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ESE 2024 : Mains Test Series

UPSC ENGINEERING SERVICES EXAMINATION

Electrical Engineering

Test-3 : Power Systems [All topics] + Systems and Signal Processing-1 + Microprocessor-1 Electrical Circuits-2 + Control Systems-2 [Part Syllabus]

Read question carefully

Name :

Roll No

Test Centres			Student's Signature
Delhi ☑	Bhopal ☐	Jaipur ☐	
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Instructions for Candidates

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

FOR OFFICE USE

Question No.	Marks Obtained
Section-A	
Q.1	45
Q.2	44
Q.3	
Q.4	54
Section-B	
Q.5	47
Q.6	
Q.7	25
Q.8	
Total Marks Obtained	215

Signature of Evaluator: Sourabh kumar

Cross Checked by

IMPORTANT INSTRUCTIONS

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

DONT'S

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

DO'S

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

Do not write in this margin

Section A : Power Systems

Q.1 (a) A 66 kV concentric cable with intersheath has a core diameter of 1.6 cm. 3 mm thick dielectric materials constitute the three zones of insulation. Determine the maximum stress in each of the three layers if 20 kV is maintained across each of the inner two layers.

[12 marks]

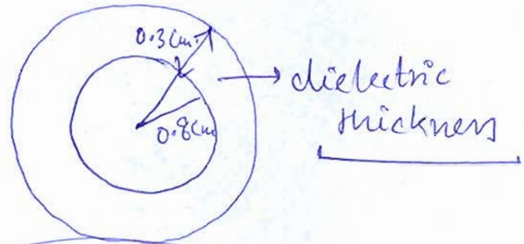
core diameter = 1.6 cm

thickness = 3 mm

= 0.3 cm.

$r = 0.8$ cm.

$r_1 = 1.1$ cm.



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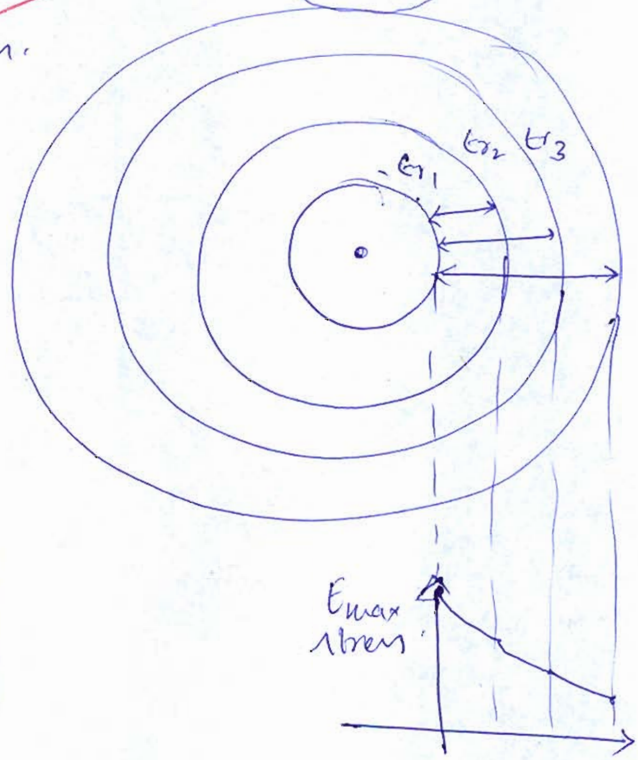

$$\boxed{E = \frac{q}{2\pi\epsilon_0 r} \text{ [illegible]}}$$

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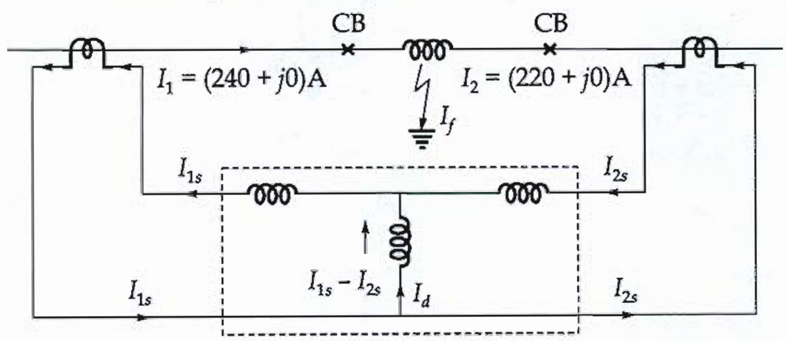
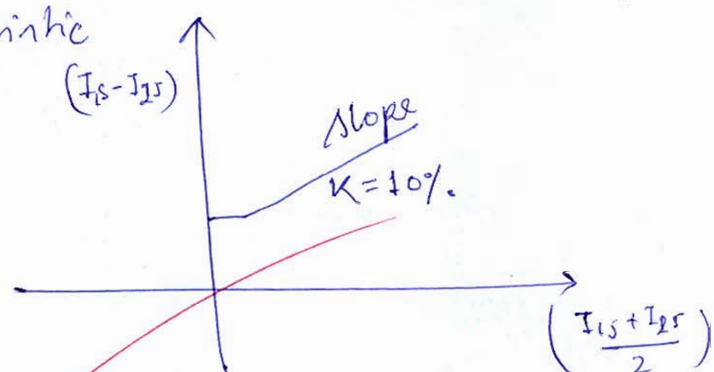
Q.1 (b) Figure below shows percentage differential relay is applied for the protection of a generator winding. The relay has 10% slope of its operating characteristic on $\frac{(I_{1s} + I_{2s})}{2}$ versus $(I_{1s} - I_{2s})$ diagram. A high resistance ground fault occurred near the grounded neutral end of the generator winding while generator is carrying load. As a consequence, the currents flowing at each end of the winding are shown in the figure below. Assuming CT ratio of 400/5 ampere, will the relay operate to trip the breaker?



[12 marks]

Operating characteristic



CT ratio given 400/5 Ampere/A

$I_1 = 240$ A

CT_1 ratio $= 400/5$

current in relay coil 1s $= \left(I_1 / CT\,ratio\right)$

$= \left(\frac{240}{400/5}\right)$

$= \frac{\cancel{240} \times 5}{\cancel{400}_{8}}$

$\boxed{I_{1s} = 3A}$

$I_2 = 220A$.

CT ratio $= \left(400/5\right)$

current in relay 2 coil $= \left(\frac{220}{400/5}\right)$

$= \frac{22\cancel{0} \times \cancel{5}}{\cancel{40}\cancel{0}_{8}}$

$= \left(\frac{11}{4}\right) = 2.75A$

relay current i_R

$i_R = I_{1S} - I_{2S}$

$= 3 - 2.75$

$= 0.25A$.

I_o is not given hence we take $I_o = 0$

10% slope is given

then

$I = \left(\frac{10}{100}\right) \times \left(\frac{I_{1S} + I_{2S}}{2}\right)$

$= \frac{1\cancel{0}}{10\cancel{0}} \times \left(\frac{5.75}{2}\right)$

$= \frac{.575}{2}$

$I = .2875 A$.

$i_R = 0.25A$

$\boxed{i_R < I}$

hence $\boxed{\text{relay will not trip}}$

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Q.1 (c) A 50 Hz, 4 pole, turbo-generator rated 100 MVA, 11 kV has an inertia constant of 8 MJ/MVA.

(i) Determine the stored energy in the rotor at synchronous speed.

(ii) If the mechanical input is suddenly raised to 80 MW for an electrical load of 50 MW, determine acceleration in elec-degree/sec^2, neglecting mechanical and electrical losses.

(iii) If the acceleration calculated in part (ii) is maintained for 10 cycle, determine the change in torque angle and rotor speed in revolutions per minute at the end of the period.

