• Simplify your answer

• Write all steps

MADE EASY

Leading Institute for ESE, GATE & PSUs

ESE 2026 : Mains Test Series

UPSC ENGINEERING SERVICES EXAMINATION

Electrical Engineering

Test-5 : Basic Electronics Engineering + Analog Electronics + Electrical Materials + Electrical Machines-1 + Power Systems-2

Name : ....

Roll No :

Test Centres			Student's Signature
Delhi ☑	Bhopal ☐	Jaipur ☐	
Pune ☐	Hyderabad ☐		

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	48
Q.2	49
Q.3	
Q.4	54
Section-B	
Q.5	33
Q.6	
Q.7	
Q.8	21
Total Marks Obtained	205

Signature of Evaluator ....

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 : B.E.E. + Analog Electronics + Electrical Materials

Q.1 (a) For a dielectric, establish an expression for the relationship between the polarizability and permittivity. How does this relation lead to Clausius-Mosotti equation?

[12 marks]

Polarizability (α) & Permittivity (ϵ)

we know for solid dielectric material

$\vec{D} = \epsilon_0 \vec{E} + \vec{P}$ so $\vec{P}$ (Polarization) $= \vec{D} - \epsilon_0 \vec{E}$

$\vec{P} = \epsilon_0 \epsilon_r \vec{E} - \epsilon_0 \vec{E} = \epsilon_0 (\epsilon_r - 1) \vec{E}$

$\vec{P} = \chi_e \epsilon_0 \vec{E} = \epsilon_0 (\epsilon_r - 1) \vec{E}_{int}$ — (1)

For N atoms/m³ & polarizability α (Fm^2)

$\vec{P} = N \alpha \vec{E}_{tot}$ — (2)

Now $E_{total} = E + \frac{\gamma P}{\epsilon_0}$

For cubical symmetrical structure $\gamma = \frac{1}{3}$.

$E_{total} = \vec{E}_{int} + \frac{\vec{P}}{3\epsilon_0}$

Put E_{total} in eqⁿ (2)

$\vec{P} = N\alpha \left[\vec{E}_{int} + \frac{\vec{P}}{3\epsilon_0} \right]$

Also $\vec{P} = \epsilon_0 (\epsilon_r - 1) \vec{E}_{int} = N\alpha \left[\vec{E}_{int} + \frac{\epsilon_0 (\epsilon_r - 1) \vec{E}_{int}}{3\epsilon_0} \right]$

So $\epsilon_0 (\epsilon_r - 1) = N\alpha \left[1 + \frac{\epsilon_r - 1}{3} \right]$

$\epsilon_0 (\epsilon_r - 1) = \frac{N\alpha}{3} (\epsilon_r + 2)$

So By solving $\boxed{\frac{N\alpha}{3\epsilon_0} = \frac{\epsilon_r - 1}{\epsilon_r + 2}}$ ← Ans

This equation lead to Clausius Mosotti eqⁿ

If that polarizability belong to electronic & ionic so

$\alpha_{tot} = \alpha_e + \alpha_i$

$$\frac{N\alpha_{tot}}{3\varepsilon_0} = \frac{\varepsilon_r - 1}{\varepsilon_r + 2}$$ ← Claussius Mosotti equation

For optical range or very high freq.

$\alpha_i = 0$, $\alpha_{Tot} = \alpha_e$, $\varepsilon_r = n^2$

So $$\frac{N\alpha_e}{3\varepsilon_0} = \frac{n^2 - 1}{n^2 + 2}$$

Good Approach

11

Do not write in this margin

Q.1 (b) (i) Hall measurements are made on a *P*-type semiconductor bar of 500 μm wide and 20 μm thick. The Hall contacts *A* and *B* are displaced 2 μm with respect to each other in the direction of current flow of 3 mA. The voltage between *A* and *B* with a magnetic field of 10^{-4} Wb/cm² pointing out of the plane of the sample is 3.2 mV. When the magnetic field direction is reversed, the voltage changes to 2.8 mV. What is the hole concentration and mobility?

[8 marks]

Given: 500 μm wide.

20 μm thick.

A —2 μm→ B, $I = 3$ mA.

$V_{AB} = 3.2$ mV

B (magnetic field) $= 10^{-4} \frac{Wb}{cm^2} = \frac{10^{-4}}{10^{-4}} = 1 \frac{Wb}{m^2}$.

If B reversed $V_{new} = 2.8$ mV.

To find Hole concentration & mobility.

Hall voltage $V_H = R_H \frac{B_z I_x}{d}$.

So $3.2 \times 10^{-3} = R_H \times \frac{10^{-4}}{10^{-4}} \times \frac{3 \times 10^{-3}}{2 \times 10^{-6}}$.

So Hall coefficient $= R_H = \frac{3.2 \times 10^{-3} \times 2 \times 10^{-6}}{3 \times 10^{-3}}$

$R_H = 2.133 \times 10^{-6}$.

So $R_H = \frac{1}{nq} = \frac{1}{ne} = \frac{1}{pe}$.

Hole concentration $= p = \frac{1}{R_H \cdot e} = \frac{1}{2.133 \times 10^{-6} \times 1.6 \times 10^{-19}}$

Hole conc. $= 0.2929 \times 10^{25} = 2.929 \times 10^{24} / m^3$. ← Ans

Do not write in this margin

we know Mobility $(\mu) = \frac{R_H}{\rho} = \frac{1}{ne\rho}$.

$\rho = \frac{RA}{l}$.

$R = \frac{\Delta V}{I} = \frac{3.2-2.8}{3} = \frac{0.4}{3}\,\Omega$.

$A = 500 \times 20 \times 10^{-12}\ m^2$.

$l = 2 \times 10^{-6}$.

$\rho = \frac{RA}{l} = \frac{0.4}{3} \times \frac{500 \times 20 \times 10^{-12}}{2 \times 10^{-6}} = \frac{0.4}{3} \times 5 \times 10^{-3}$

$\rho = \frac{2}{3} \times 10^{-3}$

Mobility $\mu = \frac{R_H}{\rho} = \frac{2.929 \times 10^{24}}{\frac{2}{3} \times 10^{-3}}$

$\mu = 4.39 \times 10^{27}\ \frac{m^2}{V\text{-}s}$ ← Ans

5

Do not write in this margin

Q.1 (b) **(ii)** A sample of Si doped with phosphorus 10^{17} atoms/cm^3. What would be its resistivity if the electron mobility is 700 cm^2/V.s? What would be the Hall voltage in a sample 100 μm thick if I_x = 1 mA and B_z = 10^{-5} Wb/cm^2.

[4 marks]

Given

$\mu_e = 700 \frac{cm^2}{V\text{-}s}$, $\eta = 10^{17} \frac{atoms}{cm^3}$.

we know

$\sigma = ne\mu = \frac{1}{\rho}$ where σ = conductivity, μ = mobility

$\rho = \frac{1}{\sigma} = \frac{1}{ne\mu}$

$= \frac{1}{10^{17} \times 1.6 \times 10^{-19} \times 700 \times 100} = 0.089 \times 10^{-2} \frac{V\text{-}s}{m^2}$

↳ Ans.

Now For Hall voltage

Given: $d = 100\ \mu m = 100 \times 10^{-6}$.

$I_x = 1\,mA$, $B_z = 10^{-5} \frac{wb}{cm^2}$.

we know Hall voltage $\frac{R_H B_z I_x}{d} = V_H$

So $V_H = \frac{\mu\rho B_z I_x}{d} = \frac{B_z I_x}{ned}$

$\rho\mu = \frac{R_H}{\rho}$

$V_H = \frac{10^{-5} \frac{wb}{10^{-4} m^2} \times 10^{-3} A}{10^{17} \frac{atoms}{10^{-6} m^3} \times 1.6 \times 10^{-19} \times 100 \times 10^{-6} m}$

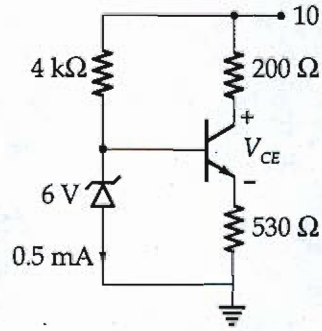
$V_H = \frac{10^{-5-3+4}}{10^{17+6-19} \times 1.6 \times 10^{-4}} = \frac{10^{-4}}{10^{4} \times 1.6 \times 10^{-4}} = 0.625 \times 10^{-4}$

$V_H = 6.25 \times 10^{-5} = 62.5\ \mu V$ ← Ans

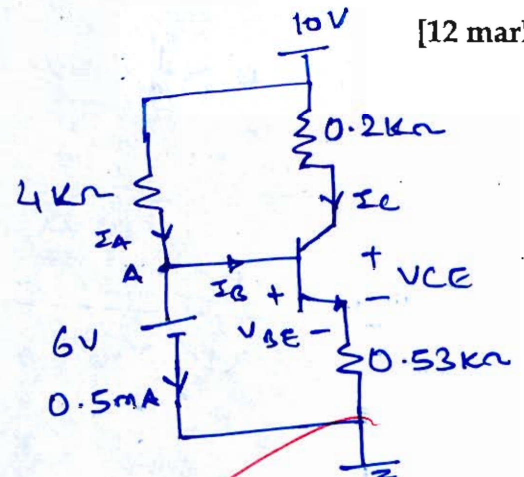
4

Good Approach

Q.1 (c) In the circuit shown below, $V_{BE} = 0.7$ V. Find the β of the transistor and V_{CE}.



