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ESE 2025 : Mains Test Series

UPSC ENGINEERING SERVICES EXAMINATION

Electrical Engineering

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

Name : ....

Roll No :

Test Centres			Student's Signature
Delhi ☑	Bhopal ☐	Jaipur ☐	
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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	42
Q.2	41
Q.3	41
Q.4	
Section-B	
Q.5	~~33~~ 32
Q.6	31
Q.7	
Q.8	
Total Marks Obtained	~~180~~ 187

Signature of Evaluator: Sourabh kumar

Cross Checked by: ....

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IMPORTANT INSTRUCTIONS

CANDIDATES SHOULD READ THE UNDERMENTIONED INSTRUCTIONS CAREFULLY. VIOLATION OF ANY OF THE INSTRUCTIONS MAY LEAD TO PENALTY.

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]

$A = 500 Km^2$

$F = 130 cm/annum$ $\quad \eta_F = 0.8 = K$

$H = 30 m$

$\eta_{Penstock} = 0.97$, $\eta_T = 0.87$, $\eta_G = 0.92$

$P_{LF} = 60\% = 0.6$

For hydro-electric station

$P = 3.14 \times 10^{-4} \times KAFH\eta$ KW

$= 3.14 \times 10^{-4} \times 0.8 \times 500 \times 130 \times 30 \times (0.97 \times 0.87 \times 0.92)$

$= 380.3$ KW

$\boxed{\text{Electricity Generation Capacity} = 380.3 KW}$

3

Q.1 (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]

(i) $P_R = S_R \times \cos\phi = 50 \times 0.8 = 40\,MW$

Also, $P_R = \frac{V_S V_R}{B} . \cos(\beta - \delta) - \frac{A V_R^2}{B} . \cos(\beta - \alpha)$

So, $40 = \frac{132 \times 132}{110} . \cos(75 - \delta) - 0.98 \times \frac{132^2}{110} \times \cos(75 - 3)$

$\delta = 18.73°$

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

$= \frac{132^2}{110} \times \left[\sin(75 - 18.73) - 0.98 \times \sin(75 - 3)\right]$

$Q_R = -15.899$ MVAR

$Q_{load} = S_R . \sin\phi = 50 \times \sin(\cos^{-1} 0.8) = 50 \times 0.6$

$= 30$ MVAR

$Q_C = Q_{load} - Q_R$

$= 30 + 15.899$

$\boxed{Q_C = 45.899 \text{ MVAR}}$ (Capacitive)

Capacity of shunt compensation

(ii) under No load ~~$P_R = 0$~~

$P_R = 0$

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

$\delta = 2.63°$

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

$= 3.33$ MVAR

$\boxed{Q_L = Q_R = 3.33 \text{ MVAR}}$ (inductive)

↳ Capacity of shunt Compensation

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Good Approach

Q.1 (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 $K\phi = 3$ V-sec.

As, $T = K\phi . I_a$

for upward direction

$69 = 3 \times I_a \Rightarrow I_a = 23A$

$V_o = \frac{2V_m}{\pi} . \cos\alpha = \frac{2 \times 230\sqrt{2}}{\pi} . \cos 15° = 200V$

as, $V_o = E_b + I_a . R_a$

$200 = E_b + 23 \times 0.5 \Rightarrow E_b = 188.5V$

Now in downward direction

$T = 180 \text{ Nm} = 3 \times I_a$

$I_a = 60A$

for maintaining speed in both direction equal.

$E \propto \omega$

So, $E_b = -188.5$ (opposite direction)

$V_o = +E_b + I_a . R_a$

$= -188.5 + 60 \times 0.5 = ~~+158~~ -158.5V$

$\Rightarrow -158.5 = \frac{230\sqrt{2} \times 2}{\pi} . \cos\alpha$

$$\boxed{\alpha = 139.9^\circ}$$

↳ Triggering angle for maintaining downward speed equal in magnitude to upward speed.

Now, for motor at holding position while moving upward

$T = 69 = 3 \times I_a \Rightarrow I_a = 23A$

and for holding position $\Rightarrow E_b = 0$

Hence, $V_o = I_a \cdot R_a = 23 \times 0.5$
$= 11.5V$

Hence,

$$\frac{2 \times 230\sqrt{2}}{\pi} \cdot \cos\alpha = 11.5$$

$$\boxed{\alpha = 86.8^\circ}$$

↳ triggering angle to keep the motor at holding position while moving upward.

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Good Approach

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Q.1 (d) Find the z-transform of the discrete time signal, $x(n) = \sin(2\omega_0 n)\, u[n]$.

[12 marks]

$$x(n) = \sin(2\omega_0 n)\, u(n)$$

$$= \frac{1}{2j} \times \left[e^{j2\omega_0 n} - e^{-j2\omega_0 n} \right] u(n)$$

$$= \left[\frac{(e^{j2\omega_0})^n}{2j} - \frac{1}{2j} \times (e^{-j2\omega})^n \right] u(n)$$

as, for

$$a^n\, u(n) \overset{Z}{\longleftrightarrow} \frac{z}{z-a} \qquad |z| > a$$

~~He~~ using this,

$$(e^{j2\omega_0})^n u(n) \longleftrightarrow \frac{z}{z - e^{j2\omega_0}} \quad , |z| > 1$$

and

$$(e^{-j2\omega_0})^n u(n) \longleftrightarrow \frac{z}{z - e^{-j2\omega_0}} \quad , |z| > 1$$

so,

$$X(z) = \frac{1}{2j} \left(\frac{z}{z - e^{j2\omega_0}} - \frac{z}{z - e^{-j2\omega_0}} \right)$$

$$= \frac{z}{2j} \left[\frac{z - e^{-j2\omega_0} - z + e^{j2\omega_0}}{z^2 - z(e^{j2\omega_0} + e^{-j2\omega_0}) + 1} \right]$$

$$= \frac{z}{2j} \left[\frac{e^{j2\omega_0} - e^{-j2\omega_0}}{z^2 - z(e^{j2\omega_0} + e^{-j2\omega_0}) + 1} \right]$$

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$$\frac{e^{j2\omega_0} - e^{-j2\omega_0}}{2j} = \sin 2\omega_0$$

and

$$e^{j2\omega_0} + e^{-j2\omega_0} = 2\cos 2\omega_0$$

Hence,

$$\boxed{X(z) = \frac{z \sin 2\omega_0}{z^2 - 2z\cos\omega_0 + 1}}, \quad |z|>1$$

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Good approach

Q.1 (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]

