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UPSC ENGINEERING SERVICES EXAMINATION

Electrical Engineering

Test-3 : Power Systems

Electrical Circuits-1 + Microprocessors-1

Digital Electronics-2 + Control Systems-2

Name : ....

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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	50
Q.2	40
Q.3	
Q.4	32
Section-B	
Q.5	44
Q.6	44
Q.7	
Q.8	
Total Marks Obtained	210

Signature of Evaluator

Cross Checked by Sourabh kumar

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Section A : Power Systems

1 (a) Estimate the corona loss for a three-phase, 110 kV, 50 Hz, 150 km long transmission line consisting of three conductors each of 10 mm diameter and spaced 2.5 m apart in an equilateral triangle formation. The temperature of air is 30° C and the atmospheric pressure is 750 mm of mercury. Take the irregularity factor as 0.85. Ionization of air may be assumed to take place at a maximum voltage gradient of 30 kV/cm.

[12 marks]

Given: 3 phase system, $V_L = 110\,kV$; $r = 5\,mm$

$f = 50\,Hz$; $D_{eq} = \sqrt[3]{(2.5)^3}$ (as equilateral triangle form)

$T = 30^\circ C$ $\quad\quad = 2.5\,m$

$h = 750\,mm = 75\,cm$

$\therefore \delta = \dfrac{3.92h}{273+T} = \dfrac{3.92 \times 75}{273+30} = 0.97029$.

$\therefore$ distruptive critical voltage, $V_d = g\, m\, \delta\, r \ln \dfrac{D}{r}$

$g = 30\,kV/cm$ (peak) $\Rightarrow g = 21.21\,kV/cm$ (rms).

$\therefore V_d = 21.21 \times 0.85 \times 0.97029 \times 0.5 \ln\left[\dfrac{2.5 \times 10^2}{0.5}\right]$

$V_d = 54.35567\,kV$ (L-N)

$V_d = 94.14679\,kV$ (L-L)

$\therefore$ Corona loss $\Rightarrow P_c = 244 \times 10^{-5} \dfrac{(f+25)}{\delta} \sqrt{\dfrac{r}{d}}\,(V_{ph} - V_{d0})^2$

$P_c = 244 \times 10^{-5} \left(\dfrac{75}{\delta}\right) \sqrt{\dfrac{0.5}{250}} \left(\dfrac{110}{\sqrt{3}} - 54.35567\right)^2 \times 10^6$

$P_c = 706.607\,kW$

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Q.1 (b) A power plant has three generators feeding a common bus:

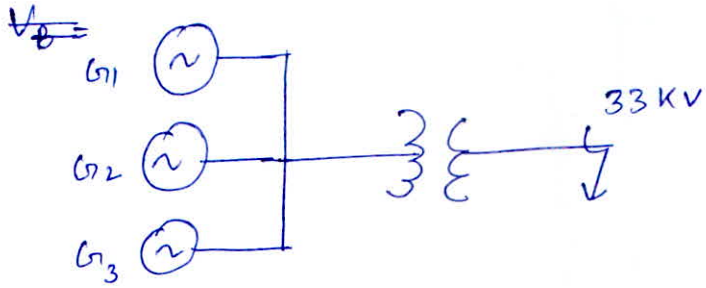
2 generators, 30 MVA, 15% reactance each

1 generator, 10 MVA, 12.5% reactance

A 10 MVA transformer steps up the voltage and feeds a 33 kV circuit. Find the safe minimum reactance of transformer so that fault level on the secondary bus of the transformer may not exceed 100 MVA.

[12 marks]

~~$V_B =$~~



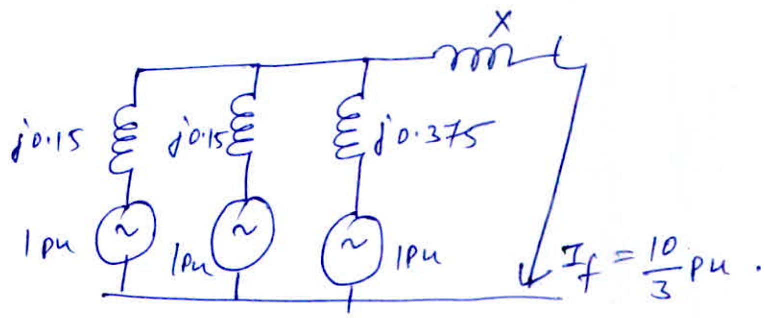
$G_1 : X = 0.15$

$G_2 : X = 0.15$

$G_3 : X = 0.375$

let $S_B = 30\,MVA$

Fault level $= 100\,MVA = \frac{10}{3}\,pu$



$Z_{th} = (0.15 \,||\, 0.15 \,||\, 0.375) + X$

$= j(0.0625 + X)$.

$V_{th} = 1\,pu$.

$\therefore \quad I_f = \frac{V_{th}}{Z_{th}} \Rightarrow \frac{1}{j(0.0625+X)} = \frac{10}{3}$

$\Rightarrow X = j0.2375\,pu$.

$\therefore$ Minimum Reactance $= j0.2375\,pu$

$\therefore$ On transformer base (~~10 MVA~~, 33 kV, 30 MVA) $V_B = 33\,kV$, $S_B = 30\,MVA$

$X = j0.2375 \times \frac{(33)^2}{300}$ ~~$= j2.5863752$~~

$= j8.62125\,\Omega$

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1 (c) A power plant has 3 units with the input output curves.

$Q_1 = 0.002\ P_1^2 + 0.86\ P_1 + 20$ tons/hour

$Q_2 = 0.004\ P_2^2 + 1.08\ P_2 + 20$ tons/hour

$Q_3 = 0.0028\ P_3^2 + 0.64\ P_3 + 36$ tons/hour

Fuel cost is Rs 500 per ton. Maximum and minimum generation level for each unit is 120 MW and 36 MW. Find optimum scheduling for a total load of 200 MW.

[12 marks]

$$\frac{dQ_1}{dt} = 0.004P_1 + 0.86$$

$$\frac{dQ_2}{dt} = 0.008\,P_2 + 1.08$$

$$\frac{dQ_3}{dt} = 0.0056\,P_3 + 0.64$$

For optimum scheduling, $\frac{dQ_1}{dt} = \frac{dQ_2}{dt} \pm \frac{dQ_3}{dt}$

$\therefore\ 0.004P_1 + 0.86 = 0.008P_2 + 1.08$

$\Rightarrow\ 0.004P_1 - 0.008P_2 = 0.22$ — (1)

$0.008P_2 + 1.08 = 0.0056P_3 + 0.64$

$\Rightarrow\ 0.008\,P_2 - 0.0056\,P_3 = -0.44$ — (2)

$P_1 + P_2 + P_3 = 200$ — (3)

Solving equations (1), (2), (3)

$P_1 = 85 \text{ MW}$

$\boxed{P_2 = 15 \text{ MW}}$ Min generation limit $= 36 \text{ MW}$

$\therefore$ P_2 is violating the limit.

$P_3 = 100 \text{ MW}$

$\therefore \boxed{P_2 = 36 \text{ MW}}$.