[2 + 5 + 5 marks]

(i) $S = 100\,MVA$, $V = 11\,KV$

Inertia constant $= 8\,MJ/MVA$

Pole $= 4$

frequency $= 50\,Hz$

Stored energy $KE = H \cdot S$

$= (8 \times 100)\,MJ$

$= 800\,MJ$

(ii) electrical load $= 50\,MW$

suddenly raised to $= 80\,MW$

$P_a = (80 - 50) = 30\,MW$

$(P_a)_{pu} = \left(\frac{30}{100}\right) = 0.3\,pu$

swing equation

$$\left(\frac{2H}{w_s}\right)\left(\frac{d^2\delta}{dt^2}\right) = (P_a)_{pu}$$

$$\left(\frac{2H}{w_s}\right) a = (P_a)_{pu}$$

$$a = \left(\frac{0.3 \times 2\pi \times 50}{2 \times 8}\right) \text{ electrical rad/sec}^2$$

$$a = \left(\frac{0.3 \times 2 \times 180 \times 50}{2 \times 8}\right) \text{ electrical-degree}/s^2$$

$$\boxed{a = 337.5 \text{ elec-rad}/s^2}$$

(iii) acc^n in mech-rad/s²

$$a = \left(\frac{0.3 \times \cancel{2} \times \pi \times 50}{\cancel{2} \times 8}\right)\left(\frac{\cancel{2}}{\cancel{4}_2}\right) \text{ mech-rad}/s^2$$

$$= \left(\frac{0.3 \times 50\pi}{16}\right)$$

$$= 2.945 \text{ mech-rad}/s^2$$

acc^n is constant for 10 cycle.

$$\frac{d^2\delta}{dt^2} = 2.945 \qquad \frac{d\delta}{dt} = 2.945t$$

$$\frac{d\delta}{dt} = \Delta\omega = 2.945\left(\frac{10}{50}\right)$$

$$\Delta\omega = 0.589 \text{ rad/s}.$$

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$$\Delta\omega = 0.589 \frac{\times 60}{2\pi} \text{ rpm}$$

$$= 5.625 \text{ rpm}$$

Good Approach

$$\omega_s = \left(\frac{\overset{3}{\cancel{120}} \times 50}{\cancel{4}}\right) = 1500 \text{ rpm}.$$

$$\omega = \omega_s + \Delta\omega = \underline{1500 + 5.625}$$

$$\boxed{\omega = 1505.625 \text{ rpm}}$$

$$\frac{d\delta}{dt} = 2.945t$$

$$\Delta\delta = \left(\frac{2.945t^2}{2}\right) \text{ rad} = 0.0589 \text{ rad}$$

$$\boxed{\Delta\delta = 3.374^\circ}$$

Q.1 (d) The per phase impedance of 3-ϕ short transmission line is $(0.3 + j0.4)\Omega$. The sending-end line to line voltage is 3300 V and the load at the receiving end is 300 kW per phase at 0.8 pf lagging. Calculate receiving end voltage and line current.

[12 marks]

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

sending end line voltage = 3300 V

load at receiving end = 300 kW per phase

0.8 pf lagg.

short transmission line

ABCD parameter = $\begin{bmatrix} 1 & Z \\ 0 & 1 \end{bmatrix}$

$$\boxed{I_s = I_R}$$

$$\boxed{V_s = V_R + Z I_R}$$

$V_s = 3.300\angle\delta$, $V_R = |V_R|\angle 0^\circ$

$$I_R = \left(\frac{300 \times 3}{\sqrt{3} \times V_R \times 0.8}\right) = \left(\frac{300\sqrt{3}}{0.8 V_R}\right) \text{ kA} \angle -36.86^\circ$$

$$\text{real}(S_R)\,P_R = (V_R\angle 0) \times \left(\frac{300\sqrt{3}}{V_R}\right)\angle 36.86^\circ$$

$$S_R = (V_R\angle 0)\left(\frac{V_s\angle\delta - V_R\angle 0}{Z\angle\theta}\right)^*$$

$$= V_R\angle 0\left(\frac{V_s\angle -\delta - V_R\angle 0}{Z\angle -\theta}\right)$$

$$\boxed{S_R = \frac{V_s V_R}{Z}\angle\theta-\delta - \frac{V_R^2}{Z}\angle\theta}$$

$$P_R = \frac{V_s V_R}{Z}\cos(\theta-\delta) - \frac{V_R^2}{Z}\cos\theta$$

$$Q_R = \frac{V_s V_R}{Z}\sin(\theta-\delta) - \frac{V_R^2}{Z}\sin\theta$$

$P_R = \frac{V_s V_R}{Z}\cos(\theta-\delta) - \frac{V_R^2}{Z}\cos\theta$

$P_R = 300$ per phase $\qquad Z = \underline{0.5\angle 53.13^\circ}$

$\boxed{P_{R3\phi} = 3\times 300 = 900}$

$900 = \frac{(3.3)V_R}{0.5}\cos(\theta-\delta) - \frac{V_R^2}{0.5\times 1000}\cos(53^\circ)$

$Q_R = 3\times 300\tan(\cos^{-1}0.8) = 675$

$675 = \frac{(3.3)V_R}{0.5}\sin(\theta-\delta) - \frac{V_R^2\sin 53^\circ}{0.5\times 1000}$

$(675+1.6\times10^{-3}V_R^2) = 6.6V_R\sin(\theta-\delta)$ —— (I)

$(900+1.2\times10^{-3}V_R^2) = 6.6V_R\cos(\theta-\delta)$ —— (II)

squaring & adding (I) & (II)

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$(675+0.16\times10^{-3}V_R^2)^2 + (900+1.2\times10^{-3}V_R^2)^2 = (6.6V_R)^2$

$\boxed{V_R = 3126.92 \text{ Volt line}}$

$\left[\frac{900+1.2\times10^{-3}(3126.92)^2}{6.6\times 3126.92}\right] = \sin(\theta-\delta)$

$\theta-\delta = 37.744$

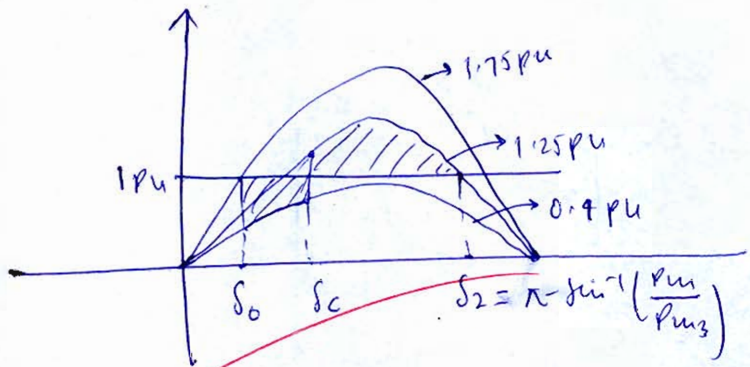
$\delta = \underline{15.385}$

$I_R = \frac{1}{\sqrt{3}}\left(\frac{3.3\angle 15.385 - 3.126\angle 0}{0.5\angle 53.13^\circ}\right) = \underline{1012.9\angle 86.966}$

Q.1 (e) A three phase generator delivers 1.0 p.u. power to an infinite bus through a transmission network when a fault occurs. The maximum power which can be transferred in pre-fault, during fault and post fault conditions are 1.75 p.u., 0.4 p.u and 1.25 p.u. respectively. Find the critical angle.

[12 marks]

Pre fault $= 1.75$ pu
during fault $= 0.4$ pu
post fault $= 1.25$ pu.



Critical angle

$$\delta_c = \cos^{-1}\left[\frac{P_m(\delta_{2max} - \delta_0) + P_{m3}\cos\delta_{2max} - P_{m2}\cos\delta_0}{P_{m3} - P_{m2}}\right]$$

$P_m = 1$ pu

$P_{m3} = 1.25$ pu (post fault)

$P_{m2} = 0.4$ (during fault)

$\delta_0 = \sin^{-1}\left(\frac{P_m}{P_{m1}}\right)$

$= \sin^{-1}\left(\frac{1}{1.75}\right) = 0.608$ rad.

$\delta_2 = \pi - \sin^{-1}\left(\frac{1}{1.25}\right) = 2.214$ rad.

$$\delta_c = \cos^{-1}\left[\frac{1(2.214-0.608)+1.25(\cos 2.214)-0.4\cos 0.608}{1.25-0.4}\right]$$

$$= \cos^{-1}\left[\frac{1.6063+1.25\cos(2.214)-0.4\cos 0.608}{1.25-0.4}\right]$$

$$= \cos^{-1}\left[\frac{1.6063-1.078}{1.25-0.40}\right]$$

$$= \cos^{-1}(0.6215)$$

$$\boxed{\delta_c = 0.9\,rad.}$$

$$\boxed{\delta_c = 51.573^{\circ}\ degree}$$

critical angle.