[12 marks]



At node A,
After Apply KCL
$I_A = I_B + 0.5$

Apply KVL in inner loop

$6 - V_{BE} - 0.53 I_E = 0$

$6 - 0.7 = 0.53 I_E$

$\frac{5.3}{0.53} = I_E \Rightarrow I_E = 10\,mA$.

Also $I_A = \frac{10-6}{4} = 1\,mA$.

& $I_A = I_B + 0.5 \Rightarrow I_B = 0.5\,mA$.

we know $I_E = I_B + I_C$

So $I_C = I_E - I_B = 10 - 0.5 = 9.5\,mA$.

$\beta = \frac{I_C}{I_B} = \frac{9.5}{0.5} = 19$

So $\beta = 19$ ↳ Ans

Apply KVL in outer loop.

$10 - 0.2 I_C - V_{CE} - 0.53 I_E = 0$

Do not write in this margin

$$V_{CE} = 10 - 0.2 I_C - 0.53 I_E$$

$$= 10 - 0.2(9.5) - 0.53(10)$$

$$= 10 - 1.9 - 5.3 = 2.8 \text{ volt}$$

So $V_{CE} > V_{Csat} = 0.2$

Our Assumption correct That Transistor is in Active region.

Hence

$V_{CE} = 2.8$ volt
$\beta = 19$

} Ans

11

Good Approach

 Do not write in this margin

Q.1 (d) Write a short note on Top-down technique and bottom-up technique used in nano-material synthesis.

[12 marks]

Two Synthesis Technique in nanomaterials

1) Top down Approach

2) Bottom up Approach.

Top down Approach

Element combined to form atom
Atom combined to form molecule

Molecule combined to form cluster.

Here Breakdown of large component into small segments.

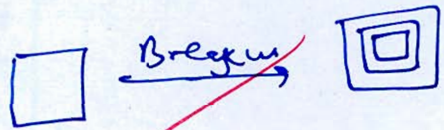
Different type of Theory are

Ion- Plasma Exchange Theory.

Bottom up Approach

Slicing of cutting of material piece wise layer by layer.

Like



Different type of synthesis technique

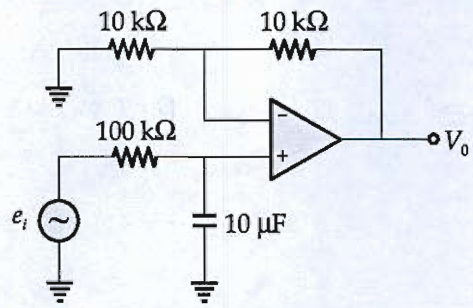
1) Sol-Gel Analysis
2) CVD (Chemical vapour decomposition)
3) Ion- distillation

Many different type of thing combined to form single element

6

Elaborate it more

Q.1 (e) In the circuit shown in figure below, if $e_i = \sin t$, find the voltage V_0.



[12 marks]

Given $e_i = \sin t$

By voltage division rule

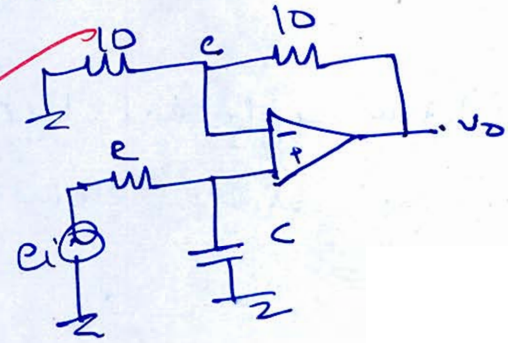
$$V_+ = \frac{1/sC}{R + \frac{1}{sC}} e_i = \frac{e_i}{sRC+1}$$

& In opamp due to Virtual Ground

$$V_+ = V_- = \frac{e_i}{sRC+1}$$

where $R = 100\,k\Omega$, $C = 10\,\mu F$, $e_i = \sin t$

Now Apply KCL at node C



$$\frac{V_c}{10} + \frac{V_c - V_0}{10} = 0$$

$$V_0 = 2V_c$$

$$V_0 = 2V_- = 2V_+$$

$$V_0 = \frac{2e_i}{sRC+1}$$

$$= \frac{2\sin t}{s \times 100 \times 10^3 \times 10 \times 10^{-6} + 1} = \frac{2\sin t}{s+1}$$

$$V_0(s) = \frac{2\sin t}{s+1}$$

$$V_0(j\omega) = \frac{2\sin t}{j\omega+1} = \frac{2}{\sqrt{\omega^2+1}} \sin(t - 45^\circ)\Big|_{\omega=1}$$

Do not write in this margin

$$V_0(t) = \sqrt{2}\sin(t - 45^\circ)$$

$$V_0(s) = \frac{2\sin t}{s+1}$$

→ Ans

11

Good Approach

Do not write in this margin

Q.2 (a) (i) Find out the velocity of light in a material which has a dielectric constant $\in_r$ of 5.5 and a magnetic susceptibility of -2.17×10^{-5}.

(ii) Consider a current of 10 A flowing through a coil of wire. The coil of wire 0.20 m long has 200 turns.

1. What is the magnitude of magnetic field strength H?
2. Calculate the flux density B if the coil is in a vacuum.
3. Calculate the flux density inside a bar of titanium (susceptibility = 1.81×10^{-4}) that is positioned within the coil.
4. Calculate the magnitude of magnetization M.

[20 marks]

i) Given $\varepsilon_r = 5.5$ &

$\chi_m = -2.17 \times 10^{-5}$

To find velocity of light (v)

we know $v = \frac{1}{\sqrt{\mu\varepsilon}} = \frac{1}{\sqrt{\mu_0\mu_r\varepsilon_0\varepsilon_r}}$

$= \frac{1}{\sqrt{\mu_r\varepsilon_r}} \times c$ $\qquad c = \frac{1}{\sqrt{\mu_0\varepsilon_0}} = 3\times10^8 \frac{m}{s}$

Now $\mu_r = 1 + \chi_m$

So $\mu_r = 1 + (-2.17 \times 10^{-5})$

$\mu_r = 0.9999783$

So $v = \frac{3\times10^8}{\sqrt{0.9999783 \times 5.5}} = 1.279 \times 10^8$ m/s.

↳ Ans.

ii) Given $I = 10A$ $\quad N = 200$

$l = 0.2m$

1) To find H (magnetic field strength)

we know By Ampere Circuital law

$\oint \vec{H} \cdot dl = NI$.

So $H = \frac{NI}{l} = \frac{200 \times 10}{0.2} = 10^4 \frac{Amp}{m}$ → Ans.

2) To find B (Magnetic flux density)

In vaccum $\mu_r = 1$

So $B = \mu H = \mu_0 \mu_r H = 4\pi \times 10^{-7} (1) \times 10^4$

$$B = 4\pi \times 10^{-3} = 0.01256 \ \frac{wb}{m^2}$$ ← Ans

3) To find flux density inside bar if:

$\chi_m = 1.81 \times 10^{-4}$

So $\mu_r = 1 + \chi_m \Rightarrow \mu_r = 1 + 1.81 \times 10^{-4}$

$\mu_r = 1.000181$.

& $B = \mu H = \mu_0 \mu_r H = 4\pi \times 10^{-7} \times 1.000181 \times 10^4$

$$B = 12.568 \times 10^{-3} = 1.256 \times 10^{-2} \ \frac{wb}{m^2}$$ ← Ans

4) Magnitude of magnetization M.

18

Good Approach

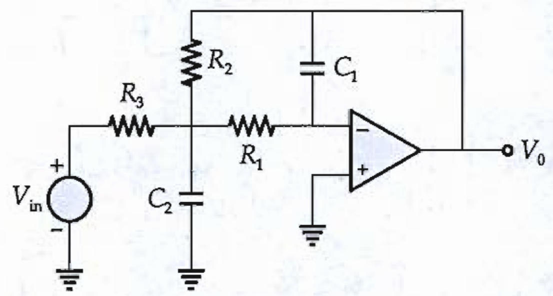
$M = \chi_m H$

& $B = \mu_0 (H + M) = \mu_0 (H + \chi_m H) = \mu_0 H (1 + \chi_m)$

$= \mu_0 \mu_r H = \mu H$.

$$M = 1.81 \times 10^{-4} \times 10^4 = 1.81 \ \frac{Amp}{m}$$ ← Ans

Q.2 (b) For the circuit shown below, find $A_v = \dfrac{V_0}{V_{in}}$, the damping factor and cutoff frequency.