$P_1 + P_3 = 200 - 36 = 164 \text{ MW}$ — (4)

$0.004 P_1 + 0.86 = 0.0056 P_3 + 0.64$

$\Rightarrow 0.004 P_1 - 0.0056 P_3 = -0.22$ — (5)

Solving (4) and (5)

$P_1 = 72.75 \text{ MW}, \quad P_3 = 91.25 \text{ MW}$

$\therefore$ Optimum scheduling:

$P_1 = 72.75 \text{ MW}, \; P_2 = 36 \text{ MW}, \; P_3 = 91.25 \text{ MW}$.

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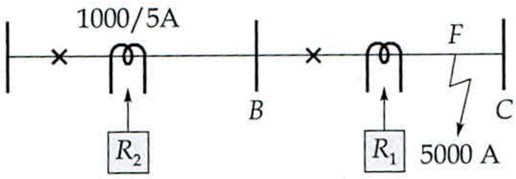
1 (d) Two relays R_1 and R_2 are connected in two sections of a feeder as shown in figure below. CT's are of ratio 1000/5 A. The plug setting of relay R_1 is 100% and R_2 is 125%. The operating time characteristic of the relays is given in table.
The TMS of relay R_1 is 0.3. The time grading scheme has a discriminative margin of 0.5 s between the relays. A three phase short circuit at F results in a fault current of 5000 A. Find the actual operating time instants of R_1 and R_2. What is the TMS of R_2?

PSM	2	4	5	8	12	20
Operating time	10	5	4	3	2.8	2.4



[12 marks]

Given:

$PS(R_1) = 100\%$ $\quad P_S(R_2) = 125\%$

$TMS(R_1) = 0.3$ $\quad$ CT Ratio $= 1000/5$

$I_F = 5000\,A$.

$\therefore PSM(R_1) = \dfrac{5000}{\frac{1000}{5} \times 1 \times 5} = 5 \Rightarrow$ for TSM = 1
Time = 4 sec.
(from table)

$\therefore$ Operating time of $R_1 = 0.3 \times 4$
$= \boxed{1.2\,sec}$

Discriminative margin $= 0.5\,sec$.

$\therefore$ Operating time of $R_2 = \boxed{1.7\,sec}$.

Also, for R_2, $\quad PSM = \dfrac{5000}{\frac{1000}{5} \times 1.25 \times 5} = 4$

$\therefore$ from table, time $= 5\,sec$.

$\therefore TMS \times 5 = 1.7 \Rightarrow \boxed{TMS(R_2) = 0.34}$

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Q.1 (e) What is the percentage copper saving in feeder if the line voltage in a two-wire dc system be raised from 220 V to 500 V for the same power transmitted? State any assumption made.

[12 marks]

Power, P in dc two wire system $\Rightarrow P = VI$

$$P = VI = \frac{V^2}{R}.$$

$\therefore$ For same power, $\frac{V^2}{R}$ = constant.

$$\therefore \frac{(220)^2}{R_1} = \frac{(500)^2}{R_2}$$

$R = \frac{\rho l}{A}$ [where, ρ = resistivity
l = length of line
A = Area of the conductor]

Assuming, ρ and l to be constant,

$$(220)^2 A_1 = (500)^2 A_2 \Rightarrow \frac{A_2}{A_1} = 0.1936$$

$$\therefore \frac{A_1 - A_2}{A_1} = 0.8064$$

$\therefore$ % copper saving = 80.64 %.

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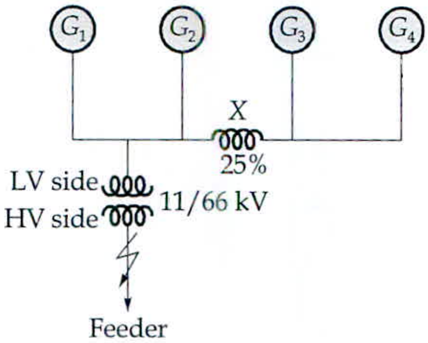
Q.2 (a) A generating station has four identical generators, G_1, G_2, G_3 and G_4 each of 20 MVA, 11 kV having 20% reactance. They are connected to a bus bar which has a busbar reactor of 25% reactance on 20 MVA base, inserted between G_2 and G_3 as shown below. A 66 kV feeder is taken off from the bus bars through a 15 MVA, 11/66 kV transformer having 7.5% reactance. A symmetrical 3-phase fault occurs at the high voltage terminals of the transformers. Calculate the current feed into the fault.



[20 marks]

Given

Generators : 20 MVA, 11 kV, $X = 0.2$

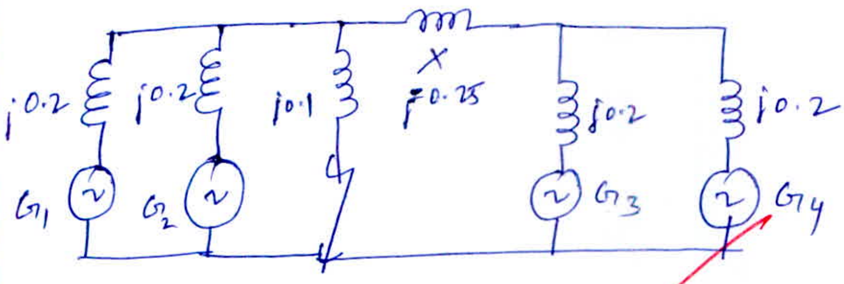
X Bus bar $= 0.25$ (20 MVA base)

Transformer : 15 MVA, 11/66 kV, $X = 0.075$

$= 0.1$ pu (20 MVA Base)

let $S_B = 20$ MVA.

$V_B = 11$ kV (LV), 66 kV (HV)



$$Z_{th} = (0.2 \parallel 0.2) \parallel [0.25 + (0.2 \parallel 0.2)] + 0.1$$

$$= j(0.1 \parallel 0.35 + 0.1)$$

$$= j\,0.1777 \text{ pu.}$$

$$V_{th} = 1 \text{ pu.}$$

$$\therefore I_f = \frac{V_{th}}{Z_{th}} = 5.625 \text{ pu.}$$

$$\therefore I_f = 5.625 \times \frac{20}{\sqrt{3} \times 66} \text{ kA}$$

$$I_f = 984.11977 \text{ A}$$

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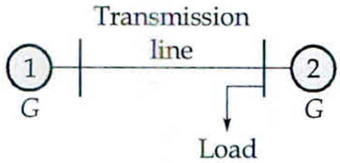
Q.2 (b) **(i)** A system consists of two plants connected by a transmission line as shown in figure below. The load is at plant-2. The transmission line loss calculations reveals that a transfer of 100 MW from plant-1 to plant-2 incurs a loss of 15 MW. Find the required generation at each plant for $\lambda = 60$. Assume that the incremental costs of the two plants are given by:

$$\frac{dC_1}{dP_1} = 0.2P_1 + 22 \text{ Rs/MWh}$$

$$\frac{dC_2}{dP_2} = 0.15P_2 + 30 \text{ Rs/MWh}$$



(ii) Find the savings in Rs per hour by scheduling the generation by considering the transmission loss rather than neglecting the transmission loss in determining the outputs of the two generators. Assume a load of 285 MW connected at bus of plant-2.

[20 marks]

for $P_1 = 100$ MW, $P_L = 15$ MW.

