X(-k)_N\} = [x(-k)]_N$$

$$= x(4-k)$$

$$= \frac{1}{4}\left[1-3i,\ 1-5i,\ -1-i,\ 1-i\right]$$

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(iii) IDFT $[Re(X(k))] \longleftrightarrow R_e\, x(n)$

$$= \frac{1}{4}\{\cancel{1, -1, 1, 1}\}$$

(iv) IDFT $(Im(X(k))] \longleftrightarrow (Im(x(n))]$

$$= \frac{1}{4}\{\cancel{-5i, -i, -i, -3i}\}$$

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3 (b) A 10 kVA, 2500/250 V, single-phase transformer gave the following test results:

Open-circuit test (l.v.) :	250 V,	0.8 A,	50 W
Short-circuit test (h.v.) :	60 V,	3 A,	45 W

Calculate :

(i) The efficiency at $\frac{1}{4}$ of full load at 0.8 power factor.

(ii) The load (kVA output) at which maximum efficiency occurs and also the value of maximum efficiency at 0.8 power factor.

(iii) The voltage regulation and the secondary terminal voltage under rated load at power factor 0.8 lagging.

[20 marks]

Given :- 10 kVA, 1 ϕ T/f

HV side rated current

$$I_{HV} = \frac{10\times10^3}{2500} = 4\,A$$

FL cu losses $W_{cu} = \left(\frac{4}{3}\right)^2 \times 45$

$W_{cu} = 80\,W$

Core losses = 50 W

① At 1/4 FL and 0.8 pf -

$$(W_{cu})_{losses} = \left(\frac{1}{4}\right)^2 \times 80 = 5\,W$$

$W_{core\ losses} = 50\,W$

$$\eta = \frac{\text{output}}{\text{output + losses}}$$

$$= \frac{0.25\times10\times10^3\times0.8}{0.25\times10\times10^3\times0.8 + 5 + 50}$$

$$\boxed{\eta = 97.32\,\%}$$

(ii) for maximum efficiency.

x^2 (FL cu loss) = W_{core} losses

$x^2 \times 80 = 50$

$x = \sqrt{\frac{50}{80}} = 0.79$

$(KVA)_{output} = 0.79 \times 10 = 7.9$ kVA

maximum efficiency at 0.8 pf

$$\eta_{max} = \frac{7.9 \times 10^3 \times 0.8}{7.9 \times 10^3 \times 0.8 + 50 \times 2}$$

$$\boxed{\eta_{max} = 98.44\%}$$

(iii) $V_{sc} = 60V \quad I_{sc} = 2A \quad W_{sc} = 45W$

$Z_{eq} = \frac{V_{sc}}{I_{sc}} = \frac{60}{3} = 20\Omega$

$R_{eq} = \frac{W_{sc}}{I_{sc}^2} = \frac{45}{(3)^2} = 5\Omega$

$X = \sqrt{Z^2 - R^2} = \sqrt{20^2 - 5^2}$

$X = 19.36\Omega$

$Z_{base} = \frac{(2500)^2}{10^4} = 625\Omega$

$R_{pu} = \frac{5}{625} = 0.008$ pu

$X_{pu} = \frac{19.36}{625} = 0.031$ pu

voltage regulation at 0.8 lagging

$= (r_{pu}\cos\phi + x_{pu}\sin\phi) \times 100$

$= (0.008 \times 0.8 + 0.031 \times 0.6) \times 100$

$\boxed{\% \text{ vtg regulation} = 2.5\%}$

$$\% \text{ vtg regulation} = \frac{V_{nl} - V_{fl}}{V_{nl}} \times 100$$

$$\Rightarrow 2.5 = \frac{250 - V_{fl}}{250} \times 100$$

$\boxed{V_{fl} = 243.75V}$

secondary terminal voltage
$V_t = 243.75V$

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Good Approach

Q.3 (c) Two 25 MVA, 11 kV identical synchronous generators are connected to a common bus-bar, which supplies a feeder. The star point of one of the generator is grounded through a resistance of 1 Ω while that of other generator is isolated. A line to ground fault occurs in phase '*a*' at the far end of feeder. Determine:

(i) Fault current.

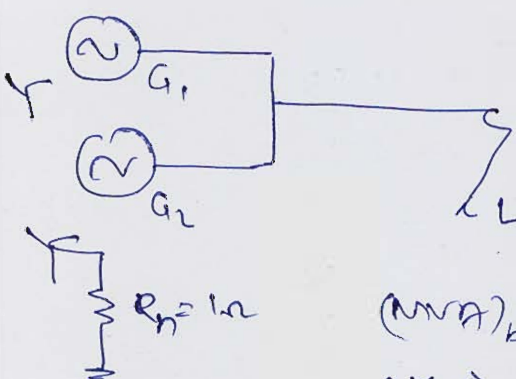
(ii) The voltage of phase '*b*' and phase '*c*'.