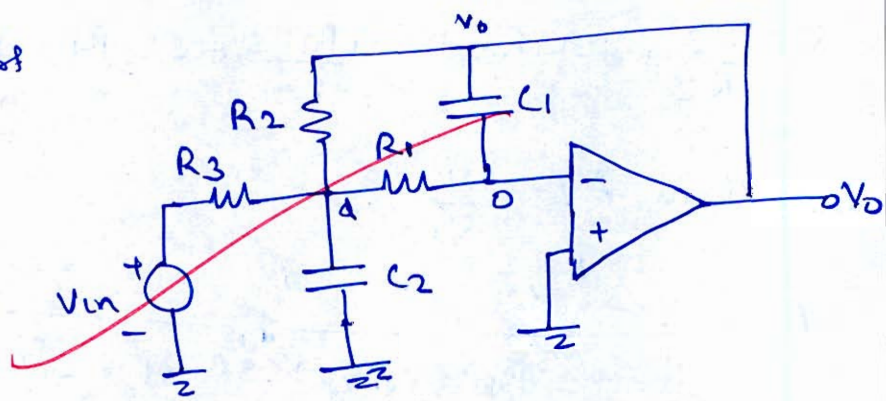
[20 marks]

Given:

To find $Av = \frac{Vo}{Vin}$ & damping factor & cutoff freq.

By virtual short

$V_+ = V_- = 0$



Apply KCL at node D

$$\frac{Vd - Vin}{R_3} + \frac{Vd - 0}{R_1} + \frac{Vd - Vo}{R_2} + \frac{Vd}{1/sC_2} = 0$$

$$Vd\left[\frac{1}{R_3} + \frac{1}{R_1} + \frac{1}{R_2} + sC_2\right] = \frac{Vo}{R_2} + \frac{Vin}{R_3} \quad \text{—(1)}$$

Now Apply KCL at (V_-) point.

so $$\frac{0 - Vd}{R_1} + \frac{0 - Vo}{1/sC_1} + I_{nt} = 0$$ ∵ (Internal current OP-AMP ≈ 0 due to high Z_{in})

so $sC_1 Vo = -\frac{Vd}{R_1}$

$Vd = -sC_1 R_1 Vo$

Put value of V_d in eq^n (1)

$$-sC_1R_1V_0\left[\frac{1}{R_1}+\frac{1}{R_2}+\frac{1}{R_3}+sC_2\right]=\frac{V_0}{R_2}+\frac{V_{in}}{R_3}$$

$$\frac{V_0}{R_2}+sC_1R_1V_0\left[\frac{1}{R_1}+\frac{1}{R_2}+\frac{1}{R_3}+sC_2\right]=-\frac{V_{in}}{R_3}.$$

$$V_0\left[\frac{1}{R_2}+sC_1R_1\left(\frac{1}{R_1}+\frac{1}{R_2}+\frac{1}{R_3}+sC_2\right)\right]=-\frac{V_{in}}{R_3}.$$

$$V_0\left[\frac{1}{R_2}+sC_1+sC_1\frac{R_1}{R_2}+sC_1\frac{R_1}{R_3}+s^2R_1C_1C_2\right]=-\frac{V_{in}}{R_3}.$$

$$V_0\left[\frac{R_3}{R_2}+sC_1R_3+\frac{sC_1R_1R_3}{R_2}+sC_1R_1+s^2R_1R_3C_1C_2\right]=-V_{in}$$

So Gain $A_V=\frac{V_0}{V_{in}}$

$$A_V=\frac{-1}{\frac{R_3}{R_2}+s^2R_1R_3C_1C_2+sC_1R_1+\frac{sR_1C_1R_3}{R_2}}$$

Put $s=j\omega$

$$A_V=\frac{-1}{\frac{R_3}{R_2}-\omega^2R_1R_3C_1C_2+j\omega C_1R_1\left(1+\frac{R_3}{R_2}\right)}.$$

See denominator what is written & rearrange.

$$s^2R_1R_3C_1C_2+sC_1R_1\left(1+\frac{R_3}{R_2}\right)+\frac{R_3}{R_2}$$

$$R_1R_3C_1C_2\left[s^2+\frac{sC_1R_1(R_2+R_3)}{R_2R_1R_3C_1C_2}+\frac{R_3}{R_2R_1R_3C_1C_2}\right].$$

Do not write in this margin

So $A_v = \dfrac{-1/R_1R_3C_1C_2}{s^2 + \dfrac{s(R_2+R_3)}{R_3R_2C_2} + \dfrac{1}{R_1R_2C_1C_2}}$ ← Ans

Compare denominator with standard 2nd order Transfer function

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

So $\omega_n^2 = \dfrac{1}{R_1R_2C_1C_2}$, $\omega = \dfrac{1}{\sqrt{R_1R_2C_1C_2}}$

So cut off freq $= f_c = \dfrac{1}{2\pi\sqrt{R_1R_2C_1C_2}}$ Hz

↳ Ans

$2\xi\omega_n = \dfrac{(R_2+R_3)}{R_2R_3C_2}$

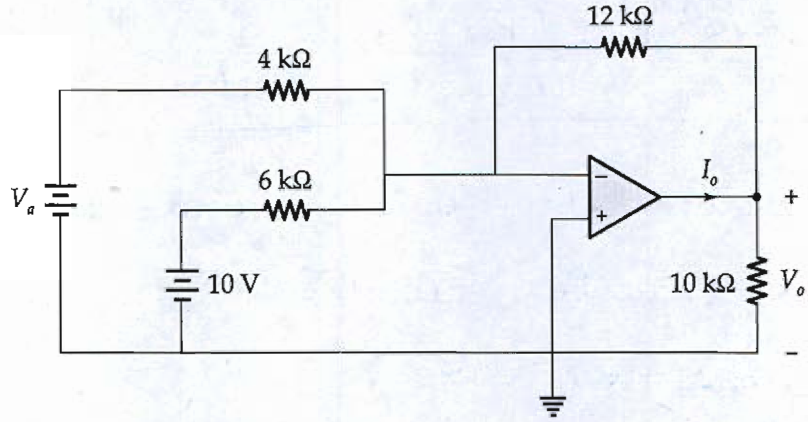
$\xi = \dfrac{(R_2+R_3)}{2R_2R_3C_2 \times}\sqrt{R_1R_2C_1C_2} = \dfrac{(R_2+R_3)}{2R_3}\sqrt{\dfrac{R_1C_1}{R_2C_2}}$

So damping factor $= \dfrac{R_2+R_3}{2R_3}\sqrt{\dfrac{R_1C_1}{R_2C_2}}$ ← Ans

17

Go through the made easy solution

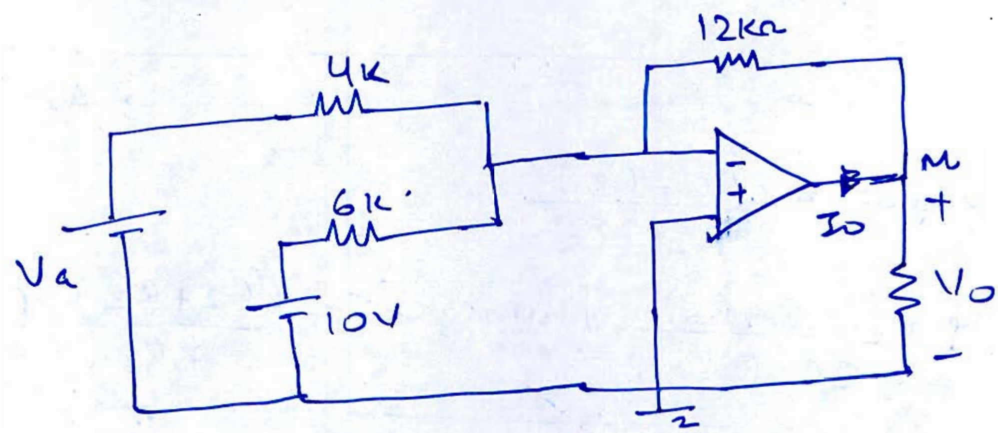
Q.2 (c) For the circuit shown below, the op-amp is considered to be ideal.



(i) For an input voltage $V_a = 4$ V, find the output voltage V_o and current I_o.

(ii) Determine the range of input voltage V_a for linear operation if the saturation voltage of op-amp is ±12 V.