$\therefore \; 15 = (100)^2 B_{11} \Rightarrow B_{11} = 15 \times 10^{-4}$ MW^{-1}

$B_{22} = B_{12} = 0.$ $\quad \therefore \boxed{P_L = B_{11} P_1^2}$

(i) $\therefore$

$$\frac{\frac{dC_1}{dP_1}}{1 - \frac{\partial P_L}{\partial P_1}} = \lambda \Rightarrow \frac{0.2P_1 + 22}{1 - 30\times10^{-4} P_1} = 60$$

$$\Rightarrow 0.38P_1 = 38$$

$$\Rightarrow \boxed{P_1 = 100 \text{ MW}}$$

$$\frac{\frac{dC_2}{dP_2}}{1 - \frac{\partial P_L}{\partial P_2}} = \lambda \Rightarrow \frac{0.15P_2 + 30}{1} = 60$$

$$\Rightarrow \boxed{P_2 = 200 \text{ MW}}$$

$\therefore \; P_D = P_1 + P_2 - P_L$

$= 100 + 200 - 15$

$P_D = 285$ MW

(ii) Neglecting transmission loss,

$0.2P_1 + 22 = 0.15P_2 + 30 \Rightarrow 0.2P_1 - 0.15P_2 = 8$ — (1)

$P_1 + P_2 = 285\ MW$ — (2)

$P_1 = 145 MW,\ P_2 = 140 MW.$

$$\left.\begin{aligned} C_1 &= 0.2P_1^2 + 22P_1 + K_1 \\ C_2 &= 0.15P_2 + 30P_2 + K_2 \end{aligned}\right\} — (3)$$

from (i), when losses considered, $P_1 = 100 MW$, $P_2 = 200 MW$

$\therefore C_1 = 4200 + K_1$ Rs/hr

$C_2 = 12\,000 + K_2$ Rs/hr

from (3) when losses neglected,

$C_1' = 7395 + K_1$ Rs/hr

$C_2' = 7140 + K_2$ Rs/hr

$\therefore$ Saving $= C_1 + C_2 - (C_1' + C_2')$

$= ₹\ 1665$ /hr.

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Q.2 (c) A 50 Hz, 3 phase transmission line 300 km long has total series impedance of (40 + j125) ohm and a total shunt admittance of 10^{-3} mho. The receiving end load is 50 MW at 220 kV with 0.8 lagging power factor. Calculate the sending end voltage, current, power and power factor using:

(i) Short line approximation.

(ii) Nominal π method.

(iii) Exact transmission line equation of long line.

(iv) Approximation of long line.

[20 marks]

$Z = 40 + j125\ \Omega$ $\qquad V_R = 220\text{kV}$

$Y = j10^{-3}\ \mho$ $\qquad I_R = 164.01996 \angle -36.869$.

(i) $V_s = V_R + Z I_R$; $I_s = I_R = 164.0199 \angle -36.869$

$= \frac{220000}{\sqrt{3}} + (40 + j125)(164.01996 \angle -36.869)$

$V_s = 145.10345 \angle 4.928^\circ$ kV (L-N)

$= 251.3265 \angle 4.928^\circ$ kV (L-L) ; pf = 0.7455

Power = 53.229 MW

(ii) $A = 1 + \frac{YZ}{2} = 0.937713 \angle 1.222$

$B = 40 + j125$

$C = 9.843 \times 10^{-4} \angle 90.291^\circ$; $D = A$

$V_s = AV_r + BI_r = 137.4499\text{kV} \angle 6.2676^\circ$ (L-N)

$= 238.07 \angle 6.2676^\circ$ kV

$I_s = CV_r + DI_r = 129.2863 \angle 15.8847^\circ$ A

∴ Sending end pf = 0.9859

$P_s = \sqrt{3} V_s I_s \cos\phi = 52.5618$ MW.

(iii) $A = \cosh \gamma l =$

$$Z_c = \sqrt{\frac{Z}{Y}} = \sqrt{\frac{131.244\angle 72.255}{10^{-3}\angle 90^\circ}} = 362.276\angle 8.8725^\circ$$

$$\gamma l = \sqrt{ZY} = \sqrt{\ }$$

$$= 0.36227\angle 81.1275$$

$$= 0.055875 + j0.3579$$

$$\therefore \cosh \gamma l = \frac{e^{\alpha l}\angle \beta l + e^{-\alpha l}\angle -\beta l}{2.}$$

$$= 0.9383\angle 1.1959^\circ$$

$$\sinh \gamma l = \frac{e^{\alpha l}\angle \beta l - e^{-\alpha l}\angle -\beta l}{2}$$

$$= 0.35474\angle 81.51178^\circ$$

$$\therefore V_s = \cosh \gamma l \, V_R + \sinh \gamma l \, Z_c I_R$$

$$I_s = \frac{\sinh \gamma l}{Z_c} V_R + \frac{\cancel{\sinh \gamma l}}{\cosh \gamma l} I_R$$

$$V_s = 133.114\angle 8.395^\circ \text{ kV}$$

$$= 230.56\angle 8.395 \text{ kV (L-L)}$$

$$I_s = 164.699\angle 10.1275^\circ \text{ A}.$$

$$\cos\phi_s = 0.949$$

$$P_s = 65.7053 \text{ MW}.$$

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3 (a) A 275 kV transmission line has following line constants :

$$A = 0.85\angle 5°;\ B = 200\angle 75°$$

(i) Determine the power at unity power factor that can be received if the voltage profile at each end is to be maintained at 275 kV.

(ii) Calculate the value of compensation required for a load of 150 MW at unity power factor with the same voltage profile as in part (i).

(iii) With the load as in part (ii), what would be the receiving end voltage if the compensation equipment is not installed?

[20 marks]

(i) $P = \frac{\cancel{E}V}{B}\cos(\beta-\delta) - \frac{AV^2}{B}\cos(\beta-\alpha)$

upf $\therefore Q = 0$

$\therefore 0 = \frac{(275)^2}{200}\sin(75-\delta) - 0.85\frac{275^2}{200}\sin(75-\cancel{0.85}\,5)$

$\Rightarrow \delta = \cancel{20.1464}° \ 21.99$

$\therefore P = 129.8923 \text{ MW}$

(ii) $150 = \frac{(275)^2}{200}\cos(75-\delta) - 0.85\frac{(275)^2}{200}\cos(75-5)$

.3 (b) A 100-MVA, 13.2 kV generator is connected to a 100 MVA, 13.2/132 kV transformer. The generator's reactances are $X_d'' = 0.15$ p.u., $X_d' = 0.25$ p.u., $X_d = 1.25$ p.u. on a 100 MVA base, while the transformer reactance is 0.1 p.u. on the same base. The system is operating on no load, at rated voltage when a three phase symmetrical fault occurs at the HT terminals of the transformer. Determine:

(i) The subtransient, transient and steady state symmetrical fault currents in p.u. and in amperes.

(ii) The maximum possible dc component.

(iii) Maximum value of instantaneous current.

(iv) Maximum rms value of the asymmetrical fault current.

