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ESE 2019 : Mains Test Series

UPSC ENGINEERING SERVICES EXAMINATION

Electrical Engineering

Test-3 : Power Systems

Electrical Circuits-1 + Microprocessors-1

Digital Electronics-2 + Control Systems-2

Name : ......

Roll No : ~~E E M T H Y~~

EE 19 MTHYA 608

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Student's Signature

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	45
Q.2	
Q.3	50
Q.4	24
Section-B	
Q.5	39
Q.6	47
Q.7	
Q.8	
Total Marks Obtained	205

Signature of Evaluator: Saurabh kumar

Cross Checked by

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Section A : Power Systems

Q.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]

$g_0 = 30\,kV/cm$. $\delta = \frac{3.92b}{273+T} = \frac{3.92 \times 750 \times 10^{-1}}{273+30} = 0.97029$.

$V_c = m_0 g r \delta \ln\left(\frac{d}{r}\right)$ kV. $d = 2.5\,m$, $r = \frac{10 \times 10^{-1}}{2}$ cm

$V_v = m_v g r \delta \left(1 + \frac{0.3}{\sqrt{r d}}\right) \ln\left(\frac{d}{r}\right)$ kV $g = 30\,kV/cm$.

$P_{loss} = 242.2 \times 10^{-10} \times \left(\frac{f+25}{\delta}\right)(V_{ph} - V_c)^2 \sqrt{\frac{r}{d}}$ Watts

2

$V_c = 0.85 \times 30 \times \frac{10 \times 10^{-1}}{2} \times 0.97029 \times \ln\left(\frac{2.5}{\frac{10 \times 10^{-3}}{2}}\right)$.

$V_c = 76.882$ KV.

and we have $V_{ph} = \frac{110}{\sqrt{3}}$ KV $= 63.50$ KV.

Since $V_c > V_{ph}$ thus there will be no corona loss.

Incomplete answer

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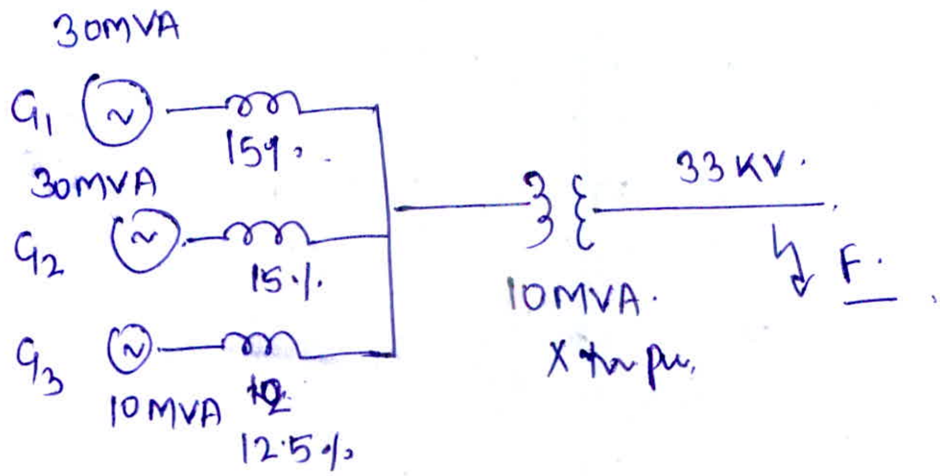
Q.1 (b) A power plant has three generators feeding a common bus:

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]



Fault MVA = 100 MVA

let the base MVA be 100 MVA

Thus, % reactance upto fault point = $\frac{\text{Fault MVA}}{\text{Base MVA}}$

$= 1\,pu$

Now, reactance $G_1 = G_2 = 0.15 \times \frac{100}{30} = 0.5\,pu$

$G_3 = 0.125 \times \frac{100}{10} = 1.25\,pu$

Thus Equivalent reactance upto fault point $= (0.5 \| 0.5 \| 1.25) + x$

$= 0.20833 + x$

which should be equal to 1 pu.

Thus $\boxed{x = 0.7916}$

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Percentance reactance of transformer = 79.16%

Also, $\left[\frac{0.7916 \times (33)^2}{100} = 8.62125\,\Omega\right]$ Ans

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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]

$P_1 + P_2 + P_3 = 200\text{MW}$ —(I), calculating incremental cost for each unit

$\frac{dQ_1}{dP_1} = (0.004P_1 + 0.86) \times 500$ Rs/MW $= (2P_1 + 430)$ Rs/MW —(II)

$\frac{dQ_2}{dP_2} = (0.008P_2 + 1.08) \times 500$ Rs/MW $= (4P_2 + 540)$ Rs/MW —(III)

$\frac{dQ_3}{dP_3} = (0.0056P_3 + 0.64) \times 500$ Rs/MW $= (2.8P_3 + 320)$ Rs/MW —(IV)

For optimum scheduling

$\boxed{IC_1 = IC_2 = IC_3}$

Thus, $2P_1 + 430 = 4P_2 + 540 = 2.8P_3 + 320$

$2P_1 + 430 = 4P_2 + 540 \rightarrow \boxed{2P_1 - 4P_2 = 110}$ —(V)

$$4P_2 + 540 = 2.8P_3 + 320 \quad -(VI).$$

$$\boxed{4P_2 - 2.8P_3 = -220}$$

From (I), (V), (VI).

$$P_1 + P_2 + P_3 = 200 \quad -(I)$$

$$2P_1 - 4P_2 = 110$$

$$4P_2 - 2.8P_3 = -220$$

solving above Equations,

$P_1 = 85$ MW, $P_2 = 15$ MW, $P_3 = 100$ MW

But $36 < P < 120$ MW

Thus, setting the value of $\boxed{P_2 = 36\text{ M}}$W

and solving for P_1 and P_3 we have.

~~$P_1 + P_3 = 164$~~ , $2P_1 + 430 = 2.8P_3 + 320$.

~~$2P_1 = 100 + 4\times36$~~ and $P_1 + P_3 = 164$ -(A)

$2P_1 - 2.8P_3 = -110$ -(B)

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By solving (A) and (B) Equations $\boxed{\begin{array}{l} P_1 = 72.75\text{ MW} \ \& \\ P_3 = 91.25\text{ MW} \end{array}}$

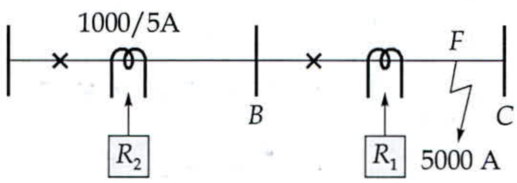
which are within limits

Thus, $P_1 = 72.75$ MW, $P_2 = 36$ MW, $P_3 = 91.25$ MW

.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]

$PSM = \dfrac{I_f}{I_{PK} \times CT\ ratio}$ $\quad I_f \rightarrow$ faultcurrent

where $I_{PK} =$ % PSB setting × CT secondary current.

we have for CT(1000/5) (Relay R_1). $\rightarrow I_{PK} = \dfrac{100}{100} \times 5 = 5$.