~~Excitatio~~ Excitation table of T flipflop

Q	Q^+	T
0	0	0
0	1	1
1	0	1
1	1	0

Now for given Condition

X	Y	Q	Q^+	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	1
1	1	1	1	0

K-MAP

	$\bar{Y}\bar{Q}$	$\bar{Y}Q$	YQ	$Y\bar{Q}$
$\bar{X}$	0	0	1	1
X	0	1	0	1

$$T = X\bar{Y}Q + \bar{X}Y + Y\bar{Q}$$

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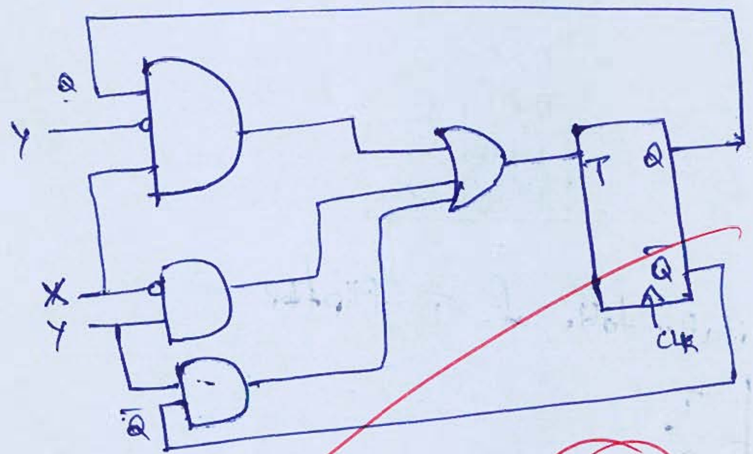
Require FF is shown!



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Q.2 (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]

$P_{cu} = 1.6\%$, $P_h = 0.9\%$, $P_e = 0.6\%$

$\eta = 1.6$

(i) Due to change in frequency, the change in resistance of windings is negligible and as the current through winding is same

and $P_{cu} \propto I^2 \cdot R$

So, neither 'I', nor R is changed

Hence
ohmic loss remain same. $\boxed{P_{cu} = 1.6\%}$

Now
Eddy current loss,

$P_e \propto B_m^2 \cdot f^2 \cdot t^2$

$P_e \propto V^2$ [$B_m \cdot f \propto V$, t = constant thickness]

Since voltage is same, eddy current loss remains the same.

$\boxed{P_e = 0.6\%}$

Also, Hysteresis loss.

$$P_h \propto B_m^n \times f$$

$$\propto B_m^{1.6} \times f \times \frac{f^{0.6}}{f^{0.6}}$$

$$\propto \frac{V^{1.6}}{f^{0.6}} \qquad [\because B_m f \propto V]$$

$$P_h \propto \frac{1}{f^{0.6}}$$

So, $\frac{P_{h1}}{P_{h2}} = \left(\frac{f_2}{f_1}\right)^{0.6}$

$$\frac{0.9}{P_{h2}} = \left(\frac{60}{50}\right)^{0.6}$$

$$\boxed{P_{h2} = 0.8067\ \%}$$

(ii)

Let $P_{in} = 100$ At $f = 50\ Hz$

$P_{out} = P_{in} - \text{losses}$

$= 100 - (1.6 + 0.9 + 0.6)$

$= 96.9$

Now at $f = 60\ Hz$

Total losses $= 1.6 + 0.6 + 0.8067$

$= 3.0067$

Output $= 100 - 3.0067$

$= 96.9933$

Now for losses to remain same as they were on $f = 50$ Hz.

$$\eta = \frac{\text{Output}}{\text{Output} + \text{losses}} \times 100$$

$$\Rightarrow 96.9933 = \frac{\text{Output}}{\text{Output} + 300} \cancel{\times 100}$$

$$\boxed{\text{Output} = 100.003\ \%}$$

Compared to previous input

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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:

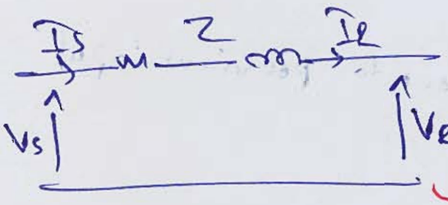
(i) The receiving end voltage and receiving end line current.

(ii) Sending end power and power factor.

(iii) Voltage regulation of the line.

[20 marks]

Given line is a short transmission line



$V_{SLL} = 3.3KV$

$$Z = (R + j\omega L) \times l = (3.75 \times 10^{-3} + j \times 2\pi \times 50 \times 15.92 \times 10^{-6}) \times 80$$

$$= 0.5 \angle 53.13^\circ \ \Omega$$

For the given transmission line ABCD parameters will be as follows:

$A = 1\angle 0^\circ$, $\quad B = Z = 0.5 \angle 53.13$

$C = 0$ $\quad , D = 1\angle 0^\circ$

Now, using power equation

~~$V_S = AV_R + BI_R$~~

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

$$P_R = S_R \times \cos\phi = 375 \times 0.8 = 300 \text{ kW}$$

$$\Rightarrow 300 \times 10^3 = \frac{3300 \times V_R}{0.5} \cos(53.13 - \delta) - \frac{V_R^2}{0.5} \times \cos(53.13)$$

—— 1

and $Q_R = S_R \sin\phi_R = 375 \times 0.6 = 225$ KVAR

$$\Rightarrow 10^3 \times 225 = \frac{3300 \times V_R}{0.5} \sin(53.13 - \delta) - \frac{V_R^2}{0.5} \times \sin(53.13) \quad \text{—(2)}$$

$$\Rightarrow \sin(\beta - \delta) = \left[225 + \frac{V_R^2}{0.5} \cdot \sin(53.13)\right] \times \frac{0.5 \times \cancel{3300}}{3300 \times V_R}$$

Using this in (1)

$$150 \times 10^3 = 3300 V_R \cos\left\{\sin^{-1}\left(225 + \frac{V_R^2}{0.5} \times 0.8\right) \times \frac{0.5 \times 3300}{V_R}\right\} - 0.2 V_R^2$$

On solving above equation.

$$\boxed{V_{RL} = 3244.4 \text{ V}}$$ Receiving end voltage

$P_{RL} = \sqrt{3} V_{RL} \times I_{RL} \times \cos\phi_R$

$\Rightarrow 375 \times 0.8 \times 10^3 = \sqrt{3} \times 3244.4 \times I_{RL} \times 0.8$

$$\boxed{I_R = 66.73 \text{ A}}$$

(iii) $I_s = CV_R + DI_R$

$$\boxed{I_s = I_R = 66.73 \text{ A}}$$

$V_s = \frac{3244}{\sqrt{3}} \angle 0^\circ + 66.73 \angle -36.87 \times 0.5 \angle 53.13$