[20 marks]

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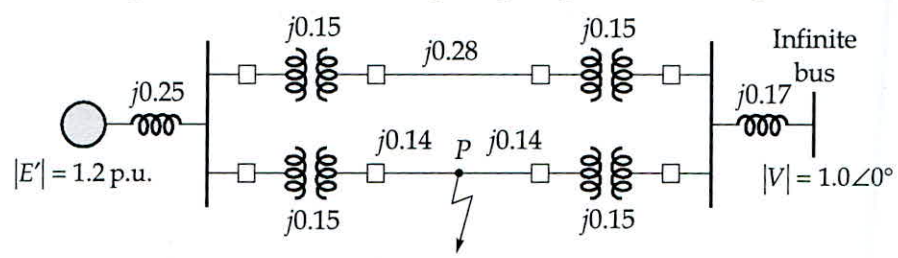
.3 (c) Find the critical clearing angle for the system in figure for a three phase fault at the point P. The generator is delivering 1.0 p.u. power under pre-fault conditions.



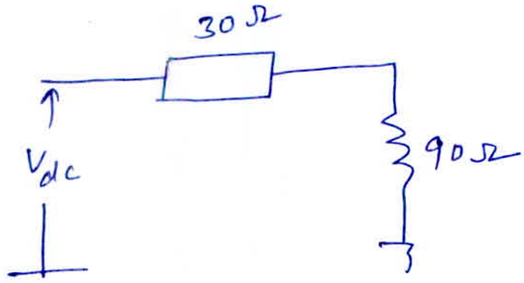
[20 marks]

Q.4 (a) A dc source of 100 V with negligible resistance is connected to a lossless line ($Z_C = 30\ \Omega$), through a switch S. If the line is terminated in a resistance of 90 Ω, on closing the switch at $t = 0$, plot the receiving end voltage (V_R) w.r.t. time until 5T. Where, T is the time for voltage wave to travel the length of the line. What will be the steady state voltage at receiving end? Also find the voltage at $t = 3.25$T on the mid length of the line.

[20 marks]

$V_{DC} = 100\ V$

$Z_c = 30\Omega$

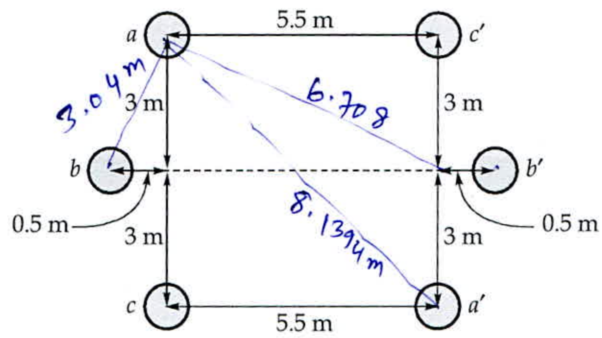


$\cancel{V_R = \frac{R}{R+Z}}$

$$V_R = \left(\frac{e^{\gamma x} + e^{-\gamma x}}{2}\right)V + \left(\frac{e^{\gamma x} - e^{-\gamma x}}{2}\right)V$$

$$V_R = V_\gamma + V_T$$

Q.4 (b) Determine the inductance of the double circuit fully transposed line shown in figure, if the self GMD of each conductor is 0.0069 m.



A B

[20 marks]

$$D_m = \left[8.1394 \times 6.708 \times 5.5 \times 6.5 \times (6.708)^2 \times 8.1394 \times 6.708 \times 5.5\right]^{1/9}$$

$$= 6.677 \text{ m}$$

$$D_{sA} = \left[(0.0069 \times 6 \times 3.04138)^2 \times 0.0069 \times (3.04)^2\right]^{1/9}$$

$$= 0.46476 \text{ m}.$$

$$D_{ab} = \sqrt[4]{[(3.04) \times 6.708]^2} = 4.5157 \text{ m}$$

$$D_{bc} = \sqrt{3.04 \times 6.708} = 4.5157 \text{ m}$$

$$D_{ca} = \sqrt{6 \times 5.5} = 5.744 \text{ m}$$

Conventionally

$$D_{sa} = \sqrt{0.0069 \times 8.1394} = 0.2369$$

$$D_{sc} = 0.2369$$

$$D_{sb} = 0.2034$$

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Find seprately each value

$$\therefore L = 2 \times 10^{-7} \ln\left[\frac{\sqrt[3]{D_{ab} D_{bc} D_{ca}}}{\sqrt[3]{D_{sa} D_{sb} D_{sc}}}\right] =$$

$$= 6.15716 \times 10^{-7} \text{ H}$$

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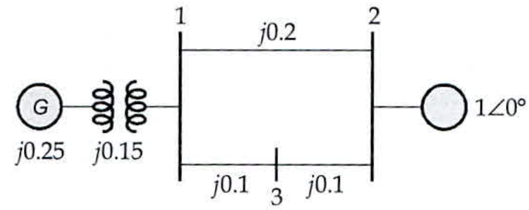
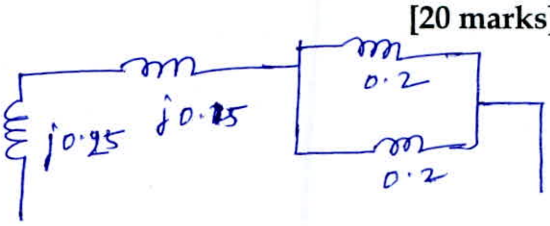
Q.4 (c) A single line diagram of a system is shown below:



All the values are in per unit on a common base. The power delivered into bus-2 is 1.0 p.u. at 0.8 p.f. lagging. Obtain the power angle equation and swing equation of the system. Neglect all losses.

[20 marks]

$$P = \frac{EV}{X} \sin\delta .$$



$$\therefore \quad 1 = \frac{E \times 1}{0.5} \sin\delta \qquad X = 0.1 + 0.15 + 0.25 = j0.5$$

$$\cancel{\Rightarrow 1 = 2\sin\delta}$$

$$\cancel{\Rightarrow \delta = 30^\circ} \qquad 1 = 2E\sin\delta$$

$P = 1\,pu$

$Q = 0.75\,pu$

as 0.8 pf lag

$$0.75 = \frac{EV}{X}\cos\delta - \frac{V^2}{X}$$

$$0.75 = 2E\cos\delta - 2$$

Squaring and adding,

$$\Rightarrow 1 + 2.75^2 = 4E^2 \Rightarrow E = 1.463\,pu .$$

$\therefore$ power angle equation :

$$P = \frac{1.463 \times 1}{0.5} \sin\delta \Rightarrow P = 2.926 \sin\delta .$$

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Swing equation :

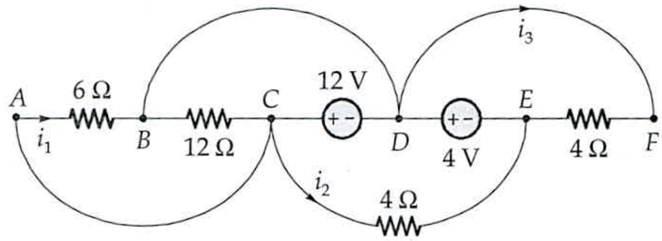
$$\frac{H}{\pi f} \frac{d^2\delta}{dt^2} = P_m - P_e$$

$$\Rightarrow \frac{H}{\pi \times 50} \frac{d^2\delta}{dt^2} = P_m - 2.926\sin\delta .$$

$$H = \frac{\cancel{K.E}\ \text{Kinetic Energy of the system}}{\text{MVA Rating}} .$$