$PSM = \dfrac{\cancel{5000}}{\cancel{5 \times \frac{1000}{5}}} = 5$.

corresponding to PSM = 5 ~~TMS~~ operating time is 5 sec acco to giventable

Thus, $T_{O/P}$ of relay R_1 $= TMS \times \cancel{5} = TMS \times 4 = 1.2$ seconds.

For relay $R_2 \rightarrow$ there is discriminative margin of 0.5 sec

$\boxed{T_{O/P\,R_2} = 1.2 + 0.5 = 1.7 \text{ seconds}}$

(1) —— $T_{O/P\,R_2} = TMS \times$ (operating time calculated from table corresponding to PSM)

$$PSM(R_2) = \frac{5000}{\frac{125}{100} \times 5 \times \frac{1000}{5}} = 4$$

Corresponding to PSM = 4, → operating time = 5 seconds.

Thus from ~~Eq~~ Equation (1)

$$TOP_{R_2} = 1.7 = TMS \times 5$$

$$\boxed{TMS_{R_2} = 0.34} \text{ = Ans}$$

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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]

If the line voltage is raised from 220V to 500V.

$\{P = \text{constant} = 2V \cdot I.\}$

$$P \text{ and } I = \frac{V}{R} = \frac{V}{\frac{\rho l}{A}} = \left(\frac{VA}{\rho l}\right)$$

$$P = 2 \cdot \left(\frac{V \cdot A}{\rho l}\right) \cdot V$$

$$P = 2\left(V^2\right) \times \frac{A}{\rho l} \quad \{\text{since } P, \rho, l \text{ are constants}\}$$

$$\boxed{A \propto \frac{1}{V^2}}$$

Thus. where $A \Rightarrow$ area of cross section of wire

$\rho \to$ resistivity

$l \to$ length.

Assumptions:

Assuming resistivity and temperature to be constant

Thus % Copper saving = $\dfrac{\left(\frac{1}{220}\right)^2 - \left(\frac{1}{500}\right)^2}{\left(\frac{1}{220}\right)^2}$

$= \underline{0.8064}$

$\boxed{80.64\text{ \% of copper is saved.}}$

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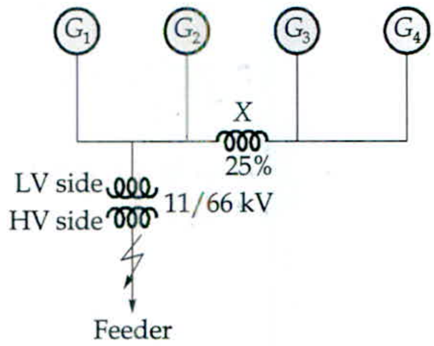
Q.2 (a) A generating station has four identical generators, G_1, G_2, G_3 and G_4 each of 20 MVA, 11 kV having 20% reactance. They are connected to a bus bar which has a busbar reactor of 25% reactance on 20 MVA base, inserted between G_2 and G_3 as shown below. A 66 kV feeder is taken off from the bus 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]

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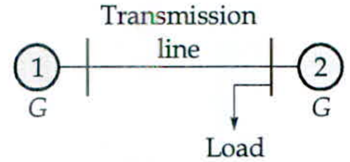
Q.2 (b) **(i)** A system consists of two plants connected by a transmission line as shown in figure below. The load is at plant-2. The transmission line loss calculations reveals that a transfer of 100 MW from plant-1 to plant-2 incurs a loss of 15 MW. Find the required generation at each plant for $\lambda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

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]

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Q.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)

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

$$P_R = \frac{275\times 275\times 10^6}{200}\cos(75-\delta) - \frac{0.85\times(275)^2\times 10^6 \times \cos 70°}{200} \quad -(1)$$

Since power is being recieved at unity power factor hence $Q_R = 0$

$$Q_R = \frac{V_S V_R}{B}\sin(\beta-\delta) - \frac{A V_R^2}{B}\sin(\beta-\alpha) = 0$$

and $V_S = V_R$.

Thus, $\sin(\beta-\delta) = A\sin(\beta-\alpha)$

$$\boxed{\delta = 21.99°}$$

Hence from (1) $P_R = \frac{(275\times 10^3)^2}{200}\left[\cos(53) - 0.85\cos(70°)\right]$

$$\boxed{P_R = 117.63\text{ MW}}$$

(ii) $Q_R = 0$ and $P_{load} = 150$ MW. From (1)

$$P_R = 150\times 10^6 = \left(\frac{275\times 10^3}{200}\right)^2\left(\cos(75-\delta) - 0.85\cos(70)\right)$$

$$\Rightarrow \boxed{\delta = 28.42°}$$

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

$$Q_R = \frac{(275\times10^3)^2}{200} \sin(75-28.42) - \frac{0.85\times(275\times10^3)^2}{200} \times \sin 70^\circ$$

$$Q_R = -27.3 \text{ MVAR}.$$

$$\boxed{Q_C = -Q_R + Q_L = 27.3 \text{ MVAR}}$$

since $Q_L = 0$.

Thus, compensation of 27.3 MVAR is required. (shunt capacitor)

(iii) If the compensation equipment is not installed then

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$Q_R = 27.3$ MVAR.

and

$$+27.3 = \frac{V_S V_R}{200} \sin(75-\delta) - \frac{0.85 (V_R)^2}{200} \sin 70^\circ$$

and

$$150 = \frac{V_S V_R}{200} \cos(75-\delta) - \frac{0.85 \times V_R^2}{200} \cos 70^\circ$$

$|V_R| = ?$

Do not write in this margin

Q.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:

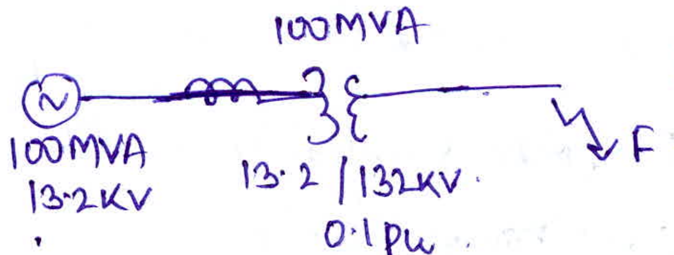
(i) The subtransient, transient and steady state symmetrical fault currents in p.u. and in amperes.

(ii) The maximum possible dc component.

(iii) Maximum value of instantaneous current.

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

[20 marks]



let baseMVA = 100MVA and.
base V = 13.2kV on LV side of T/F.

$I_B = \frac{100}{\sqrt{3} \times 13.2} \times 10^3 = 4.37KA$

(i). Subtransient current in pu =

$= \frac{V_{pu}}{X_d'' + X_T} = \frac{1}{0.15+0.1} = \cancel{0.25}\,4\ pu = \cancel{0.25}\,4 \times 4.37\ KA$

$= \cancel{1.0925}\ K\,Amp.$

$17.318\ K\,Amp.$

since the system is on no load prior to fault

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

Transient current $= \frac{V_{pu}}{X_d' + X_T} = \frac{1}{0.25+0.1} = 2.857\,pu$

Transient current in Amperes $= 2.857 \times 4.37\,KA$

$= 12.49$ K. Amperes.