[20 marks]



By Virtual short concept:

$V_+ = V_- = 0$

Apply KCL at inverting terminal of OP-AMP

$$\frac{0-V_a}{4} + \frac{0-10}{6} + \frac{0-V_o}{12} = 0$$

$$\frac{-3V_a - 20 - V_o}{12} = 0$$

$$\text{So } V_o = -(3V_a + 20) \quad \text{—(1)}$$

If $V_a = 4V$

So $V_o = -(3\times 4 + 20) = -32$ volt.

& Current I_o

Apply KCL at node M.

So $I_o = \frac{V_o}{10} + \frac{V_o - 0}{12} = V_o\left[\frac{1}{10} + \frac{1}{12}\right]$.

$= V_o\left[\frac{6+5}{60}\right] = -32 \times \frac{11}{60} = -5.866$ mA.

So $V_o = -32$ volt
$I_o = -5.866$ mA ← Ans.

ii) To find Range of V_a for linear operation

If V_{sat} of OPAMP $= \pm 12V$.

Now we proved Above by eq^n (1)

$V_o = -(3V_a + 20)$

To find Range of V_a.

$V_o = +V_{sat} = +12 = -3(V_{amin} + 20)$.

$-4 = V_a + 20$

$V_{a_{min}} = -24$ volt

If $V_o = -V_{sat} = -12 = -3(V_a + 20)$

$4 = V_a + 20$

$V_{a_{max}} = -16$ volt

So Range of $V_a = [V_{min}, V_{max}]$

Va lies b/w −16 volt to −24 volt

$V_{a\,min} = -24V$

$V_{a\,max} = -16V$

$$-24 \leq V_a \leq -16.$$

← Range of Va for linear operation if Vsat of OPAMP = ±12V

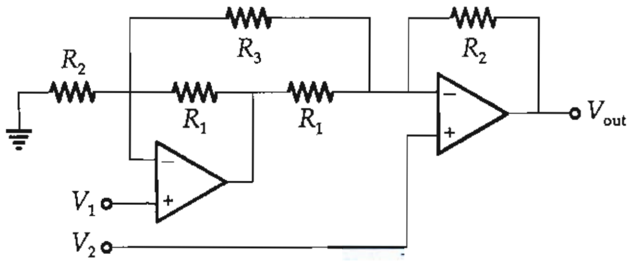
Ans

10

14

Do not write in this margin

Q.3 (a) (i) Consider the circuit shown in figure below.



Assuming the two op-amp to be ideal, calculate the value of $\frac{V_{out}}{V_2 - V_1}$.

[12 marks]

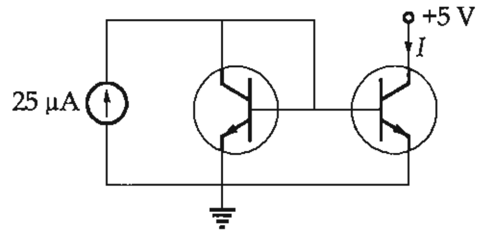
Do not write in this margin

Do not write in this margin

Q.3 (a) (ii) Discuss Matthiessen's rule and explain the influence of the factors affecting resistivity of metals.

[8 marks]

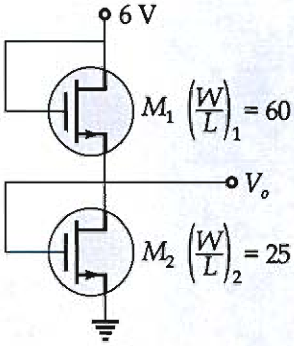
Q.3 (b) (i) The two transistors in the circuit shown below are identical. If $\beta = 25$, then find the value of current I.



[8 marks]

Do not write in this margin

Q.3 (b) **(ii)** Consider the circuit shown in figure below :



If both transistor have parameters $\mu_n C_{ox} = 40\ \mu A/V^2$ and $V_{Th} = 0.9$ V then calculate the output voltage V_o.

[6 marks]

Q.3 (b) (iii) Calculate the Fermi energy E_{FO} at 0°K for copper and estimate the average speed of the conduction electrons in Cu. The density of Cu is 8.96 gm/cm^3 and atomic weight is 63.5. Given Avogadro's number is 6×10^{23}.

[6 marks]

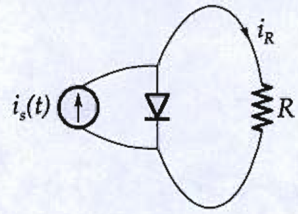
Q.3 (c) A parallel plate capacitor has an area of 25 cm^2 and the separation between the plates is 0.3 mm. The space between the plates is filled with a dielectric having the real part of dielectric constant $\varepsilon_r' = 3$ when subjected to the frequency of 1.5 MHz. The loss tangent at this frequency is 3.8×10^{-4}. Find the parameters of the equivalent circuit.

(i) Parallel R-C circuit.

(ii) Series R-C circuit.

[20 marks]

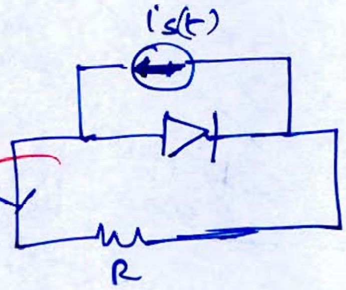
Q.4 (a) (i) The diode in the circuit is ideal. The current sources $i_s(t) = \pi \sin(3000\pi t)$mA. Find the magnitude of the average current flowing through the resistor R.



[10 marks]

$i_s(t) = \pi \sin(3000\pi t)$ mA.

To find Iavg. through R.



Soln

For +ve cycle

Diode is ON

$i_{avg} = -i_R = \frac{i_M}{\pi} = \frac{\pi}{\pi} = 1$ mA.

So $i_{avg} = i_R = -1$ mA

For -ve half cycle Diode is off

So $i_R = 0$

So Avg. current flowing through resistance R = −1 mA
↳ Ans

9
Good Approach

$I_{avg} = \frac{1}{2\pi}\int_0^{2\pi} I_m \sin\omega t\,(d\omega t) = \frac{1}{2\pi}\left[\int_0^{\pi} \pi \sin 3000\pi t\,(d\omega t) + \int_{\pi}^{2\pi} 0\, d(\omega t)\right].$

$= \frac{\pi}{2\pi}\left[-\cos\omega t\right]_0^{\pi} = \frac{1}{2}\left[-\cos\pi + \cos 0\right]$

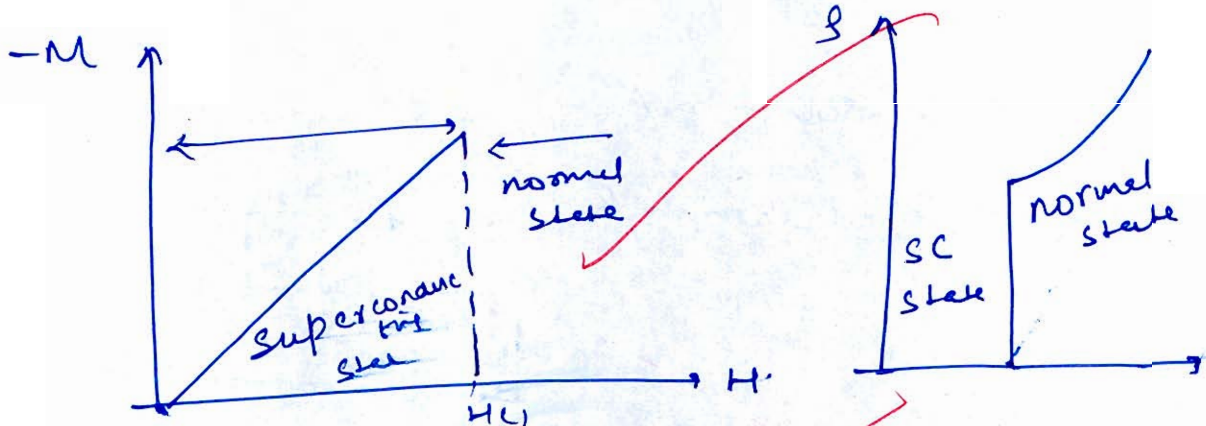
$= 1$

Q.4 (a) **(ii)** With the help of magnetization characteristics (*M* vs *H* curves) explain the difference between Type-I and Type-II superconductors.

[10 marks]

M vs H curve for Type I & Type Superconductor

For Type I Superconductor



In Type I superconductor

It is for low magnetic field & it follow Silsbee Rule & Meissner effect.

Here magnetic field changes abrupt suddenly, & for Temp below transition or critical Temp.

