• Highlights your final answer

• Try to avoid calculation mistake

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ESE 2025 : Mains Test Series

UPSC ENGINEERING SERVICES EXAMINATION

Electrical Engineering

Test-4 : Electrical Machines + Analog Electronics + Control Systems

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	38
Q.2	46
Q.3	
Q.4	48
Section-B	
Q.5	42
Q.6	
Q.7	36
Q.8	
Total Marks Obtained	210

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.

Section A : Electrical Machines + Analog Electronics + Control Systems

.1 (a) A 4-pole, 3-ϕ Slip Ring Induction Motor (SRIM) is used as a frequency changer. Its stator is excited from 3-phase, 50 Hz supply. A load requiring 3-phase, 20 Hz supply is connected to the star-connected rotor through three slip rings of SRIM.

(i) At what two speeds the prime mover should drive the rotor of this SRIM?

(ii) Find the ratio of two voltages available at the slip rings at the two speeds.

[12 marks]

Answer

(i) Rotor frequency $sf = 20\,Hz$

$$s = \frac{20}{50} = 0.4$$

$$\text{Synchronous speed} = \frac{120 \times f}{P} = \frac{120 \times 50}{4}$$

$$N_s = 1500 \text{ rpm}$$

possible speeds (when $s = s_f = 0.4$)

$$N_{r_1} = N_s(1-s)$$

$$\boxed{N_{r_1} = 1500(1-0.4) = 900 \text{ rpm}}$$

when $S_b = 2-s = 2-0.4 = 1.6$

so $N_{r_2} = N_s(2-S_b) = 1500(2-0.4)$

$$\boxed{N_{r_2} = 2400 \text{ rpm}}$$

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(i) $\boxed{\text{possible speeds} = 900,\ 2400 \text{ rpm}}$

(ii) As $E = 4.44 f \phi N$

$$E = K\phi\omega$$

$$\frac{E_2}{E_1} = \frac{N_2}{N_1} \Rightarrow \frac{E_2}{E_1} = \frac{2400}{900}$$

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$$\boxed{\frac{E_2}{E_1} = 2.67}$$

Q.1 (b) The open-loop transfer function of a unity feedback ac position control system is

$$G(s) = \frac{10K}{s(1+0.1s)}.$$

Find the minimum value of the amplifier gain K so that when the input shaft rotates at $\frac{1}{2}$ revolution per second, the steady-state velocity error is 0.2°. With that value of K, what will be the value of damping factor and natural frequency?

[12 marks]

Answer

$$G(s) = \frac{10K}{s(1+0.1s)}$$

As we know

$$K_v = \lim_{s\to 0} s\,G(s) = 10K$$

$$e_{ss} = \frac{A}{K_v}$$

Given $A = 0.5$ rev/sec

$e_{ss} = 0.2^\circ$

$A = 0.5 \times 60$ rpm

$= 30$ rpm

$A = 30 \times \frac{2\pi}{60} = \pi$ rad

or $A = 180^\circ$

Now

$$0.2 = \frac{180}{10K}$$

$$\boxed{K = 90}$$

So $G(s) = \frac{90 \times 10}{s(1+0.1s)}$

$s^2 + 0.1s + 900 = 0$ Characteristic equation

(By comparing with $s^2 + 2\zeta\omega_n s + \omega_n^2 = 0$)

$\omega_n^2 = 900$

$$\boxed{\omega_n = 30 \text{ rad/sec.}}$$

$$2\xi\omega_n = 0.1$$

$$\xi = \frac{0.1}{2\times 30}$$

$$\boxed{\xi = 0.002}$$

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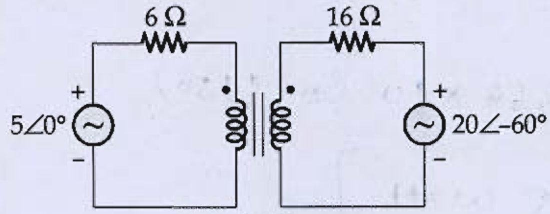
.1 (c) In the figure shown below:



1 : 2
IDEAL TRANSFORMER

Calculate :

(i) The power delivered by each source.

(ii) The power dissipated in each resistor. **[12 marks]**

Answer

(i) By referring secondary into primary side

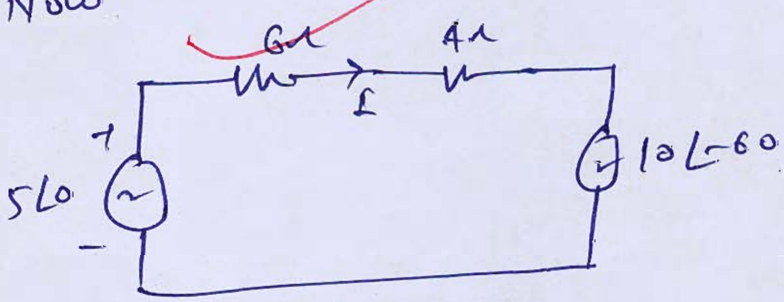
Given $\frac{N_1}{N_2} = \frac{1}{2} = K$

So, secondary Resistance $(R_2 = 16)$

$R_2' = R_2 \cdot K^2 = \frac{16}{4} = 4\Omega$

$V_2' = V_2 \cdot K = 20\angle{-60} \times \frac{1}{2} = 10\angle{-60^\circ}$

Now



$I = \frac{5\angle 0 - 10\angle{-60}}{10} = 0.866\angle 90^\circ$

power delivered by $5\angle 0^\circ$ source

$P_5 = (5\angle 0) \times 0.866 \times \cos 90^\circ$

$\boxed{P_5 = 0 \text{ Watt.}}$

power delivered by 10 ∠-60 source

$P_{10} = -0.866 \times 10 \cos(150)$

$\boxed{P_{10} = 7.5 \text{ watt.}}$

(ii) power dissipated in 6 Ω Resistor will be

$P_6 = (I)^2 \times 6 = (0.866)^2 \times 6$

$\boxed{P_6 = 4.5 \text{ watt}}$

power dissipated in 4 Ω Resistor will be

$P_4 = (0.866)^2 \times 4$

$\boxed{P_4 = 3 \text{ watt}}$

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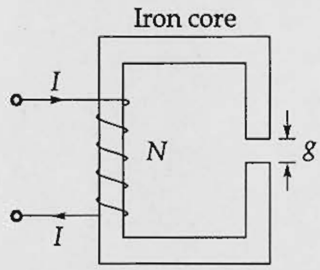
Good Approach

Q.1 (d) For the magnetic circuit shown below:



Length of iron path = 120 cm, g = 0.5 cm, area of cross-section of iron = $5 \times 5\ \text{cm}^2$, $\mu_r = 1500$, $I = 2$ A, $N = 1000$ turns.

Calculate and compare the field - energy stored and field energy density in iron as well as in air gap. Neglect fringing and leakage flux.

[12 marks]

Answer

Reluctance of Air gap $\Rightarrow R_g = \dfrac{l}{\mu a} = \dfrac{l}{\mu_0 a}$

$$R_g = \frac{0.5 \times 10^{-2}}{4\pi \times 10^{-7} \times 5 \times 5 \times 10^{-4}} = \cancel{1592356.6} \quad 1592356.68 \ (\text{A/wb})$$

Reluctance of iron path (excluding Air gap)

$$R_i = \frac{l}{\mu_0 \mu_r A} = \frac{119.5 \times 10^{-2}}{4\pi \times 10^{-7} \times 1500 \times 25 \times 10^{-4}}$$

$$R_i = 253715.49 \ (\text{A/wb})$$

~~Input~~ Total Reluctance $= R_g + R_i$

$$R_T = 1846072.179$$

5

As

$$\phi = \frac{\text{mmf}}{\text{Reluctance}} = \frac{NI}{R_T}$$

$$\phi = \frac{1000 \times 2}{1846072.179} = 0.00108 \text{ wb}$$

$$\boxed{\phi = 1.08 \text{ mwb.}}$$

.1 (e) The short-circuited tests on two single-phase transformer gave the following results:

200 kVA : 3% rated voltage ; rated current at 0.25 power factor lagging

500 kVA : 4% rated voltage ; rated current at 0.3 power factor lagging

These two transformers are connected in parallel. How do they share a load of 560 kW at 0.8 power factor lagging?

