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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 1 9 M T D L A 0 1 0

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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	52
Q.2	45
Q.3	56
Q.4	
Section-B	
Q.5	39
Q.6	45
Q.7	
Q.8	
Total Marks Obtained	237

Signature of Evaluator: [signature]

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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]

Solution for corona

critical disruptive voltage $V_c' = m_0 g r \delta \ln(d/r)$ kV/cm (RMS)

where $g = 21.1$ kV/cm (RMS)

$$V_c = 0.85 \times 21.1 \times \frac{10\times10^{-1}}{2} \times \frac{3.92\times75}{273+30} \times \ln\left(\frac{2.5}{\frac{10}{2}\times10^{-3}}\right)$$

$V_c = 54.074$ kV (RMS)

Now $V_{ph} = \frac{110}{\sqrt{3}}$ kV $= 63.50$ kV (RMS)

$\because V_{ph} > V_c$

$\therefore$ corona loss will occur

$$P_{loss} = 242.2\times10^{-5} + \left(\frac{f+25}{\delta}\right) \times \sqrt{\frac{r}{d}} \times (V_{ph}-V_c)^2 \ (\text{kW/ph/km})$$

$$= 242.2\times10^{-5} \times \frac{75}{0.97029} \times \sqrt{\frac{5\times10^{-3}}{2.5}} (63.50 - 54.074)^2$$

$$\boxed{P_{loss} = 0.7438 \text{ kW/ph/km}}$$ Ans

kW?

9

total corona loss ??

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

2 generators, 30 MVA, 15% reactance each

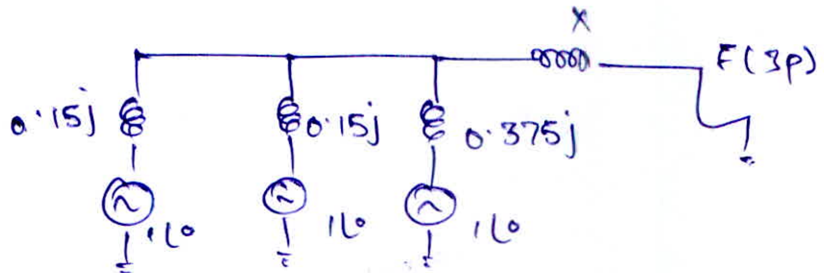
1 generator, 10 MVA, 12.5% reactance

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]

Solution

Reactance diagram : $S_b = 30\,MVA$



Now Fault level $= 100\,MVA = \dfrac{1}{X_{TH}(PU)} \times$ Base MVA

$\Rightarrow \quad X_{TH}(PU) = \dfrac{30}{100} = 0.3\,PU$

Now Applying thevenin's across Fault to Neutral

$X_{TH} = (0.15j \,||\, 0.15j \,||\, 0.375j) + xj$

$X_{TH} = (0.0625 + x)\,j$

$\therefore \quad 0.0625 + x = 0.3$

$\boxed{x = 0.2375}$

Now on T/F Base : $S_b = 10\,MVA$

$x = 0.2375 \times \dfrac{10}{30} = 0.079167\,PU$

$\therefore \boxed{X_{min} = 0.079167}$ Ans.

↳ minimum reactance of T/F

mention p.u.

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Q.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]

Solution $IC_1 = (0.004P_1 + 0.86)500$ Rs/MWHr

$IC_1 = (2P_1 + 430)$ Rs/MWHr

$IC_2 = (0.008P_2 + 1.08)\,500$ Rs/MWHr

$= (4P_2 + 540)$ Rs/MWHr

$IC_3 = (0.0056P_3 + 0.64)\,500$ Rs/MWHr

$= (2.8P_3 + 320)$ Rs/MWHr

Now $P_1 + P_2 + P_3 = 200\text{ MW}$ —(i)

$IC_1 = IC_2 \Rightarrow 2P_1 + 430 = 4P_2 + 540$

$\Rightarrow 2P_1 - 4P_2 = 110$ —(ii)

Similarly $IC_2 = IC_3 \Rightarrow 4P_2 + 540 = 2.8P_3 + 320$

$\Rightarrow 4P_2 - 2.8P_3 = -220$ — (iii)

Solving (i), (ii), (iii) $P_1 = 85MW$

$P_2 = 15MW$

$P_3 = 100MW$

Now $P_2 < P_{2min}$ ∴ P_2 will be equal to its minimum

limit i.e. $\boxed{P_2 = 36MW}$

Now $P_1 + P_3 = 164MW$ — (iv)

$IC_1 = IC_3 \Rightarrow 2P_1 + 430 = 2.8P_3 + 320$

$\Rightarrow 2P_1 - 2.8P_3 = -110$ — (v)

Solving (iv), (v)

$\left.\begin{array}{l} P_1 = 72.75\ MW \\ P_3 = 91.25MW \end{array}\right\}$ True within limits

∴ Finally

$\left.\begin{array}{l} P_1 = 72.75MW \\ P_2 = 36MW \\ P_3 = 91.25MW \end{array}\right\}$ Ans.

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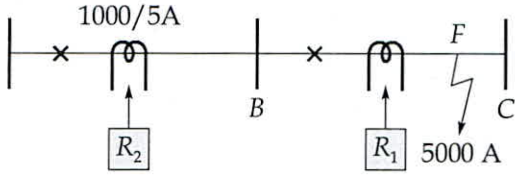
Q.1 (d) Two relays R_1 and R_2 are connected in two sections of a feeder as shown in figure below. CT's are of ratio 1000/5 A. The plug setting of relay R_1 is 100% and R_2 is 125%. The operating time characteristic of the relays is given in table.

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]

Solution For R_1

~~PSM~~ $I_{PK} = \%PSM \times$ CT Secondary Current

$I_{PK} = 1 \times 5 = 5A$

Now $PSM = \dfrac{I_{Fault}}{I_{PK} \times CT\,Ratio} = \dfrac{5000}{5 \times 1000/5} = 5$

$\therefore$ For PSM = 5, TMS = 1, $t_{op} = 4$ sec

Now $TMS_{R_1} = 0.3$

$t_{operation} = (TMS) \times (t_{operating}$ for $TMS = 1)$

$\boxed{t_{operating_{R_1}} = 0.3 \times 4 = 1.2\,sec}$ Ans

Now $t_{operating_{R_2}} = t_{delay} + t_{operating\,R_1}$

$\boxed{t_{operating_{R_2}} = (0.5 + 1.2) = 1.7\,sec}$ Ans.

For R_2 $I_{PK} = 1.25 \times 5 = 6.25A$

$PSM = \dfrac{5000}{6.25 \times 1000/5} = 4$

Now $(t_{op})_{R_2} = (TMS_{R_2}) \times (t_{op}\ R_2 \text{ for PMS } m = 4)$

$1.7 = (TMS)_{R_2} \times 5$

$\boxed{\Rightarrow (TMS)_{R_2} = 1.7/5 = 0.34 \text{ Ans}}$ Ans

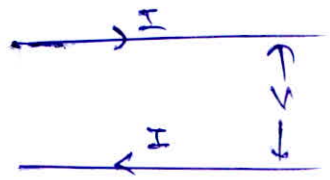
11

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]

Solution

For 2 Wire dc System



V = Line Voltage

P = Power Transmitted

Clearly $P = VI$

Power loss $= 2I^2R = W$

$\therefore R = \dfrac{W}{2I^2}$

Now $P_L = W = 2\left(\dfrac{P}{V}\right)^2 R \propto \dfrac{1}{V^2}$

Also Volume of conductor used $= A\,l$

Assumption: Length of Transmission is same in Both the cases

$\therefore$ Volume of conductor used $\propto \frac{1}{V^2}$

$\therefore$ C.S. Area $\propto \frac{1}{V^2}$

$\therefore$ ~~copper savings =~~

Avoid striking between answer.

$\therefore \frac{(C.S.A)_1}{(C.S.A)_2} = \frac{V_2^2}{V_1^2} = 5.165$

$\therefore (CSA)_2 = (0.1436)(CSA)_1$

Now copper comparision

$\%$ copper savings $= -\left(\frac{(CSA)_2 - (CSA)_1}{(CSA)_1}\right) \times 100$

$$= \frac{(CSA)_1 - 0.1436(CSA)_1}{(CSA)_1} \times 100$$

$\boxed{\% \text{ copper savings } = 80.64\%}$ Ans.