(iii) Voltage of star point of the grounded generator with respect to ground.

The sequence impedances of each generator and feeder are given below:

	Generator (per unit)	Feeder (ohm/phase)
Positive sequence	$j0.2$	$j0.4$
Negative sequence	$j0.15$	$j0.4$
Zero sequence	$j0.08$	$j0.8$

[20 marks]



$(MVA)_{base} = 25\ MVA$

$(KV)_{base} = 11\ KV$

$$Z_{base} = \frac{KV^2_{base}}{(MVA)_{base}} = \frac{(11)^2}{25} = 4.84\ \Omega$$

$$R_n = \frac{1}{4.84} = 0.206\ pu$$

Feeder sequence impedance in per unit

$$X_1 = X_2 = \frac{j0.4}{4.84} = j0.0826\ pu$$

$$X_0 = \frac{j0.8}{4.84} = j0.1653\ pu$$

Total positive sequence impedance

$$X_{1eq} = \frac{j0.2 + j0.2}{2} + j0.0826$$

$$X_{1eq} = j0.1826\ pu$$

Do not write in this margin

Total negative sequence impedance

$$X_{2eq} = \frac{j0.15 + j0.15}{2} + j0.0826$$

$$= j0.1576 \text{ pu}$$

Total zero sequence impedance

$$X_{0eq} = j0.08 + 3 \times 0.206 + j0.1653$$

$$X_{0eq} = 0.618 + j0.2453 \text{ pu}$$

(i) In LG fault

fault current

$$I_f = \frac{3 \cdot E_g}{X_{1eq} + X_{2eq} + X_{0eq}}$$

$$= \frac{3 \times 1\angle 0^\circ}{j0.1826 + j0.1576 + 0.618 + j0.2453}$$

$$\boxed{I_f = 3.524 \angle -43.45^\circ \text{ pu}}$$

$$I_{base} = \frac{25 \times 10^6}{\sqrt{3} \times 11 \times 10^3} = 1.312 \text{ kA}$$

$$|I_f| = 3.524 \times 1.312 = 4.623 \text{ kA}$$

(ii)
$$V_{a1} = E - I_{a1} X_{1eq}$$

$$= 1\angle 0^\circ - \frac{3.524}{3} \angle -43.45^\circ \times j0.1826$$

$$V_{a1} = 0.866 \angle -10.35^\circ \text{ pu}$$

$V_{a2} = -I_{a2}\, X_{2eq}$

$= -\frac{3.524}{3} \angle -43.45^\circ \times j\,0.1571$

$V_{a2} = 0.185 \angle -133.45^\circ$ pu

$V_{a0} = -I_{a0}\, X_{0eq}$

$= \frac{-3.524}{3} \angle -43.45^\circ \times (0.618 + j\,0.24537)$

$V_{a0} = 0.781 \angle 158.2^\circ$ pu

$V_b = V_{a0} + \alpha^2 V_{a1} + \alpha V_{a2}$

$= 0.781 \angle 158.2^\circ + 1\angle 240 \times 0.866 \angle -10.35^\circ + 1\angle 120 \times 0.185 \angle -133.45^\circ$

$V_b = 1.18 \angle -159.52^\circ$ pu

$\boxed{V_b = 1.18 \times \frac{11}{\sqrt{3}} = 7.49 \angle -159.52^\circ \text{ kV}}$

$V_c = V_{a0} + \alpha V_{a1} + \alpha^2 V_{a2}$

$= 0.781 \angle 158.2^\circ + 1\angle 120^\circ \times 0.866 \angle -10.35^\circ + 1\angle 240^\circ \times 0.185 \angle -133.45^\circ$

$V_c = 1.67 \angle 129.8^\circ$ pu

$\boxed{V_c = 1.67 \times \frac{11}{\sqrt{3}} = 10.6 \angle -129.8 \text{ kV}}$

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(iii) voltage at neutral

$V_n = 3 I_{a0} \times R_n$

$= 3 \times 0.781 \angle 158.2 \times 0.206$

$V_n = 0.482 \angle 158.2^\circ$ pu

$V_n = 0.482 \times \frac{11}{\sqrt{3}} = 3.065 \angle 158.2^\circ$ kV

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(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 and the harmonic factor HF.