[12 marks]

Answer

Case-1 200 KVA ! 3% rated Voltage, rated current at 0.25 power factor

$$\text{So } \% Z_1 = \frac{V_{Given}}{V_{rated}} = 3\% \text{ at } 0.25 \text{ pf}$$

$$Z = 0.03 \angle 75.52$$

Case-2 500 KVA, 4% rated voltage, rated current at 0.3 pf lag.

$$\text{So } \% Z_2 = 4\% \Rightarrow Z = 0.04 \angle 72.54$$

Let a common Base KVA = 500 KVA

$$\text{So } \% Z_1 = \frac{500}{200} \times 3 = 7.5\%$$

(on 500 kVA base)

$$\text{or } Z_1 = 0.075 \angle 75.72$$

Now Load Shared by first transformer

$$S_A = \left(\frac{Z_2}{Z_1 + Z_2}\right) \times \frac{560 \text{ kW}}{0.8}$$

$$S_A = \frac{0.04 \angle 72.54}{0.04 \angle 72.54 + 0.075 \angle 75.72} \times (700 \text{ kVA})$$

$$S_A = \frac{0.04 \angle 72.54}{0.1149 \angle 74.61} \times 700 \angle 36.86$$

$$S_A = 200 + j139$$

$$\boxed{S_A = 243.56 \angle 34.78} \text{ KVA}$$

Load shared by second transformer

$$S_B = \left(\frac{Z_1}{Z_1+Z_2}\right) \times 700 \angle 36.86$$

$$S_B' = \frac{0.075 \angle 75.72}{0.1149 \angle 74.61} \times 700 \angle 36.86$$

$$\boxed{S_B = 360.20 + j\, 281.11} \text{ K}$$

or

$$\boxed{S_B = 456.91 \angle 37.97} \text{ KVA}$$

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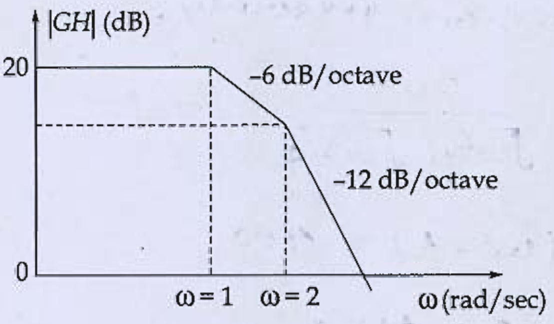
.2 (a) The asymptotic approximation to the log-magnitude versus frequency plot (Bode plot) of a unity feedback control system is shown in the figure. The system is a minimum phase system.



Determine :

(i) Gain crossover frequency in rad/sec.
(ii) Phase crossover frequency.
(iii) Gain margin in dB.
(iv) Phase margin in degrees.

[20 marks]

Answer

By finding transfer function of above Bode plot.

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

(Note: at ω=0 magnitude is constant, so term will be 'K'

at ω = 1 there is slope -6 dB/oct, so term will be a pole.

at ω = 2 there is slope addition of -6 dB/oct, so term will be a pole.)

Now for finding value of K

$20 \log K = 20$ dB

$$\boxed{K = 10}$$

So

$$G(s)H(s) = \frac{20}{(s+1)(s+2)}$$

Do not write in this margin

$$G(j\omega)H(j\omega) = \frac{20}{(j\omega+1)(2+j\omega)}$$

(i) for Gain cross over frequency.

$$|G(j\omega)H(j\omega)| = \frac{20}{\sqrt{\omega^2+1}\,\sqrt{\omega^2+4}} = 1$$

$$(\omega^2+1)(\omega^2+4) = 400$$

$$\omega^4+5\omega^2+4 = 400$$

$$\omega^4+5\omega^2-396 = 0$$

By solving

$$\boxed{\omega = \omega_{gc} = 4.2} \text{ rad/sec}$$

(ii) for phase cross over frequency

$$\angle G(j\omega)H(j\omega) = -180$$

$$-\tan^{-1}\omega - \tan^{-1}\frac{\omega}{2} = -180$$

$$\tan^{-1}\frac{\omega + \omega/2}{1-\omega^2/2} = 180$$

$$\boxed{\omega_{pc} = \sqrt{2}} \text{ rad/sec.}$$

(iii) Gain Margin $= \left.\dfrac{1}{|G(j\omega)H(j\omega)|}\right|_{\text{at } \omega = \omega_{pc}}$

$$|G(j\omega_{pc})H(j\omega_{pc})| = \frac{20}{\sqrt{2+1}\,\sqrt{2+4}} = \frac{20}{\sqrt{3\times 6}}$$

Gain Margin $= \dfrac{\sqrt{18}}{20} = 0.212$

Gain Margin (in dB) $= 20\log\left(\dfrac{1}{G(j\omega_{pc})H(j\omega_{pc})}\right)$

$GM(\text{in dB}) = 20 \log(0.212)$

$$\boxed{GM(\text{in dB}) = -13.47 \text{ dB}}$$

(iv) for phase margin

$\angle G(j\omega_{gc})H(j\omega_{gc}) = -\tan^{-1}\omega_{gc} - \tan^{-1}\frac{\omega_{gc}}{2}$

$\phi = -\tan^{-1}\sqrt{2} - \tan^{-1}\frac{\sqrt{2}}{2}$

$\phi = -90^{\circ}$

So phase margin (in degrees)

$= 180 + \phi$

$= 180 - 90$

$$\boxed{PM = 90^{\circ}}$$

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Do not write in this margin

Q.2 (b) A 150 kVA, 2500/250 V, single-phase two winding transformer is to be used as an auto transformer for stepping up the voltage from 2500 V to 2750 V. At rated load, the two winding transformer has 2.5% loss, 3% voltage regulation and 4% impedance. For the auto transformer, determine the followings:

(i) Voltage and current rating.

(ii) kVA rating.

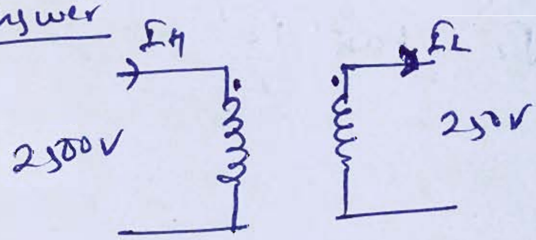
(iii) Efficiency.

(iv) Percentage impedance.

(v) Regulation, and

(vi) Short circuit current on each side. **[20 marks]**

Answer

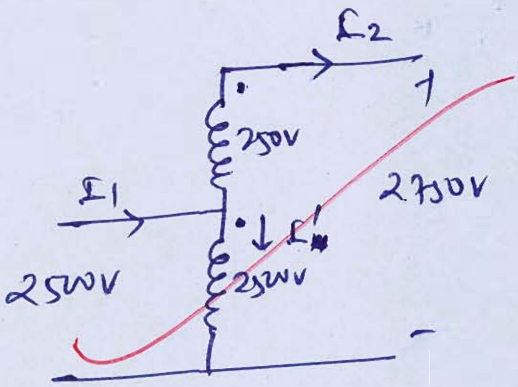


$$I_H = \frac{150\times10^3}{2500}$$

$$I_H = 60 \text{ Amp}$$

$$I_L = \frac{150\times10^3}{250} = 600A$$

Now Autotransformer (2500/2750V)



So $I_2 = 600$ Amp

$I' = 60$ Amp

$I_1 = I_2 + I'$

$I_1 = 660$ Amp

(i) Output current $I_2 = 600$ Amps

$V_2 = 2750$ V

Input current $I_1 = 660$ Amp

$V_1 = 2500$ Volt.

(ii) KVA rating $= V_2 I_2$

$= 2750 \times 600$

$\boxed{\text{KVA rating} = 1650 \text{ KVA}}$

(iii) As given loss = 2.5%

loss (in watts) = $\frac{2.5 \times 150 \times 10^3}{100} = 3750$ watt

$= 3.75$ kw

So efficiency of Autotransformer

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

$$\% \eta = \frac{1650 \times 10^3}{1650 \times 10^3 + 3750} \times 100$$

$$\boxed{\% \eta = 99.77\%}$$

(iv) given %age impedance for two winding transformer

$\% Z_{(\text{two-winding})} = 4\%$

turns Ratio of Auto transformer = $\frac{\cancel{2750}}{\cancel{2500}}$

$$a = \frac{2750}{2500} = \frac{11}{10}$$

$$\% Z_{(\text{Auto Transformer})} = \% Z_{(\text{Two-winding})} \left(1 - \frac{1}{a}\right)$$

$$= 4\left(1 - \frac{10}{11}\right)$$

$$\boxed{\% Z_{(\text{Auto-transformer})} = 0.36\%}$$

(V)

$$\% \text{ Voltage Regulation}_{(\cancel{\text{Two-winding}})\ \text{Auto Transformer}} = \% \text{ Voltage Regulation}_{(\text{Two-winding})} \left(1 - \frac{1}{a}\right)$$

% Voltage Regulation of Auto Transformer = $3\% \left(1 - \frac{10}{11}\right)$

$\boxed{\%\ VR\ (\text{Auto Transformer}) = 0.27\ \%}$

(vi) Short circuit current

I_{sc} (in two winding Transformer) $= \frac{1}{\%Z}$

$= \frac{1}{0.04} = 25$ pu.