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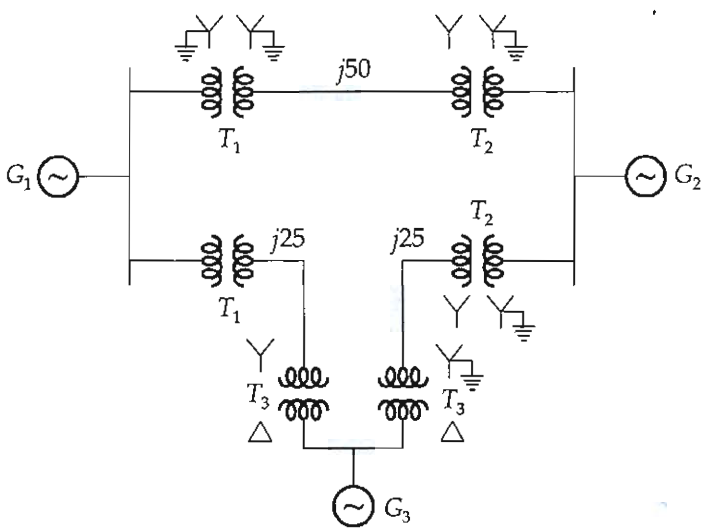
Good Approach

Q.2 (a) A 3-bus system is given in figure below. The ratings of the various components are listed below :

Generator 1 = 50 MVA;	13.8 kV;	$X'' = 0.15$ pu
Generator 2 = 40 MVA;	13.2 kV;	$X'' = 0.20$ pu
Generator 3 = 30 MVA;	11 kV;	$X'' = 0.25$ pu
Transformer 1 = 45 MVA,	11 kV Δ/110 kV Y,	$X = 0.1$ pu
Transformer 2 = 25 MVA,	12.5 kV Δ/115 kV Y,	$X = 0.15$ pu
Transformer 3 = 40 MVA,	12.5 kV Δ/115 kV Y,	$X = 0.1$ pu

The line impedances are shown in figure below. Determine the reactance diagram based on 50 MVA and 13.8 kV as base quantities in Generator 1.



[20 marks]

given base = 50MVA

voltage base = 13.8 kV

generator 1.

50MVA , 13.8 kV $X'' = 0.15$ pu

old base of generator 1 is same as new base of generator 1

hence $\boxed{X'' = 0.15 \text{ pu}}$

generator 2.

40MVA = old base , 13.2 kV (old voltage base)

$X''_{pu} = 0.2$

new base 50MVA, 13.8kV

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$$X''_{G2\,pu(new)} = X''_{G2(old)}\left(\frac{V_{old}^2}{S_{old}}\right) \times \left(\frac{S_{new}}{V_{new}^2}\right)$$

$$= 0.2\left(\frac{13.2^2}{40}\right) \times \left(\frac{50}{13.8^2}\right)$$

$$= 0.2287\ pu.$$

generator 3.

old base = 30 MVA, 11 kV

$X_{old\,pu} = 0.25$

new base = 50 MVA, 13.8 kV

$$X_{new} = X_{old}\left(\frac{V_{old}^2}{S_{old}}\right)\left(\frac{S_{new}}{V_{new}^2}\right)$$

$$= 0.25\left(\frac{11^2}{30}\right)\left(\frac{50}{13.8^2}\right)$$

$$\boxed{X_{new} = 0.2697\ pu}$$

Transformer 1.

old base 45 MVA.

new base 50 MVA

$$X_{T_1} = 0.1\left(\frac{50}{45}\right)$$

$$= 0.11\ pu.$$

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Transformer 2.

$$X_{T_2} = 0.15\left(\frac{50}{25}\right)$$

$$= 0.3\ pu.$$

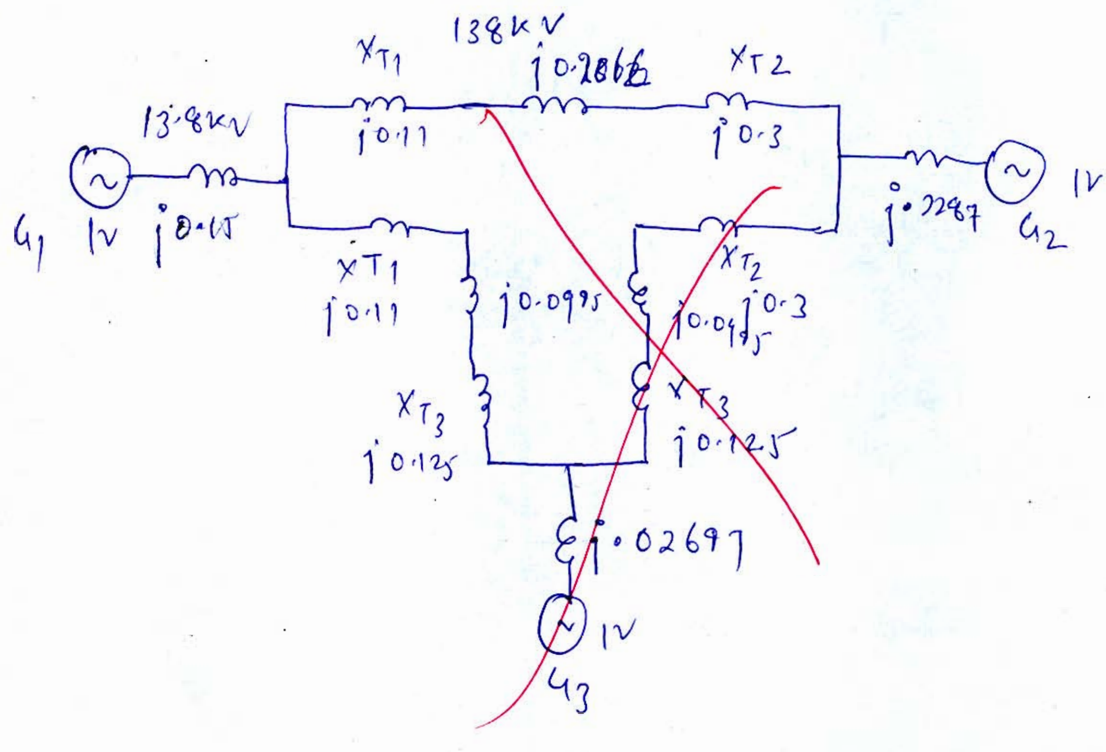
Transformer 3.

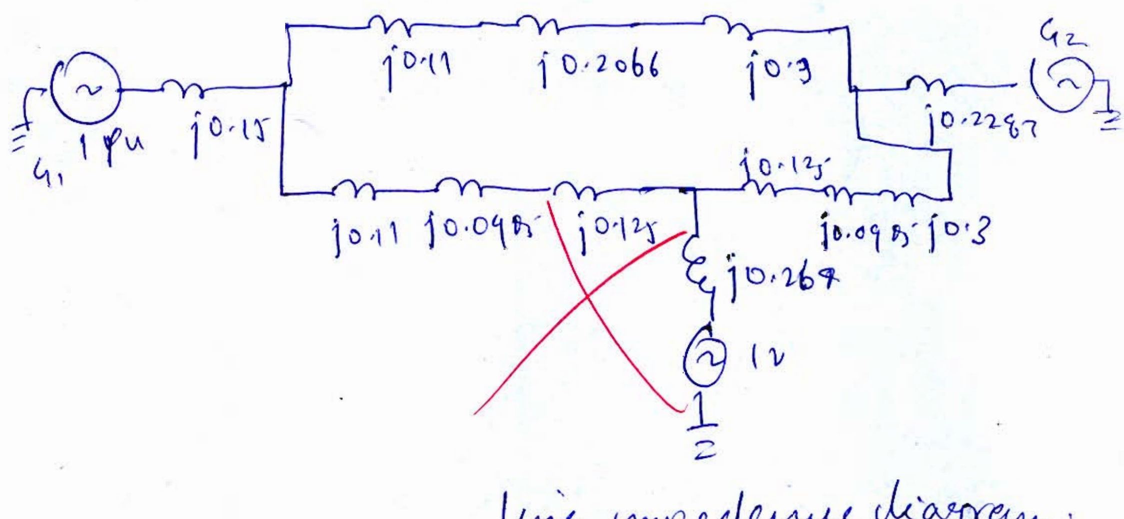
$$X_{T_3} = 0.1\left(\frac{50}{40}\right)$$

$$= 0.125\ pu.$$

$$\text{line}_1 = j50\left(\frac{50}{138^2}\right) = j0.2066\ \text{pu.}$$

$$\text{line}_2 = j25\left(\frac{50}{115^2}\right) = j0.0945$$





<u>Line impedance diagram.</u>

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Q.2 (b) Explain briefly what is swing equation and use dynamics of angular motion with time to formulate the equation for a synchronous generator of inertia constant H in seconds run by a mechanical turbine with input power P_m in p.u. to deliver electrical power P_e in p.u. to the electrical network at f Hz in terms of power angle δ in radians measured from rotating reference of generator axis.