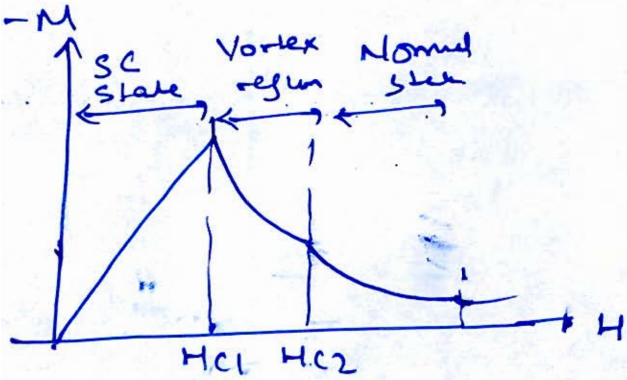
H (magnetic field strength) ↑ linear upto HC1 (critical magnetic field)

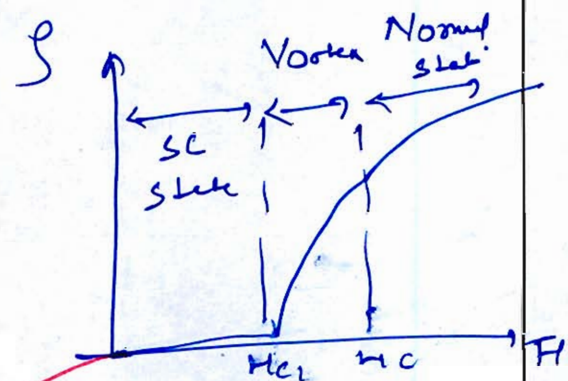
& After HC1 it enter into normal state.

Type I superconductor occur for soft magnetic material.

For Ex: NbTi, Nb3Al.

For Type II superconductor





For Type II superconductor There are two zones

1) SC state: Here Magnetic field increases linearly upto H_{c1} (critical field)

Then Superconductor enter into Vortex region

2) Vortex state: Here Abruptly changes not happens.

Here Hc varies slowly transition it decrease & goes upto H_{c2}.

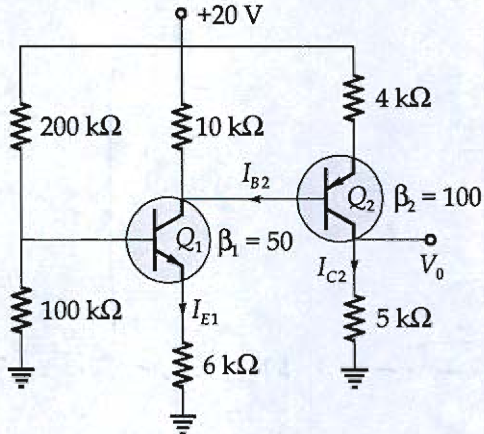
3) while after $H > H_{c2}$ superconductivity vanishes & material enter from superconductor state to normal state

& Here Magnetic field becomes zero

These valid for Hard Magnetic material & Type II Superconductor used for making permanent magnets

Ex: Fe, Co, Ni, Nb_3Ti, Nb_3Sn

Q.4 (b) Consider the transistor configuration shown below.



Determine:

(i) Base current of transistor, Q_2.

(ii) Collector current of transistor, Q_2.

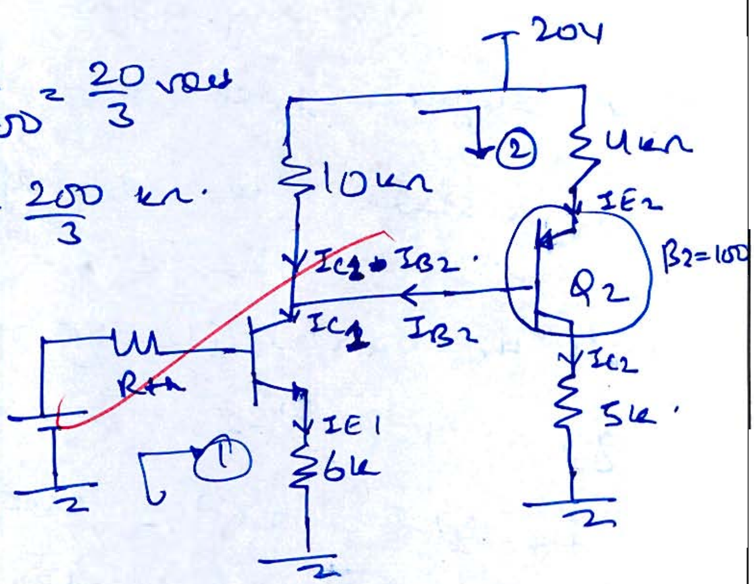
(iii) Emitter current of transistor, Q_1.

(iv) Output voltage, V_0.

[20 marks]

$V_{th}\,Q_1 = 20 \times \dfrac{100}{200+100} = \dfrac{20}{3}$ volt

$R_{th}\,Q_1 = 200 \,||\, 100 = \dfrac{200}{3}$ kΩ.



current in 10kΩ

$x + I_{B2} = I_{C1} \Rightarrow x = I_{C1} - I_{B2}$.

Apply KVL in loop 1

$V_{th} - I_{B1}R_{th} - V_{BE1} - 6I_{E1} = 0$

$6.67 - I_{B1}(66.67) - 0.7 - 6(1+\beta_1)I_{B1} = 0$

$6.67 - 66.67 I_{B1} - 0.7 - 306 I_{B1} = 0$

$I_{B1} = \dfrac{6.67 - 0.7}{306 + 66.67} = \dfrac{5.97}{372.67} = 16.01\,\mu A$

So $I_{C1} = \beta_1 I_{B1} = 0.8\,mA$.

$I_{E1} = 0.816\,mA$.

Apply KVL in loop 2.

$-4I_{E2} - V_{EB2} + 10(I_{C1} - I_{B2}) = 0$.

$-4I_{E2} - 0.7 + 10(0.8) - 10I_{B2} = 0$ $V_{EB} = 0.7$

$8 - 0.7 = 4I_{E2} + 10I_{B2}$.

$7.3 = [4(1+\beta_2) + 10] I_{B2}$

$$I_{B2} = \frac{7.3}{10 + 4(1+100)} = 17.63\,\mu A.$$

$I_{C2} = \beta_2 I_{B2} = 1.7632\,mA$.

$I_{E2} = 1.78\,mA$.

18

Good Approach

So

1) Base current of Transistor Q_2

$= I_{B2} = 17.63\,\mu A$ ← Ans

2) Collector current of transistor Q_2

$= I_{C2} = 1.7632\,mA$ ← Ans

3) Emitter current of Transistor Q_1.

$I_{E1} = 0.816\,mA$ ← Ans

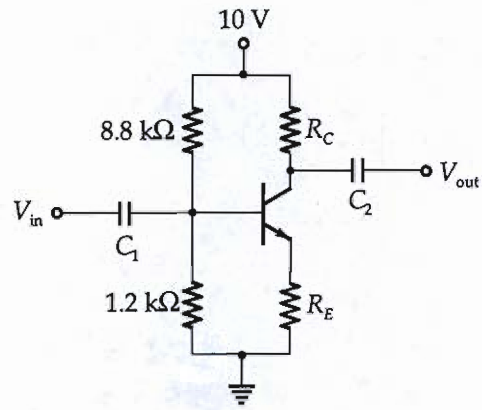
4) Output voltage V_0

$V_0 = 5 I_{C2} = 5 \times 1.7632 = 8.816$ volt

$V_0 = 8.816$ volt ← Ans

Do not write in this margin

Q.4 (c) In the amplifier circuit shown below, assume $V_{BE} = 0.7$ V and the β of the transistor and the values of C_1 and C_2 are extremely high. If the amplifier is designed such that at the quiescent point its $V_{CE} = V_{CC}/2$, where V_{CC} is the power supply voltage, find its small signal voltage gain $\left|\frac{V_{out}}{V_{in}}\right|$.



[20 marks]

Given $V_{BE} = 0.7V$, β, C_1, C_2 high

$V_{CE} = \frac{V_{CC}}{2}$, $V_{CC} = 10V$.

To find small signal voltage gain $\left(\frac{V_{out}}{V_{in}}\right)$

soln

DC Transfer Characteristics:-

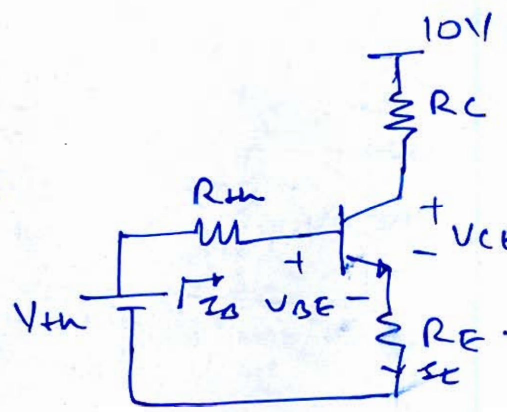
Cap - OC $\quad X_C = \frac{1}{\omega C} \approx \infty$

AC supply - Grounded

$V_{th} = 10 \times \frac{1.2}{8.8+1.2} = 1.2$ Volt

$R_{th} = 8.8 \parallel 1.2 = \frac{8.8 \times 1.2}{10}$

$= 1.056 k\Omega$



Apply KVL inner loop

$V_{th} - I_B R_{th} - V_{BE} - I_E R_E = 0$

As β high so $I_B \simeq 0$ $\quad$ So $I_E R_E = V_{th} - V_{BE} = 1.2 - 0.7$

$\boxed{I_E R_E = 0.5 \text{ Volt}}$ — (1)

Apply KVL in outer loop

$10 - I_C R_C - V_{CE} - I_E R_E = 0$.