I_{sc} (in Auto Transformer) $= \frac{1}{0.0036}$

$\boxed{I_{sc}\ (\text{in Auto TF}) = 277.77\ \text{pu}}$

Note: In Auto transformer % Z will decrease so ~~the~~ short circuit current will increase (Highly) in Auto transformer.

Good Approach

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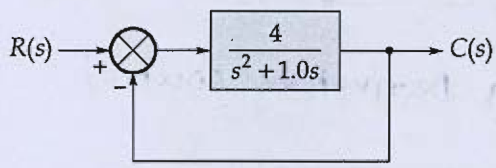
Q.2 (c) A closed-loop control system with unity feedback is shown in figure below. By using derivative control, the damping ratio is to be made 0.75. Determine the value of T_d. Also determine the rise time, peak time and peak overshoot without derivative control and with derivative control. The input to the system is a unit-step.



[20 marks]

Answer

Case-1 Without Derivative control

$$1+G(s)H(s) = 1+\frac{4}{s(s+1)}$$

$$1+G(s)H(s) = 0 \Rightarrow s^2+s+4=0$$

By comparing from standard equation

$$s^2+2\xi\omega_n s+\omega_n^2=0$$

$$2\xi\omega_n = 1, \quad \omega_n = 2 \text{ rad/sec}$$

$$\xi = 0.25$$

$$\text{Rise time } (t_r) = \frac{\pi-\phi}{\omega_d} = \frac{\pi-\cos^{-1}\xi}{\omega_n\sqrt{1-\xi^2}}$$

$$t_r = \frac{\pi-1.318}{2\sqrt{1-0.25^2}} \Rightarrow \boxed{t_r = 0.94 \text{ sec.}}$$

$$\text{Peak time } (t_p) = \frac{\pi}{\omega_d} = \frac{\pi}{2\sqrt{1-0.25^2}}$$

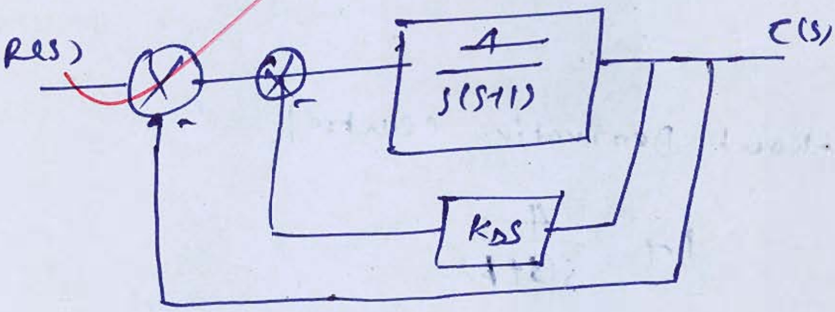
$$\boxed{t_p = 1.62 \text{ sec.}}$$

$$\% \text{ peak overshoot} = e^{-\pi\xi/\sqrt{1-\xi^2}} \times 100$$

$\% M_p = \left(e^{-\frac{\pi \times 0.25}{\sqrt{1-0.25^2}}}\right) \times 100$

$\boxed{\% M_p = 44.45\%}$

Case-2 By using Derivative control



$\frac{C(s)}{R(s)} = \frac{4}{s^2 + (4K_D + 1)s + 4}$

Characteristic equation

$s^2 + (4K_D + 1)s + 4 = 0$

$\omega_n^2 = 4 \Rightarrow \omega_n = 2$ rad/sec

$2\xi\omega_n = 4K_D + 1$

$2 \times \xi \times 2 = 4K_D + 1$ (Given $\xi = 0.75$)

$2 \times 0.75 \times 2 = 4K_D + 1$

$\boxed{K_D = 0.5}$

As $T_D = \frac{1}{K_D} = \frac{1}{0.5}$

$\boxed{T_D = 2}$

Now ch. $\xi = 0.75$, $\omega_n = 2$

rise time $(t_r) = \frac{\pi - \cos^{-1} 0.75}{\omega_n\sqrt{1-\xi^2}} = \frac{\pi - \cos^{-1} 0.75}{2\sqrt{1-0.75^2}}$

$\boxed{t_r = 1.827}$ sec.

peak time $(t_p) = \dfrac{\pi}{\omega_d} = \dfrac{\pi}{\omega_n\sqrt{1-\xi^2}} = \dfrac{\pi}{2\sqrt{1-0.75^2}}$

$\boxed{t_p = 2.37}$ sec.

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

$\% M_p = \left(e^{-\frac{\pi \times 0.75}{\sqrt{1-0.75^2}}}\right) \times 100$

$\boxed{\% M_p = 2.84 \%}$

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.3 (a) When the primary of a transformer is energized at rated voltage of 11000 V and at rated frequency of 50 Hz, it takes 3.2 A and 2400 watt at no-load. Another transformer has all its core dimension $\sqrt{2}$ times the corresponding core dimension of the first transformer. Number of primary turns, type of core material and lamination thickness are the same in both the transformers. If the primary of the second transformer is energized from 22000 V, 50 Hz supply, calculate the no-load current and power drawn by it.

[20 marks]

Q.3 (b) A 460 V, 25 hp, 60 Hz, 4-pole, *Y*-connected wound rotor induction motor has the following impedances per phase referred to stator side is *a* :

$$R_1 = 0.641\ \Omega,\ R_2 = 0.332\ \Omega$$
$$X_1 = 1.106\ \Omega,\ X_2 = 0.464\ \Omega,\ X_m = 26.3\ \Omega$$

(i) What is maximum torque of this motor? At what slip and speed does it occur?

(ii) What is the starting torque of this motor?

(iii) When the rotor resistance is doubled, what is the speed at which the maximum torque now occurs? What is the new starting torque of the motor?

[20 marks]

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.3 (c) A 440 V, 50 Hz, 6 pole, Y-connected induction motor running at 950 rpm has the following parameters referred to the stator : $R_s = 0.5\ \Omega$, $R'_r = 0.4\ \Omega$, $X_s = X'_r = 1.2\ \Omega$, $X_m = 50\ \Omega$. Motor is driving a fan load, the torque of which is given by $T_L = 0.0123\ \omega_m^2$. Now one phase of the motor falls, calculate the motor speed and current. Will it be safe to allow the motor to run for a long period? (Solve using approximate circuit)

[20 marks]

Q.4 (a) A 4-pole compound generator has armature, series-field and shunt-field resistance of 1 Ω, 0.5 Ω and 100 Ω respectively. This generator delivers 4 kW at a terminal voltage of 200 V. Allowing 1 V per brush for contact drop, calculate for both short-shunt and long-shunt connections.

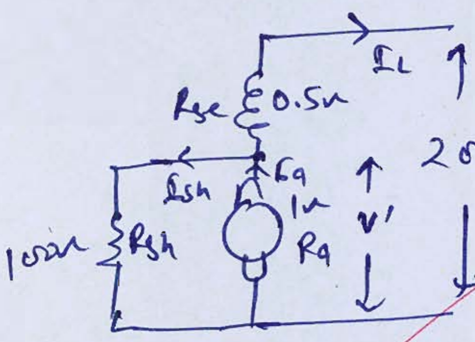
(i) The generated emf, and

(ii) The flux per pole if the armature has 200 lap-connected conductors and is driven at 750 rpm.

[20 marks]

Answer

(i) Short Shunt Compound generator



Given $P_{out} = 4000$ Watt

$V = 200\,V$

$I_L = \frac{4000}{200} = 20A$

Brush Drop = 1V / Brush

terminal voltage at Armature

$V' = 200 + I_L \times R_{se} = 200 + 20 \times 0.5$

$V' = 210$ volt

Now $I_{sh} = \frac{V'}{R_{sh}} = \frac{210}{100} = 2.1$ Amp.