[20 marks]

$$J\frac{d^2\theta_m}{dt^2} = \text{Torque}$$

J = moment of inertia

$$\text{Torque} = \left(J\frac{d\omega}{dt}\right)$$

$\theta_m = \delta - \delta_0$ (angle of load generator)

$$\frac{d\theta_m}{dt} = \left(\frac{d\delta}{dt}\right) \quad \text{(angular motion)}$$

$$\boxed{\frac{d^2\theta_m}{dt^2} = \frac{d^2\delta}{dt^2}}$$

$$J\frac{d^2\delta}{dt^2} = \text{Torque}$$

multiply by ω on both side

$$J\omega\left(\frac{d^2\delta}{dt^2}\right) = T\cdot\omega = P = (P_m - P_e)$$

$$M\frac{d^2\delta}{dt^2} = (P_m - P_e)$$

$$\boxed{M = 2H/\omega_s}$$

$$\boxed{2H/\omega_s\left(\frac{d^2\delta}{dt^2}\right) = (P_m - P_e)} \rightarrow \text{known as swing equation}$$

P_m = mechanical i/p

P_e = electrical i/p

if we disturb by an small angle

and then

synchronising power $= \left(\frac{dP}{d\delta}\right)$

$$P = P_{max} \sin\delta$$

$$\frac{dP}{d\delta} = P_m \cos\delta$$

at $\delta = \delta_0$

$$\boxed{\frac{dP}{d\delta} = P_m \cos\delta_0}$$

$$\frac{2H}{\omega_s}\frac{d^2\delta}{dt^2} + (P_m \cos\delta_0)\frac{d\delta}{dt} = 0$$

$$\omega = \sqrt{\frac{\omega_s(P_m \cos\delta_0)}{2H}}$$

$$\boxed{f_{\text{frequency of oscillation}} = \frac{1}{2\pi}\sqrt{\frac{\omega_s(P_m \cos\delta_0)}{2H}} \text{ Hz}}$$

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Q.2 (c) A 3-ϕ, 400 km, 50 Hz long transmission line with series impedance of $(0.15 + j0.78)\ \Omega/\text{km}$ and shunt admittance of $j5.0 \times 10^{-6}$ ℧/km. Determine *A*, *B*, *C*, *D* parameter of line assuming :

(i) The line could be represented by nominal-T.

(ii) The line could be represented by nominal-π.

(iii) The exact representation.

[20 marks]

3φ, 400 km, 50 Hz.

series impedance $Z = (0.15 + j0.78)$

$= 0.794\angle 79.11^\circ\ \Omega/\text{km}$

shunt admittance $= 5\times10^{-6}$ ℧/km.

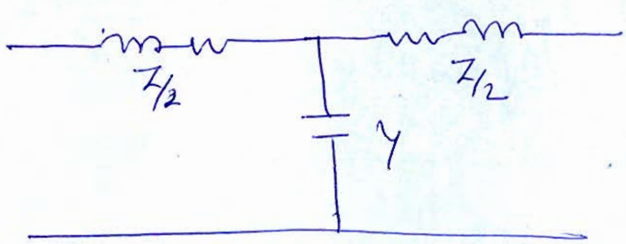
$Z = 400 \times 0.794\angle 79.11^\circ\ \Omega$

$$\boxed{Z = 317.716\angle 79.11^\circ\ \Omega}$$

$Y = 400 \times 5 \times 10^{-6}$ ℧ $\angle 90^\circ$

$Y = 2\times10^{-3}\angle 90^\circ$ ℧

(i) line represented by nominal-T



$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} 1+\frac{YZ}{2} & Z\left(1+\frac{YZ}{4}\right) \\ Y & 1+\frac{YZ}{2} \end{bmatrix}$$

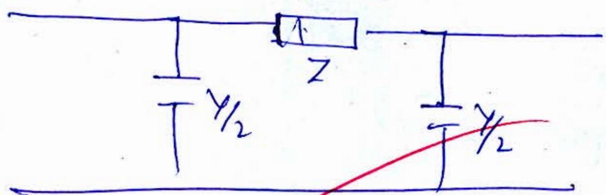
$A = \left(1+\frac{YZ}{2}\right) = 0.6906\angle 4.986^\circ$

$B = Z\left(1+\frac{YZ}{4}\right) = 268.322\angle 81.146^\circ$

$C = Y = 2\times10^{-3}\angle 90$, $D = 1+\frac{YZ}{2} = 0.6906\angle 4.98°$

ABCD parameter = $\begin{bmatrix} 0.6906\angle 4.98° & 268.322\angle 81.17° \\ 2\times10^{-3}\angle 90 & 0.6906\angle 4.986 \end{bmatrix}$

(ii) line represented by nominal π



ABCD parameter = $\begin{bmatrix} 1+\frac{YZ}{2} & Z \\ Y\left(1+\frac{YZ}{4}\right) & 1+\frac{YZ}{2} \end{bmatrix}$

$A = 1+\frac{YZ}{2} = 0.6906\angle 4.98°$

$B = Z = 317.716\angle 79.11°$

$C = Y\left(1+\frac{YZ}{4}\right)$

$= 1.689\times10^{-3}\angle 92.036°$

$D = A = 0.6906\angle 4.98°$

ABCD parameter = $\begin{bmatrix} 0.6906\angle 4.98 & 317.716\angle 79.11° \\ 1.689\times10^{-3}\angle 92.036° & 0.6906\angle 4.98 \end{bmatrix}$

(iii) exact representation
(long tx line)

ABCD parameter = $\begin{bmatrix} A(\cosh \gamma l) & Z_c \sinh \gamma l \\ \frac{\sinh \gamma l}{Z_c} & \cosh \gamma l \end{bmatrix}$

$$Z_c = \sqrt{Z/Y} = \sqrt{\frac{0.15 + j0.78}{5\times10^{-6} j}}$$

$$= \sqrt{158858.927 \angle -10.885}$$

$$= 398.57 \angle -5.442^\circ$$

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

$$= \sqrt{(0.15 + j0.78) \times 5\times10^{-6} j}$$

$$= \sqrt{3.97\times10^{-6}} \angle \frac{169.114}{2}$$

$$= 1.9924\times10^{-3} \angle 84.557$$

$$\gamma l = 1.9924\times10^{-3} \times 400 \angle 84.557$$

$$= 0.7969 \angle 84.557$$

$$\gamma l = \alpha l + j\beta l = 0.0755 + j0.793$$

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Good Approach

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

$$= \cosh(\alpha l + j\beta l)$$

$$= \cosh\alpha l \cos\beta l + j\sinh\alpha l \sin\beta l$$

$$= \cosh(0.0755)\cos(0.793) + j\sinh(0.0755)\sin(0.793)$$

$$\boxed{A = 0.7057 \angle 4.37^\circ = D}$$

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

$$= .71645 \angle 85.7144$$

$$B = Z_c \sinh(\gamma l) = 285.535 \angle 80.27$$

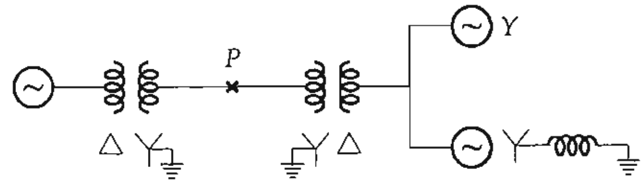
$$C = \frac{\sinh(\gamma l)}{Z_c} = 1.797\times10^{-3} \angle 91.15$$

$$ABCD \text{ parameter} = \begin{bmatrix} 0.7057\angle 4.37^\circ & 285.535\angle 80.27 \\ 1.797\times10^{-3}\angle 91.15 & 0.7057\angle 4.37^\circ \end{bmatrix}$$

Q.3 (a) A 50 Hz generator is delivering 50% of the power that it is capable of delivering through a transmission line to an infinite bus. A fault occurs that increases the reactance between the generator and infinite bus to 400% of the value before the fault. When the fault is isolated, the maximum power that can be delivered is 80% of the original maximum value. Determine critical clearing angle for the condition described.

[20 marks]

Q.3 (b) A 30 MVA, 13.8 kV, 3-phase alternator has a subtransient reactance of 15% and negative and zero sequence reactance of 15% and 5% respectively. The alternator supplies two motors over a transmission line having tensiometers of both-ends as shown on one line diagram. The motors having rated input of 20 MVA and 10 MVA both with 12.5 kV with 20% subtransient reactance and negative and zero sequence reactances are 20% and 5% respectively. Current limiting reactor of 2 Ω each are in the alternator and larger motor. The 3-phase transformers are both rated 35 MVA, 13.2 Δ - 115 Y kV with leakage reactance of 10%. Series reactance of the line is 80 Ω. The zero sequence reactance of the line is 200 Ω. Determine the fault current when (i) L-G, (ii) L-L, (iii) LLG and fault takes place at point P.



(Assume, $V_f = 120$ kV)

[20 marks]

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Q.3 (c) **(i)** Give the methods of improving string efficiency for an insulator.

(ii) A transmission line has a span of 375 m between level supports. The conductor has an effective diameters of 1.96 c.m. and weight 0.865 kg/m. Its ultimate strength is 9060 kg. If the conductor has ice coating of radial thickness 1.27 c.m. and subjected to a wind pressure of 3.9 gm/cm^2 of projected area. Calculate sag for a safety factor of 2. (Weight of 1 c.c. of ice is 0.91 gm).