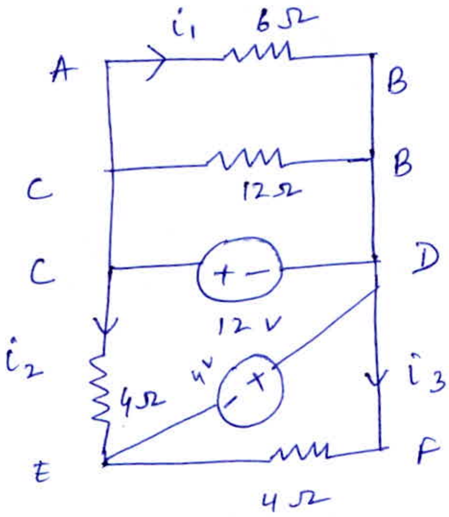
Section B : Electrical Circuits-1 + Microprocessors-1 + Digital Electronics-2 + Control Systems-2

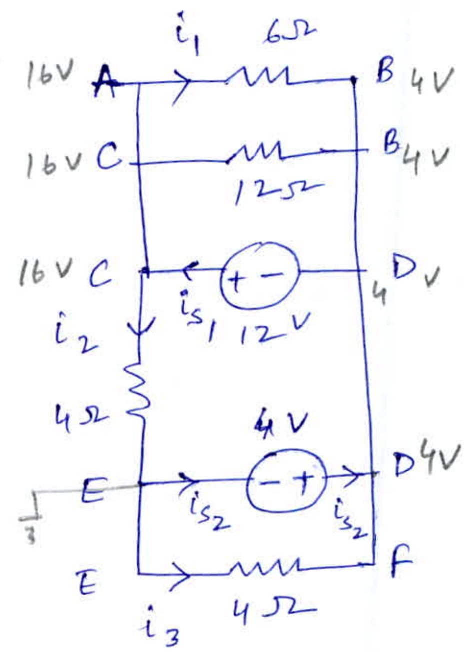
Q.5 (a) Find the current i_1, i_2, i_3 and power delivered by the sources of the network shown in figure.



[12 marks]

Redrawing the circuit,





$i_1 = \frac{12}{6} = 2\,A$

$i_3 = -\frac{4}{4} = -1\,A$ 1A

$i_2 = \frac{16-0}{4} = 4\,A$ (using nodal eq^n)

$\therefore i_{s_1} = 2 + \frac{12}{12} + 4$ (using KCL at C)

$= 7\,A$

$\therefore$ Power delivered $= 7 \times 12 = \underline{84\,W}$.

11

$i_{s_2} = i_2 - i_3 = 4 + 1 = 5\,A$

$\therefore$ Power delivered $= 5 \times 4 = \underline{20\,W}$

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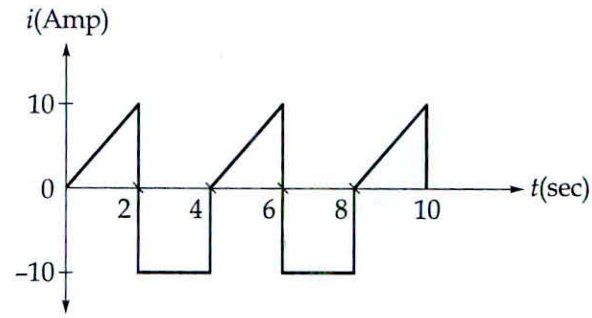
Q.5 (b) Determine the rms value of the waveform. If the current is passed through a 9 Ω resistor. Find the average power absorbed by the resistor.



[12 marks]

$I_{rms} = \sqrt{\frac{1}{T}\int_0^T i^2 dt}$ where T = time period

Here $T = 4$

$\therefore I_{rms} = \left[\frac{1}{4}\left\{\int_0^2 (5t)^2 dt + \int_2^4 (-10)^2 dt\right\}\right]^{1/2}$

$= \frac{1}{2}\left[\frac{25\times 8}{3} + 100\times 2\right]^{1/2} \Rightarrow I_{rms} = 8.1649\ A.$

Average power absorbed by 9Ω resistor :

$(I_{rms})^2 R = 599.99\ W.$

Equation of current, $i = \begin{cases} 5t & 0 \le t \le 2 \\ -10 & 2 < t \le 4 \\ \text{repeat for } t \pm T \end{cases}$

Here, time period, $T = 4$ sec.

11

Q.5 (c) A third order system has state space model matrices as follows:

$$A = \begin{bmatrix} 1 & 3 & 1 \\ 0 & 1 & 0 \\ 2 & -4 & 6 \end{bmatrix}; \quad B = \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix}; \quad C = \begin{bmatrix} 1 & 1 & 0 \end{bmatrix}$$

Determine whether the system is state controllable or not. What will be the output controllability of the system?

[12 marks]

Controllability Matrix : $[B \quad AB \quad A^2B \ldots A^{n-1}B]$

$$A = \begin{bmatrix} 1 & 3 & 1 \\ 0 & 1 & 0 \\ 2 & -4 & 6 \end{bmatrix} \qquad A^2 = \begin{bmatrix} 8 & 2 & 7 \\ 0 & 1 & 0 \\ 14 & -22 & 38 \end{bmatrix}$$

Here $n = 3$.

$$\therefore AB = \begin{bmatrix} 1 \\ 0 \\ 6 \end{bmatrix} \qquad A^2B = \begin{bmatrix} 7 \\ 0 \\ 38 \end{bmatrix}$$

$\therefore$ Controllability Matrix :

$$Q_c = \begin{bmatrix} 0 & 1 & 7 \\ 0 & 0 & 0 \\ 1 & 6 & 38 \end{bmatrix}$$

Rank of $Q_c = 2 \; (\neq 3)$

$\therefore$ The system is not state controllable.

6

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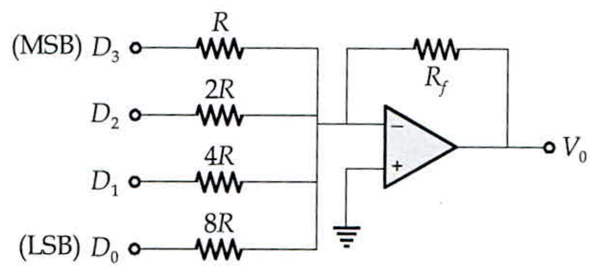
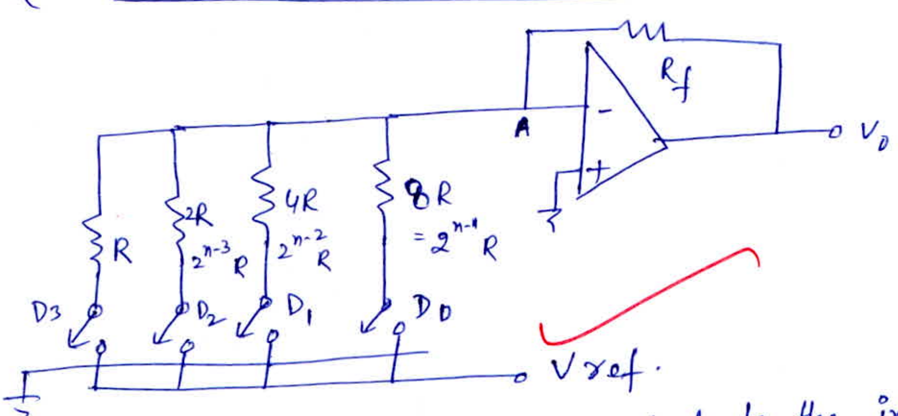
Q.5 (d) **(i)** With a neat block diagram, explain the operation of 4-bit weighted-resistor type DAC.