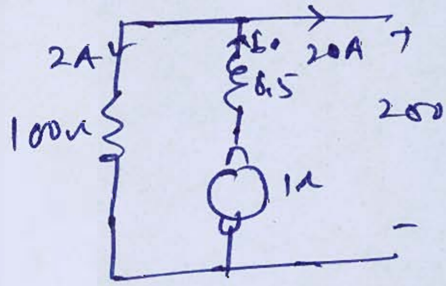
So $I_a = I_L + I_{sh} = 20 + 2.1 = 22.1$ Amp.

So generated emf

$E_g = V' + I_a R_a = 210 + 22.1 \times 1 + 2 \times V_{BD}$

$\boxed{E_g = 234.1 \text{ Volt}}$

→ By using Long shunt compound Generator



$I_{sh} = \frac{200}{100} = 2A$

$I_a = I_L + I_{sh}$

$I_a = 2 + 20 = 22$ Amp.

generated emf

$E_g = 220 + I_a R_a + I_a \times R_{se} + 2 \times 1$ 4X1

$E_g = 220 + 22 \times 1 + 22 \times 0.5 + 2$

$\boxed{E_g = 255 \text{ Volt.}}$

(ii) $Z = 200$, $A = P = 4$, $N = 750$ rpm

for short shunt coumpound generator

$E_g = \frac{\phi Z N P}{60 A} \Rightarrow \phi = \frac{E_g \times 60 A}{Z N P}$

So

$\phi = \frac{234.1 \times 60 \times 4}{200 \times 750 \times 4}$

$\boxed{\phi = 0.0936 \text{ wb.}}$

for Long-shunt.

$\phi = \frac{E_g \times 60 \times A}{Z N P}$

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$\phi = \frac{255 \times 60 \times 4}{200 \times 750 \times 4}$

$\boxed{\phi = 0.102 \text{ wb.}}$

Q.4 (b) Obtain the time response of the system described by

$$\begin{bmatrix}\dot{x}_1\\ \dot{x}_2\end{bmatrix}=\begin{bmatrix}0 & 1\\ -1 & -2\end{bmatrix}\begin{bmatrix}x_1\\ x_2\end{bmatrix}+\begin{bmatrix}1\\ -1\end{bmatrix}u$$

with the initial conditions $\begin{bmatrix}x_1(0)\\ x_2(0)\end{bmatrix}=\begin{bmatrix}0\\ 1\end{bmatrix}, y=\begin{bmatrix}0 & 1\end{bmatrix}\begin{bmatrix}x_1\\ x_2\end{bmatrix}$.

[20 marks]

Answer

First calculating zero input Response (ZIR)

$$c'(t) = \left[\mathcal{L}^{-1} c(sI-A)^{-1}\right] x(0)$$

$$= \mathcal{L}^{-1}\left[c\left[\begin{matrix}s & 0\\ 0 & s\end{matrix}\right]-\left[\begin{matrix}0 & 1\\ -1 & -2\end{matrix}\right]\right]^{-1} x(0)$$

$$= \mathcal{L}^{-1}[c]\left[\begin{matrix}s & -1\\ 1 & s+2\end{matrix}\right]^{-1} x(0) = \mathcal{L}^{-1}\left[\frac{1}{s^2+2s+1}\left[\begin{matrix}s+2 & 1\\ -1 & s\end{matrix}\right]\right] x(0)$$

$$= \mathcal{L}^{-1}[c]\frac{1}{s^2+2s+1}\left[\begin{matrix}s+2 & 1\\ -1 & s\end{matrix}\right]\left[\begin{matrix}0\\ 1\end{matrix}\right] = \mathcal{L}^{-1}[c]\frac{1}{s^2+2s+1}\left[\begin{matrix}1\\ s\end{matrix}\right]$$

$$= \mathcal{L}^{-1}\left[\frac{1}{s^2+2s+1}\left[\begin{matrix}0 & 1\end{matrix}\right]\left[\begin{matrix}1\\ s\end{matrix}\right]\right] = \mathcal{L}^{-1}\left[\frac{s}{s^2+2s+1}\right]$$

$$= \mathcal{L}^{-1}\frac{s}{(s+1)^2} = \mathcal{L}^{-1}\left[\frac{1}{s+1} - \frac{1}{(s+1)^2}\right]$$

$$c'(t) = \left[e^{-t} - te^{-t}\right]u(t) \quad \text{———} \ (1)$$

(By taking Inverse Laplace transform).

Now By calculating zero state Response

$$c''(s) = c(sI-A)^{-1}B\,U(s) \quad , \quad U(s) = 1/s$$

$$= [C]\left[\begin{bmatrix} s & 0 \\ 0 & s \end{bmatrix} - \begin{bmatrix} 0 & 1 \\ -1 & -2 \end{bmatrix}\right]^{-1} \begin{bmatrix} 1 \\ -1 \end{bmatrix} 1/s$$

$$= [C]\begin{bmatrix} s & -1 \\ 1 & s+2 \end{bmatrix}^{-1} \begin{bmatrix} 1 \\ -1 \end{bmatrix} 1/s$$

$$= \frac{[C]}{s^2+2s+1}\underbrace{\begin{bmatrix} s+2 & 1 \\ -1 & s \end{bmatrix}}_{2\times 2}\underbrace{\begin{bmatrix} 1/s \\ -1/s \end{bmatrix}}_{2\times 1}$$

$$= [C]\begin{bmatrix} \frac{s+2}{s} & -1/s \\ -1/s & -1 \end{bmatrix} \times \frac{1}{s^2+2s+1}$$

$$= \begin{bmatrix} 0 & 1 \end{bmatrix}\begin{bmatrix} \frac{s+2}{s} & -1/s \\ -1/s & -1 \end{bmatrix} \frac{1}{s^2+2s+1}$$

$$c''(s) = \frac{-(1+s)}{s(s^2+2s+1)} = \frac{-(s+1)}{s(s+1)^2}$$

$$c''(s) = \frac{-1}{s(s+1)} = \frac{A}{s} + \frac{B}{s+1}$$

$$c''(s) = \frac{-1}{s} + \frac{1}{s+1}$$

By taking Inverse Laplace transform

$$c''(t) = -(1-e^{-t})\,u(t) \quad \text{—— (2)}$$

from equation ① and ②

Total Response $c(t) = ZSR + ZSR$

$c(t) = (e^{-t} - te^{-t})u(t) + [-(1-e^{-t})]u(t)$

$c(t) = (e^{-t} - te^{-t} - 1 + e^{-t})u(t)$

$\boxed{c(t) = (2e^{-t} - te^{-t} - 1)u(t)}$

18

Good Approach

Q.4 (c) A 10 kVA, 380 V, 4-pole, 50 Hz, 3-ϕ, star-connected cylindrical rotor alternator has a stator resistance and synchronous reactance of 1 ohm and 15 ohms respectively. It supplies a load of 8 kW at rated voltage and 0.8 lagging power factor.

(i) Draw a phasor diagram of operation.

(ii) Express the resistance and synchronous reactance in per unit values with the machine rating as the base.

(iii) Calculate the percentage regulation.

(iv) What is the terminal voltage if the load is suddenly removed (with the speed and excitation unaltered)?

[20 marks]

Answer

Given, $R_a + jX_s = 1 + j15$

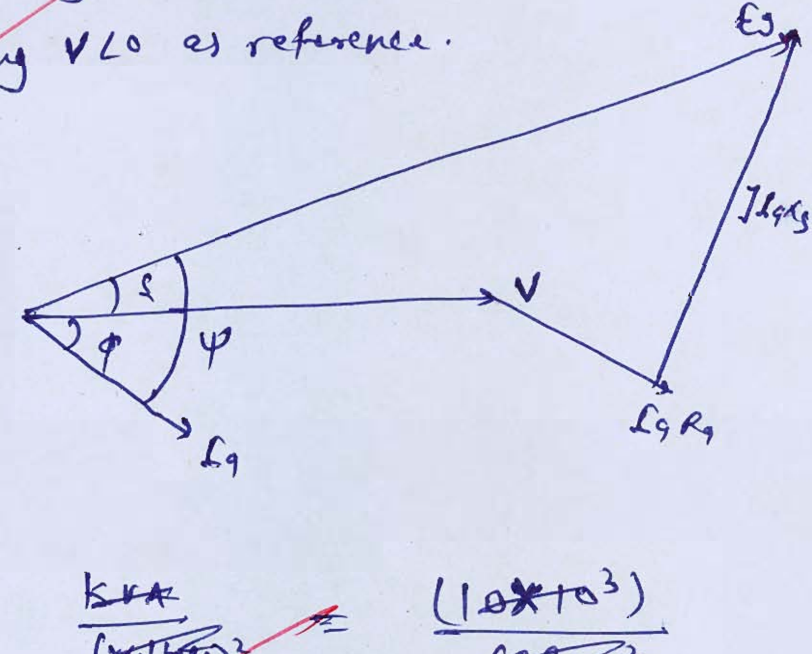
Load = 8 kW, 0.8 pf Lag.

$$I_a = \frac{8000}{\sqrt{3} \times 380 \times 0.8} = 15.2 \text{ Amp.}$$

$$I_a = 15.2 \angle -36.86 \text{ Amp.}$$

(i) Phasor Diagram.