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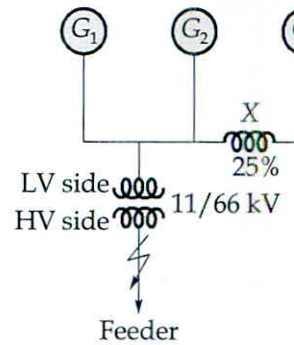
Q.2 (a) A generating station has four identical generators, G_1, G_2, G_3 and G_4 each of 20 MVA, 11 kV having 20% reactance. They are connected to a bus bar which has a busbar reactor of 25% reactance on 20 MVA base, inserted between G_2 and G_3 as shown below. A 66 kV feeder is taken off from the bus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



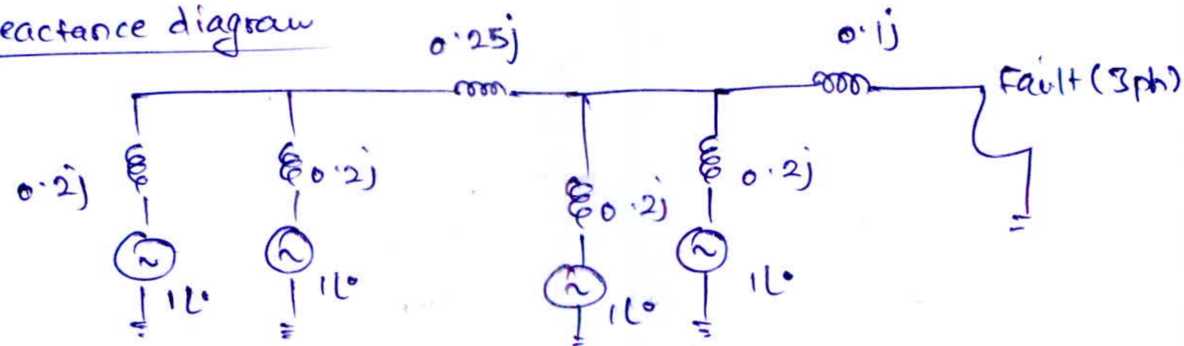
[20 marks]

Solution

Take $S_b = 20\,MVA$

$V_b = 11\,KV$ ('G' side)

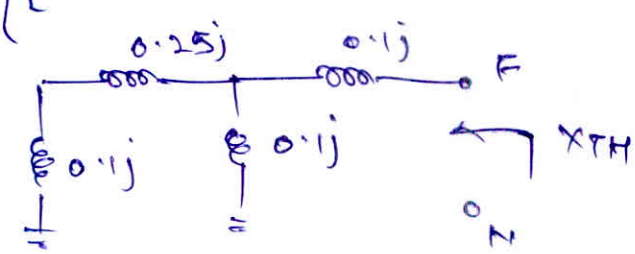
Reactance diagram



∴ Applying thevenin's across Fault to Neutral

$$X_{TH} = \left\{\left[(0{\cdot}2j \,||\, 0{\cdot}2j) + 0{\cdot}25j\right] \,||\, 0{\cdot}2j \,||\, 0{\cdot}2j\right\} + 0{\cdot}1j$$

∴



$$= \quad X_{TH} = (0{\cdot}35j \,||\, 0{\cdot}1j) + 0{\cdot}1j$$

$$X_{TH} = 0{\cdot}17778j$$

$\therefore$ $I_{fault} = \dfrac{1\angle 0}{X_{TH}} = (-5.625i)$ pu

Now $I_{Base} = \dfrac{20 \times 10^6}{\sqrt{3} \times 66 \times 10^3} = 174.95$ A

$\therefore$ $\boxed{I_{fault} = 984.12 \text{ A}}$ Ans.

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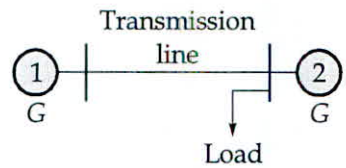
Q.2 (b) **(i)** A system consists of two plants connected by a transmission line as shown in figure below. The load is at plant-2. The transmission line loss calculations reveals that a transfer of 100 MW from plant-1 to plant-2 incurs a loss of 15 MW. Find the required generation at each plant for $\lambda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

solution (i) For the given single line diagram

$P_{Loss} = B_{11}P_1^2$

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

$\therefore \; 15 = B_{11}(100)^2 \Rightarrow \boxed{B_{11} = 1.5\times10^{-3}\,(\text{MW})^{-1}}$

Now given $\lambda = 60 = L_i IC_i$

For $i=1$ $\quad L_1 = \dfrac{1}{1 - \dfrac{\partial P_L}{\partial P_1}} = \dfrac{1}{1 - 2B_{11}P_1}$

$\therefore \; \dfrac{0.2P_1 + 22}{1 - 2\times1.5\times10^{-3}P_1} = 60 \Rightarrow 0.2P_1 + 22 = 60 - 0.18P_1$

$\Rightarrow \; 0.38P_1 = 38 \Rightarrow \boxed{P_1 = 100\text{MW}}$

For $i=2$ $\quad L_2 IC_2 = 60$; $L_2 = \dfrac{1}{1 - \dfrac{\partial P_L}{\partial P_2}} = 1$

$\therefore \; 0.15P_2 + 30 = 60 \Rightarrow \boxed{P_2 = 200\text{MW}}$ Ans

(ii) Without considering Transmission loss (Assuming $\lambda = 60$)

~~$P_1 + P_2 = 285MW$~~ — (i)

$IC_1 = IC_2 \Rightarrow 0 \cdot 2P_1 + 22 = 0 \cdot 15P_2 + 30 = 60$

$\Rightarrow$ ~~$0 \cdot 2P_1 - 0 \cdot 15P_2 = 8$ — (ii)~~

Solving (i) & (ii) $P_1 = \cancel{145MW}\ 190MW$; $P_2 = \cancel{140MW}\ 200MW$

Now

Saving in Rs/Hr by scheduling the generation by considering T/L loss = Savings in unit 1 + Savings in unit 2

$$= \int_{100MW}^{P_1 = 190MW} (0 \cdot 2P_1 + 22)\, dP_1 + \int_{P_2 = 200MW}^{P_2 = 200MW} (0 \cdot 15P_2 + 30)\, dP_2$$

$$= \frac{0 \cdot 2P_1^2}{2} + 22P_1 \Big|_{100}^{190} + \frac{0 \cdot 15}{2}P_2^2 + 30P_2 \Big|_{200}^{200}$$

$= \cancel{2092 \cdot 5} + 4590\ Rs/Hr$

$\therefore$ $\boxed{\text{Savings in Rs/Hr} = 4590\ Rs/Hr}$

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Q.2 (c) A 50 Hz, 3 phase transmission line 300 km long has total series impedance of (40 + *j*125) 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]

Solution

given $Z = 131.244\angle 72.25^\circ \,\Omega$

$Y = 10^{-3}\angle 90\ \mho$

$$I_R = \frac{50\times10^6}{\sqrt{3}\times 220\times10^3\times0.8}\angle -\cos^{-1}(0.8) = 164.02\angle -36.87^\circ A$$

(i) Short line Approximation

$I_S = I_R = 164.02\angle -36.87^\circ A$ Ans

$V_S = V_R + Z I_R = 145.104\angle 4.927^\circ$ kV (L-N)

~~$V_S(L-L) = 205.2\angle 4.927^\circ$ (kV)~~

~~$I_S = 164.02\angle -36.87^\circ A$~~

$\boxed{V_S = 251.32\angle 4.927\ kV\ (L-L)}$

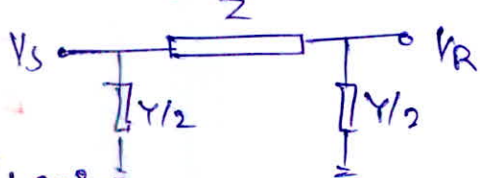
pf = cos(4.927 + 36.87) lagg

$\boxed{pf = 0.7455\ lagg}$

power at sending ~~poto~~ end = $\sqrt{3}V_S I_S \cos\phi_S$

= ~~53.46 MW~~ 53.22 MW Ans

(ii) Nominal π method :



$A = 1 + \frac{YZ}{2} = D = 0.9377\angle 1.22^\circ$

$B = Z = 131.244\angle 72.25^\circ$

$C = Y\left(1+\frac{YZ}{4}\right) = 9.68\times10^{-4}\angle 90.6^\circ$

Now $V_s = AV_R + BI_R = 137.45 \angle 6.26^\circ$ kV (L-N)

$\therefore V_s(L-L) = \cancel{194.38kV}$ 238.07 kV (L-L) Ans

Now

$I_s = CV_R + DI_R = 128.1 \angle 15.07^\circ$ A Ans

$pf = \cos(6.26 - 15.07)$ lead

$pf = 0.988$ lead Ans

Power $= \sqrt{3} V_s I_s \cos\phi_s = 52.188$ MW Ans.