Steady state current $= \frac{V_{pu}}{X_d + X_T} = \frac{1}{1.25+0.1} = 0.7407\,pu$

in amperes $= 0.7407 \times I_B = 0.7407 \times 4.37\,KA$

$= 3.23 \times 10^3$ Amp

(ii)

Max^m possible dc current

$= \sqrt{2} \times (I_f'') = \sqrt{2} \times$ (subtransient current)

$= \sqrt{2} \times 4$

$= 5.656\,pu$

$= 5.656 \times I_B$

$= 24.72 \times 10^3$ amperes.

(iii)

Maximum value of instantaneous current

$= \sqrt{2} \times$ (~~max possible~~ dc current)

$+ \sqrt{2} \times$ (~~Max possible~~ ac current)

$= 2\sqrt{2} \times$ (~~Max~~ subtransient current)

$= 2\sqrt{2} \times 4 = 11.31\,pu.$

$= 11.31 \times 4.37 \times 10^3$ amperes.

$=$ ~~34.96×10^3~~ amperes.

~~490~~ 49.42×10^3 amperes.

(iv). Maximum rms value of asymmetrical fault current $= \sqrt{(I_f'')^2 + (\text{Max possible dc current})^2}$

$= \sqrt{3} \times I_f''$

$= \sqrt{3} \times 4 = 6.928$ pu

$= 6.928 \times 4.37 \times 10^3$ amperes

$= \underline{30.276 \times 10^3 \text{ amperes}}$

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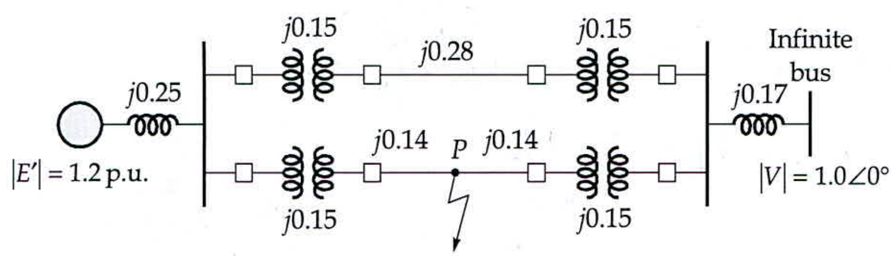
Q.3 (c) Find the critical clearing angle for the system in figure for a three phase fault at the point *P*. The generator is delivering 1.0 p.u. power under pre-fault conditions.



[20 marks]

For a 3 phase fault at P.

under prefault condition $P = \frac{E_f V_t}{X} \sin\delta$.

$P = \frac{1.2 \times 1}{X} \sin\delta$

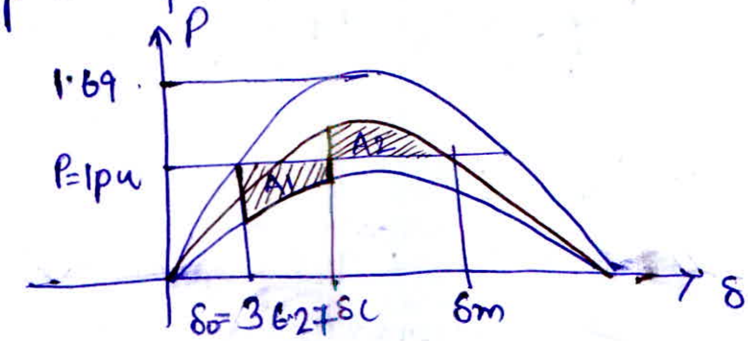
$X = 0.25 + (0.58 \parallel 0.58) + 0.17 = 0.71$.

Thus, $P = \frac{1.2 \times 1}{0.71} \sin\delta = 1$ pu.

$\boxed{\delta_0 = 36.27^\circ}$

For a 3 phase fault at P.

~~the~~ -



During fault the equivalent reactance

From Y/Δ ~~Δ/Y~~ conversion

$R_1 = R_a + R_b + \frac{R_a R_b}{R_c}$

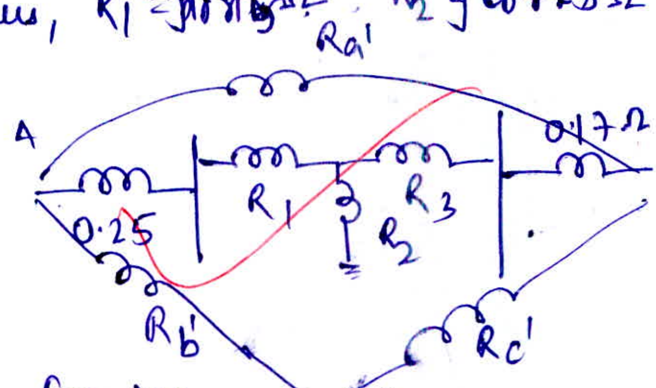
$R_2 = R_a + R_c + \frac{R_a R_c}{R_b}$

$R_3 = R_b + R_c + \frac{R_b R_c}{R_a}$

For Δ/Y conversion

$R_1 = \frac{R_c \times R_a}{R_c + R_a + R_b}$

Thus, $R_1 = j0.145\,\Omega$, $R_2 = j0.0725\,\Omega$, $R_3 = j0.145\,\Omega$



$Ra' = (R_1 + 0.25)^{0.395} + (R_3 + 0.17)^{0.315} + \frac{(R_1 + 0.25)(R_3 + 0.17)}{R_2}$

From Y/Δ conversion

$Ra' = \frac{\cancel{(R_1 + 0.25)(R_3 + 0.17)}}{\cancel{R_1 + R_2 + R_3 + 0.25 + 0.17}} = \cancel{0.6898}$ ~~$\frac{R_1 + R_2 + R_3}{+0.25 + 0.17}$~~

$= 0.8690$

Then. during fault $P_{max} = \frac{1.2 \times 1}{\cancel{0.6808}\ \cancel{0.8690}\ 2.426} = \cancel{1.380 pu}\ 0.4945 pu.$

After fault clearing $P_{max} = \frac{1.2 \times 1}{(0.25+0.15+0.28+0.15+0.17)} = 1.2 pu.$

Then, $\delta_m = 123.55^\circ$.