Note: taking $V\angle 0$ as reference.



(ii) $Z_{Base} = \frac{\text{KVA}}{(\text{Voltage})^2} = \frac{(10 \times 10^3)}{(380)^2}$

$$Z_{Base} = \frac{(\text{Voltage})^2}{\text{KVA}} = \frac{(380)^2}{10000}$$

$$Z_{Base} = 14.44\ \Omega$$

$$(R_a)_{pu} = \frac{R_a(\text{in } \Omega)}{Z_{Base}} = \frac{1}{14.44}$$

$$\boxed{R_{a(pu)} = 0.0692} \text{ pu.}$$

$$(X_s)_{pu} = \frac{15}{14.44}$$

$$\boxed{(X_s)_{pu} = 1.0387} \text{ pu.}$$

(iii)

$$E_g \angle \delta = \frac{V}{\sqrt{3}} + I_a Z_s$$

$$= \frac{380}{\sqrt{3}} \angle 0 + (15.2 \angle -36.86) \times (1 + j15)$$

$$E_g \angle \delta = 407.05 \angle 25.19^\circ$$
(Phase).

$$\% \text{ Voltage Regulation} = \frac{|E_g| - |V|}{|V|} \times 100$$

$$= \frac{407.05 - 380/\sqrt{3}}{\frac{380}{\sqrt{3}}} \times 100$$

$$\boxed{\% \text{V.R.} = 85.53 \%}$$

(iv) if Load is suddenly removed and N and E are constant i.e

$$N = \frac{120 \times 50}{4} = 1500 \text{ rpm}$$

$$E = 407.05 \text{ volt}$$

Do not write in this margin

then Load Angle $\delta = 0$

then E_q can be calculated and terminal voltage also can be calculated.

$E_q = E_g$

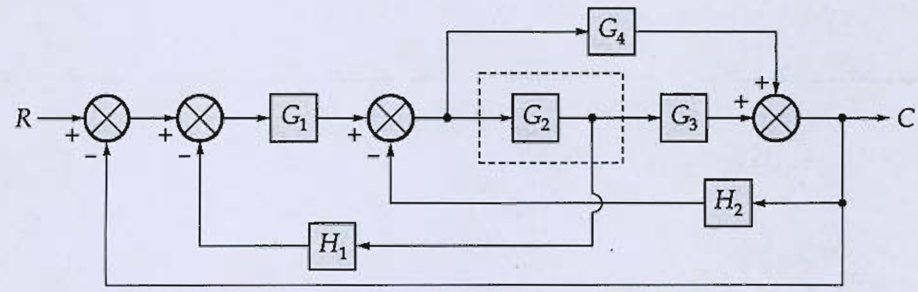
With Load removed terminal voltage become equal to the generated emf which is very high.

18

Good Approach

Section B : Electrical Machines + Analog Electronics + Control Systems

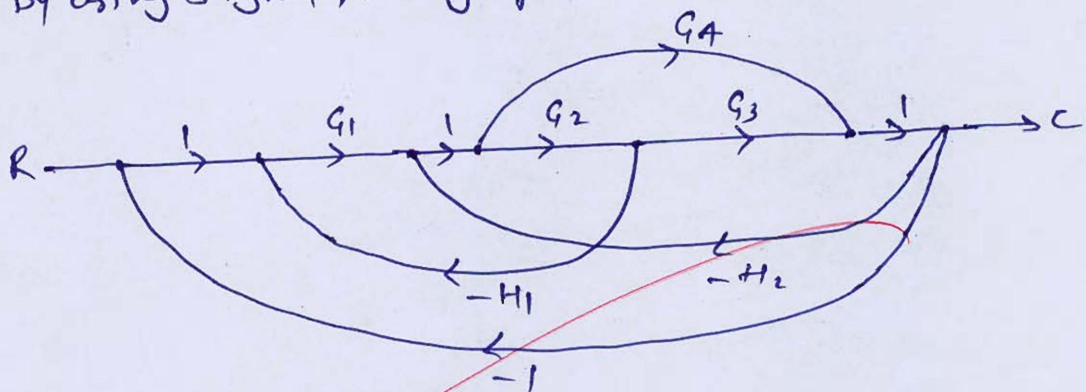
Q.5 (a) Obtain the transfer function of the feedback control system shown by using signal flow graph method.



[12 marks]

Answer

By using signal flow graph



forward paths.

$P_1 = G_1 G_2 G_3$

$P_2 = G_1 G_4$

$\Delta_1 = 1 - 0 = 1$

$\Delta_2 = 1 - 0 = 1$

Single Loops

$L_1 = -G_1 G_2 H_1$

$L_2 = -G_2 G_3 H_2$

$L_3 = -G_1 G_2 G_3$

$L_4 = -G_4 H_2$

$L_5 = -G_4$

According to mason gain formula

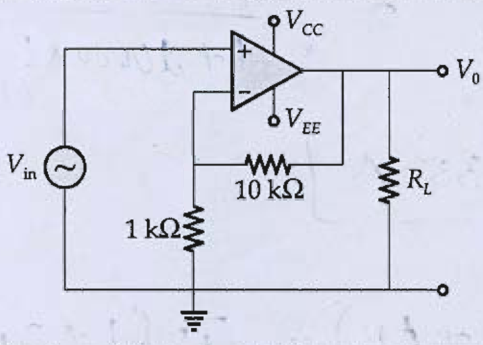
$$\frac{C}{R} = \frac{P_1 \Delta_1 + P_2 \Delta_2}{1 - (L_1 + L_2 + L_3 + L_4 + L_5)}$$

$$\boxed{\frac{C}{R} = \frac{G_1 \cancel{G_2} G_3 + G_1 \cancel{G_4}}{1 + G_1 G_2 H_1 + G_2 G_3 H_2 + G_1 G_2 G_3 + G_4 H_2 + G_4}}$$

G_1

10

Q.5 (b) The 741 C Op-Amp having the following parameters is connected as shown in the figure.

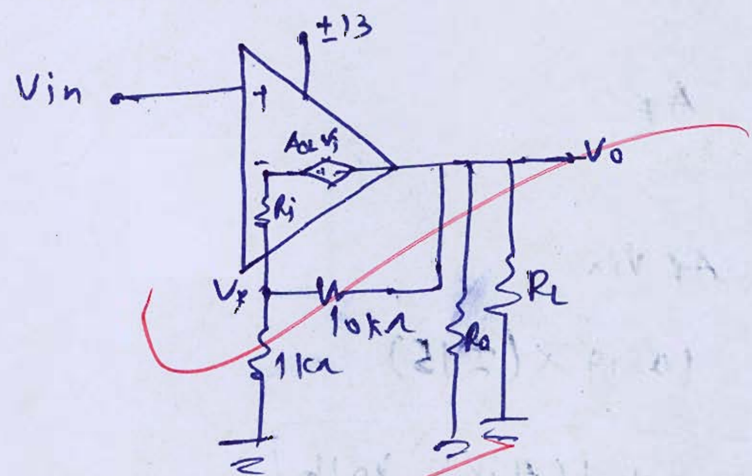


$A = 20000$, $R_i = 2\ \text{M}\Omega$, $R_0 = 75\ \Omega$, $f_0 = 5$ Hz, supply voltage = ±15 V, output voltage swing = ±13 V. Identity the circuit.

Compute the values of A_F, R_{iF}, R_{OF} and V_{OUT}.