(iii) Exact long line equation

$\gamma l = \sqrt{ZY} = 0.3622 \angle 81.125 = 0.0558 + 0.3578i$

$Z_c = \sqrt{\frac{Z}{Y}} = 362.27 \angle -8.875$

Now $A = \cosh\gamma l = \cosh(\alpha l + j\beta l) = \cosh\alpha l \cos\beta l + j\sinh\alpha l \sin\beta l$

$A = 0.9383 \angle 1.2^\circ = D$

$B = Z_c \sinh\gamma l = Z_c[\sinh(\alpha l + j\beta l)]$

$= Z_c[\sinh\alpha l \cos\beta l + j\cosh\alpha l \sin\beta l] = 128.47 \angle 72.64$

$C = \frac{\sinh\gamma l}{Z_c} = \frac{B}{Z_c^2} = 9.789 \times 10^{-4} \angle 90.39$

Now $V_s = AV_R + BI_R = 137.053 \angle 6.2^\circ$ kV (L-N)

$\boxed{V_s(L-L) = 237.38 \text{ kV}}$

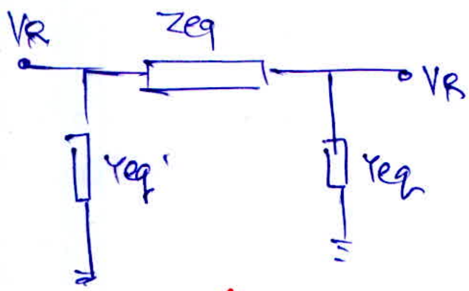
$I_s = CV_R + DI_R = 128.9 \angle 15.56^\circ$ A Ans

Now $pf = \cos(15.56 - 6.2)$ lead

$= 0.9866$ lead

Power $= \sqrt{3} V_s I_s \cos\phi_s = 52.28$ MW Ans

(iv) Approximation of long line



$Zeq = Z_c \sinh \gamma l$

$= 128.47 \angle 72.64°$

$Yeq = \frac{\tanh(\gamma l/2)}{Z_c} = \frac{\sinh(\gamma l/2)}{Z_c \cosh(\gamma l/2)}$

$Yeq =$

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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]

Solution (i) ∵ given at UPF ∴ $Q_R = 0$

$|V_S| = V_R = 275\,kV$

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

$$\therefore 0 = \left|\frac{275 \times 275 \times 10^6}{200}\right| \sin(75 - \delta) - \left(\frac{0.85 \times 275^2 \times 10^6}{200}\right) \sin(70)$$

$$\Rightarrow \frac{0.85 \times \cancel{275^2} \times \cancel{10^6}}{\cancel{200}} \sin 70 = \frac{275 \times \cancel{275} \times \cancel{10^6}}{\cancel{200}} \sin(75 - \delta)$$

$$\Rightarrow \boxed{\delta \simeq 22°}$$

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

$$\therefore P_R = \left|\frac{275 \times 275}{200}\right| \cos(75 - 22) - \left|\frac{0.85 \times 275^2}{200}\right| \cos(70)\ MW$$

$$\boxed{P_R = 117.63\,MW}$$ Ans.

↓ Power at UPF that can be received

(ii) Now given $P_R = 150\,MW$

$$\therefore 150 \times 10^6 = \left|\frac{275 \times 275 \times 10^6}{200}\right| \cos(\beta - \delta) - \left(\frac{275^2 \times 10^6 \times 0.85}{200}\right) \cos(70)$$

Solving $\boxed{\delta = 28.42°}$

Now $Q_R = \left|\frac{275^2 \times 10^6}{200}\right| \sin(75 - 28.42) - \left|\frac{0.85 \times 275^2 \times 10^6}{200}\right| \sin(70)$

$Q_R = -27.37$ MVAR

∴ compensation Required is shunt capacitor at Receiving end with $Q_C = 27.37$ MVAR Ans.

(iii) Now with $P_R = 150$ MW, compensation equipment not installed at UPF

again

$Q_R = 0$; $P_R = 150$ MW ; $V_R = ?$

$$0 = \left|\frac{275 V_R \times 10^3}{200}\right| \sin(75-\delta) - \left|\frac{0.85 V_R^2}{200}\right| \sin(70)$$

$$\Rightarrow \frac{0.85 V_R^{\cancel{2}}}{\cancel{200}} \sin 70 = \frac{275 \times 10^3 \cancel{V_R}}{\cancel{200}} \sin(75-\delta)$$

$$\Rightarrow V_R = \frac{275 \times 10^3}{0.85 \sin 70} \sin(75-\delta) \text{ Volts.} \quad -(1)$$

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

$$\Rightarrow 150 = \frac{275}{200} \times 344.3 \sin(75-\delta)\cos(75-\delta)$$

$$- \frac{0.85}{200} \times 40542.2 \sin^2(75-\delta)$$

$\Rightarrow 150 = \frac{473.4125}{2} \sin(150-2\delta) - 172.3 \sin^2(75-\delta)$

Solving $\boxed{\delta = 29.816^\circ}$

From eqn (i)

$\therefore V_R = \frac{275}{0.85 \sin 70} \sin(75-\delta)$ kV

$\boxed{V_R = 244.23 \text{ kV}}$ Ans

good

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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.

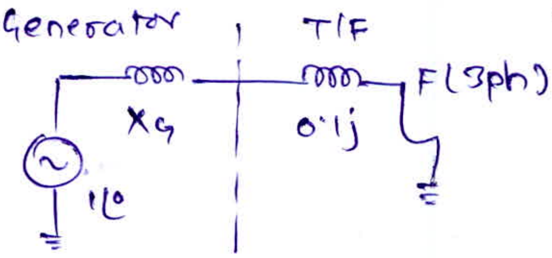
(ii) The maximum possible dc component.

(iii) Maximum value of instantaneous current.

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

[20 marks]

Solution Reactance diagram



$S_b = 100$ MVA

$V_b = 13.2$ kV ('G' side)

$V_b = 132$ kV (HV side of T/F)

I_b

(i) Subtransient current

$I''_{F(PU)} = \frac{1\angle 0}{X_d'' + 0.1j} = \frac{1}{(0.15+0.1)j} = (-4i)$ PU

$\therefore I_F'' = 4 \times \frac{100\times10^6}{\sqrt{3}\times 132\times 10^3}$ A $= 1749.54$ A Ans

Do not write in this margin

Transient Current

$$I_F'(pu) = \frac{1\angle 0}{x_d' + 0.1j} = \frac{1}{0.25j + 0.1j} = (-2.857i)\ pu$$

$$\boxed{I_F' = 1249.61A}$$ Ans

Steady state Symmetrical Fault current

$$I_F(pu) = \frac{1\angle 0}{x_d + 0.1j} = \frac{1\angle 0}{1.25j + 0.1j} = (-0.7407i)\ pu$$

$$\boxed{I_F = 823.97A}$$ Ans

(ii) Maximum possible DC component $= \sqrt{2}\, I_F''$

$= 2474.22\ A$ Ans

(iii) Maximum value of instantaneous current

$=$ (DC component max) $+$ (max value of AC current)