[20 marks]

Q.4 (b) **(i)** Determine the damping ratio, undamped natural frequency of oscillations and % M_p for a unit step input given to a unity negative feedback system with open loop transfer function shown below:

$$\frac{C(s)}{E(s)} = \frac{1}{s(1+0.5s)(1+0.2s)}$$

(ii) The closed-loop transfer function of a unity negative feedback control system is given below:

$$\frac{C(s)}{R(s)} = \frac{Ks+\beta}{s^2+\alpha s+\beta}$$

Determine the steady state error for unit ramp input.

[10 + 10 marks]

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Q.4 (c) A 220 V, 50 Hz, 3-phase star-connected salient pole alternator has six poles. With a field current of 2.4 A, it produces rated terminal voltage on open circuit condition. On short circuit, it requires 0.8 A field current to produce an armature current of 27 A. The alternator has direct axis reactance (X_d) to quadrature axis reactance (X_q) ratio of 1.5. It is connected to bus bars of 220 V (line to line voltage) and its excitation required under this condition is 250 V. (Assuming negligible armature resistance)

Determine:

(i) The maximum power that the alternator can deliver and corresponding load angle with the excitation remaining unchanged.

(ii) The maximum power that the alternator can deliver if a sudden loss of excitation occurs during the synchronized condition.

(Assume linear magnetic circuit)

[20 marks]

Section-B

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]

clock frequency, $f = 3\,MHz$

$1\,T$ state time $= \frac{1}{f} = \frac{1}{3} = 0.33\,\mu sec$

Total T-states required

$= \frac{10 \times 10^{-3}}{0.33 \times 10^{-6}}$

$= 30000$ T-states

Total T-states by memory instruction

$= 3 + 3 + 10 + 6$

$= 22\,T$

$\therefore wxyz = 30000 - 22$

$= (29978)_{10}$

4

$= 16 \,|\, 29978 \quad 10$
$16 \,|\, 1873 \quad 1$
$16 \,|\, 117 \quad 5$
$\quad\; 7$

$(29978)_{10} = (751A)_{16}$

Hence, minimum value of $(wxyz)_H = (751A)_{16}$

Do not write in this margin

Q.5 (b) A message signal, X contains five symbols 'h', 'e', 'l', 'l', 'o' where each sample $x_i \in B^{D\times 1}$ and $B \in \{0, 1\}$.

(i) Find the probability of the unique symbols in X.

(ii) Find the entropy of message signal, X.

(iii) Create a balanced Huffman tree for this message signal X.

(iv) Create the Huffman code book.

[12 marks]

(i) $X = \{h, e, l, l, o\} = 5$

probability of unique x

~~$P(X) = 5 \log$~~

~~$P(X) =$~~

$P(x) = \frac{3}{5} = 0.6$

2

(ii) Entropy of message signal x

$P(x_1) = P(x_2) = P(x_5) = \frac{1}{5} = 0.2$

$P(x_3) = P(x_4) = \frac{2}{5} = 0.4$

$H(x) = 0.2 \log_2 \frac{1}{0.2} \times 3$

$+ 2 \times 0.4 \log_2 \frac{1}{0.4}$

$= 0.2 \times 3 \times 2.323$

$+ 2 \times 0.4 \times 1.32$

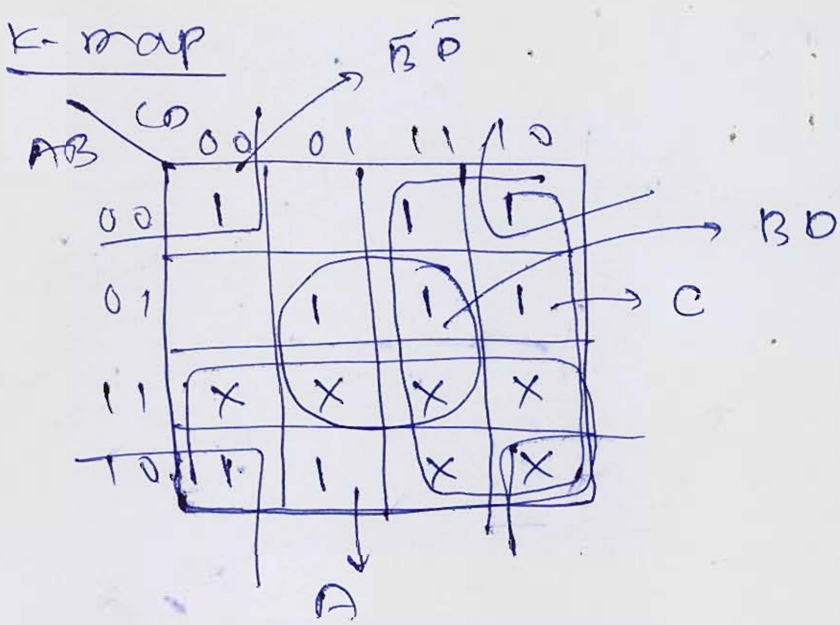
$\boxed{H(x) = 2.4498}$

Do not write in this margin

Q.5 (c) $f(A, B, C, D) = \Sigma m(0, 2, 3, 5, 6, 7, 8, 9) + \Sigma d(10, 11, 12, 13, 14, 15)$. Realize the minimized function using only NOR gates.