[12 marks]

Answer By Drawing Op-Amp with internal parameter



$$\beta = \frac{V_f}{V_o} = \frac{1}{1+10} = \frac{1}{11}$$

Given $A = 20\times10^3$

As above circuit is Negative feedback, and circuit is Voltage Amplifier, So.

$$A_f = \frac{A}{1+A\beta} = \frac{20000}{1+20000\times\frac{1}{11}}$$

$$\boxed{A_f = 10.99}$$

$$R_{if} = \frac{R_i}{1+A\beta} = \frac{2\,M\Omega}{1+20000\times\frac{1}{11}}$$

$$\boxed{R_{if} = 1099.35\,\Omega}$$

$$R_{of} = R_o(1+A\beta) = 75\left(1+20000\times\frac{1}{11}\right)$$

$$\boxed{R_{of} = 136.438\,k\Omega}$$

Now

$$\frac{V_{out}}{V_{in}} = A_f$$

$$V_{out} = A_f V_{in}$$

$$V_{out} = 10.99\times(\pm 15)$$

$$\boxed{V_{out} = \pm 164.85\ \text{Volt}}$$

4

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

$$G(s) = \frac{K}{s(1+sT)}.$$

(i) By what factor the amplifier gain K should be multiplied so that the damping ratio is increased from 0.2 to 0.8?

(ii) By what factor the time constant T should be multiplied so that the damping ratio is reduced from 0.9 to 0.3?

[12 marks]

Answer (i)

$$G(s) = \frac{K}{s(1+sT)}$$

Characteristic equation $1 + G(s)H(s) = 0$

$$s^2 T + s + K = 0$$

$$s^2 + \frac{s}{T} + \frac{K}{T} = 0$$

Standard characteristic equation

$$s^2 + 2\xi\omega_n s + \omega_n^2 = 0$$

$$2\xi\omega_n = 1/T, \quad \omega_n = \sqrt{\frac{K}{T}}$$

$$\xi = \frac{1}{T \times 2\omega_n} = \frac{1}{T \times 2 \times \sqrt{\frac{K}{T}}} \quad \text{——— (1)}$$

$$\xi = \frac{1}{2\sqrt{TK}} \Rightarrow \xi \propto \frac{1}{\sqrt{K}}$$

Now given $\xi_1 = 0.2$, and $\xi_2 = 0.8$

So

$$\frac{\xi_2}{\xi_1} = \sqrt{\frac{K_1}{K_2}} \Rightarrow \frac{0.8}{0.2} = \sqrt{\frac{K_1}{K_2}}$$

$$\frac{K_1}{K_2} = 16 \qquad (\text{Note: } K_1 = K)$$

$$K_1 = 16 K_2$$

or

$$K_2 = \frac{K_1}{16} \Rightarrow \boxed{K_2 = \frac{K}{16}}$$

Do not write in this margin

So K should be multiplied by $\frac{1}{16}$ to increase ξ from 0.2 to 0.8.

(ii) from equation ①

$\xi \propto \frac{1}{\sqrt{T}}$ (By keeping K constant).

Now

$$\frac{\xi_2}{\xi_1} = \sqrt{\frac{T_1}{T_2}}$$

Given $\xi_1 = 0.9$

$\xi_2 = 0.3$

$$\frac{T_1}{T_2} = \frac{1}{9} \Rightarrow \boxed{T_2 = 9T}$$

$\cancel{T_1 = 9}T_2$

$$\boxed{T_2 \cancel{= \frac{T_1}{9} = \frac{T_1}{9^2}}}$$

Note: $T_1 = T$

So T should be multiplied by 9 to decrease ξ from 0.9 to 0.3.

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Good Approach

Q.5 (d) Consider a negative feedback system having the characteristic equation,

$$1+\frac{K}{(1+s)(1.5+s)(2+s)}=0.$$

It is desired that all the roots of the characteristic equation have real parts less than –1. Extend the Nyquist stability criterion to find the largest value of K satisfying the condition.

[12 marks]

Answer

$$G(s)H(s) = \frac{K}{(1+s)(1.5+s)(2+s)}$$

$$G(j\omega)H(j\omega) = \frac{K}{(1+j\omega)(1.5+j\omega)(2+j\omega)}$$

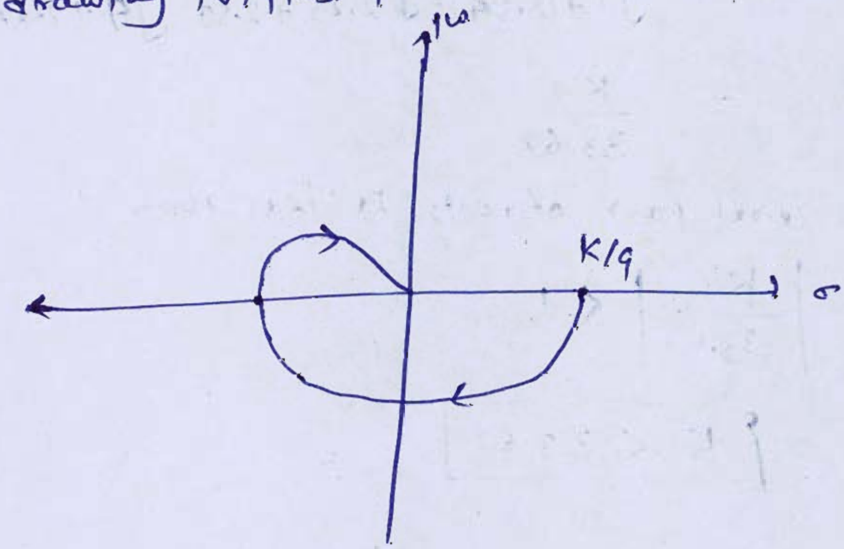
$$|G(j\omega)H(j\omega)| = \frac{K}{\sqrt{1+\omega^2}\sqrt{2.25+\omega^2}\sqrt{4+\omega^2}}$$

$$\angle G(j\omega)H(j\omega) = -\tan^{-1}\omega - \tan^{-1}\frac{\omega}{1.5} - \tan^{-1}\frac{\omega}{2}$$

Now

ω	$\lvert G(j\omega)H(j\omega)\rvert$	$\angle G(j\omega)H(j\omega)$
0	$\frac{K}{9}$	0
⋮		
∞	0	$-270°$

By drawing Nyquist plot



At $\phi = -180$

$$-180 = -\tan^{-1}\omega - \tan^{-1}\frac{\omega}{1.5} - \tan^{-1}\frac{\omega}{2}$$

$$180 = \tan^{-1}\left(\frac{\omega + \frac{\omega}{2}}{1 - \frac{\omega^2}{2}}\right) + \tan^{-1}\frac{\omega}{1.5}$$

$$180 = \tan^{-1}\frac{\frac{\frac{3\omega}{2}}{1-\omega^2/2} + \frac{\omega}{1.5}}{1 - \frac{\frac{3\omega}{2}}{1-\frac{\omega^2}{2}} \times \frac{\omega}{1.5}}$$

6

so

$$\frac{1.5\omega}{1-\frac{\omega^2}{2}} + \frac{\omega}{1.5} = 0$$

$$\frac{3\omega}{2-\omega^2} + \frac{\omega}{1.5} = 0 \Rightarrow 3\omega \times 1.5 + \omega(2-\omega^2) = 0$$

$$-\omega^3 + 6.5\omega = 0$$

$$\omega = 2.54 \text{ rad/sec.}$$

At $\omega = 2.54$, $G(j\omega)H(j\omega)$ will be

$$|G(2.54)H(2.54)| = \frac{K}{\sqrt{1+(2.54)^2}\sqrt{2.25+2.54^2}\sqrt{4+2.54^2}}$$

$$= \frac{K}{33.62}$$

As given Real part of roots is less than -1

So $\left|\frac{K}{33.62}\right| < 1$

$$\boxed{K < 33.62}$$

Q.5 (e) Sketch the polar plots of the transfer function $G(s) = \frac{1}{s(1+s)(1+2s)}$. Determine whether the polar plots cross the real axis. If so, determine the frequency at which the plots cross the real axis and the corresponding magnitude $|G(j\omega)|$.