$V_{sph.} = 1905 \angle 0.28^\circ$ V

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$P_s = \sqrt{3} \times V_{sL} \times I_s \times \cos\phi_s$

$= \sqrt{3} \times 3300 \times 66.73 \times \cos(36.87 + 0.281)$

$\boxed{P_s = \underline{\underline{304.004}} \text{ KW}}$

$\boxed{\cos\phi_s = 0.797 \text{ lag.}}$

(iii) $V.R = \dfrac{V_{RNL} - V_{RFL}}{V_{RFL}} \times 100$

$V_{RL} = \dfrac{V_s}{A} = 3300$

$\% V.R = \dfrac{3300 - 3244.4}{3244.4} \times 100$

$\boxed{\% VR = 1.714 \%}$

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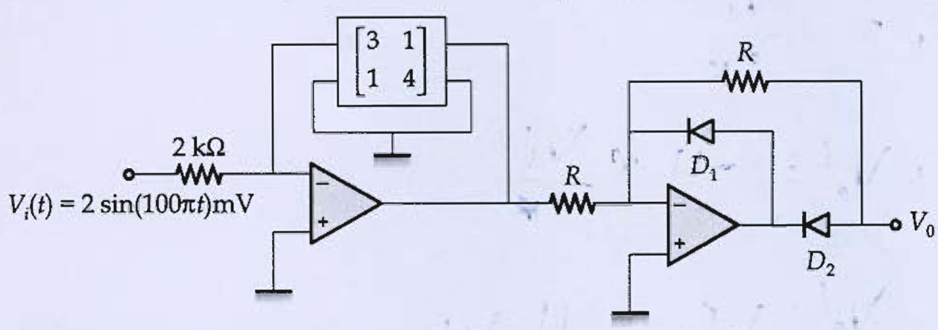
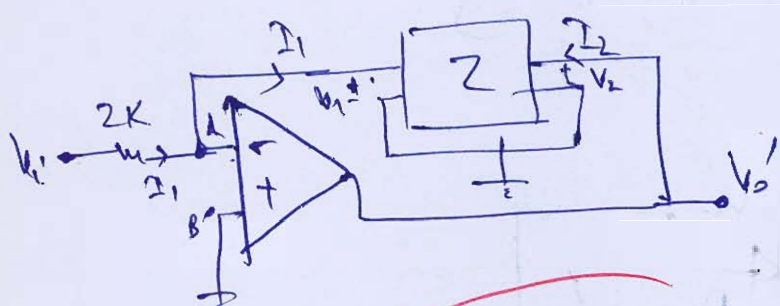
Q.2 (c) In the circuit shown in figure below, all the op-amps and diodes are ideal.



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]



By ~~Z-T~~ Z-Parameter Equation

$$V_1 = Z_{11} I_1 + Z_{12} I_2$$

$$V_2 = Z_{21} I_1 + Z_{22} I_2$$

$$V_1 = 3 I_1 + I_2$$

$$V_2 = I_1 + 4 I_2$$

$V_A = V_B = V_1 = 0$ (from the circuit)