[12 marks]

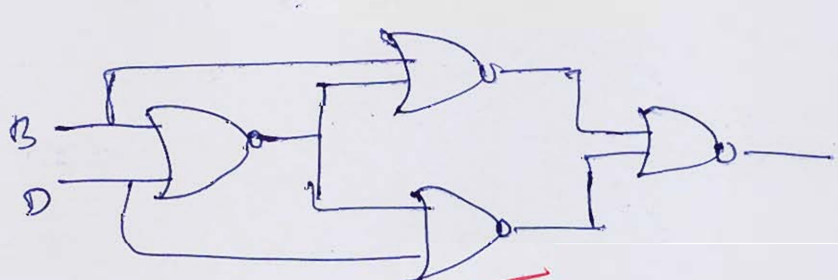
K-map



$$\therefore f(A,B,C,D) = \bar{B}\bar{D} + BD + A + C$$

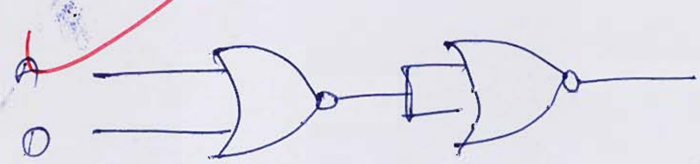
$$= \underbrace{B \odot D}_{x_1} + \underbrace{A + C}_{x_2}$$