So $V_{CE} = \frac{V_{CC}}{2} = \frac{10}{2} = 5V$.

$10 - I_C R_C - 5 - 0.5 = 0$

$I_E R_E = 0.8$ (Prooved Above)

$\boxed{I_C R_C = 4.5 \text{ volt}}$ —(II)

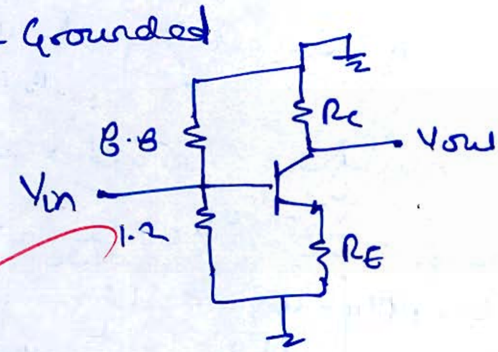
Divide (I) ÷ (II)

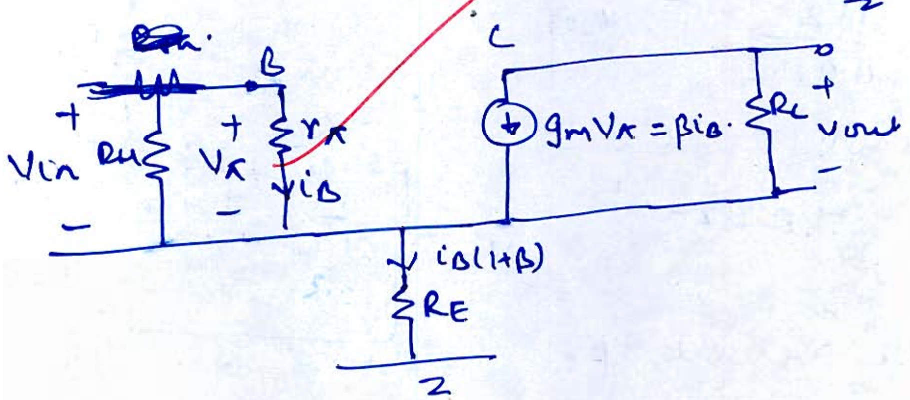
$\frac{I_E R_E}{I_C R_C} = \frac{0.5}{4.5} \Rightarrow \boxed{\frac{I_C R_C}{I_E R_E} = 9}$

Now

Draw AC equivalent circuit

Cap → SC , DC supply - Grounded





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

$V_{out} = -g_m V_\pi R_C = -g_m r_\pi i_B R_C = -\beta i_B R_C \Rightarrow$

$V_{in} - \quad - V_\pi - i_B(1+\beta)R_E = 0$

$V_{in} = i_B[\quad + r_\pi + (1+\beta)R_E]$

$$\frac{V_{out}}{V_{in}} = \frac{-\beta i_B R_C}{i_B[\quad + r_\pi + (1+\beta)R_E]}$$

$$= \frac{-\beta R_C}{\quad + r_\pi + (1+\beta)R_E}$$

$r_\pi = \frac{\beta}{g_m} \Rightarrow g_m = \frac{I_C}{V_T} \Rightarrow r_\pi = \frac{\beta V_T}{I_C}$

$$\frac{V_{out}}{V_{in}} = \frac{-\beta R_C}{\frac{\beta V_T}{I_C} + (1+\beta)R_E} = \frac{-R_C}{\frac{V_T}{I_C} + \left(\frac{1+\beta}{\beta}\right)R_E}$$

$$= \frac{-R_C/R_E}{\frac{V_T}{I_C R_E} + \left(\frac{1}{\beta}+1\right)}$$

If β very high so $\frac{1}{\beta} \approx 0$

$$\frac{V_{out}}{V_{in}} = \frac{-R_C/R_E}{\frac{V_T}{I_C R_E} + 0 + 1} = \frac{-R_C/R_E}{\frac{V_T + I_C R_E}{I_C R_E}}$$

$$= \frac{-R_C R_E I_C}{R_E(V_T + I_C R_E)} = \frac{-I_C R_C}{V_T + I_C R_E} = \frac{-I_C R_C}{V_T + I_E R_E}$$

18

$$\boxed{\frac{V_{out}}{V_{in}} = \frac{-9 I_E R_E}{I_E R_E + 0.026}}$$ ← Ans

Try to avoid over writing

Section B : Electrical Machines-1 + Power Systems-2

Q.5 (a) A monopolar HVDC link energized from a 3-ϕ, 50 Hz, 400 kV source produces a DC current of 1000 A with a 6-pulse rectifier and the DC output voltage rectifier is 400 kV. For a delay angle of 15°.

(i) Calculate commutation resistance.

(ii) Calculate commutation angle 'μ'.

(iii) If AC voltage is reduced to 200 kV, find commutation angle assuming dc current is constant.

[12 marks]

$I_{DC} = 1000\,A$

6 pulse rectifier

$V_{odc} = 400\,kV$

3ϕ 50Hz 400kV

For $\alpha = 15$

$V_o = \frac{3V_{ML}}{\pi}\cos\alpha - 6fL_s I_o$

$V_o = \frac{3\times400\sqrt{2}}{\pi}\cos 15 - 0 = 521.78$ real

i) Commutation Resistance = $R = \frac{V_o}{I_{dc}} = \frac{521.78}{1000}$

$= 0.52178\,\Omega$

(ii) $V_o = \frac{3V_{ML}}{\pi}[\cos\alpha + \cos(\alpha+\mu)]$

$V_o = \frac{3\times400\sqrt{2}}{\pi}[\cos\alpha + \cos(\alpha+\mu)]$

$I_o R = 0.52178\times1000 = 521.78$

$521.78 = 540$

Do not write in this margin

$I_0 = \frac{V_{ML}}{3\omega L_p}[\cos\alpha - \cos(\alpha+\mu)]$

$V_0 = 400\,kV = \frac{3V_{ML}}{\pi}[\cos\alpha + \cos(\alpha+\mu)]$

$400 = \frac{3\times 400\sqrt{2}}{\pi}[\cos 15 + \cos(15+\mu)]$

$0.74 = 0.965 = \cos(15+\mu)$

$15+\mu = 103.05$

$\boxed{\mu = 88.05}$ ← Ans

(iii) If AC = 200 kV

$V_0 = 400 = \frac{3\times 200\sqrt{2}}{\pi}[\cos 15 + \cos(15+\mu)]$

$4 = 3\times 0.9[\cos 15 + \cos(15+\mu)$

$\cos(15+\mu) = 0.515$

$15+\mu = 58.96$

(6)

$\boxed{\mu = 43.96}$ ← Ans

Q.5 (b) An induction motor has an efficiency of 0.9 when the shaft load is 45 kW. At this load, stator ohmic loss and rotor ohmic loss each is equal to the iron loss. The mechanical loss is 1/3rd of the no load losses. Neglect ohmic losses at no load, and calculate the slip.

[12 marks]

$P_{sh} = 45 kW \quad \eta = 0.9$

Stator ohmic loss, Rotor ohmic loss = Iron loss.

Mech. loss = $\frac{1}{3}$(No load losses)

$P_{sh} = P_{out}$ − F&W loss = P_{dev} − F&W loss.

$P_{dev} = P_g$ − rotor cu loss $= P_g(1-s)$

$P_g = P_{in}$ − stator cu & Iron loss.

Mech loss = $\frac{1}{3}$rd (No load loss) ⇒

Mech = $\frac{1}{3}$(Iron loss + Mech loss) ⇒ Iron loss = 2 Mech loss.

Pinput = $\frac{P_{sh}}{\eta} = \frac{45}{0.9} = 50 kW$, losses = I/P − O/P
= 50 − 45 = 5 kW

4

Iron loss = 2(Mech losses)

$P_{dev} = P_g$ − Stator ohmic − rotor ohmic loss
$= P_g - 2 \times$ Iron loss.

$P_{sh} = P_g$ − 2 Iron loss − F&W loss

Go through the made easy solution

$P_d = P_g(1-s)$.