[8 + 12 marks]

Q.4 (a) A star connected 3-phase, 10 MVA, 6.6 kV alternator has a per phase reactance of 20%. It is protected by Merz-price circulating current principle not less than 170 A. Calculate of the value of earthing resistance to be provided in order to ensure that only 20% of the alternator winding remains unprotected.

[20 marks]

10MVA, 6.6KV alternator

$X_{generator} = 0.2\,pu$

merge price circulating current $= 170A = I_n$

$$\%\ \text{unprotected} = \frac{I_n R_n}{\sqrt{V_{phase}^2 + (I_n X_G)^2}}$$

$$0.2 = \frac{170 \times R_n}{\sqrt{\left(\frac{6600}{\sqrt{3}}\right)^2 + (170 \times 0.8712)^2}}$$

$\Big(X_G = 0.2\,pu \longrightarrow$ pu is given but we have to convert in Ω because here we done calculation in original value

$X_G = \frac{0.2 \times 6.6^2}{10} \Big)$

$\underline{X_G = 0.8712\,\Omega}$

$170 \times R_n = 0.2 \times 3813.388$

$170 R_n = 762.677$

$R_n = \frac{762.677}{170}$

$$\boxed{R_n = 4.486\,\Omega}$$

for 20% alternator winding is unprotected to required 4.486 Ω resistor.

80% winding are protected when we use 4.486 Ω resistor.

$\boxed{R_n = 4.486\,\Omega}$

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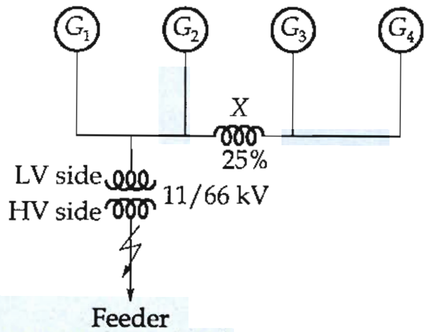
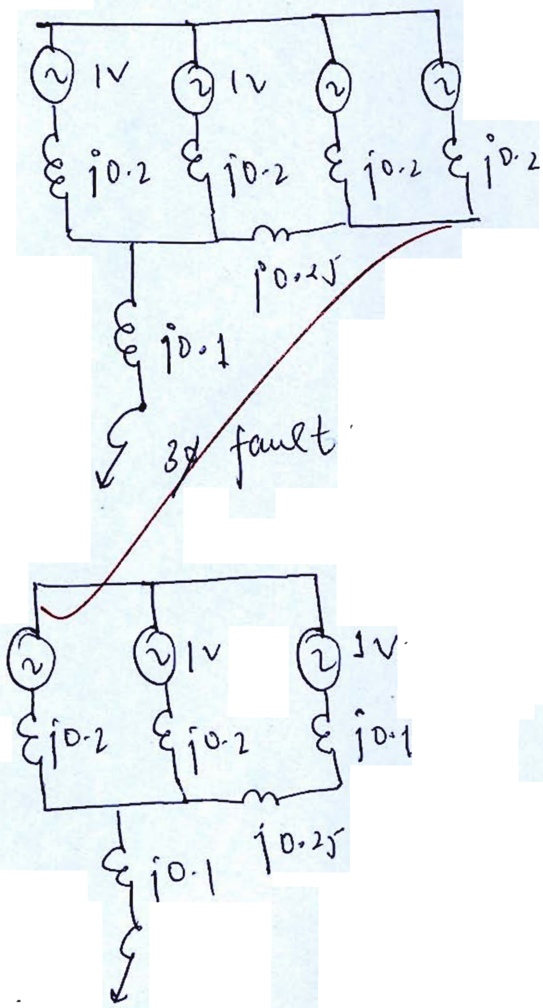
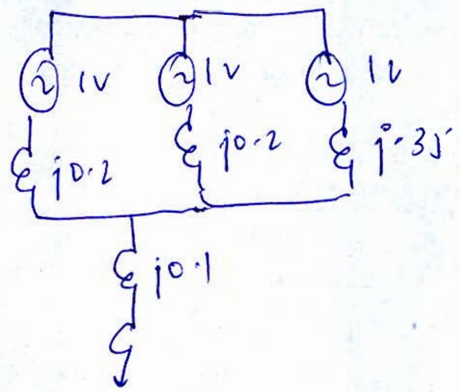
Q.4 (b) A generating station has four identical generators, G_1, G_2, G_3 and G_4 each of 20 MVA, 11 kV having 20% reactance. They are connected to a busbar which has a busbar reactor of 25% reactance on 20 MVA base, inserted between G_2 and G_3 as shown below. A 66 kV feeder is taken off from the bus 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 fed into the fault.



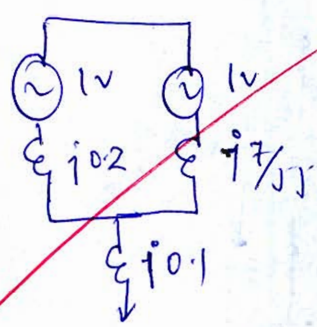
Let base = 20MVA, 11 kV

[20 marks]

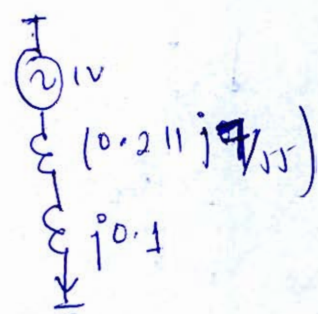




$\Rightarrow$



$\Rightarrow$



18

$$Z_{eq} = \left(j\frac{7}{90} + j0.1\right)$$

$$= \left(j\frac{8}{45}\right)$$

$$\text{fault current} = \left|\frac{V}{Z_{eq}}\right| = \left|\frac{1}{8/45}\right| \angle -90$$

$$= 5.625 \angle -90^\circ$$

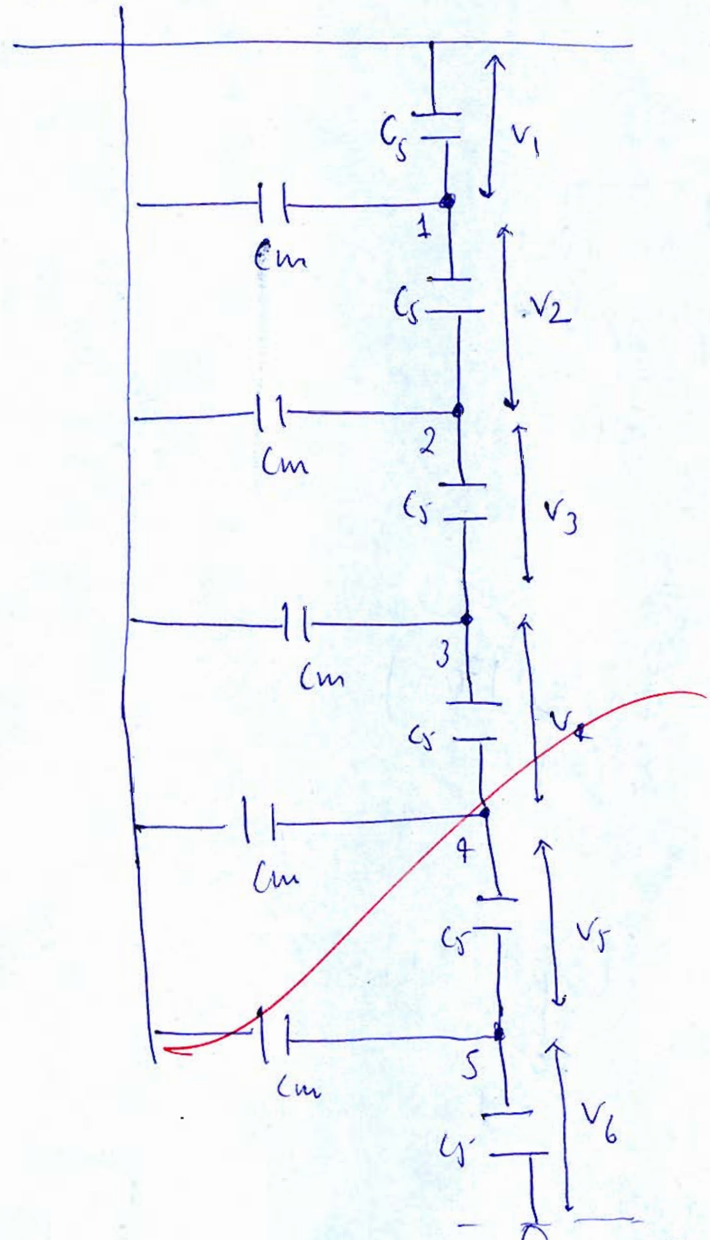
$$\text{fault current} = 5.625 \times \left(\frac{20 \times 10^3}{\sqrt{3} \times 66}\right)$$

$$= \left|984.12 \angle 90^\circ\right| A.$$

Q.4 (c) A string of six insulation unit has mutual capacitance 10 times the capacitance to ground. Determine the voltage across each unit as a fraction of the operating voltage. Also, determine string efficiency.