$B \odot D$ using ~~K-map~~ NOR gates -



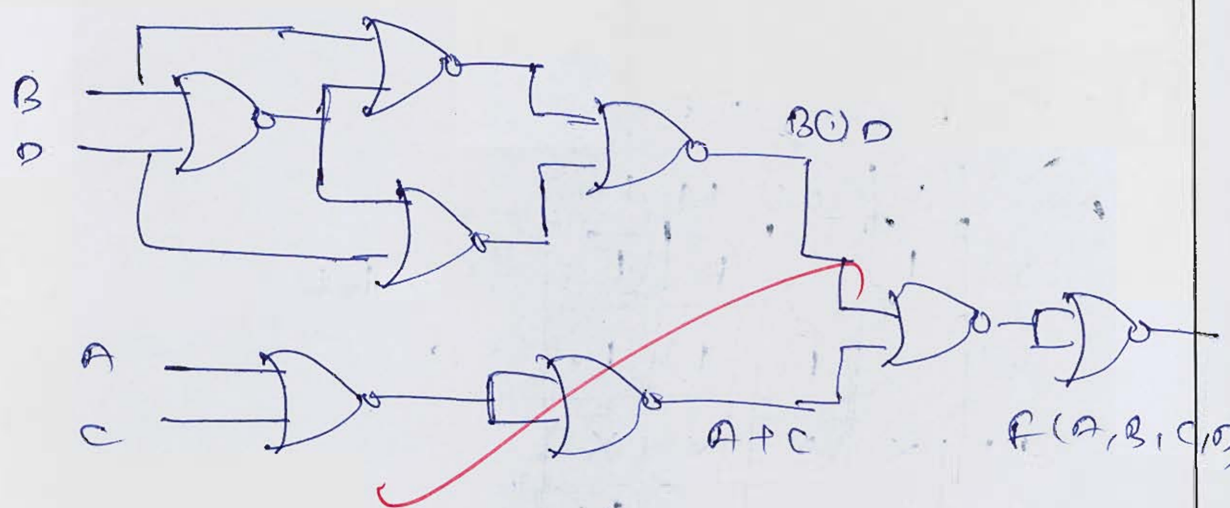
$B \odot D = x_1$

A + C using NOR gates



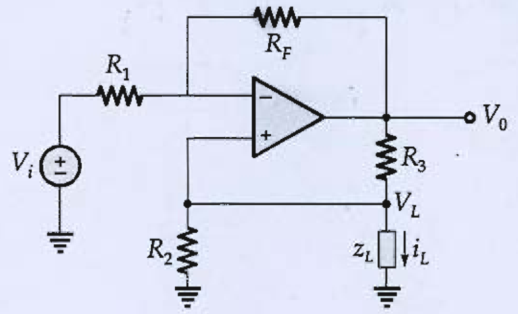
~~A⊙B~~

$A + C = x_2$

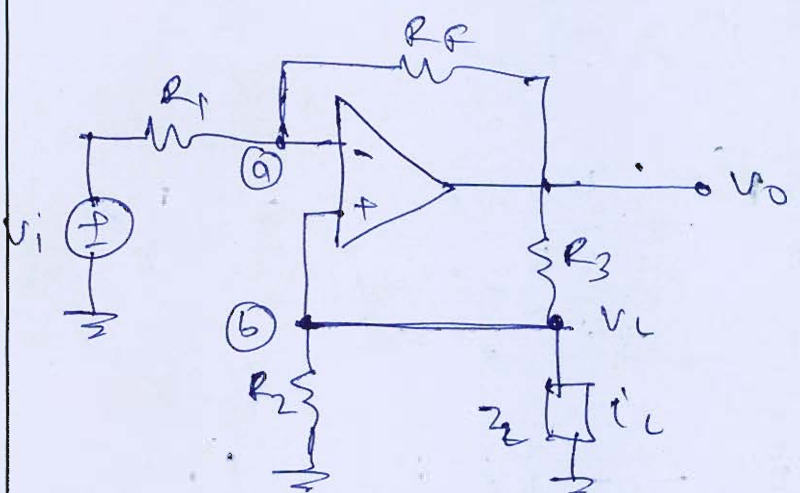


9

Q.5 (d) In the circuit shown below, obtain the equation of i_L (load current) independent of z_L.



[12 marks]



KCL at node (a) -

$$\frac{v_a - v_i}{R_1} + \frac{v_a - v_0}{R_f} = 0$$

$$v_a\left[\frac{1}{R_1} + \frac{1}{R_f}\right] = \frac{v_i}{R_1} + \frac{v_0}{R_f} \quad -(1)$$

KCL at node (b) :-

$$\frac{v_L - v_0}{R_3} + \frac{v_L}{R_2} + i_L = 0 \quad -(2)$$

Now $v_a = v_b = v_L$

from eq - (1) put $v_a = v_L$ we get -

$$v_L\left(\frac{R_1 + R_f}{R_1 R_f}\right) = \frac{v_i \cdot R_f + v_0 R_1}{R_1 R_f}$$

$$v_L = \frac{v_i R_f + v_0 R_f}{R_1 + R_f}$$

Put in equation (2) -

$$v_L \left[\frac{1}{R_3} + \frac{1}{R_2} \right] - \frac{v_0}{R_3} + i_L = 0$$

$$\Rightarrow \left(\frac{v_i R_f + v_0 R_f}{R_1 + R_f} \right) \left(\frac{R_3 + R_2}{R_3 + R_2} \right) - \frac{v_0}{R_3} + i_L = 0$$

$$\therefore i_L = \frac{v_0}{R_3} - v_i \left(\frac{R_f}{R_1 + R_f} \right) \left(\frac{1}{R_3} + \frac{1}{R_2} \right) - v_0 \left(\frac{R_1}{R_1 + R_f} \right) \left(\frac{1}{R_3} + \frac{1}{R_2} \right)$$

$$i_L = v_0 \left[\frac{1}{R_3} - \left(\frac{R_1}{R_1 + R_f} \right) \left(\frac{1}{R_3} + \frac{1}{R_2} \right) \right] - v_i \left(\frac{R_f}{R_1 + R_f} \right) \left(\frac{1}{R_3} + \frac{1}{R_2} \right)$$

6

.5 (e) The open-loop transfer function of a unity feedback system is given by

$$G(s) = \frac{K}{s(s+3)(s^2+s+1)}.$$

Determine the values of K that will cause sustained oscillations in the closed-loop system. Also, find the oscillation frequency.

[12 marks]

characteristics equation –

$$1 + G(s) = 0$$

$$\Rightarrow 1 + \frac{K}{s(s+3)(s^2+s+1)} = 0$$

$$\Rightarrow s(s+3)(s^2+s+1) + K = 0$$

$$\Rightarrow s(s^3 + s^2 + s + 3s^2 + 3s + 3) + K = 0$$

$$s^4 + 4s^3 + 4s^2 + 3s + K = 0$$

R-H table

s^4	1	4	K
s^3	4	3	0
s^2	2.25	K	0
s^1	$\frac{6.75 - 4K}{2.25}$	0	0
s^0	K	0	0

For sustained oscillation s^1 row element is zero.

$$\frac{6.75 - 4K}{2.25} = 0$$

$$\boxed{K = 1.6875}$$

Now, Auxiliary eqn -

$$2.25 s^2 + K = 0$$

$$2.25 s^2 + 1.6875 = 0$$

$$s = j\omega$$

$$-2.25\omega^2 + 1.6875 = 0$$

$$\boxed{\omega = 0.866 \text{ r/s}}$$

Hence, value of $K = 1.6875$

and frequency, $\omega = 0.866$ r/s

11

Good Approach

.6 (a) (i) A 3-phase full-converter charges a battery from a three-phase supply of 240 V, 50 Hz. The battery emf is 190 V and its internal resistance is 0.6 ohm. On account of inductance connected in series with the battery, charging current is constant at 22 A. Calculate the firing angle and supply power factor.