[12 marks]

Answer

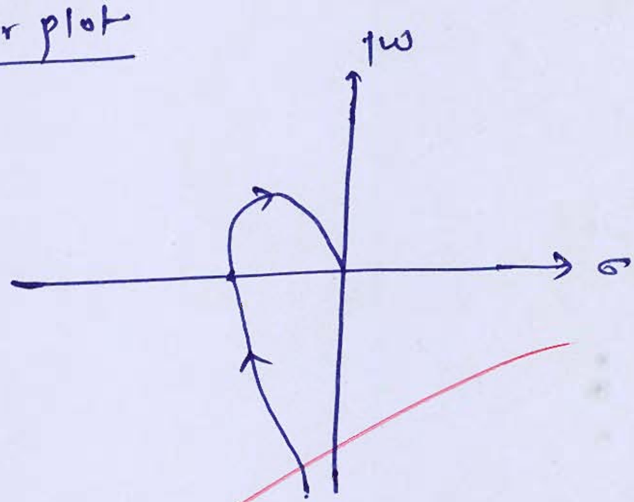
$$G(j\omega) = \frac{1}{j\omega(1+j\omega)(1+2j\omega)}$$

$$|G(j\omega)| = \frac{1}{\omega\sqrt{1+\omega^2}\sqrt{1+4\omega^2}}$$

$$\angle G(j\omega) = -90 - \tan^{-1}\omega - \tan^{-1}2\omega$$

ω	$\lvert G(j\omega)\rvert$	$\angle G(j\omega)$
0	∞	-90
$\vdots$		
∞	0	-270

polar plot



As polar plot crossing the real Axis. As we know plor plot cross the real axis at Angle $-180°$

so

$$-180 = -90 - \tan^{-1}\omega - \tan^{-1}2\omega$$

$$\tan^{-1}\left(\frac{\omega + 2\omega}{1 - 2\omega^2}\right) = 90$$

$$1 - 2\omega^2 = 0$$

$$\boxed{\omega = \frac{1}{\sqrt{2}}} \text{ rad/sec}$$ (Also called phase cross over frequency)

Now at $\omega = \frac{1}{\sqrt{2}}$ rad/sec

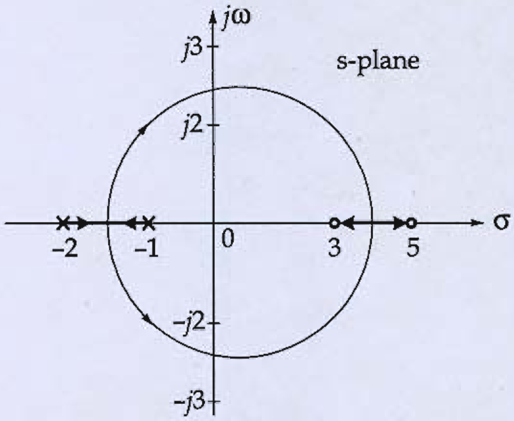
$$|G(j\omega)| = \frac{1}{\frac{1}{\sqrt{2}}\sqrt{1+\frac{1}{2}}\sqrt{1+4\times 1/2}}$$

$$\boxed{|G(j/\sqrt{2})| = \frac{2}{3}}$$

11

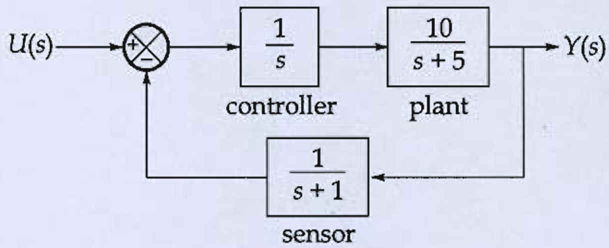
Good Approach

Q.6 (a) **(i)** The root locus plot for the certain control system is shown below:



Find the break-away and break-in points for the above root locus plot.

(ii) Obtain a state-space model of the system shown in figure below:



[10 + 10 marks]

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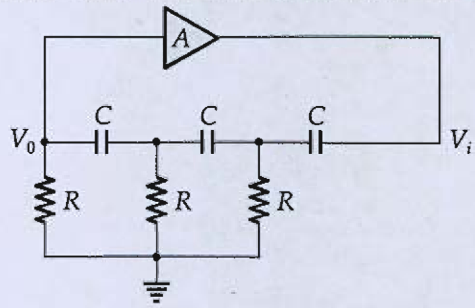
Q.6 (b) Derive the condition of oscillation and the expression for the frequency of oscillations for the circuit shown. (Use mesh analysis and Barkhausen's criteria). Draw actual oscillator circuit with one operational amplifier and minimum number of RC elements.



[20 marks]

Q.6 (c) (i) Using the Routh criterion, check whether the system represented by the following characteristic equation is stable or not. Comment on the location of the roots. Determine the frequency of sustained oscillations if any,

$$s^4 + 2s^3 + 6s^2 + 8s + 8 = 0$$

[10 marks]

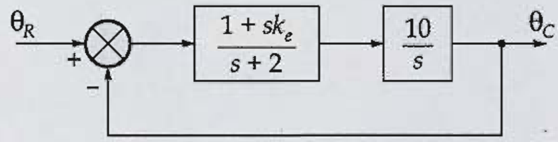
Q.6 (c) **(ii)** A control system with open loop transfer function is represented by $G(s)H(s) = \dfrac{K}{(s+2)^2(s+3)}$. Determine the range of value of K for which value of gain margin $(GM) \geq 4$ and position error constant is $K_p > 2$ when unit step input is applied.

[10 marks]

Q.7 (a) The control system shown in figure employs proportional plus error rate control. Determine the value of error rate constant K_e so that the damping ratio is 0.6.

(i) Determine the value of setting time and maximum overshoot.
Find the steady-state error if the input is a unit-ramp.

(ii) What will be the those values (as calculated in part-i) without error rate control?



[20 marks]

Answer characteristic equation

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

$s(s+2) + 10(1 + sk_e) = 0$

$s^2 + (2 + 10k_e)s + 10 = 0$ —— ①

By comparing with $s^2 + 2\xi\omega_n s + \omega_n^2 = 0$

$\omega_n = \sqrt{10}$ rad/sec, $2\xi\omega_n = 2 + 10k_e$

given $\xi = 0.6$

$2 \times 0.6 \times \sqrt{10} = 2 + 10k_e$

$\boxed{k_e = 0.18}$

Now for

Setting time $t_s = \frac{4}{\xi\omega_n}$

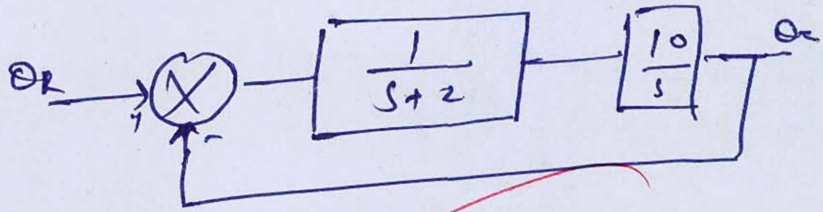
$t_s = \frac{4}{0.6 \times \sqrt{10}} = 2.10$

$\boxed{t_s = 2.10 \text{ sec.}}$

% Maximum overshoot $= \left(e^{-\frac{\pi \times 0.6}{\sqrt{1 - 0.6^2}}}\right) \times 100$

$\boxed{\% M_p = 9.48\,\%}$

(iii) Without error-rate control



Characteristic equation

$$s^2 + 2s + 10 = 0$$

$\omega_n = \sqrt{10}$ rad/sec, $\quad 2\xi\omega_n = 2$

$$\xi = \frac{1}{\sqrt{10}} = 0.316$$

18

Settling time $(t_s) = \frac{4}{\xi\omega_n}$

$$= \frac{4}{0.316 \times \sqrt{10}}$$

Good Approach

$$\boxed{t_s = 4 \text{ sec.}}$$

% Maximum Overshoot $= \left(e^{-\frac{\pi \times 0.316}{\sqrt{1-0.316^2}}}\right) \times 100$

$$\boxed{\% M_p = 35.14\%}$$

Note! As Damping Ratio Decreases maximum overshoot will increases.

Q.7 (b) A negative unity feedback control system is provided with compensator in cascade with system, for system to be stable. The transfer function of plant and compensator are respectively $\frac{1}{s(s+2)(s+4)}$ and $\frac{(s+a)}{s+1}$. Calculate the range of value of 'a' for system to be stable and also represent complete system in form of block diagram. At critical stability condition, what will be the nature of compensator?