Hence,

$$I_2 = -3 I_1$$

So, $V_2 = I_1 - 3\times 4\, I_1 = -11\, I_1$

$V_o' = -11 I_1$ $(V_2 = V_o')$

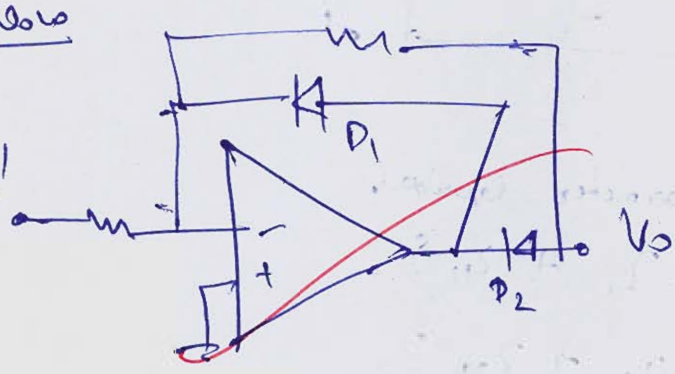
$$I_1 = \frac{V_i'}{2K}$$

So, $V_o' = -11 \times \frac{V_i'}{2K}$

$$\frac{V_o'}{V_i'} \quad V_o' = -\frac{11}{2} V_i'$$

$$\boxed{V_o' = -5.5 V_i}$$

Now



In +ve cycle

~~D1 → D2 → Reverse Bias.~~

$D_1 \rightarrow$ Forward Bias and $D_2 \rightarrow$ Reverse Bias

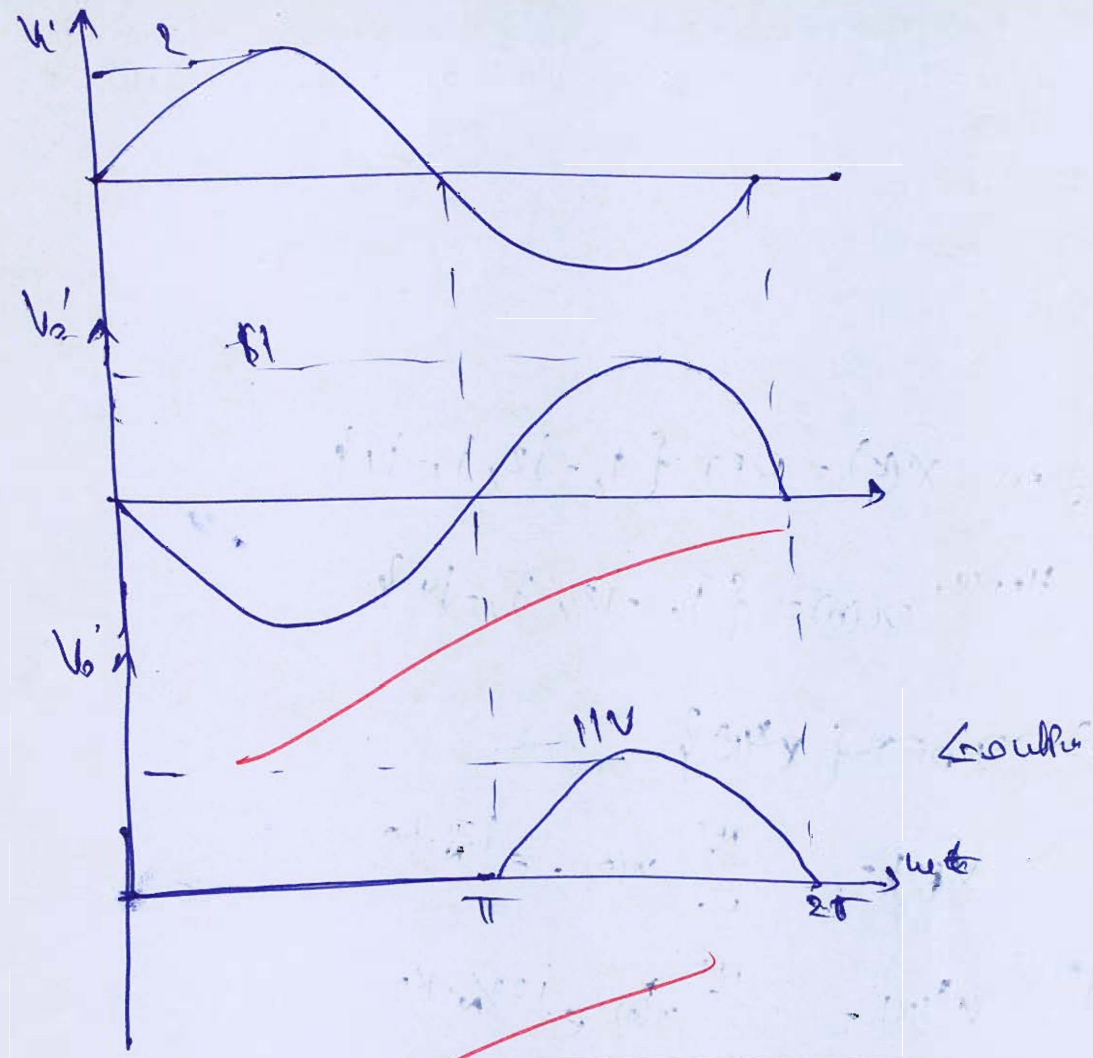
Hence,

$V_o = 0$

In -ve cycle

$D_2 \rightarrow$ Forward Bias and $D_1 \rightarrow$ Reverse bias

$$\frac{V_o}{V_o'} = \frac{-R}{R} = -1 \Rightarrow V_o = V_o'$$



$$\boxed{(V_o)_{Avg.} = \frac{V_m}{\pi} = \frac{11}{\pi} = 3.5\,V}$$

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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]

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

Hence, $x(n) = \{1, -j2, j, -j4\}$

~~(i) IDFT$\{X^*(K)\}$~~

$$X(K) = \sum_{K=0}^{N-1} x(n) \cdot e^{-j\frac{2\pi}{N}\cdot Kn}$$

(i) $$X^*(K) = \sum_{K=0}^{N-1} x^*(n)\, e^{j\,2\pi/N \cdot Kn}$$

$$= X(N-K)$$

and $x^*(n) \rightleftharpoons X^*(K)$

So, $$X^*(K) \rightleftharpoons x^*(-n)$$
$$= x(N-n)$$
$$= x(3-n)$$

~~IDF$(X^*(K))$~~

$x(n+3) = \{-j4, 1, -j2, j\}$

$$\boxed{\text{IDFT}\{X^*(K)\} = x(-n+3) = \{-j4, j, -j2, 1\}}$$

(ii) IDFT $\{X(-K)\}$

$x(n) \rightleftharpoons X^*(-K)$

So, $\boxed{\text{IDFT}\{x(-K)\} = x(-n) = \{1, -j4, j, -j2\}}$

(iii) $Re(X(K)) = \dfrac{X(K) + X^*(-K)}{2}$

$\text{IDFT}\{Re\, X(K)\} \rightleftharpoons \frac{1}{2} x(n) + \frac{1}{2} \times x^*(n)$

$= \frac{1}{2}\left\{\{1, -j2, j, -j4\} + \{1, j4, -j, j2\}\right\}$

$= \{1, j2, 0, -j2\}$

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(iv) $Im(X(K)) = \dfrac{X(K) - X^*(K)}{2j}$

$= \frac{1}{2j}\{x(n) - x^*(-n)\}$

$= \frac{1}{2j}\left\{\{1, -j2, j, -j4\} - \{1, j4, -j, j2\}\right\}$

$= \frac{1}{2j}\{0, -3, 1, -3\}$

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Q.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]

From Open circuit test (iron loss)

$$P_{oc} = 50 \text{ W}$$

$$Z_{oc} = \frac{V_{oc}}{I_{oc}} \angle \cos^{-1}\left(\frac{P_o}{V_{oc} I_{oc}}\right)$$

$$= \frac{250}{0.8} \angle \cos^{-1}\left(\frac{50}{250 \times 0.8}\right) = 312.5 \angle 75.52 \ \Omega$$

From Short Circuit test

$$Z_{sc} = \frac{V_{sc}}{I_{sc}} \angle \cos^{-1}\left(P_{sc}/V_{sc}I_{sc}\right)$$

$$= \frac{60}{3} \angle \cos^{-1}\left(\frac{45}{60 \times 3}\right) = 20 \angle 75.22 \ \Omega$$

Cu loss at full load

$$P_{cu} = P_{sc} \times \left(\frac{I_{FL}}{I_{sc}}\right)^2 \qquad I_{FL} = \frac{10 \times 10^3}{2500} = 4 \text{ A}$$

$$= 45 \times \left(\frac{4}{3}\right)^2 = 80 \text{ W}$$

(i) $$\% \eta = \frac{\text{Output}}{\text{Output} + \text{losses}} \times 100$$

Taking $S_{Base} = 10\,KVA$

Output $= \frac{1}{4} = 0.25$ pu

P.F $= 0.8$

iron loss $(P_i) = \frac{50}{10\times10^3} = 5\times10^{-3}$ pu

P_{cu} at $\frac{1}{4}$ load $= \left(\frac{1}{4}\right)^2 \times \frac{80}{10\times10^3} = 5\times10^{-4}$ pu

$$\eta = \frac{0.25\times0.8}{0.25\times0.8 + 5\times10^{-3} + 5\times10^{-4}} \times 100$$

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

(ii) ~~For~~ At maximum efficien

copper loss = iron loss

$\Rightarrow x^2 \times \frac{80}{10\times10^3} = 5\times10^{-3}$

($x \Rightarrow$ pu load)

$x = 0.79$

load is KVA $= 0.79\times10$

$$\boxed{\text{load (KVA output)} = 7.9\ KVA}$$

$$\eta = \frac{0.79 \times 0.8}{0.79 \times 0.8 + 5\times10^{-3} + \frac{80}{10\times10^3} \times 0.79^2} \times 100$$

$$\boxed{\eta = 98.44\ \%}$$ → maximum efficiency

(iii) $V.R = (R_{pu} \cos\phi + X_{pu} \sin\phi) \times 100$

$Z_{HV} = 20 \angle 75.22 = 5.102 + j19.338$

$Z_{base} = \frac{V_{HV}^2}{S_b} = \frac{2500^2}{10\times10^3} = 625\ \Omega$

$Z_{pu} = \frac{Z_{HV}}{Z_{base}} = \frac{5.102 + j19.338}{625}$

$= 8.163\times10^{-3} + j0.03094$ pu

$V.R = (8.163\times10^{-3} \times 0.8 + j0.03094 \times 0.6) \times 100$

$$\boxed{\%\ V.R = 2.51\ \%}$$

Secondary terminal voltage at rated load $= 250V$

and at winding side,

$250 \times 1.0251 = 256.275$ V

14

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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.