(ii) If it is desired that power flows from dc source to ac source in part (i), calculate the firing angle delay for the same value of current.

[20 marks]

(i) Given :- 3 ϕ, full converter

$V_s = 240V \quad E = 190V \quad r = 0.6\Omega$

$I_0 = 22A$

Average output voltage

$V_0 = E + 2 I_0 r$

$\Rightarrow \frac{3V_{ml}}{\pi} \cos\alpha = 190 + 2\times 22 \times 0.6$

$\Rightarrow \frac{3 \times 240 \times \sqrt{2}}{\pi} \cos\alpha = 216.4$

$\boxed{\alpha = 48.11^\circ}$

firing angle, $\alpha = 48.11^\circ$

power supplied to load

$= E I_0 + 2 I_0^2 \times r$

$= 190 \times 22 + 2 \times (22)^2 \times 0.6$

$= 4760.8$

Input power $= \sqrt{3} V_s I_s$

$I_s = I_0 \sqrt{\frac{2}{3}} = 22 \sqrt{\frac{2}{3}} = 17.96A$

Supply power factor

$$\cos\phi = \frac{E I_0 + I_0^2 R}{\sqrt{3} V_s I_s}$$

$$= \frac{4760.8}{\sqrt{3} \times 240 \times 17.96}$$

$$\boxed{\cos\phi = 0.6376 \text{ lag}}$$

(ii) power flows from DC to AC supply

$$V_0 = -E + I_0 r$$

$$\Rightarrow \frac{3 V_{mp}}{\pi} \cos\alpha = -190 + 22 \times 0.6$$

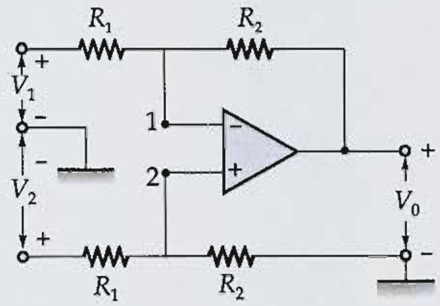
$$\Rightarrow \frac{3 \times 240\sqrt{2}}{\pi} \cos\alpha = -163.6$$

$$\boxed{\alpha = 120.315^\circ}$$

Hence for firing angle $\alpha = 120.315^\circ$ power flows from DC to AC supply.

13

Q.6 (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.



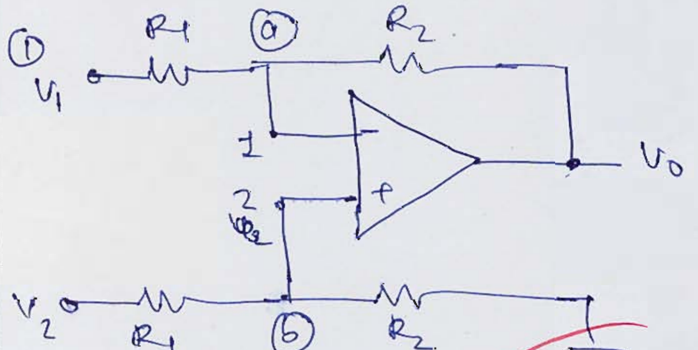
(ii) Draw the pin diagram of the 555 timer.

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:

1. Output frequency.
2. Duty cycle.
3. Average power dissipated if 1 kΩ resistive load is connected between source and the output pin.

[8 + 12 marks]



Ideal opamp input current is zero

KCL at node ⓑ

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

$$\Rightarrow V_b\left(\frac{1}{R_1} + \frac{1}{R_2}\right) = \frac{V_2}{R_1}$$

$$V_b = \frac{R_1 R_2}{(R_1 + R_2)} \times \frac{V_2}{R_1}$$

$$V_b = V_2\left(\frac{R_2}{R_1 + R_2}\right) \quad - ①$$

KCL at node (a)

$$\frac{V_a - V_1}{R_1} + \frac{V_a - V_0}{R_2} = 0$$

$$\Rightarrow V_a\left[\frac{1}{R_1} + \frac{1}{R_2}\right] = \frac{V_1}{R_1} + \frac{V_0}{R_2}$$