[20 marks]

string of six insulation unit



$C_m = \left(\frac{C_s}{10}\right)$

$\boxed{C_m = 0.1 C_s}$ given

Let $K = 0.1$.

$\boxed{C_m = K C_s}$

KCL at node 1.

$$\cancel{j\omega} C_s V_2 = \cancel{j\omega} C_m V_1 + \cancel{j\omega} C_s V_1$$

$$C_s V_2 = V_1 (C_m + C_s)$$

$$C_s V_2 = V_1 (C_m + C_s) = V_1 (K C_s + C_s)$$

$$\boxed{V_2 = V_1 (1+K)} \quad \text{—— (I)}$$

KCL at node 2.

$$\cancel{j\omega} C_s V_3 = \cancel{j\omega} C_s V_2 + \cancel{j\omega} C_m (V_1 + V_2)$$

$$\cancel{C_s} V_3 = \cancel{C_s} V_2 + K \cancel{C_s} (V_1 + V_2)$$

$$V_3 = V_2 (1+K) + K V_1 \quad \text{—— (II)}$$

put value of V_2 in (II) equation

$$V_3 = V_1 \left(K + (1+K)^2 \right) = V_1 (K^2 + 3K + 1)$$

KCL at node 3.

$$\cancel{j\omega} C_s V_4 = \cancel{j\omega} C_s V_3 + \cancel{j\omega} C_m (V_1 + V_2 + V_3)$$

$$\cancel{C_s} V_4 = \cancel{C_s} V_3 + K \cancel{C_s} (V_1 + V_2 + V_3)$$

$$V_4 = V_1 (K^2 + 3K + 1) + K V_1 + K(1+K) V_1 + K V_1 (K^2 + 3K + 1)$$

$$V_4 = V_1 (K^3 + 5K^2 + 6K + 1) \quad \text{—— (III)}$$

KCL at node 4.

$$\cancel{j\omega} C_s V_5 = \cancel{j\omega} C_s V_4 + \cancel{j\omega} C_m (V_1 + V_2 + V_3 + V_4)$$

$$V_5 = V_1 (K^3 + 5K^2 + 6K + 1) + K V_1 (1 + 1 + K + K^2 + 3K + 1 + K^3 + 5K^2 + 6K + 1)$$

$$V_5 = V_1 (K^4 + 7K^3 + 15K^2 + 10K + 1) \quad \text{—— (IV)}$$

KCL at node5

$$V_6 = V_1 (K^4 + 7K^3 + 15K^2 + 10K + 1) + K V_1 (K^3 + 6K^2 + 10K + 4 + V_5)$$

$$V_6 = V_1 (K^5 + 9K^4 + 28K^3 + 35K^2 + 15K + 1)$$

$K = 0.1$

$V_1 = V_1$

$V_2 = 1.1\,V_1$

$V_3 = 1.31\,V_1$

$V_4 = 1.651\,V_1$

$V_5 = 2.1571\,V_1$

$V_6 = 2.87891\,V_1$

$$\text{String efficiency} = \left(\frac{V_1+V_2+V_3+V_4+V_5+V_6}{6V_6}\right)\times 100\%$$

$$= \left(\frac{V_1 + 1.1V_1 + 1.31V_1 + 1.651V_1 + 2.157V_1 + 2.8789V_1}{6\times 2.8789\,V_1}\right)\times 100\%$$

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$$= \left(\frac{10.097}{6\times 2.8789}\right)\times 100\%$$

Good Approach

$$= 0.5845\times 100\%$$

$$\boxed{\eta = 58.45\%}$$

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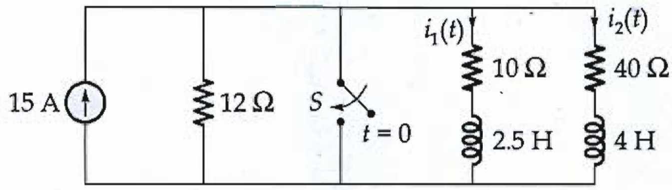
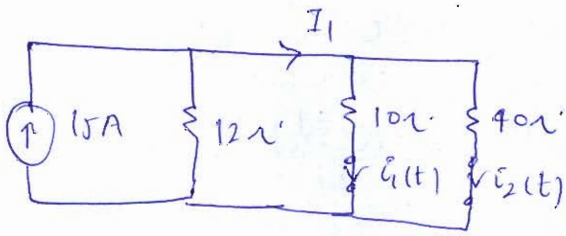
Section B : Systems and Signal Processing-1 + Microprocessor-1 + Electrical Circuits-2 + Control Systems-2

Q.5 (a) The switch 'S' in the circuit shown below is opened for a long time and closed at $t = 0$. Find the time domain expressions for currents $i_1(t)$ and $i_2(t)$ for $t > 0$.



[12 marks]

initially when $t<0$

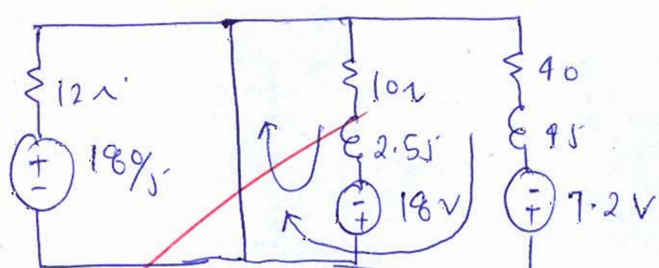


$$I_1 = \left(\frac{15\times12}{12+8}\right) = \frac{\cancel{15}^{3}\times\cancel{12}^{3}}{\cancel{20}_{4}} = 9A$$

$$i_1(t) = \frac{9\times4\cancel{0}}{5\cancel{0}} = \frac{18\times3}{5}A = \frac{36}{5} = 7.2\,A$$

$$i_2(0^-) = \frac{9\times1\cancel{0}}{5\cancel{0}} = \frac{9}{5}A = 1.8\,A$$

at $t>0^-$



$$J_1(s) = \left(\frac{18}{10+2.5s}\right) = \left(\frac{18/2.5}{s+10/2.5}\right) = \left(\frac{7.2}{s+4}\right)$$

$$\boxed{I_1(t) = 7.2e^{-4t}u(t)}$$

$$I_2(s) = \left(\frac{7.2}{4s+40}\right)$$

$$I_2(s) = \left(\frac{7.2/4}{s+10}\right) = \left(\frac{1.8}{s+10}\right)$$

take laplace inverse transform

$$\boxed{\begin{aligned} I_2(t) &= 1.8e^{-10t}u(t) \\ I_1(t) &= 7.2\, e^{-4t}\, u(t) \end{aligned}}$$

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Good Approach

Do not write in this margin

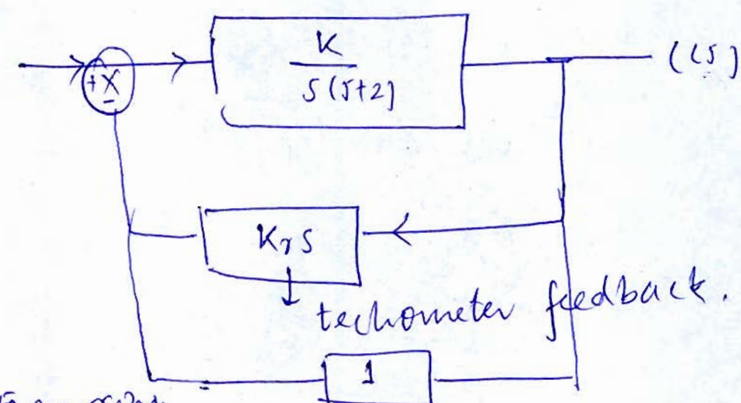
Q.5 (b) The open-loop transfer function of a unity feedback control system is given by

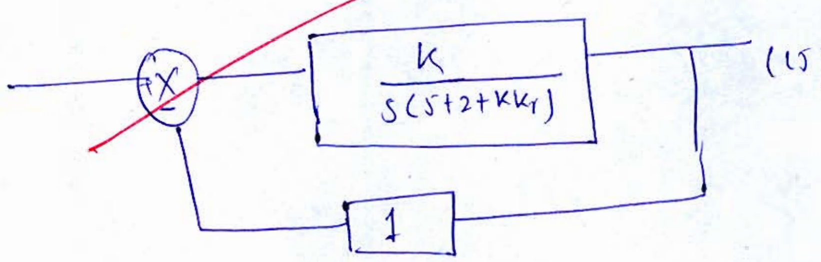
$$G(s) = \frac{K}{s(s+2)}$$

The system is to have 25% maximum overshoot and peak time 1.0 second. Determine the value of K and tachometer feedback constant K_r.