$sP_g = 5$

$s = \frac{5}{50} = 0.1$

slip = 0.1 ← Ans

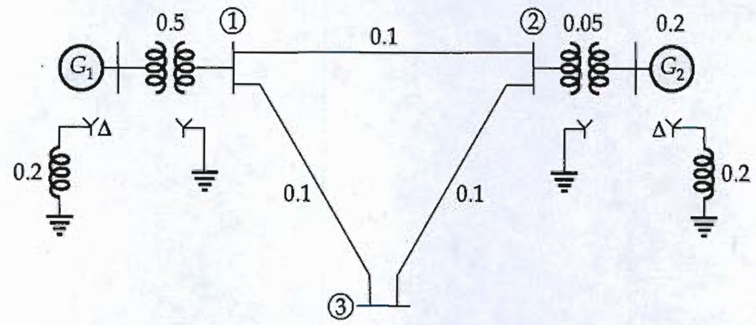
Do not write in this margin

Q.5 (c) For the power system shown in figure, the pu reactances are shown therein. For a solid 3-phase fault on bus 3. Calculate the following :

(i) Fault current **(ii)** V_1^f and V_2^f

(iii) I_{12}^f, I_{13}^f and I_{23}^f **(iv)** I_{G1}^f and I_{G2}^f

Assume pre-fault voltage to be 1 pu. (Where *f* represents post fault event)



Z_{Bus} for the above system, $Z_{Bus} = j\begin{bmatrix} 0.1397 & 0.1103 & 0.1250 \\ 0.1103 & 0.1397 & 0.1250 \\ 0.1250 & 0.1250 & 0.1750 \end{bmatrix}$

[12 marks]

i) 3Ø fault on bus 3.

$I_f = \frac{V_3}{Z_{33}} = \frac{1\angle 0}{j\,0.1750} = 5.714 \angle -90°$

(ii) $V_1^f = V_{1pref} - I_f Z_{13}$.

$= 1\angle 0 - 5.714\angle -90 \times 0.125\angle 90$

$= 1 - 0.714$

$V_1^f = 0.2857$ pu

Similarily $V_2^f = V_{2pref} - I_3 Z_{23}$

$= 1\angle 0 - 5.714\angle -90 \times 0.125\angle 90$

$V_2^f = 0.2857$ pu

(iii) $I_{12}^{f} = \dfrac{V_1^{(F)} - V_2^{(F)}}{Z_{12}+Z_{L}}$.

$V_3^{f} = V_3^{pre} - I_3 Z_{33}$

$= 1\angle 0 - 5.714\angle -90 \times 0.175$

$= 0$ volt

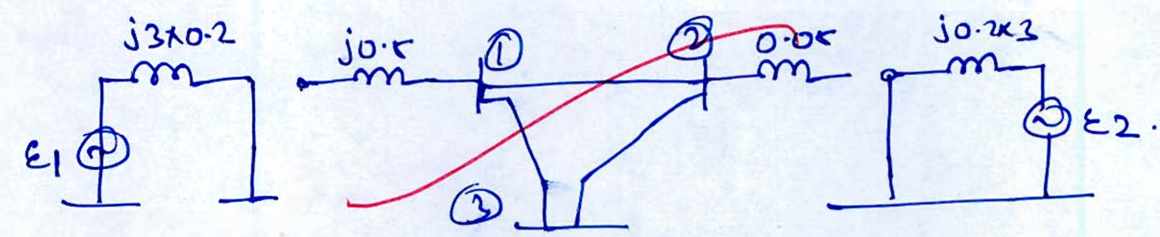
So $I_{12}^{f} = \dfrac{0.2857 - 0.2857}{0.1103+0.1} = 0$.

$I_{13}^{f} = \dfrac{V_1^{F} - V_3^{F}}{Z_{13}+j0.1} = \dfrac{0.2857-0}{j0.125+j0.1} = 1.269\angle -90^\circ$

$I_{23}^{f} = \dfrac{V_2^{F} - V_3^{F}}{Z_{23}+j0.1} = \dfrac{0.2857}{j0.125+j0.1} = 1.269\angle -90^\circ$

7

Draw equivalent circuit



iv) $I_{G1}^{f} = \dfrac{E_1}{j0.6} = \dfrac{1}{0.6} = 1.67\angle -90$

$I_{G2}^{f} = \dfrac{E_2}{j0.6} = 1.67\angle -90$

↳ Ans

Do not write in this margin

Q.5 (d) A 3-ϕ, 500 kW, 3.3 kV, 50 Hz, star-connected induction motor works at a full load power factor of 0.7 lag. A delta connected capacitor bank is used to raise the full load power factor to 0.9 lag. Calculate the capacitance of the bank. If each capacitor is rated at 420 V, 50 Hz, compute the capacitance of each unit. The motor efficiency is 86%. If this induction motor is fed by distribution circuit, calculate the percentage saving in the energy lost in this distribution circuit, as the power factor is improved from 0.7 to 0.9 lag.

[12 marks]

3ϕ, 500 kW, 3.3 kV, 50 Hz

Y connected IM $\cos\phi = 0.7$ lag.

Δ connected cap. Bank. $\cos\phi_2 = 0.9$ lag.

$P = 500$ kW

$Q_1 = P\tan\phi = 500 \times \tan(\cos^{-1}0.7) = 510.10$ kVAr

$Q_2 = P\tan\phi_2 = 500\tan(\cos^{-1}0.9) = 242.161$ kVAr

$Q_c = P(\tan\phi_1 - \tan\phi_2)$

$= 500(\tan 45.572 - \tan 25.84) = 267.95$ kVAr

Now $Q_c = 3\omega C_{ph} V_{ph}^2 \tan\phi$.

~~$Q_c = VI$.~~ $\dfrac{267.95}{3} = 2\pi(50) C_{ph}\, 420^2$.

$C_{ph} = \dfrac{267.95}{3 \times 150\pi \times 420^2} = 1.611\ \mu F$.

Total capacitance of Bank $= 3C_{ph} = 4.83\ \mu f$.

If motor $\eta = 86\%$.

$P_{in} = \dfrac{P_{out}}{\eta} = \dfrac{500}{0.86} = 581.39$ kW.

% Saving in energy

$$= \frac{E_2 - E_1}{E_1}$$

$$= \frac{P_2 - P_1}{P_1} = \left(\frac{P_2}{P_1} - 1\right)$$

$$= \left(\frac{Q_2 / \tan\phi_2}{Q_1 / \tan\phi_1} - 1\right)$$

$$= \left(\frac{Q_2}{Q_1} \frac{\tan\phi_1}{\tan\phi_2} - 1\right)$$

5

$$= \left(\frac{242.161}{510.10} \frac{\tan 45.872}{\tan 25.84} - 1\right)$$

% saving = 100%

Do not write in this margin

Q.5 (e) A 50 Hz, single-phase transformer draws a short circuit current of 30 A at 0.2 pf lag when connected to 16 V, 50 Hz source. What will be the short circuit current and its p.f. when the same transformer is energized from 16 V, 25 Hz source?

[12 marks]

50Hz, 1ϕ X' $I_{sc} = 30A$ @ 0.2pf lag @16V, 50Hz

$I_{sc} = ?$ & pf = ? if 16 V, 25Hz

Now $Z = \frac{V}{I} = \frac{16}{30\angle -\cos^{-1}0.2} = \frac{16}{30\angle -78.46}$

$= 0.533\angle 78.46 = 0.1066 + j0.52255$

If freq. changed:

so $X \propto f \Rightarrow \frac{X_2}{X_1} = \frac{f_2}{f_1}$

$\frac{X_2}{0.5255} = \frac{25}{50} \Rightarrow X_2 = 0.26127\,\Omega$

So $Z_{2new} = R_2 + jX_2 = 0.1066 + j0.26127$

So $Z_2 = 0.2822\angle 67.79$

$I_{sc} = \frac{V}{Z_2} = \frac{16}{0.2822\angle 67.79} = 56.69\angle -67.79$

So $I_{sc} = 56.7$ Amp

power factor = $\cos(67.79) = 0.378$ lag ← Ans

@ 16V, 25Hz.

11

Good Approach

Do not write in this margin

Q.6 (a) A 150 kW, 400 V, 8-pole, 50 Hz, star-connected induction motor has the following impedance parameters in ohms per phase referred to stator.

$r_1 = 0.02\ \Omega,\quad r_2 = 0.04\ \Omega,\quad x_1 = x_2 = 0.2\ \Omega,\ X_m = 9.8\ \Omega$

At rated shaft output, it runs with a slip of 4% and with an efficiency of 93%.

(i) Calculate the rotational and core losses at rated load from the data given above.

(ii) If this motor is driven as a generator at a slip of 4 percent, determine:

1. electric power output,
2. pf at the generator terminals and
3. efficiency.

The induction generator is connected to a distribution system of 400 V.