For ideal opamp $V_a = V_b = V_2\left(\frac{R_2}{R_1+R_2}\right)$

$$\Rightarrow V_2\left(\frac{R_2}{R_1+R_2}\right) \times \frac{(R_1+R_2)}{R_1 R_2} = \frac{V_1}{R_1} + \frac{V_0}{R_2}$$

$$\Rightarrow \frac{V_2}{R_1} = \frac{V_1}{R_1} + \frac{V_0}{R_2}$$

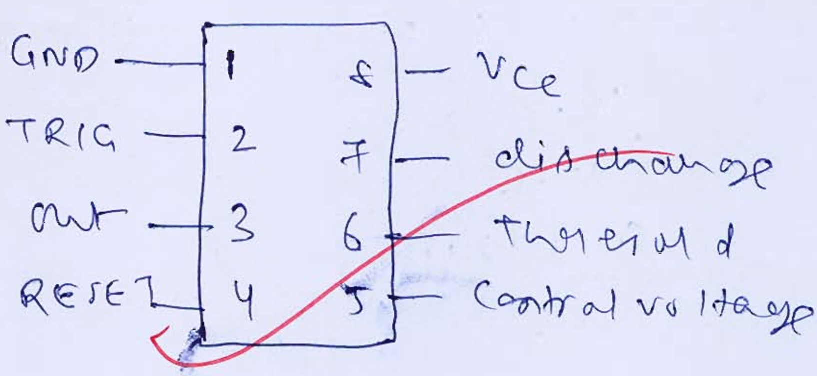
$$V_0 = R_2\left[\frac{V_2}{R_1} - \frac{V_1}{R_1}\right]$$

$$\boxed{V_0 = \frac{R_2}{R_1}(V_2 - V_1)}$$

8

Good Approach

(11) 555 timer pin diagram



Given:- $V_{CC} = 12\ V$

$R_A = 10\,k\Omega$ $R_B = 2.3\,k\Omega$ $C = 0.1\mu F$

① Total time period

$T = 0.693 (R_A + 2R_B) C$

$= 0.693 (10 + 2.3 \times 2) \times 10^3 \times 0.1 \times 10^{-6}$

$T = 1.01178\ ms$

Output frequency,

$f = \frac{1}{T} = \frac{1}{1.01178 \times 10^{-3}}$

$\boxed{f = 988.35\ Hz}$

② Duty cycle $= \frac{R_A + R_B}{R_A + 2R_B}$

$= \frac{10 + 2.3}{10 + 2 \times 2.3}$

$= \frac{12.3}{14.6}$

$= 0.8424$

③ $R_L = 1\,k\Omega$

Average power dissipated

$(V_0)_{avg} = D V_{ce}$

$= 0.8424 \times 12$

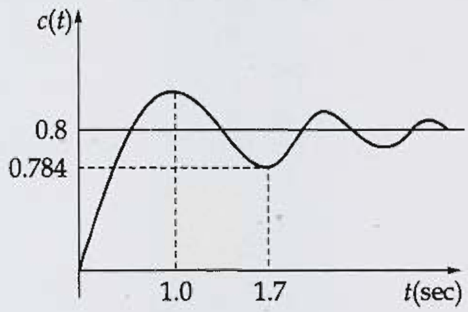
$= 10.1$

$P = \frac{V_0^2}{R} = \frac{(10.1)^2}{1k\Omega}$

$\boxed{P = 0.102\,W}$

10

Q.6 (c) (i) The unit step response of a second order underdamped system is shown in the figure below. Determine the transfer function of the system.



[8 marks]

From the graph 1^{st} peak time, $t_p = 1$ sec

$$t_p = \frac{\pi}{\omega_d} = 1$$

$$\Rightarrow \boxed{\omega_d = \pi = 3.14 \text{ sec}}$$

2^{nd} undershoot percentage

$$\% M_p = \frac{0.8 - 0.784}{0.8} \times 100 = 2\%$$

$$\Rightarrow e^{\frac{-2\xi\pi}{\sqrt{1-\xi^2}}} = 2\% = 0.02$$

$$\Rightarrow \frac{-2\xi_e \pi}{\sqrt{1-\xi_p^2}} = \ln(0.02) = -3.912$$

$$\Rightarrow \frac{4\xi_p^2 \pi^2}{1-\xi_p^2} = (3.912)^2$$

$$\Rightarrow 4\xi_p^2 \pi^2 = (3.912)^2 - (3.912)^2 \xi_p^2$$

$$\xi^2 \left[4\pi^2 + (3.912)^2\right] = (3.912)^2$$

$$\boxed{\xi_p = 0.5285}$$

$$\omega_d = \omega_n \sqrt{1 - \xi^2}$$

$$\Rightarrow 3.14 = \omega_n \sqrt{1 - 0.5285^2}$$

$$\boxed{\omega_n = 3.7 \text{ r/s}}$$

Transfer function of 2^{nd} order system

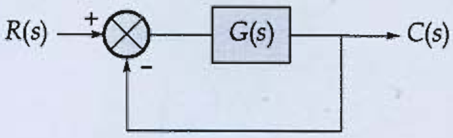
$$\frac{C(s)}{R(s)} = \frac{\omega_n^2}{s^2 + 2\xi\omega_n s + \omega_n^2}$$