Now, acco to equal area ~~the~~ criterion

$A_1 = A_2$

$$\int_{\delta_0}^{\delta_c} (1 - 0.45 \sin\delta) = \int_{\delta_c}^{\delta_m\,123.55} (1.2\sin\delta - 1).$$

$$(\delta_c - \delta_0) + 0.45(\cos\delta_c - \cos\delta_0) = 1.2(\cos\delta_c - \cos\delta_m) - (\delta_m - \delta_c).$$

$\cancel{1-0.4}$

$$(\delta_m - \delta_0) - 0.45\cos\delta_0 + 1.2\cos\delta_m = (1.2 - 0.45)\cos\delta_c$$

$$\cos\delta_c = \frac{(\delta_m - \delta_0) - 0.45\cos\delta_0 + 1.2\cos\delta_m}{0.75}.$$

$\cancel{1.6233} = 0.6630$

$\boxed{\delta_c = 48.4639.}$ Ans

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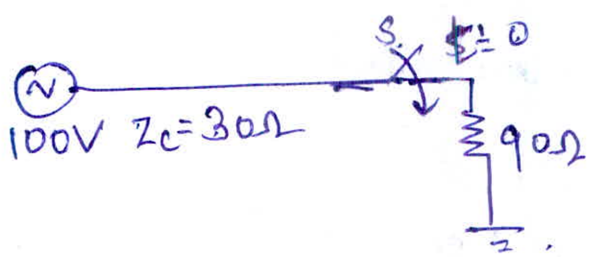
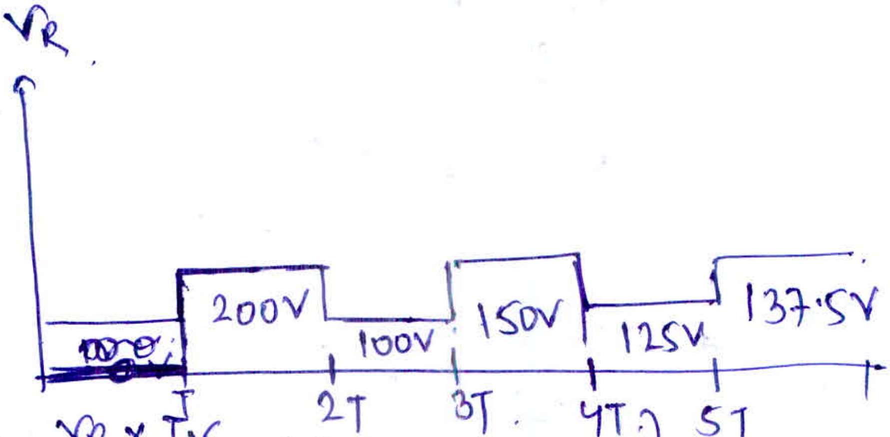
Q.4 (a) A dc source of 100 V with negligible resistance is connected to a lossless line ($Z_C = 30\ \Omega$), through a switch S. If the line is terminated in a resistance of 90 Ω, on closing the switch at $t = 0$, plot the receiving end voltage (V_R) w.r.t. time until 5T. Where, T is the time for voltage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

[20 marks]





$V_{R1} = V_R \times T_V \rightarrow 1.5$

$= 100 \times \dfrac{90 \times 2}{90+30} = 150V$

$0 < t < T$

$RV = \dfrac{90-30}{90+30} = 0.5 \Rightarrow B$

$V_{Reflected} = 50$ volts

For source $\rightarrow RV = -1$

Thus, $V_{2f} = -50 \times 1.5 = -75$ $\quad T < t < 2T$

$V_{2R} = -25$

2

$2T < t < 3T$. $V_{2f} = 25 \times 1.5 = 37.5$

$V_{2R} = 12.5$

$3T < t < 4T$. $V_{2f} = -18.75$

$V_{2R} = -12.5 \times 0.5 = -6.25$

$4T < t < 5T$ $V_{2f} = 9.375$

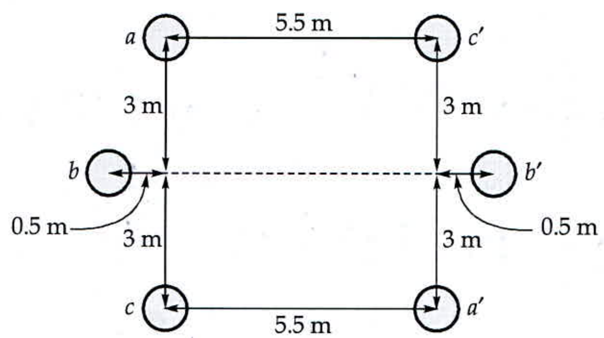
$V_{2R} = 3.125$

steady state voltage at recieving end = 150 volts

and voltage at $t = 3.25T$ at mid length

$\Rightarrow$ $\boxed{V = 150V}$

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.



[20 marks]

$D_{ab} = \sqrt{3^2+(0.5)^2} = 3.041\,m$. $D_{ab'} = \sqrt{3^2+6^2} = 6.708\,m$

~~Inductance of a double~~ circuit line.

$D_{aa'} = \sqrt{6^2+(5.5)^2} = 8.139\,m$

$$\text{Inductance} = 2\times10^{-7} \ln \frac{(D_{m1} D_{m2} D_{m3})^{1/3}}{(D_{S1} D_{S2} D_{S3})^{1/3}}$$

$D_{m1} = (D_{ab} D_{ab'} D_{ac} D_{ac'} D_{a'b} D_{a'b'} D_{a'c} D_{a'c'})^{1/8}$

$= (3.041 \times 6.708 \times 6 \times 5.5)^{1/4}$

$= 5.0936\,m$.

$D_{m2} = (D_{bc} \cdot D_{bc'} D_{ba} D_{ba'} D_{b'c'} D_{b'c} D_{b'a'} D_{b'a})^{1/8}$

$= (6.708 \times 3.041 \times 3.041 \times 6.708)^{1/4} = 4.5165\,m$.

$D_{m3} = (D_{ca} D_{ca'} D_{cb} D_{cb'} D_{c'a} D_{c'a'} D_{c'b} D_{c'b'})^{1/8}$

$= (3.041 \times 6.708 \times 6 \times 5.5)^{1/4} = 5.0936\,m$.

$D_{S1} = (D_{aa} D_{aa'} D_{a'a'} D_{a'a})^{1/4} = (0.0069^2 \times 8.139^2)^{1/4}$

$= 0.2369\,m$.