$= \sqrt{2}\, I_F'' + \sqrt{2}\, I_F''$

$= 2\sqrt{2}\, I_F''$

$= 4948.44A$ Ans

18

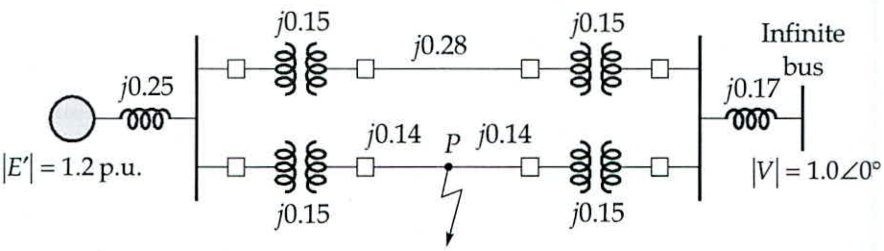
(iv) maximum rms value of Asymm. Fault current

$= \sqrt{(\text{DC component})^2 + (\text{AC Fault Current})^2}$

$= \sqrt{(\sqrt{2} I_F'')^2 + (I_F'')^2}$

$= \sqrt{3}\, I_F'' = 3030.3\ A$ Ans

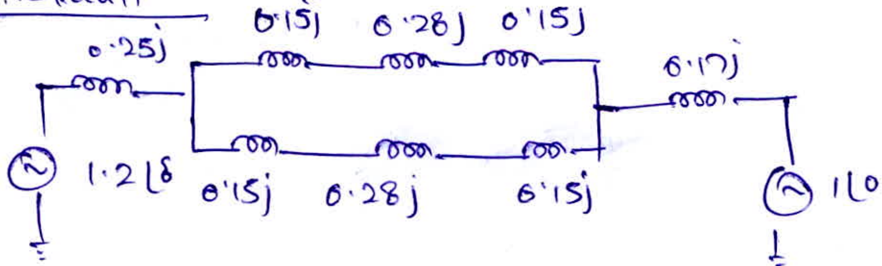
Q.3 (c) Find the critical clearing angle for the system in figure for a three phase fault at the point *P*. The generator is delivering 1.0 p.u. power under pre-fault conditions.



[20 marks]

Solution

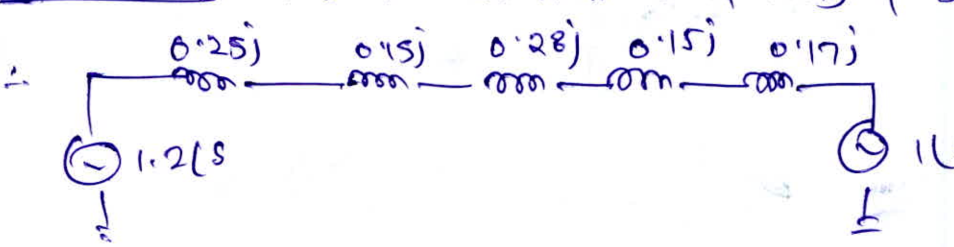
Pre Fault



$$\therefore P_{max} = \left|\frac{1\cdot 2 \times 1}{0\cdot 25j + 0\cdot 17j + \frac{0\cdot 58j}{2}}\right| = 1\cdot 69 \text{ PU}$$

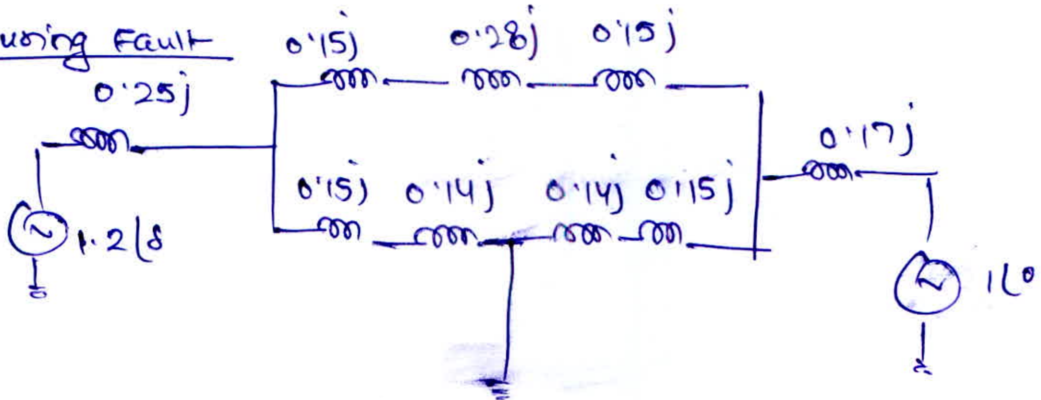
Post Fault : Assume Simultaneous opening of CB poles

$\therefore$



$$P_{max} = \left| \frac{1.2 \times 1}{0.25j + 0.17j + 0.58j} \right| = 1.2\,PU$$

<u>during Fault</u>



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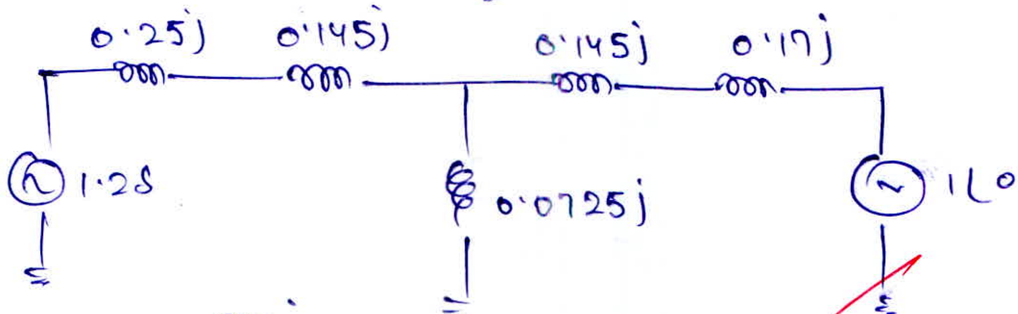

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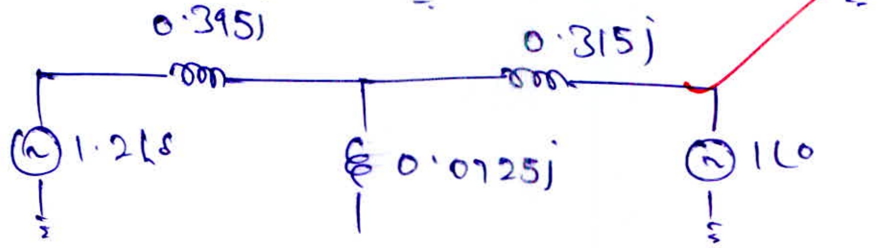
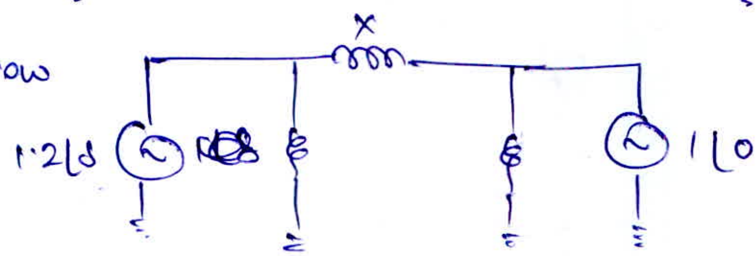


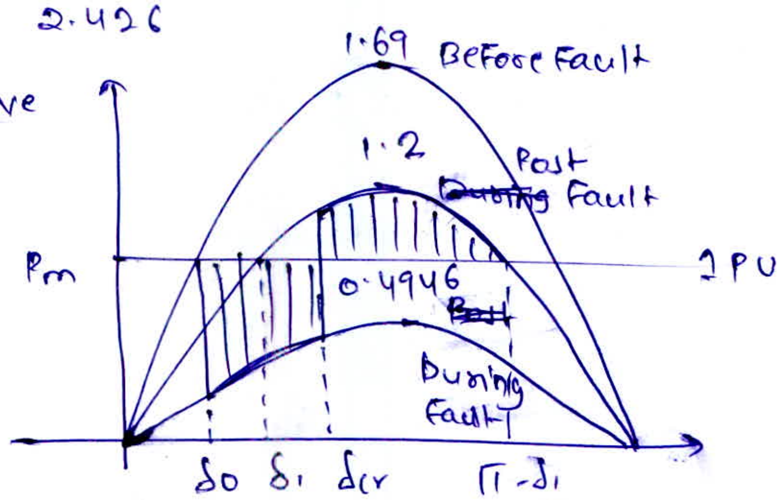
Now



$x = 2.426j$

$$\therefore P_{max} = \frac{1.2 \times 1}{2.426} = 0.4946\,PU$$

<u>$\therefore$ Power angle Curve</u>



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Now $\delta_0 = \sin^{-1}(1/1.69) =$; $\delta_1 = \sin^{-1}(1/1.2) = 56.44°$