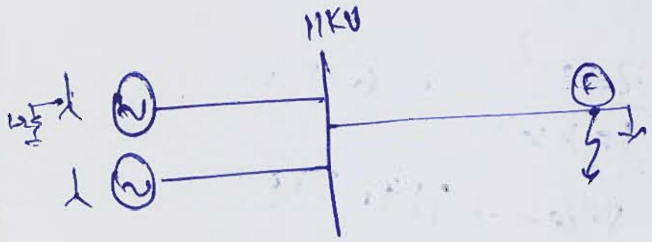
(ii) The voltage of phase '*b*' and phase '*c*'.

(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	*j*0.2	*j*0.4
Negative sequence	*j*0.15	*j*0.4
Zero sequence	*j*0.08	*j*0.8

[20 marks]



Positive Sequence Circuit

Taking

$S_{Base} = 25\,MVA$

$V_{Base} = 11\,KV$

$$Z_{Base} = \frac{V_{Base}^2}{S_{Base}} = \frac{11^2}{25} = 4.84\,\Omega$$

For feeder

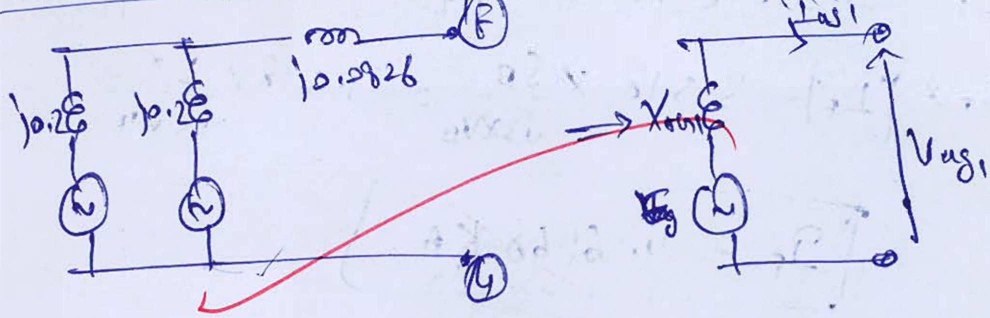
$$X_1 = \frac{0.4}{4.84} = 0.0826\ pu = X_2$$

$$X_0 = \frac{0.8}{4.84} = 0.1653\ pu$$

and netural Resistance

$$R_N = \frac{1}{4.84} = 0.2066\,pu$$

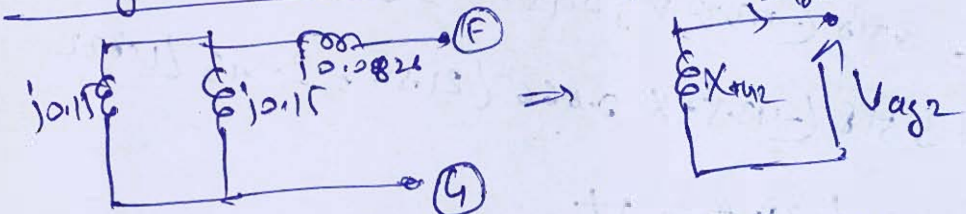
Positive Sequence Circuit



$E = 1\angle 0^\circ$, $X_{th1} = j\{(0.2 \| 0.2) + 0.0826\}$

$= j0.1826$ pu

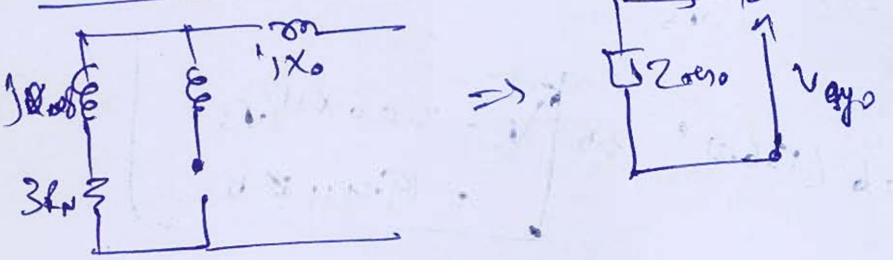
Negative Sequence Circuit



$X_{th} = j\{(0.15 \| 0.15) + 0.0826\}$

$= j\,0.1576$ pu

Zero sequence Circuit



$Z_{th0} = 3R_N + jX_{g0} + jX_0$

$= 3\times\frac{1}{484} + j(0.08+0.1653) = 0.6666\angle 21.59^\circ$ pu

For line to ground fault

$I_F = 3\times\frac{1}{X_{th1} + X_{th2} + Z_{th0}} = \frac{3}{j0.1826 + j0.1576 + 0.6666\angle 21.59}$

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$I_F = 3.518 \angle -43.37^\circ$ pu

$\cancel{I_F \times}\ |I_F| = 3.518 \times \frac{S_B}{\sqrt{3} \times V_B} = 3.518 \times \frac{25}{\sqrt{3} \times 11}$

$\boxed{I_F = 4.6168 \text{ KA}}$

(ii) $\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ 1 & \alpha^2 & \alpha \\ 1 & \alpha & \alpha^2 \end{bmatrix} \begin{bmatrix} V_{a0} \\ V_{a1} \\ V_{a2} \end{bmatrix}$

$V_{a1} = 1 - 3.518 \angle -43.37 \times j\,0.1826 = 0.7283 \angle -39.68^\circ$

$V_{a2} = -3.518 \angle -43.37 \times j\,0.1576 = 0.5544 \angle -133.37$

$V_{a0} = -3.518 \angle -43.37 \times 0.666 \angle 21.59 = 2.343 \angle 158.22$

~~$V_b = 0.7283 \angle -39.88 + 1\angle$~~

$V_b = 2.343 \angle 158.22 + 1 \angle 240 \times 0.7283 \angle -39.88$
$+ 1 \angle 120 \times 0.5544 \angle -133.37$