(ii) For the 4-bit weighted-resistor DAC shown in below figure. Determine the weight of each input bit if the inputs are 0 V and 5 V and also determine the full-scale output, if $R_f = R = 1\ k\Omega$. Also, find the full scale output if R_f is changed to 500 Ω.



[12 marks]

(i) 4-bit Weighted-resistor type DAC :



Here, the digital input is applied to the inverting terminal of the Op-Amp. If the corresponding bit is zero then the switch is connected to ground. If the input bit is 1, then the switch is connected to reference voltage. The current through MSB resistor should be 2^{n-1} times that of through LSB resistor. ∴ If the MSB resistor is R, the LSB resistor should be $2^{n-1}R$, where n is the number of bits in input.

On writing KVL at node A, $V_0 = \dfrac{V_{ref}}{2^{n-1}} \cdot \dfrac{R_f}{R} \underbrace{\sum_{i=0}^{n-1}(2^i D_i)}_{\text{Decimal equivalent of input}}$

(ii) $V_{ref} = 5$

$\therefore V_0 = \dfrac{5}{2^3} \cdot \dfrac{1}{1}(1)$ for i/p = 0001

$\Rightarrow V_0 = 0.625\,V$ (weight of each input bit)

for full scale output, i/p $= (1111)_2 = (15)_{10}$

$$\therefore V_0 = \frac{5}{2^3} \times \frac{1}{1} \times 15 = 9.375 \text{ volts}.$$

if $R_f = 500\Omega$, $R = 1000\Omega$,

full scale output =

$$V_0 = \frac{5}{2^3} \times \frac{500}{1000} \times 15 = 4.6875 \text{ volts}.$$

8

Q.5 (e) Explain the generation of control signals for memory and I/O devices of 8085 microprocessors?

[12 marks]

The various control signals of 8085 microprocessor are :

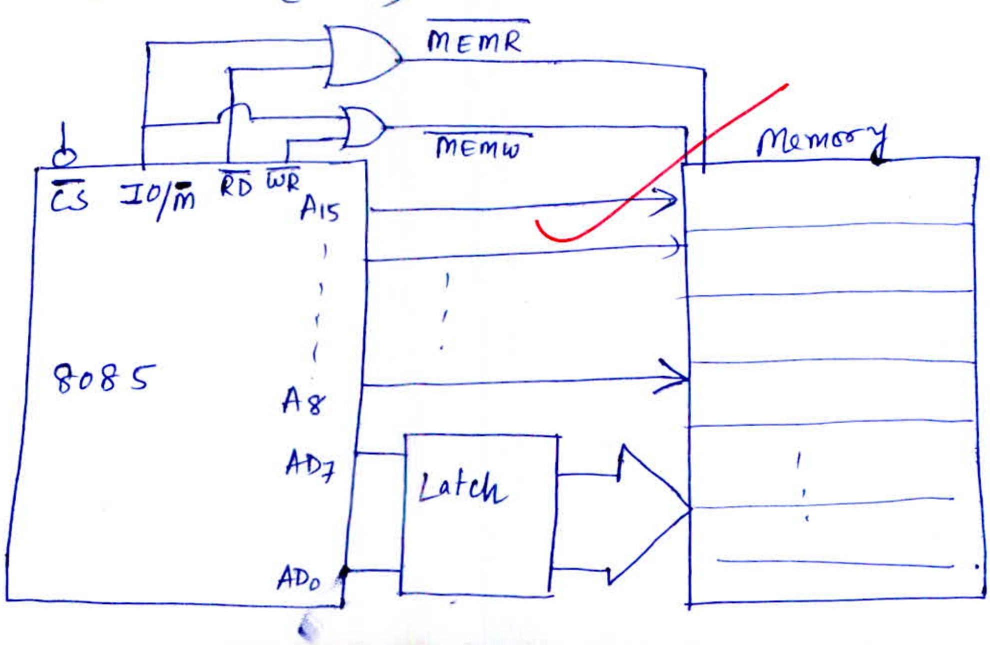
(i) Opcode fetch

(ii) Memory Read ($\overline{MEMR}$) $S_1 S_0 = 10$

(iii) Memory write ($\overline{MEMW}$) $S_1 S_0 = 01$

(iv) Input-Output Read ($\overline{IOR}$) $S_1 S_0 = 10$

(v) Input-output write ($\overline{IOW}$) $S_1 S_0 = 01$



For Memory,

$I0/\bar{M} = 0$ (Low)

→ when $\overline{RD}$ goes low, memory read signal is generated.

→ when $\overline{WR}$ goes low, memory write signal is generated.

For IO

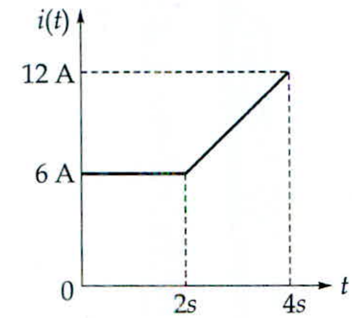
$I0/\bar{M} = 1$

→ when $\overline{RD}$ goes low, input-output read signal is generated

→ when $\overline{WR}$ goes low, input-output write signal is generated

8

Q.6 (a) **(i)** Figure below shows the waveform of the current passing through an inductor of resistance 2 Ω and inductance 2 H. Find the energy absorbed by the inductor in the first four seconds.



$E = \frac{1}{2} L i^2$

[12 marks]

Energy absorbed by inductor $= \int L \frac{di}{dt} \cdot i \, dt$

$i = 6A \quad 0 \leq t \leq 2$ ~~for constant current~~

$i = 3t A \quad 2 \leq t \leq 4$ $= \frac{1}{2} L i^2$

$\therefore$ Energy absorbed

$= 2 \int_2^4 3 \cdot 3t \, dt + \frac{1}{2} \times 2 \times 6^2$

$= 18 \int_2^4 t \, dt + 36 = \frac{18}{2} [16-4] + 36$

$= 144 \text{ J}$

$$i(t) = \begin{cases} 6 & 0 \leq t < 2 \text{ sec} \\ 3t & 2 \leq t \leq 4 \text{ sec.} \end{cases}$$

for $0 \leq t \leq 2$ sec

$E_1 = i^2 R t$

$= 36 \times 2 \times 2 = 144 \text{ J.}$

for $2 < t \leq 4$

$$v_L = L\frac{di}{dt}$$

$$= 2 \times 3 = 6\ V$$

$$\therefore\ E_2 = \int_2^4 6 \times 3t\, dt + \int_2^4 (3t)^2 R\, dt$$

$$= \frac{18}{2}[16-4] + \frac{9\times 2}{3}[64-8]$$

$$= 444\ J$$

$$\therefore\ E = 588\ J.$$

12

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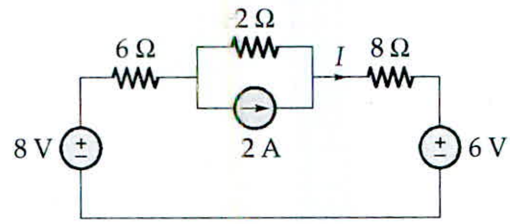
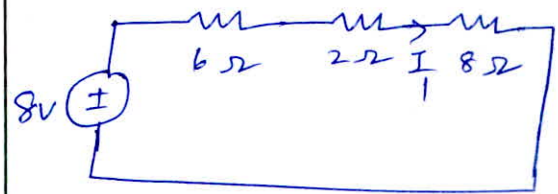
Q.6 (a) **(ii)** Find the current I in the circuit shown below using the superposition theorem.