$= 36.278°$; $\pi - \delta_1 = 123.55°$

Now by equal Area criterion

$$\int_{36.278°}^{\delta_{cr}} (1 - 0.4946\sin\delta)\,d\delta = \int_{\delta_{cr}}^{123.55°} (1.2\sin\delta - 1)\,d\delta$$

$\Rightarrow$ $\cancel{\delta_{cr}} - 36.278 \times \frac{\pi}{180} + 0.4946\cos\delta_{cr} - 0.4946\cos(36.278)$

$= 1.2\cos\delta_{cr} - 1.2\cos 123.55 - 123.55 \times \frac{\pi}{180} + \cancel{\delta_{cr}}$

$\Rightarrow$ $0.46126 = 0.7054\cos\delta_{cr}$

$\Rightarrow$ $\boxed{\delta_{cr} = 49.16°}$

critical clearing angle Ans

good

19

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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 $t = 3.25$T on the mid length of the line.

[20 marks]

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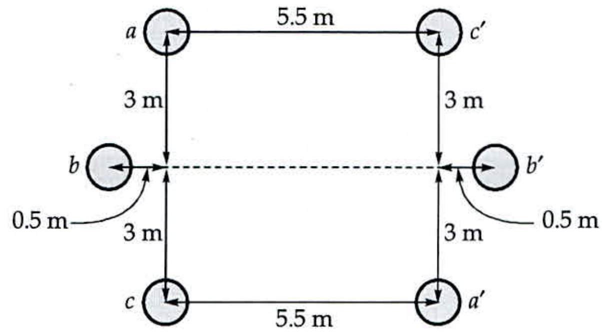
Q.4 (b) Determine the inductance of the double circuit fully transposed line shown in figure, if the self GMD of each conductor is 0.0069 m.



[20 marks]

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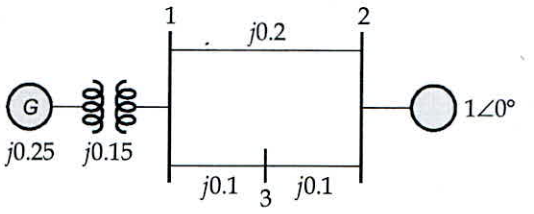
Q.4 (c) A single line diagram of a system is shown below:



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]

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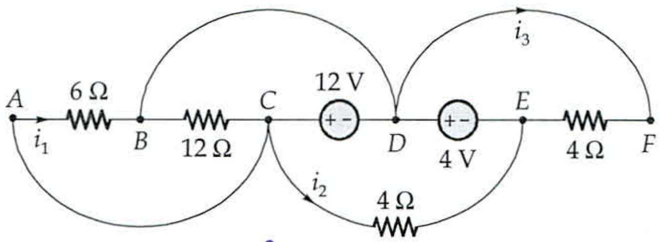
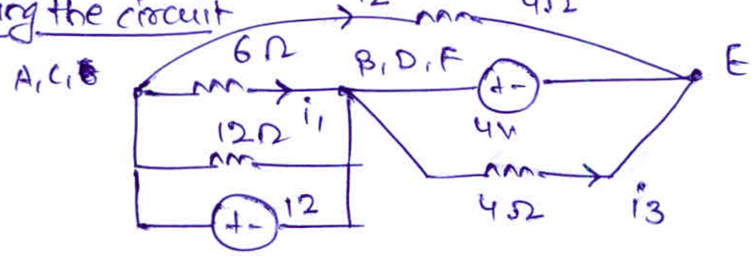
Section B : Electrical Circuits-1 + Microprocessors-1 + Digital Electronics-2 + Control Systems-2

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

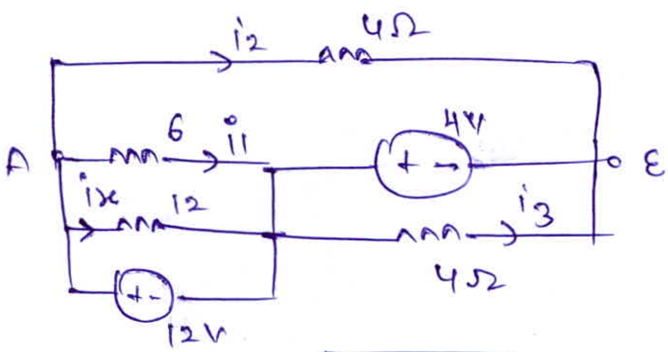


[12 marks]

Solution Rearranging the circuit



Now



Power delivered by sources = ?

clearly $4i_3 = 4 \Rightarrow \boxed{i_3 = 1A}$ An,

$i_1 = \left(\frac{12}{6 \| 12}\right) \times \frac{12}{6+12} = \frac{12}{\frac{6 \times 12}{6+12}} \times \frac{12}{6+12} = 2A$

$\therefore \boxed{i_1 = 2A}$

8

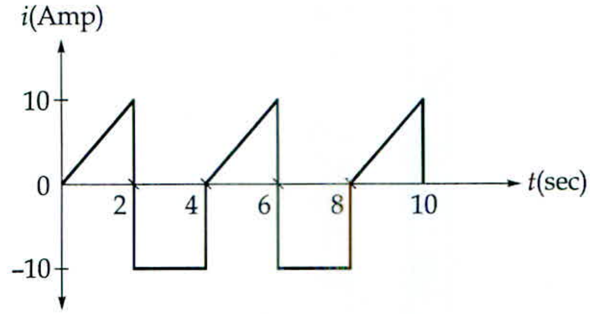
$\boxed{i_x = 1A}$

~~At Node A KCL : $i_2 + i_1 + i_x$~~

Now KVL $4i_2 - 4 - 12 = 0 \Rightarrow i_2 = 16/4 = 4A$

$\therefore$ $\left.\begin{array}{l} i_1 = 2A \\ i_2 = 4A \\ i_3 = 1A \end{array}\right\}$ An

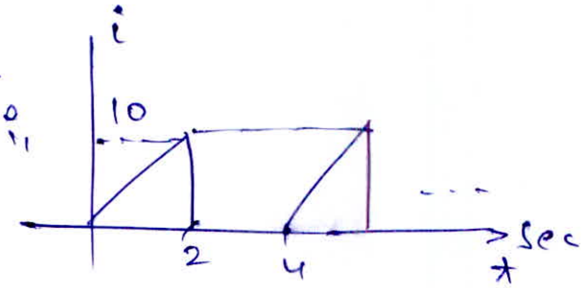
Q.5 (b) Determine the rms value of the waveform. If the current is passed through a 9 Ω resistor. Find the average power absorbed by the resistor.