[12 marks]

$$G(s) = \frac{K}{s(s+2)}$$





characteristic equation

$$= s^2 + (2+KK_r)s + K$$

compared to standard characteristic equation

$$\omega_n = \sqrt{K} \text{ rad/sec.}$$

$$2\xi\omega_n = 2 + KK_r$$

given % overshoot = 25%

$$\xi = \sqrt{\frac{\ln(0.25)^2}{\pi^2 + \ln(0.25)^2}}$$

$$\xi = \sqrt{\frac{1.9218}{\pi^2 + 1.9218}}$$

$$\xi = \sqrt{\frac{1.9218}{10 + 1.9218}} = 0.4037.$$

peak time $= (\pi/\omega_d) = 1$

$$\omega_d = \pi \text{ rad/sec}.$$

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

$$\sqrt{K} = \left(\frac{\pi}{\sqrt{1-0.4037^2}}\right) = 3.4338$$

$$\underline{K = 11.79}$$

11

$2\xi\omega_n = 2 + KK_r$

$2 \times 0.4037 \times 3.4338 = 2 + KK_r$

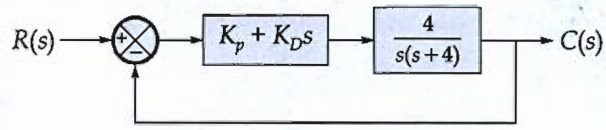
Good Approach

$$2 + KK_r = 2.772$$

$$KK_r = 0.772$$

$$\boxed{K_r = 0.0655}$$

Q.5 (c) A control system with PD controller is shown below :



Determine the value of K_P and K_D such that the damping ratio of the system will be 0.75 and the steady state error for unit ramp input will be 0.20.

[12 marks]

$$OLTF = \frac{4(K_p + K_D s)}{s(s+4)}$$

unit ramp i/p is applied

$$K_V = \lim_{s \to 0} s\,G(s)$$

$$= \lim_{s \to 0} \frac{4(K_p + K_D s)}{(s+4)}$$

$$K_V = \frac{\cancel{4}K_p}{\cancel{4}} = K_p$$

steady state error $= \left(\frac{1}{K_V}\right)$

$$0.2 = \frac{1}{K_V}$$

$$\boxed{K_V = K_p = 5}$$

CE equation

$$= s^2 + 4s + 4K_D s + 4K_p$$

$$\omega_n = \sqrt{4K_p} = \sqrt{4 \times 5} = \sqrt{20} \text{ rad/sec.}$$

$$2\xi\omega_n = (4 + 4K_D)$$

$\xi = 0.75$ given in Question

$$2(0.75) \times \sqrt{20} = (4 + 4K_D)$$

$$4 + 4K_D = 6.708$$

$$4K_D = 2.708$$

$$\boxed{K_D = 0.677}$$

for given condition

$$\boxed{\begin{array}{l} K_P = 5 \\ K_D = 0.667 \end{array}}$$

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Q.5 (d) The Fourier transform $X(\omega)$ of a continuous time periodic signal $x(t)$ is given by

$$X(\omega) = j\delta\left(\omega - \frac{\pi}{3}\right) + 2\delta\left(\omega - \frac{\pi}{7}\right)$$

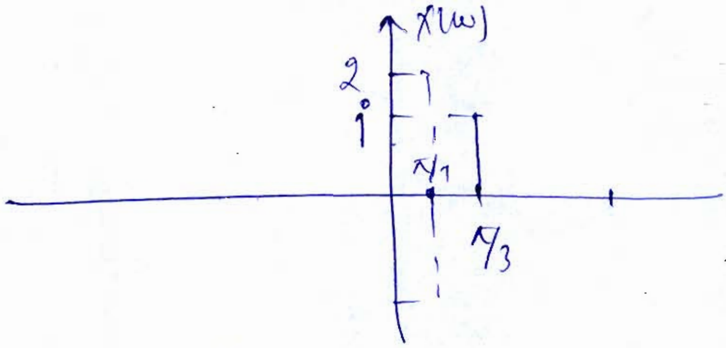
Determine :

(i) The fundamental frequency of the signal $x(t)$.

(ii) The complex Fourier series coefficients of the signal $x(t)$.

(iii) The time domain expression of $x(t)$.

[12 marks]



(I) $\omega_1 = \pi/3$ rad/sec.

$\omega_2 = \pi/7$ rad/sec.

HCF ~~x~~ (ω_1, ω_2)

$= (\pi/7, \pi/3)$ (HCF)

6

$\omega_0 = (\pi/21)$

fundamental frequency of $x(t) = (\pi/21)$ rad/sec.

(II) complex fourier series coefficient of $x(t)$

~~x(t)~~ $\qquad X(\omega) = \int (x(t)\, e^{-j\omega t} d\omega t$.

~~ω_0~~ $\boxed{\begin{array}{l} C_3 = 2 \\ C_7 = j \end{array}}$

In complete Solution

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Q.5 (e) Explain the following instructions:

(i) XCHG **(ii)** IN **(iii)** OUT **(iv)** DAA

[12 marks]

(i) XCHG

means exchange operation is done

It is implicit addressing mode

(ii) IN

IN is input port

IN is used when (~~mi~~ microprocessor to i/p+o/p devices operate)

It is also implicit addressing mode

(iii) OUT

OUT is output port of I/O device

in this case (memory are not used)

implicit addressing mode)

8

(iv) DAA

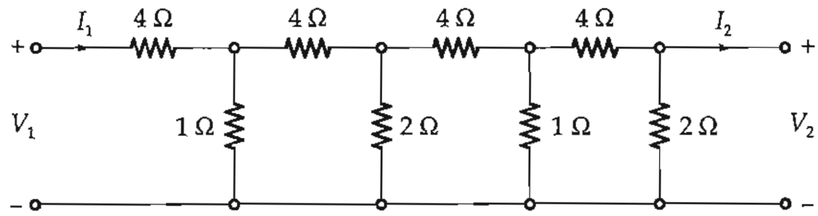
It is arithmatic operation

double addition with carry

Elaborate it more

Q.6 (a) **(i)** Two 2-port network are connected in cascade. Prove that the overall transmission parameter matrix equals to the multiplication of individual transmission parameter matrices.

(ii) Determine the transmission parameters of the 2-port network shown in the figure below:



[20 marks]

Q.6 (b) (i) Explain the similarities and differences between :

1. JUMP and CALL instructions.
2. STA and STAX instructions.

[10 marks]

Q.6 (b) (ii) Write an assembly language program for an 8085 microprocessor, to find 2's complement of a 16-bit number. Write comments for selected instructions.

[10 marks]

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Do not write in this margin

Q.6 (c) Check whether given signal $x(t) = \sum_{n=-\infty}^{\infty} e^{-(2t-n)}u(2t-n)$ is periodic. If yes, compute its average power.

[20 marks]

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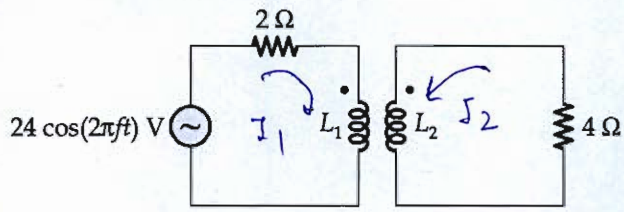
Q.7 (a) The coupled circuit shown below has a coefficient of coupling $K = 1$. Determine the energy stored in the mutually coupled inductor at $t = 5$ msec.