$$D_{S_2} = (D_{bb'} D_{b'b} D_{b'b'} D_{bb})^{\frac{1}{4}}$$

$$= (6.5 \times 0.0069)^{\frac{1}{2}} = 0.2117\,m.$$

$$D_{S_3} = (D_{c'c'} D_{cc} D_{c'c} D_{cc'})^{\frac{1}{4}}$$

$$= (8.139 \times 0.0069)^{\frac{1}{2}} = 0.2369\,m$$

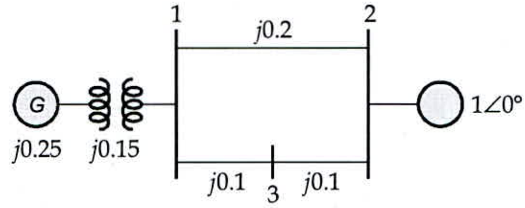
Then $L_{/ph} = 2 \times 10^{-7} \times \ln \left\{ \dfrac{(5.0936 \times 4.5165 \times 5.0936)^{1/3}}{(0.2369^2 \times 0.2117)^{1/3}} \right\}$

$$L_{/ph} = 2 \times 10^{-7} \ln \left(\frac{4.89347}{0.22823} \right)$$

$$\boxed{L_{ph} = 6.130 \times 10^{-7}\ H/m.}$$ Answer

18 +2

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]

$$P = \frac{V_1 V_2}{X} \sin\delta$$

$$V_1 = [j(0.25+0.15) + j(0.1)] \times I\angle\phi + 1.$$

$$I\angle\phi = \frac{1}{0.8 \times 1} = 1.25 \angle -36.86$$

$$= 2$$

$$V_1 = 2.305 \angle 32.83^\circ.$$

Thus $\left[P = \frac{2.305 \times 1}{0.5} \sin\delta = 4.61 \sin\delta \right]$

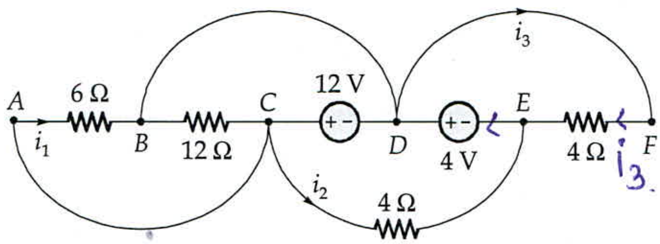
power angle equation.

Swing equation $M\frac{d^2\delta}{dt^2} = P_a$.

2

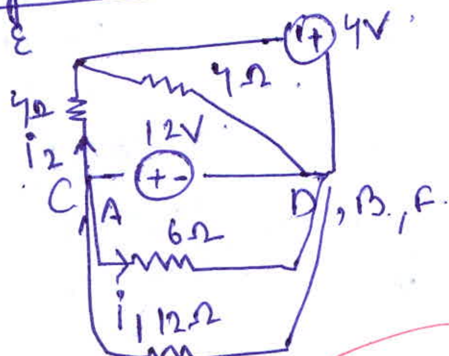
Section B : Electrical Circuits-1 + Microprocessors-1 + Digital Electronics-2 + Control Systems-2

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

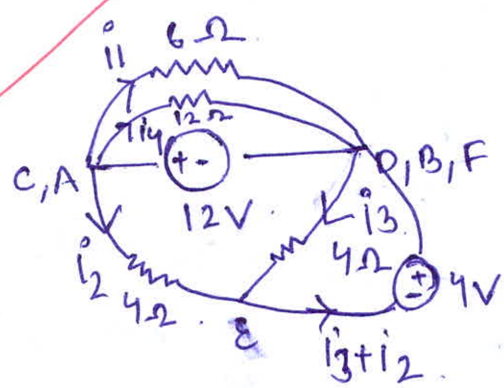


[12 marks]

Redrawing the network



11



let current in 12Ω branch be i_4

$i_4 = \frac{12}{12} = 1$ amp.

Thus, $\boxed{i_3 = \frac{4V}{4\Omega} = 1 \text{ amp}}$

and $\boxed{i_1 = \frac{12}{6} = 2 \text{ amp}}$

and applying KVL in AED ~~node~~ loop

$12 - 4i_2 + 4 = 0$

$\boxed{i_2 = \frac{16}{4} = 4 \text{ amp}}$

Power delivered by 4V source

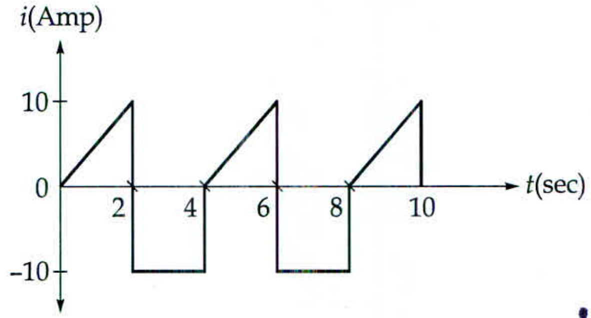
$= 4(i_3 + i_2) = 20$ Watts Ans

Power delivered by 12V source

$= 12(i_2 + i_1 + i_4) = 84$ Watts Ans

Do not write in this margin

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]

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

$$\boxed{T = 4\ sec}$$

$$= \left\{\frac{1}{T}\left[\left(\frac{25t^3}{3}\right)_0^2 + (100)(4-2)\right]\right\}^{1/2}$$

$$= \frac{1}{2}\left\{\frac{25}{3}(8-0) + 100 \times 2\right\}^{1/2}$$

$$\boxed{i_{rms} = \cancel{7.9056\ amperes}\ \ 8.1649\ amperes}$$

4

$$\left[P_{avg}\ \text{absorbed by resistor} = I_{rms}^2 \times R = 600\ \text{watts}\right]$$

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

$$= \frac{1}{4}\left[\frac{5 \times 4}{2} + 2 \times (-10)\right]$$

$$= \frac{-10}{4} = \frac{-5}{2}\ \text{amperes.}$$

~~$P_{avg} = V_{avg} I_{avg} = -5/2$~~

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]

For state controllable <u>Kalman's rule</u>.

$$[B \;\; AB \;\; A^2B].$$

$$AB = \underset{3\times 3}{\begin{bmatrix} 1 & 3 & 1 \\ 0 & 1 & 0 \\ 2 & -4 & 6 \end{bmatrix}} \underset{3\times 1}{\begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix}} = \underset{3\times 1}{\begin{bmatrix} 1 \\ 0 \\ 6 \end{bmatrix}}.$$

$$A^2B = \begin{pmatrix} 1 & 3 & 1 \\ 0 & 1 & 0 \\ 2 & -4 & 6 \end{pmatrix} \begin{pmatrix} 1 \\ 0 \\ 6 \end{pmatrix} = \underset{3\times 1}{\begin{pmatrix} 7 \\ 0 \\ 8 \end{pmatrix}}$$

For controllability

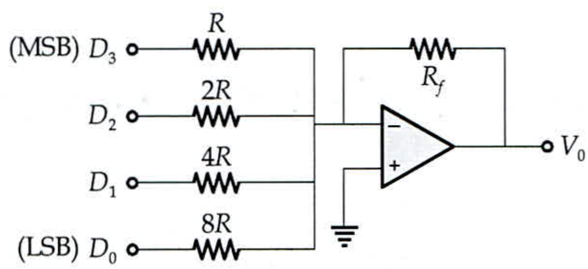
$$\begin{pmatrix} 0 & 1 & 7 \\ 0 & 0 & 0 \\ 1 & 6 & 8 \end{pmatrix}$$ whose determinant is zero.

Hence the matrix is not controlable.