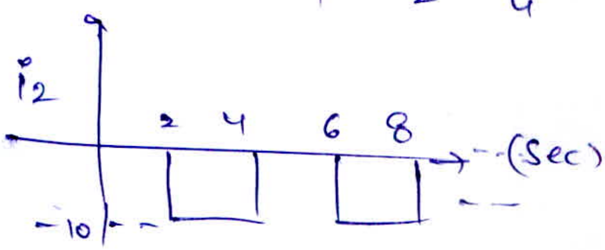


[12 marks]

Solution $i = i_1 + i_2$

where i_1





clearly i_1 & i_2 are orthogonal signals

$\therefore P_{Total} = P_{i_1} + P_{i_2} = \frac{(10)^2}{2 \times 3} + \frac{(10)^2}{2}$

Power total in w/f = 200/3

Now RMS value of waveform $= \sqrt{\text{Power}} = \sqrt{200/3}$

$\boxed{\text{RMS value of waveform} = 8.165A}$ Ans

P_{avg} (absorbed by Resistor) $= (8.165)^2 \times 9$

$\boxed{P_{avg} = 600 W}$ Ans

4

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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]

Solution

To check Controllability

Kalman's Test $Q = [B \quad AB \quad A^2B]$

$$AB = \underset{3\times3}{\begin{bmatrix} 1 & 3 & 1 \\ 0 & 1 & 0 \\ 2 & -4 & 6 \end{bmatrix}} \underset{3\times1}{\begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix}} = \begin{bmatrix} 1 \\ 0 \\ 6 \end{bmatrix}$$

$$A^2B = A \cdot AB = \begin{bmatrix} 1 & 3 & 1 \\ 0 & 1 & 0 \\ 2 & -4 & 6 \end{bmatrix} \begin{bmatrix} 1 \\ 0 \\ 6 \end{bmatrix} = \begin{bmatrix} 7 \\ 0 \\ 38 \end{bmatrix}$$

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

clearly $|Q| = 0$

$\therefore$ above System is Non-controllable System

6

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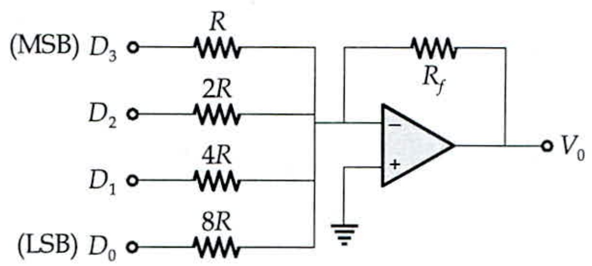
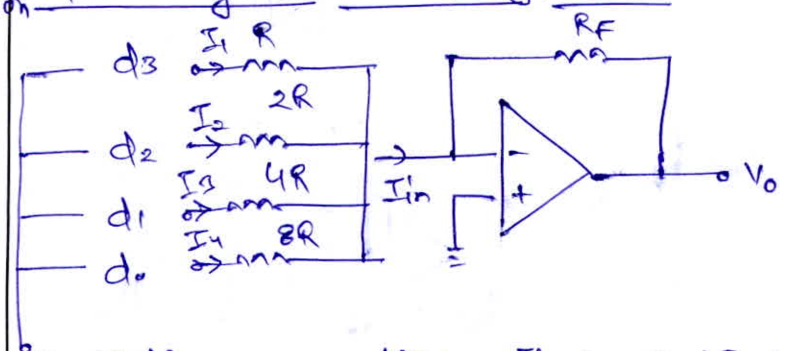
Q.5 (d) **(i)** With a neat block diagram, explain the operation of 4-bit weighted-resistor type DAC.

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



[12 marks]

Solution: 4 Bit Weighted Resistor Type DAC



V_R if $d_i = 1$
OR GND if $d_i = 0$

Now $I_{in} = I_1 + I_2 + I_3 + I_4$

$$= \frac{V_R d_3}{R} + \frac{V_R d_2}{2R} + \frac{V_R d_1}{4R} + \frac{V_R d_0}{8R}$$

Now $V_{output} = -I_{in} R_F$

$$V_{o/p} = \frac{-V_R}{R}(R_F)\left[d_3 + \frac{d_2}{2} + \frac{d_1}{2^2} + \frac{d_0}{2^3}\right]$$

$$V_{o/p} = \frac{V_R}{2^3}\left(\frac{-R_F}{R}\right)\left[d_3 \cdot 2^3 + d_2 \cdot 2^2 + d_1 2^1 + d_0 2^0\right]$$

$$\therefore V_{o/p} = \frac{-V_R R_F}{(2^{n-1})R} \left(\text{decimal equivalent of digital i/p}\right)$$

where n: no of bits in digital i/p

$(2^{n-1})R$: LSB Resistor

(ii) if i/p's are 0V and 5V

weight of D_3 bit $= R_f \frac{V_R}{R} = \frac{5 \times 1K}{1K} = 5V$ Ans

D_2 bit $= \frac{V_R}{2R} \times R_f = \frac{5 \times 1K}{2K} = 2.5V$ Ans

D_1 bit $= \frac{V_R}{4R} \times R_f = 1.25V$ Ans

D_0 bit $= \frac{V_R}{8R} \times R_f = 0.625V$ Ans

6

Now if $R_F = 500\Omega$

$(V_{o/p})_{\text{Full scale}} = \frac{V_R}{2^3 R}(R_F)$ [decimal input equivalent]

$= (10 + 5 + 2.5 + 1.25) = \cancel{18}.75V$ Ans

??

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

[12 marks]

Solution

Control Signals For memory and I/O

(i) $\overline{MEMR}$: memory Read

if $\overline{MEMR}$: 0 = memory read operation takes place

$\overline{MEMR}$: 1 = disabled

(ii) $\overline{MEMW}$: memory write operation

$\overline{MEMW}$: 0 = memory write operation takes place

$\overline{MEMW}$: 1 = disabled

(iii) $\overline{IOR}$: I/O device read operation

$\overline{IOR}$: 0 : Enabled

1 : disabled

(iv) $\overline{IOW}$: I/o device write operation

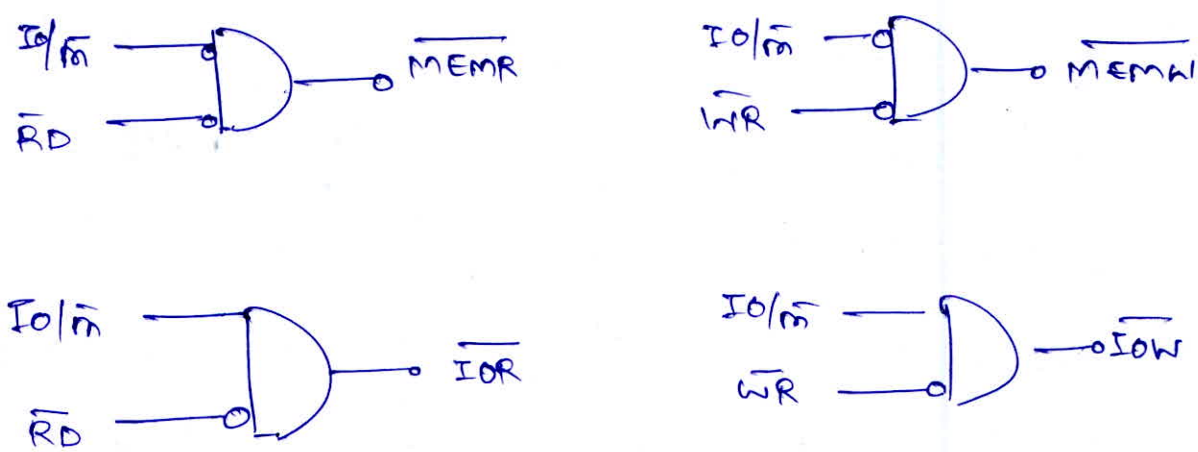
$\overline{IOW}$: 0 : enabled
1 : disabled

Now

$IO/\overline{m}$: Selecting I/o or memory

$IO/\overline{m}$: 0 : memory is selected

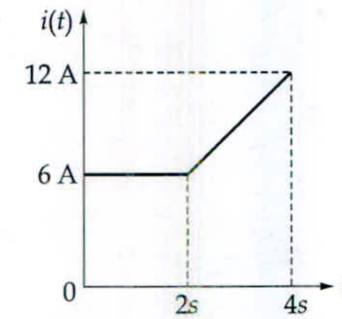
$IO/\overline{m}$: 1 : ~~mem~~ I/o is selected



8

table and circuit

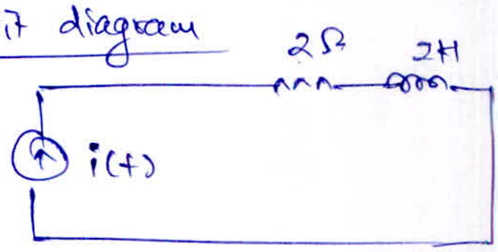
Q.6 (a) **(i)** Figure below shows the waveform of the current passing through an inductor of resistance 2 Ω and inductance 2 H. Find the energy absorbed by the inductor in the first four seconds.