$V_b = 2.37 \angle 168$

$\boxed{V_b = 2.37 \times \frac{11}{\sqrt{3}} = 15.05 \text{ KV}}$

Similarly

$V_c = 3.06 \angle 136.21^\circ \Rightarrow \boxed{V_c = 3.06 \times 11/\sqrt{3} = 19.44 \text{ KV}}$

14

(iii) $V_g = 3 R_n \times I_{a0}$

$= 3 \times \frac{1}{4.84} \times 3.518 \angle -43.37 = 0.7268$ pu

$\boxed{V_g = 0.7268 \frac{\times 11}{\sqrt{3}} = 4.616 \text{ KV}}$

↳ voltage at star point

Q.4 (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]

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]

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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]

For 10 ms delay,

$$\# \text{ Clock Cycles} = \frac{\text{delay tim}}{\text{Cycle time}} = \text{delay} \times f_s$$

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

$$= 3 \times 10^{4} \quad \text{T-states.}$$

Now given Program

	T states
MVI B, wx H	7
MVI C, yz H	7
L1: DCX B	6
JNZ L1	10/7 (True / False)

$$\text{So, } \# \text{ states} = 7 + 7 + n \times 6 + (n-1) \times 10 + 7$$

$$(n)_{10} \Rightarrow (wxyz)_H$$

$$30000 = 7 + 7 + 6n + 10n - 10 + 7$$

$$16n = 29989$$

$$n = 1874.3$$

$$n \approx 1875 \Rightarrow \boxed{(753)_H \Rightarrow (wxyz)_H}$$

10

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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.

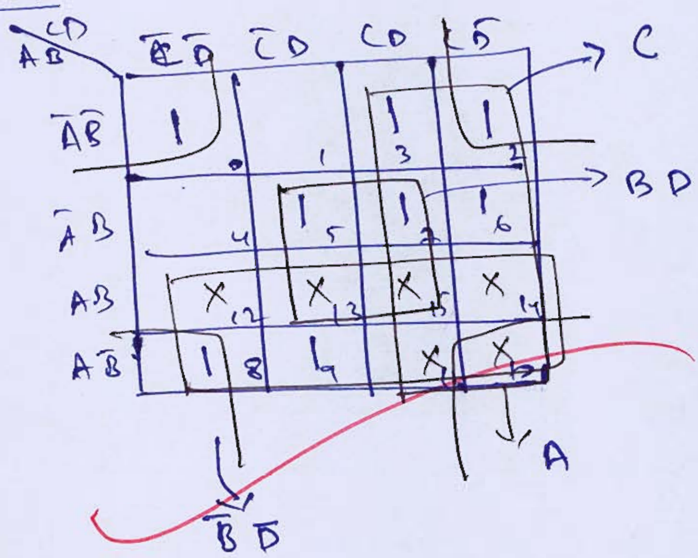
(iv) Create the Huffman code book.

[12 marks]

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

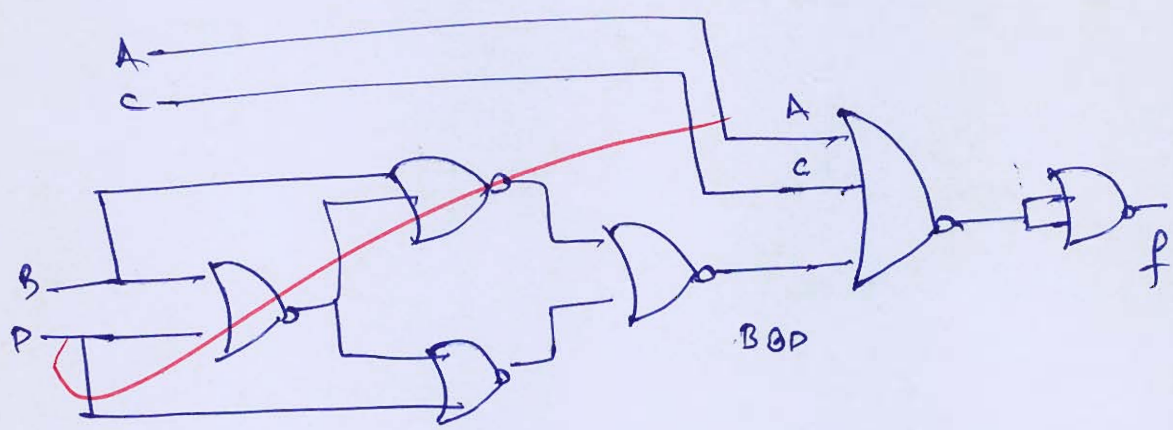


$f(A, B, C, D) = A + C + BD + \bar{B}\bar{D}$

$= A + C + B \odot D$

So, Realizing using NOR Gates.

10



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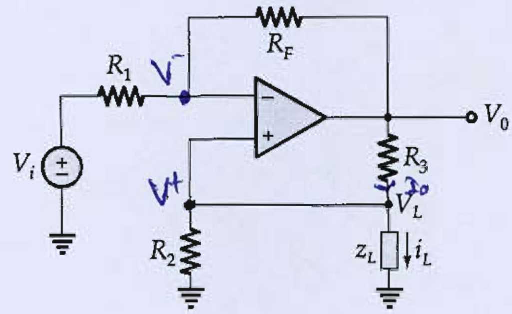
Q.5 (d) In the circuit shown below, obtain the equation of i_L (load current) independent of z_L.