$$= \frac{(3.7)^2}{s^2 + 2 \times 0.5285 \times 3.7 s + (3.7)^2}$$

$$\boxed{\frac{C(s)}{R(s)} = \frac{13.68}{s^2 + 3.91 s + 13.68}}$$

7

Q.6 (c) **(ii)** For the system shown in figure below, $G(s) = \dfrac{60s+K}{s^2(s^2+6s+30)}$. Determine the range of values of K for which all the closed loop poles lie to the left of $s = -1$.



[12 marks]

Characteristics equation =

$$1 + G(s) = 0$$

$$1 + \frac{60s + K}{s^2(s^2+6s+30)} = 0$$

$$\Rightarrow \quad s^2(s^2+6s+30) + 60s + k = 0$$

$$\Rightarrow \quad s^4 + 6s^3 + 30s^2 + 60s + k = 0$$

For all closed loop poles lies to the left of $s = -1$

~~put~~ replace s by $z-1$

$$(z-1)^4 + 6(z-1)^3 + 30(z-1)^2 + 60(z-1) + k = 0$$

$$\Rightarrow (z^2-2z+1)(z^2-2z+1) + 6(z^3 - 3z^2 + 3z - 1) + 30(z^2-2z+1) + 60z - 60 + k = 0$$

$$\Rightarrow z^4 - 2z^3 + z^2 - 2z^3 + 4z^2 - 2z + z^2 - 2z + 1 + 6z^3 - 18z^2 + 18z - 6 + 30z^2 - 60z + 30 + 60z - 60 + k = 0$$

$\Rightarrow \quad z^4 + 2z^3 + 18z^2 + 14z + k - 35 = 0$

RHC $\Rightarrow z^4 + 2z^3 + 18z^2 + 14z + k - 35 = 0$

RH table

z^4	1	18	$k-35$
z^3	2	14	
z^2	11	$k-35$	
z^1	$\frac{11 \times 14 - 2(k-35)}{11}$		
z^0	$k-35$		

$k - 35 > 0 \Rightarrow k > 35$

$\Rightarrow 11 \times 14 - 2k + 70 > 0$

$k < 112$

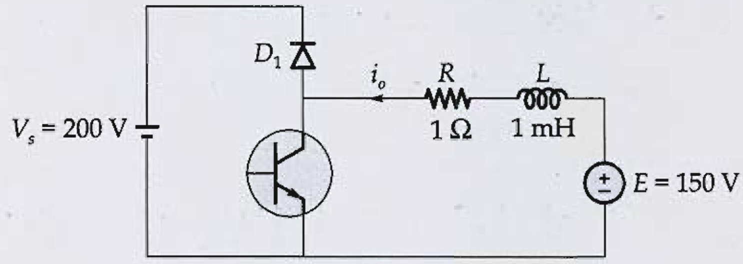
$\therefore \boxed{35 < k < 112}$

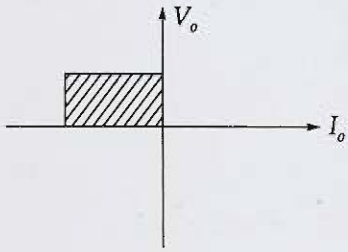
For the range of k for which all the poles lies to the left of $s = -1$ is $35 < k < 112$

11

Good Approach

Q.7 (a) A dc-to-dc chopper capable of second-quadrant is used in 200 V dc battery electric vehicle. The machine armature has 1 Ω in series with 1 mH inductance.





(i) The machine is used for regenerative braking. At a constant speed downhill, the back emf is 150 V, which results in 10 A braking current. What is the switch on-state duty cycle if the machine is delivering continuous output current? What is the minimum chopping frequency for these conditions?

(ii) At this speed (that is $E = 150$ V), determine the minimum duty cycle for continuous inductor current, if the switching frequency is 1 kHz. What is the average braking current at the critical duty cycle?

(iii) If the chopping frequency is increased to 5 kHz, at the same speed (that is $E = 150$ V), what is the critical duty cycle and corresponding average dc machine current?

[20 marks]