[12 marks]

Solution

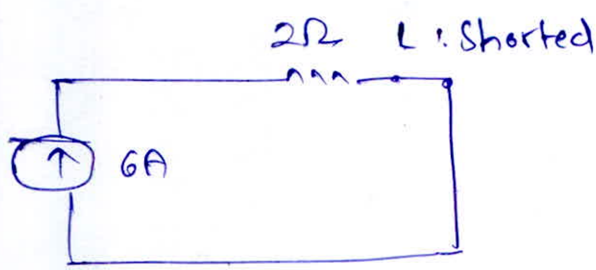
Circuit diagram



Now From $t=0$ to $t=2$ sec

$i(t) = \text{constant} = 6A$

$\therefore$ equivalent circuit :



$\therefore$ energy absorbed by inductor in First 2 Seconds $= 0$

From $t=2$ sec to $t=4$ sec

$i_L(2^-) = i_L(2^+) = 6A$

Now energy Stored by inductor in (2 to 4) Sec.

$$\text{Energy} = \int_2^4 V_L i_L \, dt$$

$$= \int_2^4 L \frac{di_L}{dt} i_L \, dt$$

$$\text{Energy} = L\int_{2}^{4} i_L \, di_L = L\frac{i_L^2}{2}\Big|_2^4$$

$\therefore$ energy stored $= \frac{1}{2}L\left(i(4)^2 - i(2^+)^2\right)$

$$= \frac{1}{2} \times 2\left[(12)^2 - (6)^2\right]$$

$$= 108 \text{ Joules}$$

$\therefore$ total energy stored in inductor from (0-4 sec)

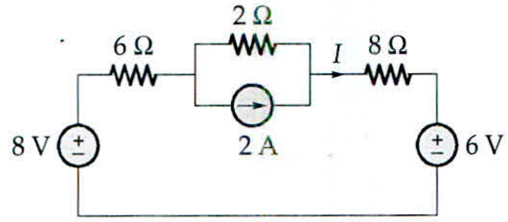
$$= E_1 + E_2$$

$$= 0 + 108$$

$$= 108 \text{ Joules}$$

4

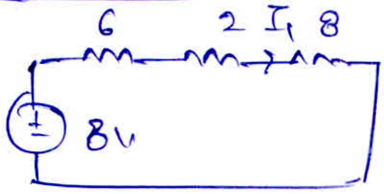
Q.6 (a) **(ii)** Find the current I in the circuit shown below using the superposition theorem.



[8 marks]

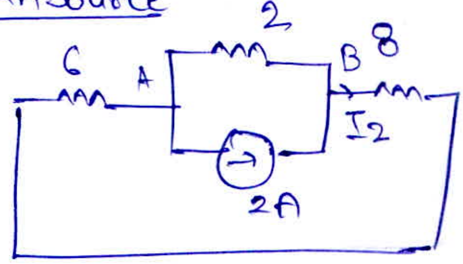
Solution

8V Source



$$I_1 = \frac{8}{8+6+2} = 0.5A$$

2A Source



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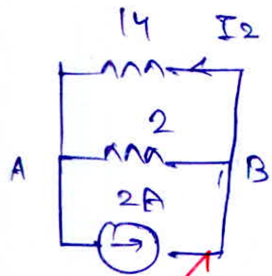
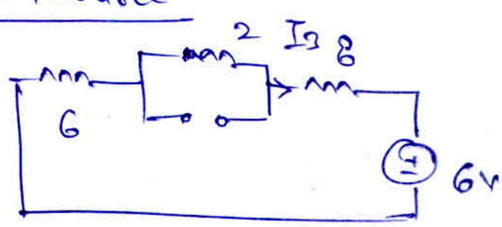


$\therefore$

$$I_2 = 2 \times \frac{2}{16} = \frac{1}{4}A$$

6V Source



$$I_3 = \frac{-6}{6+2+8} = -3/8\,A$$

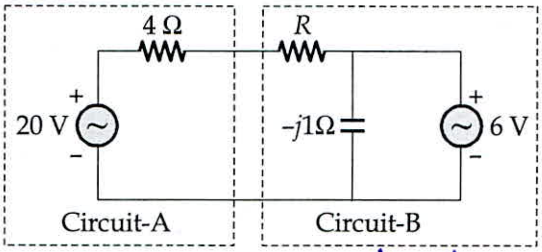
$\therefore$ By superposition Theoram

$$\boxed{I = I_1 + I_2 + I_3 = 3/8 \text{ A} \quad \text{Ans}}$$

$= 0.375A$ Ans

7

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.

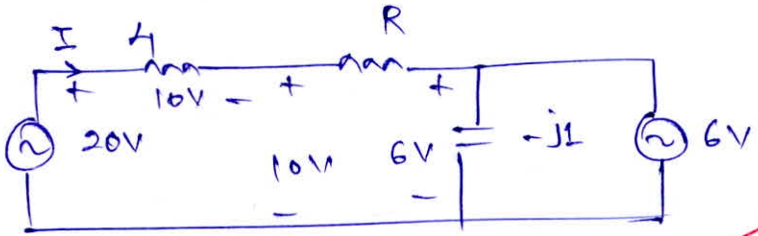


[12 marks]

Solution At Max power Transfer

V_{TH} gets divided equally b/w R_{TH} & load

Here let circuit B : LOAD



$I = \frac{10}{4} A = 2.5A$

Now clearly Voltage across R = $10 - 6 = 4V$

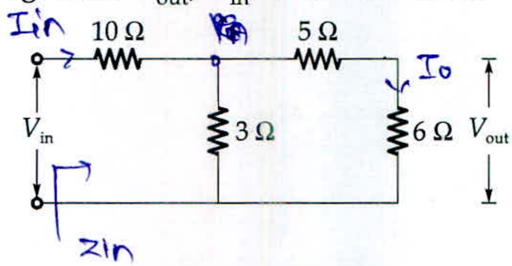
Current through R = $2.5A$

$\therefore \boxed{R = \frac{4}{2.5} = 1.6\Omega}$ Ans

For maximum power Transfer

10

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



[8 marks]

Solution

$Z_{in} = 10 + 3 \| 11 = 173/14 \ \Omega$

$\therefore I_{in} = \frac{V_{in}}{Z_{in}} = \frac{14 V_{in}}{173} \ A$

Now $I_o = I_{in} \times \frac{3}{14}$

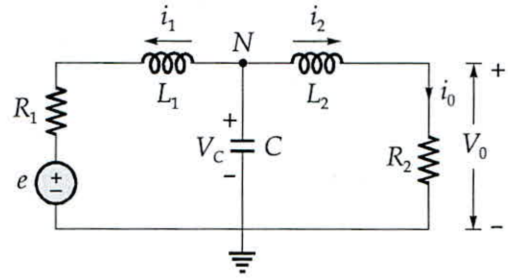
$I_o = \frac{3 V_{in}}{173} \ A$

Now $\frac{V_{out}}{V_{in}} = \frac{6 \times \frac{3 V_{in}}{173}}{V_{in}} = \frac{18}{173}$

$\boxed{\frac{V_{out}}{V_{in}} = 0.104 = \frac{18}{173}}$ Ans

7

Q.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)



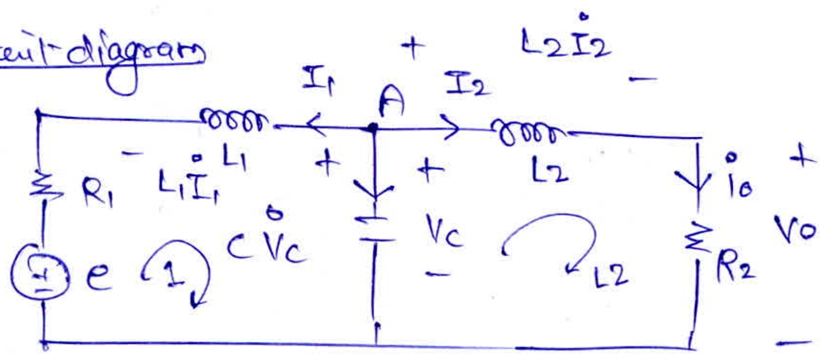
[10 marks]