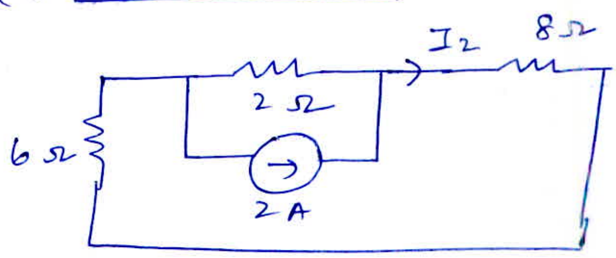
[8 marks]

(i) with 8 V source



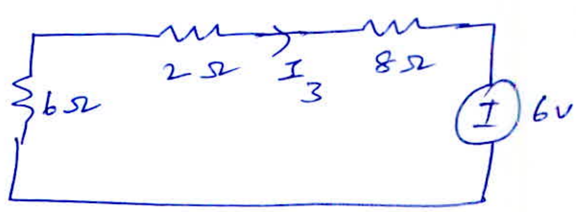
$$I_1 = \frac{8}{16} = 0.5\,A$$

(ii) with 2A source



$$I_2 = 2 \times \frac{2}{8+6+2}$$
$$= 0.25\,A.$$

(iii) with 6V source

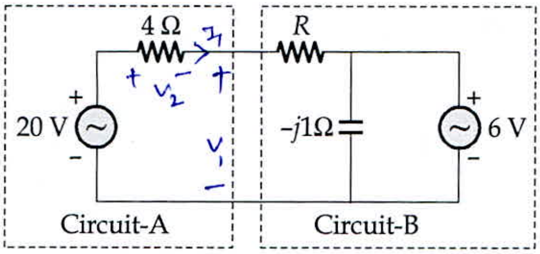


$$I_3 = -\frac{6}{16}$$
$$= -0.375\,A$$

$$\therefore I = I_1 + I_2 + I_3 = 0.375\,A$$

7

.6 (b) **(i)** Assuming both the voltage sources are in phase, find the value of R for which maximum power is transferred from circuit A to circuit B.



[12 marks]

for maximum power transfer, $V_1 = V_2$ (using Max. power transfer theorem)

$\therefore \; V_1 = V_2 = \frac{20}{2} = 10\,V.$

$\therefore \; I_1 = \frac{10}{4} = 2.5\,A$, I_1 also flows through R.

$\therefore \; V_1 = I_1 R + 6$ (using KVL)

$\Rightarrow 10 = 2.5R + 6 \Rightarrow \underline{R = 1.6\,\Omega.}$

8

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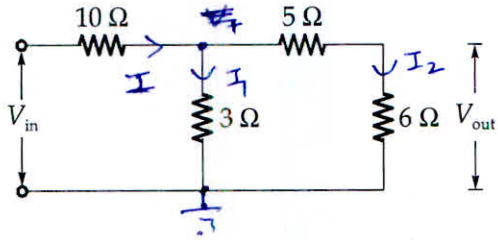
Q.6 (b) **(ii)** Determine the voltage ratio V_{out}/V_{in} for the circuit shown below:



[8 marks]

~~using Nodal equation,~~ $\cancel{\frac{V_{in} - V_1}{10} = \frac{V_1}{3} + \frac{V_1}{11}}$

$\Rightarrow$

$V_{in} = 10I + 3I_1$ — (1)

$V_{out} = 6I_2$ — (2)

using current division, $I_1 = \frac{11}{14} I$ — (3)

$I_2 = \frac{3}{14} I$ — (4)

from (1), (2), (3), (4),

$$\frac{V_{out}}{V_{in}} = \frac{\frac{6 \times 3}{14}}{\left(10 + \frac{3 \times 11}{14}\right)} = \frac{18}{140 + 33} = 0.1040$$

7

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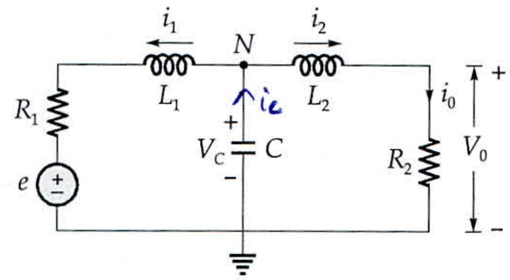
.6 (c) Obtain the state space model considering current through the two inductors and voltage across the capacitor as state variables. Consider the output variables as current through R_2 and voltage across R_2 and input variable as 'e' as shown in figure. (Consider initial conditions to be zero)



[10 marks]

$$e + R_1 i_1 + L_1 \frac{di_1}{dt} - V_c = 0 \quad - (1)$$

$$V_c - L_2 \frac{di_2}{dt} - i_2 R_2 = 0 \quad - (2)$$

$i_1 = x_1$ $\quad \therefore \quad \dot{x}_1 = -\frac{x_1 R_1}{L_1} + \frac{x_3}{L_1} - \frac{u}{L_1} \quad - (3)$

$i_2 = x_2$

$V_c = x_3$ $\quad \dot{x}_2 = -x_2 \frac{R_2}{L_2} + \frac{x_3}{L_2} \quad - (4)$

$e = u$

$y_1 = i_0 ; \quad y_2 = R_2 i_0$

Also, $\quad i_c = i_1 + i_2$

$$-C \frac{dV_c}{dt} = i_1 + i_2 \Rightarrow \dot{x}_3 = \frac{i_1}{c} + \frac{i_2}{c} \quad - (5)$$

$$\begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} = \begin{bmatrix} -\frac{R_1}{L_1} & 0 & \frac{1}{L_1} \\ 0 & -\frac{R_2}{L_2} & \frac{1}{L_2} \\ \frac{1}{c} & \frac{1}{c} & 0 \end{bmatrix} \begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \\ \dot{x}_3 \end{bmatrix} + \begin{bmatrix} -\frac{1}{L_1} \\ 0 \\ 0 \end{bmatrix} u$$

$$y = \begin{bmatrix} 0 & 1 & 0 \\ 0 & R_2 & 0 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix}$$