$L_1 = 3.185$ mH; $L_2 = 12.74$ mH; $f = 50$ Hz



[20 marks]

coupling $K = 1$

$$M = \sqrt{L_1 L_2}$$
$$= 6.37 \text{ mH.}$$

$$24\cos(2\pi f t) - 2I_1 - L_1\frac{di_1}{dt} - M\frac{di_2}{dt} = 0$$

$$-L_2\frac{di_2}{dt} - M\frac{di_1}{dt} - 4I_2 = 0$$

$$L_2\frac{di_2}{dt} + M\frac{di_1}{dt} + 4I_2 = 0 \quad \text{—— (11)}$$

3

take laplace transform. in eq^n (11)

$$(L_2 s + 4) I_2 = -M s I_1$$

$$I_2 = \left(\frac{-Ms}{L_2 s + 4}\right) I_1$$

$$\left(\frac{24s}{s^2+\omega^2}\right) = (2 + L_1 s) I_1 + M\left(\frac{-Ms}{L_2 s + 4}\right) I_1$$

$$I_1 = \frac{\frac{24s}{s^2+\omega^2}(L_2 s + 4)}{\left[(2+L_1 s)(L_2 s + 4) - M^2 s\right]}$$

Incomplete Solution

Q.7 (b) Obtain eigen values, eigen vectors and the state model in canonical form for a system described by

$$\dot{x}(t) = \begin{bmatrix} 0 & 1 & 0 \\ 3 & 0 & 2 \\ -12 & -7 & -6 \end{bmatrix} x(t) + \begin{bmatrix} 1 \\ 0 \\ 2 \end{bmatrix} u(t)$$

$$y(t) = [1 \ 0 \ 0]\, x(t)$$

[20 marks]

$$A = \begin{bmatrix} 0 & 1 & 0 \\ 3 & 0 & 2 \\ -12 & -7 & -6 \end{bmatrix}$$

$$|S-AI| = \begin{vmatrix} S & -1 & 0 \\ -3 & S & -2 \\ 12 & 7 & S+6 \end{vmatrix}$$

$CE = |S-AI| = 0$

$$\begin{vmatrix} S & -1 & 0 \\ -3 & S & -2 \\ 12 & 7 & S+6 \end{vmatrix} = 0$$

$$S(S^2+6S+14) + 1(-3S-18+24) = 0$$

$$S^3 + 6S^2 + 14S - 3S + 6 = 0$$

$$S^3 + 6S^2 + 11S + 6 = 0$$

$$\boxed{S = -3, -2, -1}$$

obtain eigen value is $-3, -2, -1$

$$\left.\begin{array}{l} \lambda_1 = -3 \\ \lambda_2 = -2 \\ \lambda_3 = -1 \end{array}\right\}$$

find eigenvector.

$\boxed{\lambda_1 = -3}$ $|A - \lambda_1 I| X = 0$

$$\begin{vmatrix} 0 & 1 & 0 \\ 3 & 0 & 2 \\ -12 & -7 & -6 \end{vmatrix} + 3\begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} X = 0$$

$$\begin{bmatrix} 3 & 1 & 0 \\ 3 & 3 & 2 \\ -12 & -7 & -3 \end{bmatrix}\begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} = 0$$

$$\begin{array}{cccc} \frac{x_1}{\ } & \frac{x_2}{\ } & \frac{x_3}{\ } & \\ 1 & 0 & 3 & 1 \\ 3 & 2 & 3 & 3 \end{array}$$

$$\frac{x_1}{2} = \frac{x_2}{-6} = \frac{x_3}{6}$$

$$\text{eigenvector} = k\begin{bmatrix} 1 \\ -3 \\ 3 \end{bmatrix}$$

for $\boxed{\lambda = -2}$

$$\begin{vmatrix} 2 & 1 & 0 \\ 3 & 2 & 2 \\ -12 & -7 & -4 \end{vmatrix}\begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} = 0$$

$$\begin{array}{cccc} x_1 & x_2 & x_3 & \\ 1 & 0 & 2 & 1 \\ 2 & 2 & 3 & 2 \end{array}$$

$$\frac{x_1}{2} = \frac{x_2}{-4} = \frac{x_3}{1}$$

$$= k\begin{bmatrix} 2 \\ -4 \\ 1 \end{bmatrix}$$

for $\lambda_3 = -1$

$$\begin{bmatrix} 1 & 1 & 0 \\ 3 & 1 & 2 \\ -12 & -7 & -5 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} = 0$$

x_1	x_2	x_3	
1	0	1	1
1	2	3	1

$$\frac{x_1}{2} = \frac{x_2}{-2} = \frac{x_3}{-2}$$

eigenvector $= k\begin{bmatrix} 1 \\ -1 \\ -1 \end{bmatrix}$

corresponding eigenvector

$\lambda_1 = -3$
$v_1 = k\begin{bmatrix} 1 \\ -3 \\ 3 \end{bmatrix}$

$\lambda_2 = -2$
$v_2 = k\begin{bmatrix} 2 \\ -8 \\ 1 \end{bmatrix}$

$\lambda_3 = -1$
$v_3 = k\begin{bmatrix} -1 \\ 1 \\ 1 \end{bmatrix}$

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Incomplete Solution

Read question carefully

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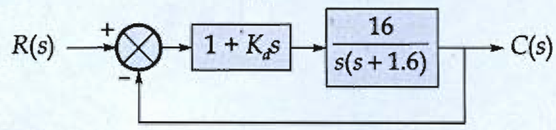
Q.7 (c) A control system employing proportional and derivative control as shown below, has damping ratio equal to 0.8. Find the time instant at which the step response of system attains the peak value. Also find the percent maximum overshoot of system.



[20 marks]

given damping ratio

$$\boxed{\xi = 0.8}$$

CE: $= s^2 + 1.6s + 16K_D s + 16$

$\omega_n = 4$ rad/sec.

$$2\xi\omega_n = (1.6 + 16K_D)$$

$$2\times(0.8)\times 4 = 1.6 + 16K_D$$

$$\boxed{K_D = 0.3}$$

8

Controller $= (1 + 0.3s)$

step response attain peak value at time $= \left(\pi/\omega_d\right)$

$$= \left(\frac{\pi}{\omega_n\sqrt{1-\xi^2}}\right) \text{sec}$$

$$= \left(\frac{\pi}{4\sqrt{1-0.8^2}}\right)$$

$$\boxed{t_p = 1.309 \text{ sec.}}$$

percent maximum overshoot $= e^{\frac{-\pi\xi}{\sqrt{1-\xi^2}}} \times 100\%$

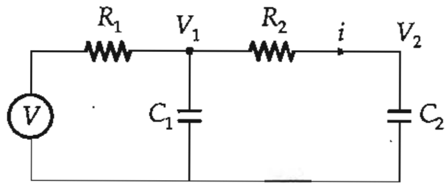
$$= \left(e^{\frac{-\pi\times 0.8}{\sqrt{1-0.8^2}}}\right) \times 100\%$$

$$= 0.01516 \times 100\%$$

$$= \underline{\cancel{1.516\%}}$$

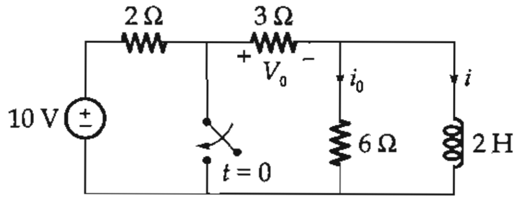
when $\xi \uparrow$ percent overshoot decreases.

Q.8 (a) (i) Determine the state model for the network shown below considering $V_1 = x_1$; $V_2 = x_2$ and $y = i$.



[10 marks]

Q.8 (a) (ii) In the circuit shown below:



Find i_0, V_0 and i for all time, assuming that the switch was open for a long time.

[10 marks]

Q.8 (b) Consider a discrete time system with input $x(n)$ and output $y(n)$ related by

$$y(n) = \sum_{k=n-n_0}^{n+n_0} x(k)$$

where n_0 is a finite positive integer

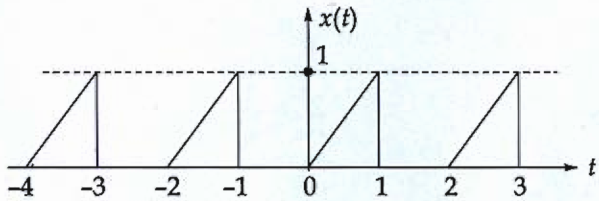
(i) Is this system linear?

(ii) Is this system time-invariant?

(iii) If $x(n)$ is known to be bounded by a finite integer B_x [i.e. $|x(n)| < B_x$ for all n], it can be shown that $y(n)$ is bounded by a finite number C. We conclude that the given system is stable. Express C in terms of B_x and n_0.

[20 marks]

Q.8 (c) Find the trigonometric Fourier series for the waveform shown in figure and sketch the line spectrum.



[20 marks]

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Space for Rough Work

θ_m

$\theta_c = \frac{1}{2}\theta_m$

$\frac{\cancel{10}^{2} \times 9\cancel{0}}{8\cancel{0}}$ 9

$\frac{\frac{K}{s(s+2)}}{1 + \frac{K}{s(s+2)} \cdot (K_T s)}$

$s^2 + 2s + KK_T s$

$K^3 + 3K^2 + K + K^2 + K + K^2 + 3K + 1 + K$

$K^3 + 5K^2 + 6K + 1$