[12 marks]

$V^+ = V_L = V^-$ (by virtual short concept)

KCL at V^-

$$\frac{V^- - V_i}{R_1} + \frac{V^- - V_o}{R_F} = 0$$

$$V_o = -\frac{R_F}{R_1} \cdot V_i + \left(1 + \frac{R_F}{R_1}\right) \cdot V_L \qquad (\because V^- = V_L)$$

~~$V_L = V_o - i_L \cdot R_3$~~

using current division,

$$i_L = I_o \times \frac{R_2}{Z_L + R_2}$$

$$I_o = \frac{i_L (Z_L + R_2)}{R_2}$$

So, $V_L = V_o - I_o R_3$

$$= V_o - i_L R_3 \left(\frac{Z_L + R_2}{R_2}\right)$$

7

Q.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]

Characteristic equation of the system,

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

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

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

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

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

By Routh Hurwitz Criteria

s^4	1	4	K
s^3	4	3	
s^2	$13/4$	K	
s^1	$\frac{39/4 - K}{13/4}$	0	
s^0	K		

$\Rightarrow \cancel{13}\ 39/4 - K = 0$

for sustained oscillation

So, $\boxed{K = 9.75}$

at, then auxillary equation

$$13/4\, s^2 + K = 0$$

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$\frac{13}{4}(-\omega^2) + 9.75 = 0$

$$\boxed{\omega = \sqrt{3} = 1.732 \text{ rad/s}}$$

→ oscillation frequency

5

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Q.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) $E = 190V$, $R_a = 0.6\Omega$, $I_o = 22A$

So, $V_o = E + I_o R_a$ (since current is constant)

$V_o = 190 + 22 \times 0.6$

$V_o = 203.2 \text{ V}$

For 3phase full converter,

$V_o = \frac{3V_{mL}}{\pi} \cos\alpha$ (For continuous current operation)

$203.2 = \frac{3 \times 240\sqrt{2}}{\pi} \cdot \cos\alpha$

$\boxed{\alpha = 51.17^\circ}$ → firing angle.

$P_o = V_o I_o = 203.2 \times 22 = 4470.4 \text{ W}$

~~P.F = $\frac{P_o}{\sqrt{3} \times V_{rms} \times I_{rms}} = \frac{4470.4}{\sqrt{3} \times 240 \times 22}$~~

~~P.F = 0.4888 lag~~

~~$(I_{s1})_{rms} = \frac{4 I_o}{\pi\sqrt{2}} = \frac{4 \times 22}{\sqrt{2}\pi} = 19.807$ A~~

$$P.F = \frac{P}{S} = \frac{4470.4}{\sqrt{3} \times 240 \times 22}$$

$$\boxed{P.f = 0.4888 \text{ lag}}$$

(ii) for same value of current, $I_0 = 22A$

for, Power flow from DC to AC side,

$\alpha > 90°$ (for inversion mode)

So, $V_o = -E + I_o R_a$

$= -190 + 22 \times 0.6$

$= -176.8$

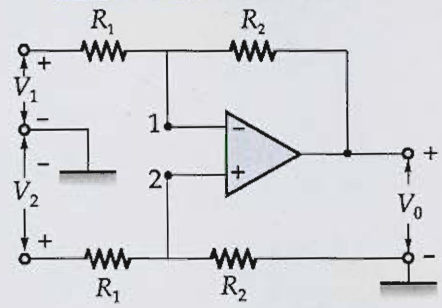
$$V_o = \frac{3V_{mL}}{\pi} \cos\alpha = -176.8$$

$$\Rightarrow \frac{3 \times 240\sqrt{2}}{\pi} \cdot \cos\alpha = -176.8$$

$$\boxed{\alpha = 123.05°}$$

14

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.

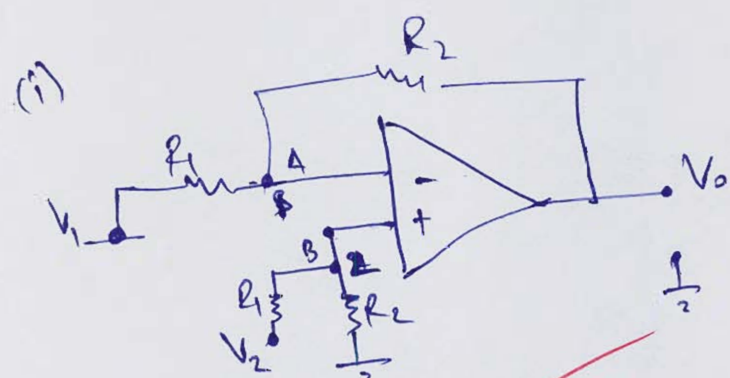
A 555 timer is connected for Astable operation with V_{CC} = 12 V. The component values are selected as $R_A = 10\ k\Omega$, $R_B = 2.3\ k\Omega$ and $C = 0.1\ \mu F$.

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]

(i)



At node 2

$$V_B = V_2 \times \frac{R_2}{R_1+R_2}$$ (using voltage division)

using virtual short

$$V_A = V_B = V_2 \frac{R_2}{R_1+R_2} \quad \text{—(1)}$$

KCL at No 1

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

$$V_A\left(\frac{1}{R_1}+\frac{1}{R_2}\right) = \frac{V_1}{R_1} = \frac{V_0}{R_2}$$

$$V_0 = V_A\left(1+\frac{R_2}{R_1}\right) - \frac{R_2}{R_1}\cdot V_1$$

using (1)

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

$$V_0 = V_2 \times \frac{R_2}{R_1} - \frac{R_2}{R_1}\cdot V_1$$

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

7

(ii)

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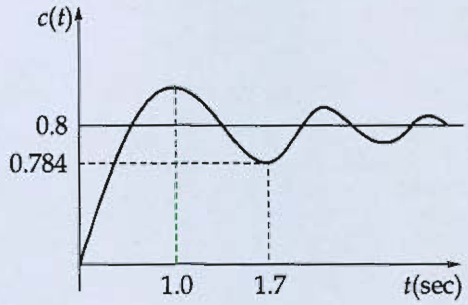
Q.6 (c) (i) The unit step response of a second order underdamped system is shown in the figure below. Determine the transfer function of the system.



[8 marks]

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

$\omega_d = \omega_n \sqrt{1-\xi^2} = \pi$ rad/s

and ~~$t_{p_2} = \frac{2\pi}{\omega_d} = 1.7$~~

$\Rightarrow$ ~~$1.7\,\omega_d = 2\pi$~~

$M_p = A \times e^{-\xi\pi/\sqrt{1-\xi^2}}$

$0.784 = 0.8 \times e^{-\xi \times 2\pi/\sqrt{1-\xi^2}}$

$\xi = 3.21 \times 10^{-3}$

Now using this

$\pi = \omega_n \sqrt{1-(3.21\times10^{-3})^2}$

$\omega_n \simeq \pi$ rad/s.