6

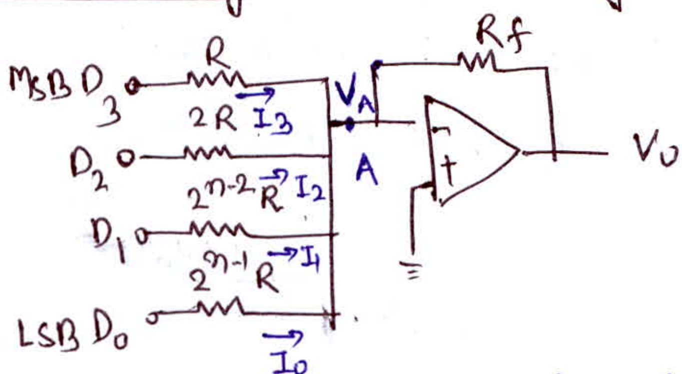
Q.5 (d) **(i)** With a neat block diagram, explain the operation of 4-bit weighted-resistor type DAC.

(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 $R_f = R = 1\text{ k}\Omega$. Also, find the full scale output if R_f is changed to 500 Ω.



[12 marks]

4 bit weighted resistor type DAC.



The D_3, D_2, D_1, D_0 bits are either connected to Vcc or to ground. Let the voltage at A be V_A.

Acco to virtual short concept the voltage at $V_A = 0$ since the positive terminal of opamp is grounded.

Hence $V_0 = -(I_0 + I_1 + I_2 + I_3) \times R_f + \cancel{V_A}^{\,0}$.

$n = 4$

$I_0 = \dfrac{V_{D0} - V_A}{2^{n-1}R} = \dfrac{D_0 V_R}{2^{n-1}R} = \dfrac{D_0 V_R}{8R}$.

$I_1 = \dfrac{D_1 V_R}{2^{n-2}R} = \dfrac{D_1 V_R}{4R}$ & $I_2 = \dfrac{D_2 V_R}{4R}$.

$I_3 = \dfrac{D_3 V_R}{R}$ Thus, $V_0 = -R_f V_R \left(\dfrac{D_0}{8R} + \dfrac{D_1}{4R} + \dfrac{D_2}{2R} + \dfrac{D_3}{R}\right)$

$\Rightarrow V_0 = -\dfrac{R_f V_R}{R}\left\{\dfrac{D_0}{8} + \dfrac{D_1}{4} + \dfrac{D_2}{2} + D_3\right\}$

$$V_0 = -\frac{R_f}{R} \times \frac{2^4 \cdot V_R}{2^4}\left(\frac{D_0}{8} + \frac{D_1}{4} + \frac{D_2}{2} + D_3\right)$$

$$= -\frac{R_f}{R} \times \frac{V_R}{2^4}\left\{D_3 \times 2^4 + D_2 \times 2^3 + D_1 \times 2^2 + D_0 \times 2\right)$$

$$\left[V_0 = -\frac{R_f}{R} \times \frac{V_R}{2^3}\left\{D_3 \times 2^3 + D_2 \times 2^2 + D_1 \times 2 + D_0\right\}\right]$$

(ii) Full scale output $R = R_f = 1k\Omega$

$$V_0 = -1 \times \frac{5}{8}\left(8+4+2+1\right) = -9.375 \text{ volts}$$

Full scale output $R_f = 500\Omega$ and $R = 1k\Omega$

$$= \frac{-500}{1000} \times \frac{5}{8}(15) = 4.6875 \text{ volts}.$$

10

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

[12 marks]

control signals are Read, Write, etc, we use the same bus and memory just the control signals are different we use active low signal for memory operation and active high for input/output output as shown.

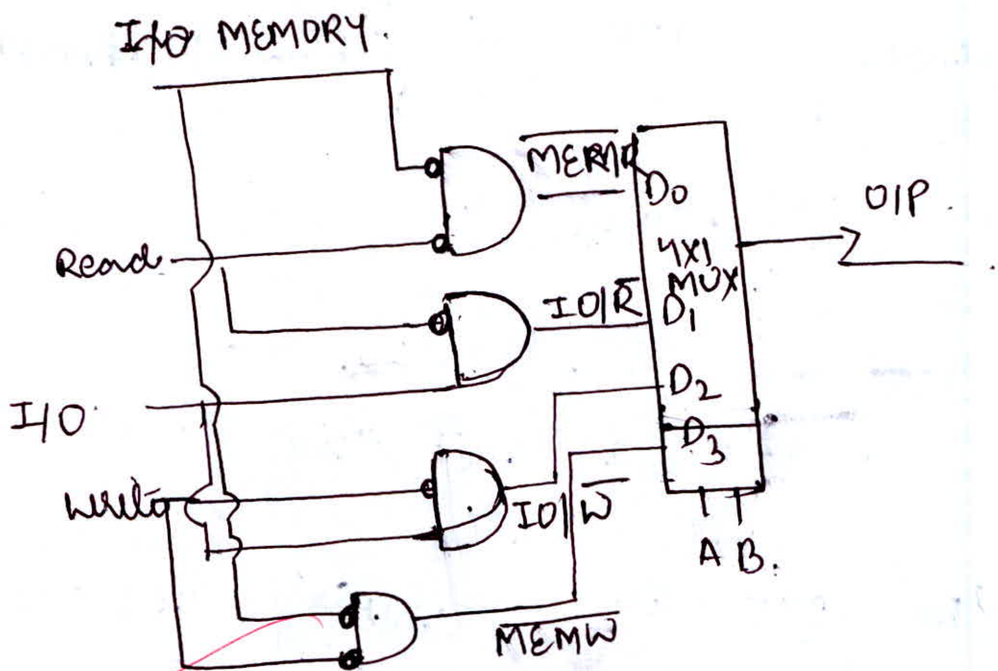
$\overline{MEMR}$

$\overline{MEMW}$

$IO/\overline{R}$

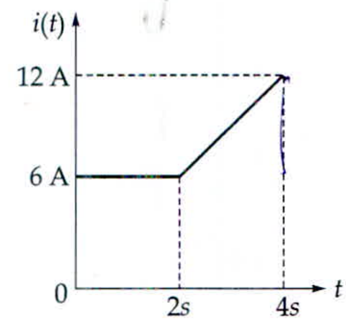
$IO/\overline{W}$

	Memory	I/O	Read	WR	
$\overline{MEMR}$	0	0	0	1	1
$\overline{MEMW}$	0	0	1	0	1
$IO/\overline{R}$	1	1	0	1	1
$IO/\overline{W}$	1	1	1	0	1



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.