Solution Now $U = e$

$$Y = \begin{pmatrix} Y_1 \\ Y_2 \end{pmatrix} = \begin{pmatrix} i_0 \\ V_0 \end{pmatrix}$$

$$X = \begin{pmatrix} X_1 \\ X_2 \\ X_3 \end{pmatrix} = \begin{pmatrix} I_1 \\ I_2 \\ V_C \end{pmatrix} \quad ; \quad \dot{X} = \begin{pmatrix} \dot{X}_1 \\ \dot{X}_2 \\ \dot{X}_3 \end{pmatrix} = \begin{pmatrix} \dot{I}_1 \\ \dot{I}_2 \\ \dot{V}_C \end{pmatrix}$$

circuit diagram



At node A, KCL $\quad I_1 + I_2 + C\dot{V}_C = 0$

$$\therefore \dot{V}_C = -\frac{I_1}{C} - \frac{I_2}{C}$$

$$\boxed{\dot{X}_3 = -\frac{X_1}{C} - \frac{X_2}{C}} \quad -(1)$$

KVL in loop 1

$$-L_1\dot{I}_1 + V_C - e - I_1R_1 = 0$$

$$\Rightarrow -L_1\dot{I}_1 = e - V_C + I_1R_1$$

$$\Rightarrow \frac{V_C - e - I_1R_1}{L_1} = \dot{I}_1 \Rightarrow \boxed{\dot{X}_1 = -\frac{R_1}{L_1}X_1 + \frac{X_3}{L_1} - \frac{U}{L_1}}$$

In Loop2 KVL, $+L_2\dot{I}_2 + I_2R_2 - V_C = 0$

$$\dot{I}_2 = -\frac{I_2R_2}{L_2} + \frac{V_C}{L_2}$$

$$\therefore \boxed{\dot{X}_2 = -\frac{R_2}{L_2}X_2 + \frac{X_3}{L_2}}$$

Now $Y_1 = i_0 = I_2 = X_2$

$Y_2 = V_0 = I_2R_2 = R_2X_2$

Now state space model

$$\begin{pmatrix} \dot{X}_1 \\ \dot{X}_2 \\ \dot{X}_3 \end{pmatrix} = \begin{pmatrix} -R_1/L_1 & 0 & 1/L_1 \\ 0 & -R_2/L_2 & 1/L_2 \\ -1/C & -1/C & 0 \end{pmatrix} \begin{pmatrix} x_1 \\ x_2 \\ x_3 \end{pmatrix} + \begin{pmatrix} -1/L_1 \\ 0 \\ 0 \end{pmatrix} u$$

$$Y = \begin{pmatrix} Y_1 \\ Y_2 \end{pmatrix} = \begin{pmatrix} 0 & 1 \\ 0 & R_2 \end{pmatrix} \begin{pmatrix} x_1 \\ x_2 \end{pmatrix}$$ Ans

7

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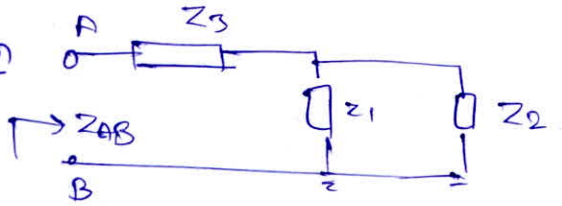
Q.6 (d) Two impedances $Z_1 = 5\ \Omega$ and $Z_2 = (5 - jX_C)\Omega$ are connected in parallel and this combination is connected in series with $Z_3 = (6.25 + j1.25)\Omega$. Determine the value of capacitance of X_C to achieve resonance if the supply is 100 V, 50 Hz.

[10 marks]

Solution



Now $Z_{AB} = Z_3 + Z_1 || Z_2$

$$= (6.25 + 1.25j) + \frac{5(5 - jX_C)}{5 + 5 - jX_C}$$

$$= (6.25 + 1.25j) + \frac{(25 - 5jX_C)(10 + jX_C)}{(10 - jX_C)(10 + jX_C)}$$

$$= 6.25 + 1.25j + \frac{1}{(100) + X_C^2}\left[250 + j25X_C - 50X_Cj + 5X_C^2\right]$$

Now For Resonance

$Im(Z_{ab}) = 0$

$$\Rightarrow 1.25 + \frac{1}{(100) + X_C^2}(-25X_C) = 0$$

$$\Rightarrow 1.25 = \frac{25X_C}{100 + X_C^2}$$

$$\Rightarrow 125 + 1.25X_C^2 - 25X_C = 0$$

$\therefore$ Solving $X_C = 10\Omega$

Now $\frac{1}{\omega C} = 10 \Rightarrow C = \frac{1}{2\pi \times 50 \times 10}$

$$\boxed{C = 318.31\ \mu F}$$ Ans

10

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

[8 marks]

Q.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:

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

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.

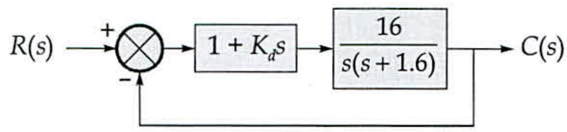
[20 marks]

Q.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]

Q.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]

Solution Given System

$$\frac{C(s)}{R(s)} = \frac{(1+K_d s)\frac{16}{s^2+1.6s}}{1+\frac{(1+K_d s)16}{s^2+1.6s}}$$

$$\frac{C(s)}{R(s)} = \frac{(1+K_d s)16}{s^2+1.6s+16+K_d s\,16} = \frac{(1+K_d s)16}{s^2+(1.6+16K_d)s+16}$$

$$\frac{C(s)}{R(s)} = \frac{16(1+K_d s)}{s^2+s(1.6+16K_d)+16}$$

$$= \frac{16(1+K_d s)}{\left(s+\frac{1.6+16K_d}{2}\right)^2+16-\left(\frac{1.6+16K_d}{2}\right)^2}$$

$$\text{Now } C(s) = \frac{16(1+K_d s)}{s\left\{\left(s+\frac{1.6+16K_d}{2}\right)^2+16-\left(\frac{1.6+16K_d}{2}\right)^2\right\}}$$

$$= \frac{1}{s} + \frac{}{\left(s+\frac{1.6+16K_d}{2}\right)^2+16-\left(\frac{1.6+16K_d}{2}\right)^2}$$

NOT ATTEMPTED

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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]

Q.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]

OOOO

I V

$P = VI$

$W = 2I^2R$

$\frac{\rho l}{A}$ $\cancel{R} = \frac{2I^2}{W} = \frac{2}{\omega}\left(\frac{P}{V}\right)^2$

$l \to$ const.

$A = \frac{\rho \omega V^2}{2P^2}$

$P = VI$

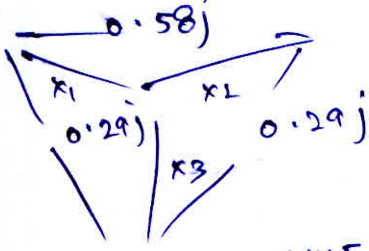
volume $\propto \frac{1}{V^2}$

$I = \frac{P}{V}$

$W = \cancel{2I^2R}\ 2\left(\frac{P}{V}\right)^2 R$

$16 - 0.8 - 8Kd$

Space for Rough Work



$x(t) = e^{At} x(0)$

$L^{-1}\{(sI-A)^{-1}\}\begin{pmatrix}1\\-2\end{pmatrix}$

$\begin{pmatrix}e^{-t}\\-2e^{-t}\end{pmatrix} = e^{At}\begin{pmatrix}1\\-2\end{pmatrix}$

$= \begin{pmatrix}e^{At}\\e^{-2At}\end{pmatrix}$

0.145   0.145

0.0725

$\begin{pmatrix}1 & 0\\0 & 1\end{pmatrix}$

$4^2 - (0.8+8Kd)^2$

$A = 1$

e^{t}

$\lambda = -1$

$\lambda = -2$

character

$(\lambda+1)(\lambda+2)$

$(3.2-8Kd)(4.8+8Kd)$

$|sI-A| = s^2+3s+2=0$

$$\frac{16(1+Kds)}{s\left[\left[s+(0.8+8Kd)\right]^2+(3.2-8Kd)(4.8+8Kd)\right]}$$

$$\left\{\frac{A}{s}+\frac{B}{(s+0.8+8Kd)^2+(3.2-8Kd)(4.8+8Kd)}\right\}$$

$16(1+Kds) = Bs + A\left(s^2+(0.8+8Kd)^2+(1.6+16Kd)s\right)$

$+ A(3.2-8Kd)(4.8+8Kd)$

16

$16Kd = B +$

190