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

Final value of the output is $c(t)\big|_{t\to\infty} = 0.8$

Hence, $A = 0.8$

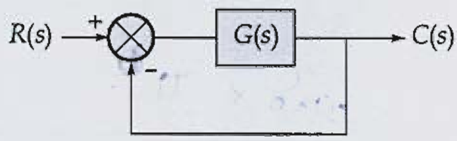
So,

$$\frac{C(s)}{R(s)} = \frac{0.8 \times \pi^2}{s^2 + 2\times 3.21\times 10^{-3}\times \pi s + \pi^2}$$

$$\boxed{\frac{C(s)}{R(s)} = \frac{2.513}{s^2 + 0.02017 s + 9.87}}$$

5

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]

Replacing → $S \to S-1$

So, $G(s) = \dfrac{60(S-1) + K}{(S-1)^2\left[(S-1)^2 + 6(S-1) + 30\right]}$

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

$$= \frac{60s + K - 60}{(s^2-2s+1)(s^2+4s+25)}$$

Characteristic Equation

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

$$1 + \frac{60s + K - 60}{(s^2-2s+1)(s^2+4s+25)} = 0$$

$$\Rightarrow (s^2-2s+1)(s^2+4s+25) + 60s + K - 60 = 0$$

$$\Rightarrow s^4 + 4s^3 + 25s^2 - 2s^3 - 8s^2 - 50s + s^2 + 4s + 25 + 60s + K - 60 = 0$$

$$\Rightarrow s^4 + 2s^3 + 18s^2 + 14s + K - 35 = 0$$

Using Routh Hurwitz Criteria

s^4	1	18	K-35
s^3	2	4	
s^2	16	K-35	
s^1	$\frac{134-2K}{16}$	0	
s^0	K-35		

for poles ~~to~~ lies to left of $s=-1$

Sign of ~~Cot~~ 1st column should be same, Hence Positive,

So, $K-35 > 0$

$K > 35$ — ①

and $134-2K < 0$

$\Rightarrow K < 67$

Range of K

$\boxed{35 < K < 67}$

5

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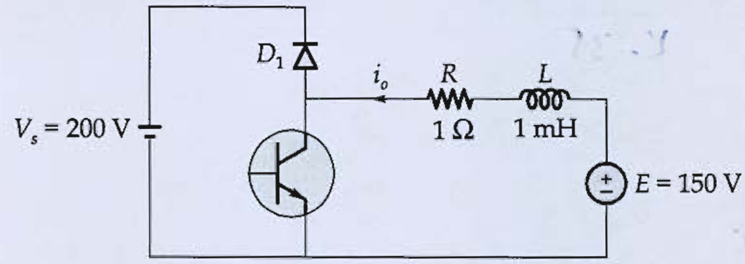
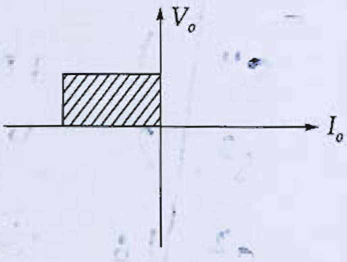
Q.7 (a) A dc-to-dc chopper capable of second-quadrant is used in 200 V dc battery electric vehicle. The machine armature has 1 Ω in series with 1 mH inductance.





(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]

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Q.7 (b) A 50-Hz, 100 MVA, 4-pole, synchronous generator has inertia constant of 3.5 sec and supply 0.16 pu power on a system base of 500 MVA. The input to the generator is increased to 0.18 pu.

Determine:

(i) Kinetic energy stored in the rotor.

(ii) Acceleration of the generator.

(iii) If acceleration continues for 7.5 cycles, calculate the change in rotor angle.

(iv) Speed in rpm at the end of the acceleration.

[20 marks]

(c) The fuel-cost function in Rs/hr of two thermal power plants are :

$$C_1 = 320 + 6.2P_1 + 0.004P_1^2$$
$$C_2 = 320 + 6P_2 + 0.003P_2^2$$

where P_1 and P_2 are in MW. The plant outputs are subjected to following limits (in MW):

$$50 \leq P_1 \leq 250$$
$$50 \leq P_2 \leq 350$$

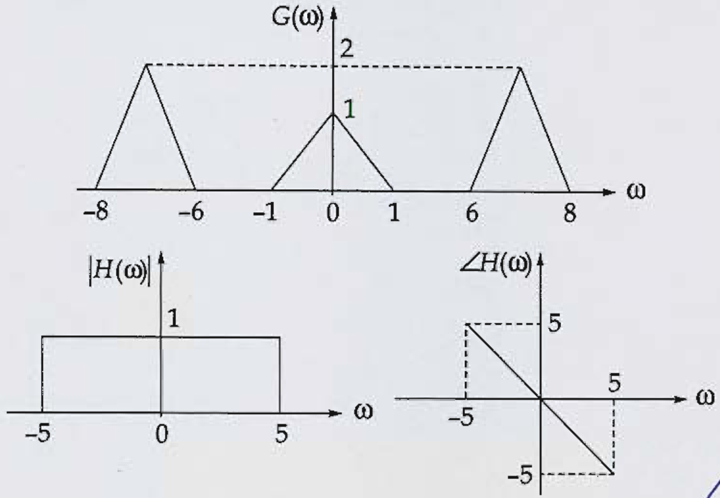
The per unit system real power loss with generation expressed in pu on a 100 MVA base are given by

$$P_L = 0.0125P_1^2 + 0.00625P_2^2$$

The total load is 412.35 MW. Determine the optimal load dispatch of generation. Start with an initial estimate of $\lambda = 7$ Rs/MWh. Use the gradient method of optimization for 3-iterations.

[20 marks]

Q.8 (a) (i) Suppose $g(t)$ is the input to an LTI system with transfer function $H(\omega)$ and $G(\omega)$ is the Fourier transformer of $g(t)$ as shown below:



Find the output of the LTI system, $y(t)$.

[10 marks]

~~$y(t) = g(t) * h(t)$~~

~~Applying Fourier transform~~

~~$Y(\omega) = G(\omega) \cdot H(\omega)$~~

~~So $Y(\omega) =$~~

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Q.8 (a) **(ii)** Find the inverse Laplace transform for $F(s) = \dfrac{1}{s^2(s+1)^2}$ using continuous convolution method.

[10 marks]

Q.8 (b) The open-loop transfer function of a feedback control system is

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

Find the restriction on K for stability. Find the value of K for the system to have a gain margin of 3 dB. With this value of K, find the phase cross over frequency and phase margin.

[20 marks]

(c) A single phase full bridge controlled rectifier is supplied from a single phase ac source of 230 V, 50 Hz. The converter is delivering power to an R-L load where $R = 20\ \Omega$ and $L = 0.2$ H. For the firing angle of 60°,

(i) check whether the load current is continuous or not.

(ii) determine the dc component of the load current.

(iii) determine the power absorbed by the load considering only first dominant harmonic.

[20 marks]

OOOO

Space for Rough Work

$X(K) = DFT[\_\_\_]$

$IDF\ X^{*}\ 12$

$X^{*}(k) = X(N-K)$

Space for Rough Work