[12 marks]

Energy stored by inductor $= \cancel{\frac{L}{2}LI^2} \int_0^t v_L(t) I_L(t) + \cancel{I^2(t)} R$

Where $v_L = \frac{L\,dI}{dt} + I(t)R$.

$$\left\{\begin{array}{lll} I(t) = & 6A & 0 < t < 2\,sec \\ = & 3t & \cancel{2<t}\ 2sec < t < 4sec \end{array}\right\}$$

2

$$v_L = \left\{\begin{array}{ll} 2\times 0 + 6\times 2 = 12 \text{ volts} & 0<t<2sec \\ 2\times 3 + 3t\times 2 = (6+6t)\text{ volts} & 2sec<t<4sec \end{array}\right.$$

Energy absorbed $= \int_0^2 12\cdot 6\,dt + \int_2^4 (6+6t)\,dt$

$= \cancel{72\times}\ 144 + (6t)_2^4 + \left(\frac{6t^2}{2}\right)_2^4$

$= 144 + 12 + 36$

$= 192$ Joules

Thus the energy stored by inductor in first 4 seconds is 192 joules.

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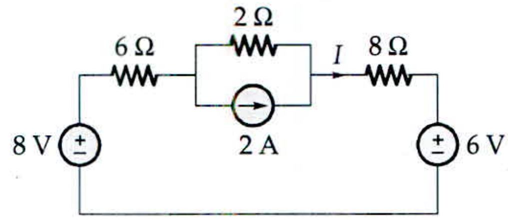
Q.6 (a) **(ii)** Find the current I in the circuit shown below using the superposition theorem.

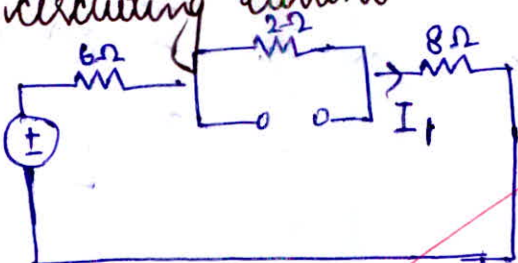


[8 marks]

using superposition theorem

considering (8V) voltage source and shorting other voltage sources and open circuiting current sources.

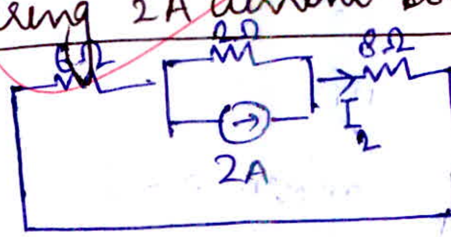
(I)



$I_1 = \frac{8V}{16} = 0.5amp$

$\boxed{I_1 = 0.5 \text{ amperes}}$

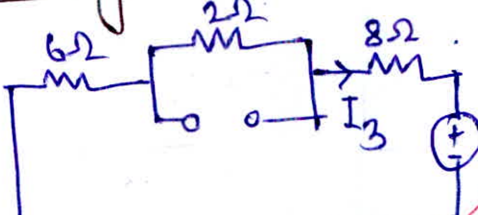
(II) considering 2A current source.



$I_2 = \frac{2 \times 2}{2+14}$

$\boxed{I_2 = 0.25 \text{ ampere}}$

(III) considering 6V current source



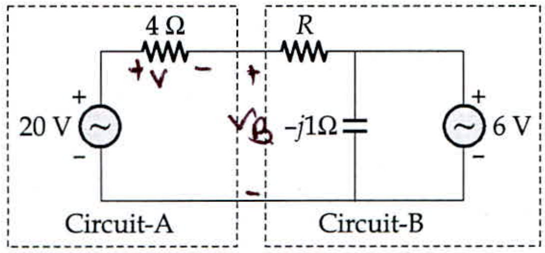
$I_3 = \frac{-6}{16}$

$\boxed{I_3 = -0.375 \text{ amp.}}$

Thus, $[I = I_1 + I_2 + I_3 = 0.375 \text{ amperes}]$

8

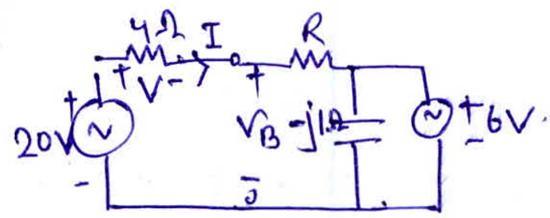
Q.6 (b) (i) Assuming both the voltage sources are in phase, find the value of R for which maximum power is transferred from circuit A to circuit B.



[12 marks]

For maximum power to be transferred from circuit A to circuit B.

voltage drop across 4Ω resistor should be same as voltage across circuit B.



i.e. $\boxed{V = V_B}$

i.e. $V = 10V$ and

$V_B = 10$ Volts

Thus, $I = \frac{10}{4} = 2.5$ amperes and

~~$V_B = IR + 6$~~

$V_B - IR - 6 = 0 \Rightarrow V_B = IR + 6$.

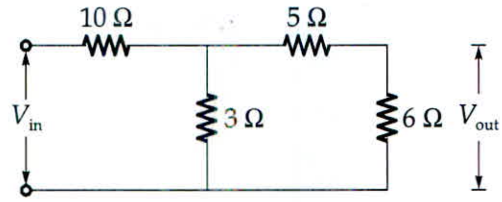
where $V_B = 10 = (2.5)R + 6$.

Thus, $\boxed{R = \frac{4}{2.5} = 1.6\ \Omega}$

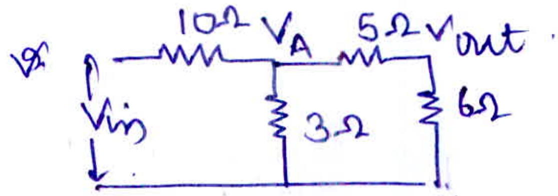
For maximum power transfer

10

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



[8 marks]



Applying KCL at node A

$$\cancel{\frac{V_A}{3} + \frac{V_A - V_{in}}{10} = \frac{V_A - V_{out}}{5} = \frac{V_A}{11\Omega}}$$

$$\frac{V_A}{3} + \frac{V_A}{11} + \frac{V_A - V_{in}}{10} = 0$$

$$V_A\left(\frac{1}{3} + \frac{1}{11} + \frac{1}{10}\right) = \frac{V_{in}}{10}$$

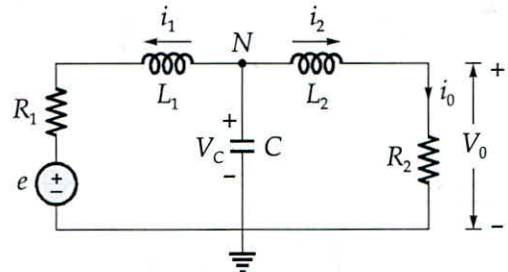
$$\boxed{V_{in} = 5.2424\, V_A} \quad -(1)$$

Also, $V_{out} = \frac{V_A}{11} \times 6 = \frac{V_{in}}{5.2424} \times \frac{6}{11}$ {From (1)}

$$\boxed{\frac{V_{out}}{V_{in}} = 0.1[illegible]}$$ Answer.

8

.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)

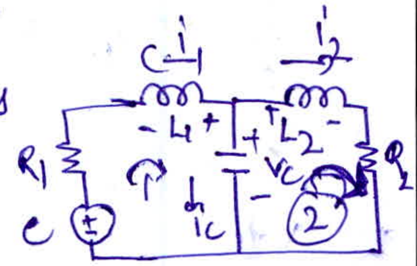


[10 marks]

i_1, i_2, v_C are state variables

i_0 and V_0 are output variables

and e is input variable.