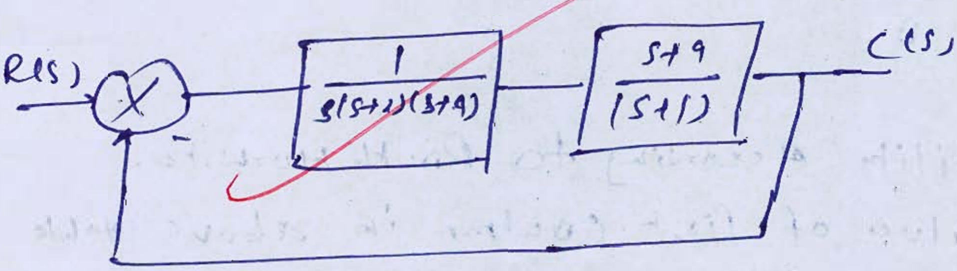
[20 marks]

Answer

Given $G_1(s)_{plant} = \frac{1}{s(s+2)(s+4)}$

$G_2(s)_{Comp.} = \frac{(s+a)}{(s+1)}$

Block Diagram



Characteristic equation

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

$s(s+2)(s+4)(s+1) + s+a = 0$

$(s^3 + 6s^2 + 8s)(s+1) + s + a = 0$

$s^4 + 6s^3 + 8s^2 + s^3 + 6s^2 + 8s + s + a = 0$

$s^4 + 7s^3 + 14s^2 + 9s + a = 0$

By Routh Hurwitz Stability Criterion

s^4	1	14	a
s^3	7	9	0
s^2	$\frac{7\times 14-9}{7}$	a	
s^2	$\frac{89}{7}$	9	
s^1	$\frac{\frac{89}{7}\times 9-7a}{\frac{89}{7}}$	0	
s^0	0		

for stability According to Routh Hurwitz.
All value of first coulmn in above table must be positive, so

$$\frac{89\times 9}{7}-7a>0$$

$$a<\frac{89\times 9}{49}$$

$a < 16.35$, and $a>0$

for critical stability

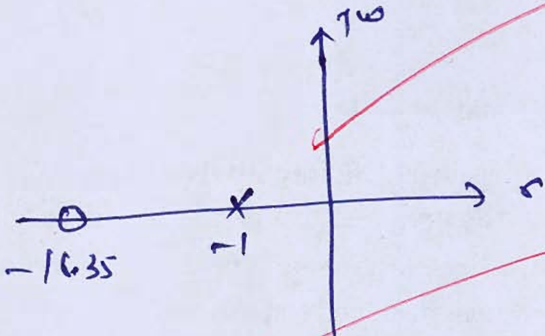
$$\boxed{a=16.35}$$

for stable system

$$\boxed{0<a<16.35}$$

Now compensator

$$G_2(s) = \frac{s+9}{s+1} = \left(\frac{s+16.35}{s+1}\right)$$



pole ⇒ s = −1
zero ⇒ s = −16.35

As pole lies near to origin, so this will be a Lag compensator.

So Nature of compensator will be Lag compensator

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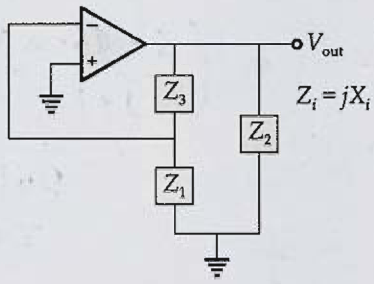
Good Approach

Q.7 (c) In the figure shown below:

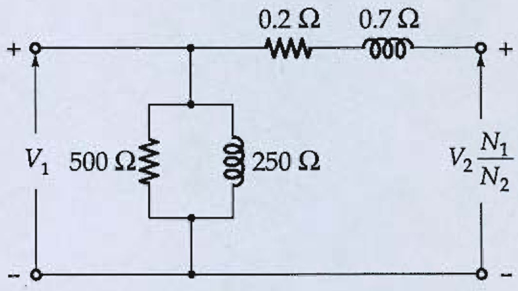


The op-amp in the circuit has a finite open loop gain (A_v), finite output resistance ($R_0 > 0$) and it is ideal in all other aspects. Z_1, Z_2 and Z_3 are purely reactive elements with magnitudes $|X_1|, |X_2|$ and $|X_3|$. Prove that X_1 and X_2 must be of the same type of reactance (i.e., both must be either capacitive or inductive) to produce sustained oscillations.

[20 marks]

Answer

Q.8 (a) The equivalent circuit referred to the low-tension side of a 250/2500 V single phase transformer is shown in figure.



The load impedance connected to the high-tension terminals is $380 + j230\ \Omega$. For a primary voltage of 250 V,

Find:

(i) The secondary terminal voltage.

(ii) Primary current and power factor, and

(iii) Power output and efficiency.

[20 marks]

Q.8 (b) Given the transfer function,

$$\frac{Y(s)}{U(s)} = \frac{1}{(s+5)(s+4)}$$

Obtain the state equation using :

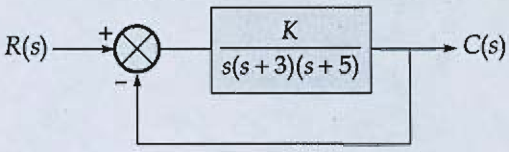
(i) Cascade decomposition

(ii) Direct decomposition

It is desired that the closed loop poles are to be placed at $s = (-1 \pm j2)$. Determine the feedback gain matrix K for part (i) and (ii).

[20 marks]

Q.8 (c) Using the Nyquist criterion, find the range of K for stability for the system shown in figure. Also find the value of gain K and frequency of oscillation for marginal stability.



[20 marks]

OOOO

Space for Rough Work

200 kVA

0.03 Vrated ~~× 0.03~~

3%

0.03% (1)

$0.03 \frac{V_{rated}}{I_{rated}}$

4%

0.04% (2)

Space for Rough Work

Space for Rough Work

0.2° 0.5×60

30 rpm

0.2°

$\omega t = \theta$

$\frac{2\pi N}{60} t = \frac{0.2 \times \pi}{180}$ 0.5 rev/sec

$e_{ss} = \lim_{s \to 0} \frac{s \times R(s)}{1 + G(s)H}$

$\frac{2\pi N}{60} \times t = \frac{0.2 \times \pi}{180}$

$N t = \frac{0.1}{3}$

$s \frac{0.5}{1 + \frac{10k}{s(1+0.1s)}}$

$N = \frac{0.1}{3} \times 60$ 0.2°

$\frac{0.2}{360} = \frac{0.5}{10k}$

$\omega t = \theta \times \frac{\pi}{180}$

$\theta \times \frac{180}{\pi}$ $\frac{0.2^\circ}{360}$

$k = \frac{0.5 \times 360}{10 \times 0.2} = 90$

ω

$s^2 + 0.1 s + 900$

$2\zeta\omega_n = 0.1$ $\omega_n = 30$ $\frac{30}{360} = \frac{1}{12 \times 10k}$ $= 0.2$

0.2°

$= \frac{0.1}{60}$

$k = 10$

$N = 60$

$\frac{2\pi N}{60} = \omega$

$\frac{180}{10k} = 0.2$ $\frac{60}{2\pi} \times \cdot \frac{2\pi}{60} \times 30$

$\frac{180 \; 90}{10 \times 0.2} = k$

$\frac{\pi \times 180}{\pi}$

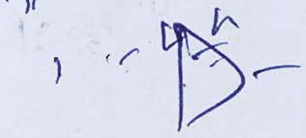
180°

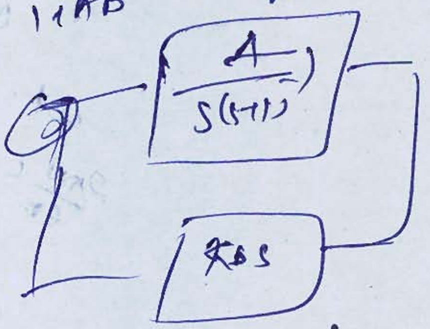
$\frac{60}{2\pi} \times \cdot \frac{2\pi}{60} \times 30$

Space for Rough Work

$$A_f = \frac{A_o}{1+AB}$$

$$R_i = \frac{R_i}{1+AB}$$





Volt. A_L

$$\frac{\frac{A}{S(S+1)}}{1 + \frac{AK_DS}{S(S+1)}}$$

$$\frac{A}{S(S+1)+AK_DS}$$

$$\frac{A}{S^2+(AK_D+1)S}$$

$$\frac{A}{S(S+AK_D+1)}$$

$A(S+1) + BS = 1$

$A = 1$

$A+B=0$

$B = -1$

$$L^{-1}\left[(SI-A)^{-1} B\, U(s)\right]$$

$$\frac{A}{S+1} + \frac{B}{(S+1)^2}$$

$$\frac{S+1-1}{(S+1)^2}$$

$$\frac{1}{S+1} - \frac{1}{(S+1)^2}$$

$$e^{-t} - te^{-t}$$

$$\phi = \frac{mmf}{R}$$

$$R = \frac{NE}{\phi}$$