$y_1 = i_0 = i_2 = x_2$

$y_2 = V_0 = i_0 R_2 = R_2 x_2$

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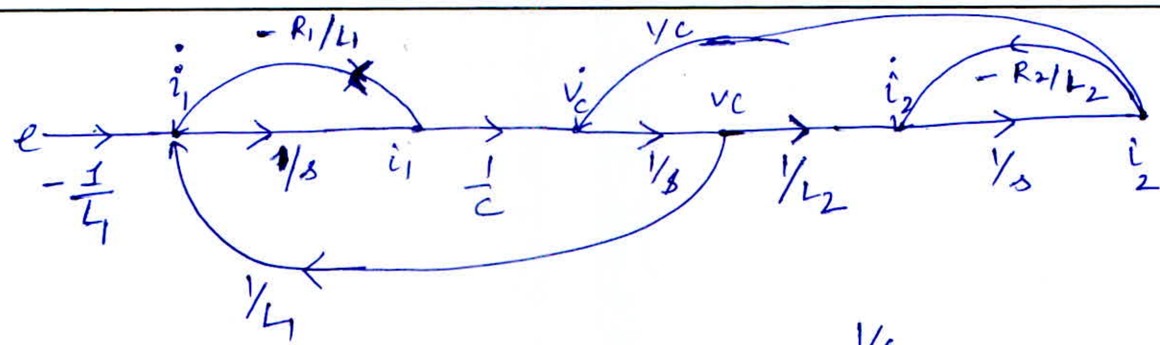
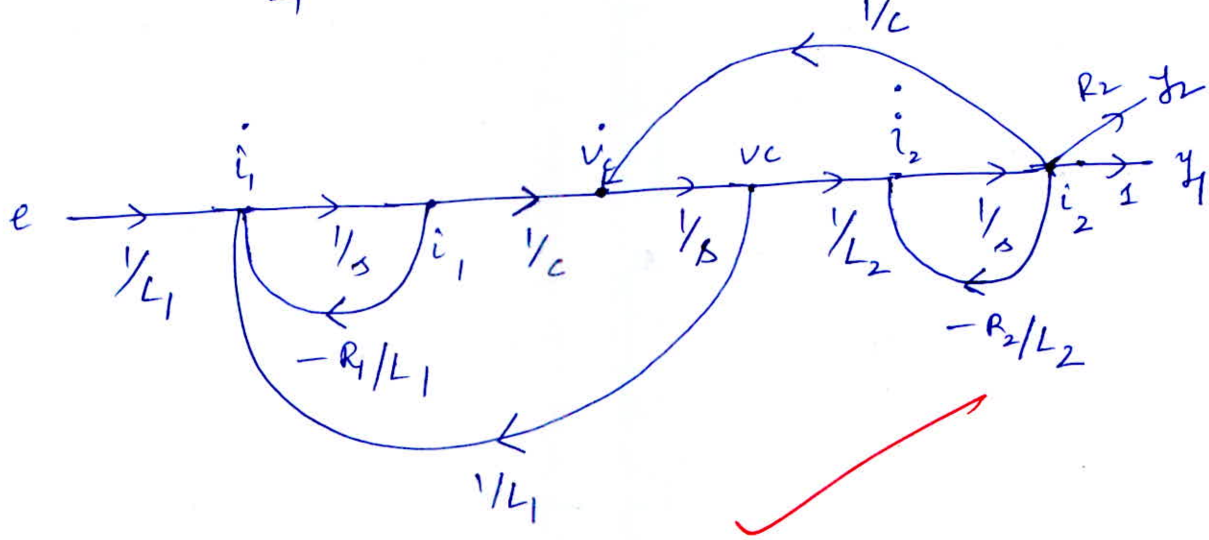
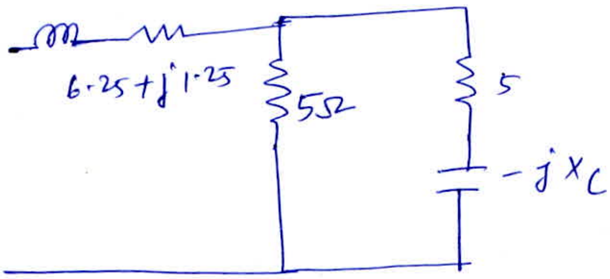




8

.6 (d) Two impedances $Z_1 = 5\ \Omega$ and $Z_2 = (5 - jX_C)\Omega$ are connected in parallel and this combination is connected in series with $Z_3 = (6.25 + j1.25)\Omega$. Determine the value of capacitance of X_C to achieve resonance if the supply is 100 V, 50 Hz.

[10 marks]



Supply = 100 V, 50 HZ

$X_L = 1.25$
$= \omega 3.9788$ mH

$\omega = 50 \times 2\pi$ rad/sec

$$Z_{eq} = \frac{5(5-jX_c)}{10-jX_c} + 6.25 + j1.25$$

$$= \frac{5(5-jX_c)}{10-jX_c} + 6.25 + j\omega L$$

$$= \frac{25 - 5jX_c}{10-jX_c} + 6.25 + j\omega L$$

$$= \frac{(25-5jX_c)(10+jX_c)}{100+X_c^2} + 6.25 + j\omega L$$

2

Equating imaginary part to zero, $25X_C - 50X_C + \omega L = 0$

$$\Rightarrow \omega L = \frac{25}{\omega C}$$

$$\left[X_c = \frac{1}{\omega C} \right]$$

$$\Rightarrow C = \frac{25}{\omega^2 L} = \frac{25}{\omega \times 1.25}$$

$$\Rightarrow \boxed{C = 63.66\text{ mF}}$$

To achieve resonance at 50Hz

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Q.7 (a) **(i)** Clearly differentiate between latches and flip-flops.

[8 marks]

.7 (a) **(ii)** Realize *T*-flip flop using *D*-flip flop.

[12 marks]

Q.7 (b) **(i)** For a control system, the input output transfer function is given below:

$$\frac{Y(s)}{U(s)} = \frac{b_0 s^n + b_1 s^{n-1} + \ldots + b_{n-1}s + b_n}{s^n + a_1 s^{n-1} + a_2 s^{n-2} \ldots a_{n-1}s + a_n}$$

Construct a state diagram by direct decomposition using the first companion form. Use state diagram to obtain dynamic equations and state space model.

(ii) Obtain the second companion form for the system whose input output transfer function is given by,

$$\frac{Y(s)}{U(s)} = \frac{s^2 + 4s + 1}{s^3 + 3s^2 + 4s + 8}$$

Draw corresponding state diagram for above form and derive state space model for above system.

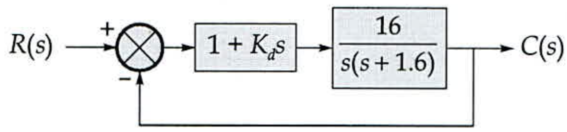
[20 marks]

.7 (c) **(i)** Write an assembly language program for an 8085 microprocessor, to find 2's complement of a 16-bit number. Write comments for selected instructions.

(ii) Enumerate all internal registers present in 8259 programmable interrupt controller? Write short notes on their individual functionality?

[12 + 8 marks]

.8 (a) A control system employing proportional and derivative control as shown below, has damping ratio equal to 0.8. Find the time instant at which the step response of system attains the peak value. Also find the percent maximum overshoot of system.



[20 marks]

Q.8 (b) Design a 3-bit gray UP/DOWN synchronous counter using T-flip flops with a control for UP/DOWN counting.

[20 marks]

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3 (c) A control system is represented by the state equation given below,

$$\dot{x}(t) = Ax(t)$$

If the response of the system is $x(t) = \begin{pmatrix} e^{-t} \\ -2e^{-t} \end{pmatrix}$ when $x(0) = \begin{pmatrix} 1 \\ -2 \end{pmatrix}$ and $x(t) = \begin{pmatrix} e^{-2t} \\ -e^{-2t} \end{pmatrix}$ when $x(0) = \begin{pmatrix} 1 \\ -1 \end{pmatrix}$.

Calculate the system matrix A and the state transition matrix for the system.

[20 marks]

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Space for Rough Work