$i_C + i_1 + i_2 = 0$

{KCL at node N and considering i_C current through capacitor C}

$$C\frac{dv_C}{dt} = -(i_1 + i_2)$$

$$\boxed{\dot{v}_C = -\frac{1}{C}(i_1 + i_2)} \text{ -(1).}$$

Applying KVL in loop 1.

$e + i_1 R_1 + v_{L1} - v_C = 0$

$v_{L1} = e + i_1 R_1 - v_C.$

$L\frac{di_1}{dt} = e + i_1 R_1 - v_C.$

$$\left[\dot{i}_1 = \frac{i_1 R_1}{L} - \frac{v_C}{L} + \frac{e}{L}\right] \text{-(11)}$$

Applying KVL in loop 2 $v_C - v_{L2} - i_2 R_2 = 0.$

$v_{L2} = v_C - i_2 R_2$

$$\frac{L\,di_2}{dt} = v_C - i_2 R_2 .$$

$$\left[\dot{i}_2 = \frac{1}{L}(-i_2 R_2) + \frac{v_C}{L}\right] \quad -(III)$$

from (I), (II) and (III)

$$\begin{bmatrix} \dot{i}_1 \\ \dot{i}_2 \\ \dot{v}_C \end{bmatrix} = \begin{bmatrix} \frac{R_1}{L} & 0 & -1/L \\ 0 & -R_2/L & 1/L \\ -\frac{1}{C} & -\frac{1}{C} & 0 \end{bmatrix} \begin{bmatrix} i_1 \\ i_2 \\ v_C \end{bmatrix} + \begin{bmatrix} \frac{1}{L} \\ 0 \\ 0 \end{bmatrix} e .$$

which is the required state equation

~~As~~ ~~y~~ Also $i_0 = i_2$.

let $i_2 = i_0 = y_1 \Rightarrow y_1 = \begin{bmatrix} 0 & -\frac{R_2}{L} & \frac{1}{L} \end{bmatrix} \begin{bmatrix} i_1 \\ i_2 \\ v_C \end{bmatrix}$.

and $y_2 = v_0 = i_0 \cdot R_2$.

Thus output equation

$$\begin{pmatrix} y_1 \\ y_2 \end{pmatrix} \cancel{(y_1\, y_2) = \begin{bmatrix} 0 & -\frac{R_2}{L} & \frac{1}{L} \\ 0 & -\frac{R_2^2}{L} & \frac{R_2}{L} \end{bmatrix} \begin{pmatrix} i_1 & i_1 \\ i_2 & i_2 \\ v_C & v_C \end{pmatrix}}$$

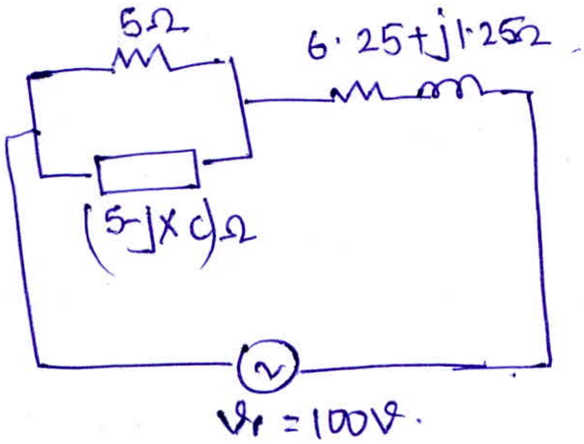
9

$$(y_2) = \left(0 \quad -\frac{R_2^2}{L} \quad \frac{R_2}{L}\right) \begin{pmatrix} i_1 \\ i_2 \\ v_C \end{pmatrix} .$$

$$A = \begin{pmatrix} \frac{R_1}{L} & 0 & -\frac{1}{L} \\ 0 & -R_2/L & 1/L \\ -1/C & -1/C & 0 \end{pmatrix} \qquad B = \begin{pmatrix} \frac{1}{L} \\ 0 \\ 0 \end{pmatrix} \qquad C = \begin{pmatrix} 0 & -\frac{R_2}{L} & \frac{1}{L} \\ 0 & -\frac{R_2^2}{L} & \frac{R_2}{L} \end{pmatrix}$$

.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]



For resonance Imaginary part of Equivalent input impedance should be zero.

i.e. $\dfrac{(5)(5-jX_c)}{5+5-jX_c} + 6.25 + j1.25$

$$\frac{(25-j5X_c)(10+jX_c)}{(10-jX_c)(10+jX_c)} + 6.25 + j1.25 = 0$$

10

$$\frac{(25-j5X_c)10}{100+X_c^2} + \frac{jX_c(25-j5X_c)}{100+X_c^2} + 6.25 + j1.25$$

Equating imaginary part = 0.

$$\frac{-50X_c}{100+X_c^2} + \frac{X_c 25}{100+X_c^2} + 1.25 = 0$$

$$-25X_c + 1.25(100+X_c^2) = 0$$

$$X_c^2 \times 1.25 - 25X_c + 125 = 0 \rightarrow \boxed{X_c = 10\,\Omega}$$

$$\left[C = \frac{1}{2\pi f X_c} = 0.318\,mF\right]$$

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

[8 marks]

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.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.

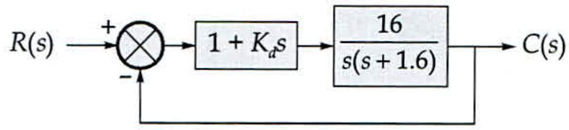
[20 marks]

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]

Q8 (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]

Do not write in this margin

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]

8 (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]

$\dot{x}(t) = A x(t)$. applying laplace transform

$~~SI~~ = SX(S) - X(0) = AX(S)$.

$X(S) = ~~X(0)~~ (SI-A)^{-1} X(0)$

$\downarrow$

$x(t) = e^{At} x(0)$. applying inverse laplace transform

~~Thus~~, $X(t) = \begin{pmatrix} e^{-t} \\ -2e^{-t} \end{pmatrix}$. when $x(0) = \begin{pmatrix} 1 \\ -2 \end{pmatrix}$

~~$\text{let } A = \begin{pmatrix} a & b \\ c & d \end{pmatrix}$ then $(SI-A)^{-1} = \begin{pmatrix} d & -b \\ -c & a \end{pmatrix}$.~~

~~$\text{Then } x(t) = \begin{pmatrix} \; \end{pmatrix} \begin{pmatrix} 1 \\ -2 \end{pmatrix}$.~~

$x(t) = \begin{pmatrix} e^{-t} \\ -2e^{-t} \end{pmatrix} = e^{At} \begin{pmatrix} 1 \\ -2 \end{pmatrix}$.

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Space for Rough Work

Space for Rough Work

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