[20 marks]

Q.6 (b) The primary, secondary and tertiary winding of a three-winding transformer are rated as 11 kV, 6 MVA, star/3.3 kV, 3 MVA, star/400 V, 3 MVA, delta respectively. The short circuit tests on this transformer gave the following results:

Secondary shorted ; primary excited : 500 V, 100 A,
Tertiary shorted ; primary excited : 600 V, 100 A and
Tertiary shorted ; secondary excited : 100 V, 200 A

(i) Find the per unit leakage reactances of the star equivalent circuit. Neglect resistance.

(ii) The primary is energized at rated voltage and the secondary is open circuited. For a three-phase balanced short circuit at the tertiary terminals, calculate the short circuit current and the secondary terminal voltage.

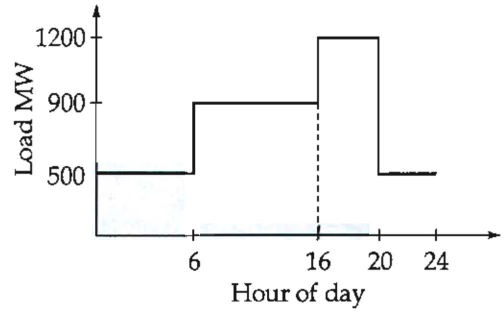
[20 marks]

Q.6 (c) The fuel cost characteristics of two thermal plants are as under,

$C_1 = 7700 + 52.8P_1 + 5.5 \times 10^{-3} P_1^2$ Rs./hour

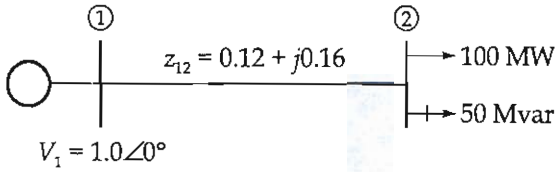
$C_2 = 2500 + 15P_2 + 0.05 P_2^2$ Rs./hour

The limit of generation for the two units are $200 \le P \le 800$ MW. The load curve is shown in figure below. Find the daily operating schedule to minimize the operating costs. The cost of taking a unit off and then putting it on is Rs. 1000.00.



[20 marks]

Q.7 (a) In the two-bus system shown in figure below, bus-1 is a slack bus with $V_1 = 1.0\angle 0°$ p.u. A load of 100 MW and 50 MVar is taken from bus-2. The line impedance is $z_{12} = 0.12 + j0.16$ p.u. on a base of 100 MVA. Using Newton-Raphson method, obtain the voltage magnitude and phase angle of bus-2. Start with an initial estimate of $|V_2|^{(0)} = 1.0$ p.u. and $\delta_2^{(0)} = 0°$. Perform two iterations.



[20 marks]

Q.7 (b) (i) Compare the overhead distribution system to underground distribution system in regards to deciding factors for selection of above systems as transmission network.

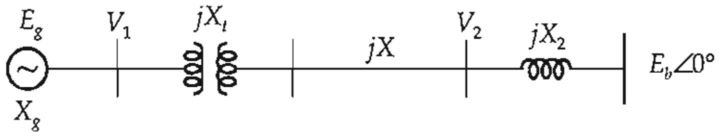
[10 marks]

Do not write in this margin

Q.7 (b) (ii) Draw basic structure of HVDC transmission. Clearly showing main components of HVDC transmission. Why there is requirement of reactive power at HVDC converter station. How this reactive power demand is fulfilled?

[10 marks]

Q.7 (c) A single machine is connected to a load centre through a transmission line as shown in figure. The load centre is represented by a reactance connected to an infinite bus. The generator is initially operating with $P_e = 1.0$ pu and the magnitudes of voltages V_1 and V_2 are 1.0 pu. Assume $X_g = 0.3$ pu, $X_t = 0.1$ pu, $X = 0.4$ pu and $X_2 = 0.1$ pu.



(i) Find the maximum step increase in mechanical power that will not cause transient instability.

(ii) Find the critical clearing angle and time for a three phase fault at the generator terminal. Generator is initially supplying power of 1.0 pu. Assume that post-fault system is identical to the prefault system. ($H = 4.0$ sec, $f_B = 50$ Hz).

[20 marks]

Q.8 (a) The following test data were taken on a 7.5 hp, four-pole, 208-V, 60-Hz, design A, Y-connected induction motor having a rated current of 28 A.

DC test:

$V_{DC} = 13.6$ V, $I_{DC} = 28.0$ A

No-load test:

$V_T = 208$ V, $f = 60$ Hz

$I_A = 8.12$ A, $P_{in} = 420$ W

$I_B = 8.20$ A

$I_C = 8.18$ A

Locked-rotor test:

$V_T = 25$ V, $f = 15$ Hz

$I_A = 28.1$ A, $P_{in} = 920$ W

$I_B = 28.0$ A

$I_C = 27.6$ A

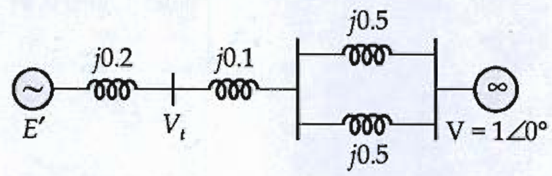
(i) Sketch the per-phase equivalent circuit for this motor.

(ii) Find the slip at the pullout torque and find the value of the pullout torque itself.

[20 marks]

Do not write in this margin

Q.8 (b) (i) Consider the power system shown below. With parallel transmission impedance of $j0.5\Omega$ and delivered power is 0.8 p.u. when both the terminal voltage of the machine and the voltage of the infinite bus is 1 p.u. Determine the power angle equation of the system during above specified conditions.

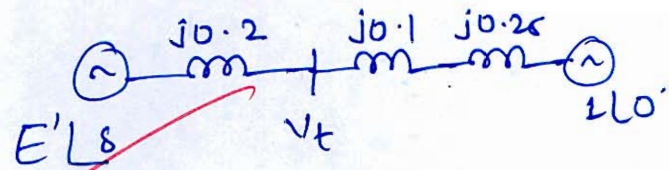


(ii) A 60 Hz generator is supplying 60% of P_{max} to an infinite bus through a reactive network. A fault occurs which increases the reactance of the network between the generator internal voltage and the infinite bus by 400%. When the fault is cleared, the maximum power that can be delivered is 80% of the original value. Determine the critical clearing angle in degree considering above condition.

[20 marks]

i) $P_{del} = 0.8pu$

$V_t = V = 1\angle 0$



$$P = \frac{E'V}{X_{eq}} \sin(\delta - 0)$$

$$0.8 = \frac{E' \times 1}{0.55} \sin\delta$$

$$\boxed{E' \sin\delta = 0.44} \quad (1)$$

$$I = \frac{E'\angle\delta - V_t\angle\theta}{j0.2} = \frac{V_t\angle\theta - 1\angle 0}{j0.35} \qquad V_t = 1pu$$

$$E'\angle\delta - 1\angle\theta = (1\angle\theta - 1)\frac{20}{35} = \frac{4}{7}\angle\theta - \frac{4}{7}$$

$$E'\angle\delta = \frac{11}{7}\angle\theta - \frac{4}{7}.$$

Also Gen Eq^n $E' = V_t + j0.2 I_a$.

$E'\cos\delta + jE'\sin\delta = \frac{11}{7}\cos\theta + j\frac{11}{7}\sin\theta - \frac{4}{7}$.

compare real & imag. part

$E'\cos\delta = \left(\frac{11\cos\theta - 4}{7}\right)$, $E'\sin\delta = \frac{11}{7}\sin\theta$

So $0.44 = \frac{11}{7}\sin\theta \Rightarrow \sin\theta = 0.28$,

$\boxed{\theta = 16.26^\circ}$ $\boxed{\text{So } V_t = 1\angle 16.26^\circ}$

So $E'\cos\delta = \frac{11\cos\theta - 4}{7} \Rightarrow E'\cos\delta = 0.937$ —(2)

$1^2 + 2^2$

$(E'\cos\delta)^2 + (E'\sin\delta)^2 = (0.44)^2 + (0.937)^2$

$E' = 1.035$.

& (1) ÷ (2) So $\frac{E'\sin\delta}{E'\cos\delta} = \frac{0.44}{0.937} \Rightarrow \tan\delta = 0.469$.

$\delta = 25.13^\circ$

$\boxed{\text{So } \vec{E} = 1.035\angle 25.13}$ ← Ans.

(c) 60Hz.

$P_m = 60\%\ P_{max}$.

If fault occur $X' = 5X_1 = X_2$.

If fault cleared $P = 0.8\ P_{max}$.

To find δ_{cr}.

$P_m = 0.6\ P_{max}$.

$P_{max}\sin\delta_0 = 0.6\ P_{max}$

$\delta_0 = \sin^{-1} 0.6 = 36.86^\circ$

$P_{max1} = \frac{EV}{X_1}$

Do not write in this margin

$P_2 = \frac{E_2 V_2}{X_2} = \frac{EV}{5X_1} = 0.2 P_{m1} =$

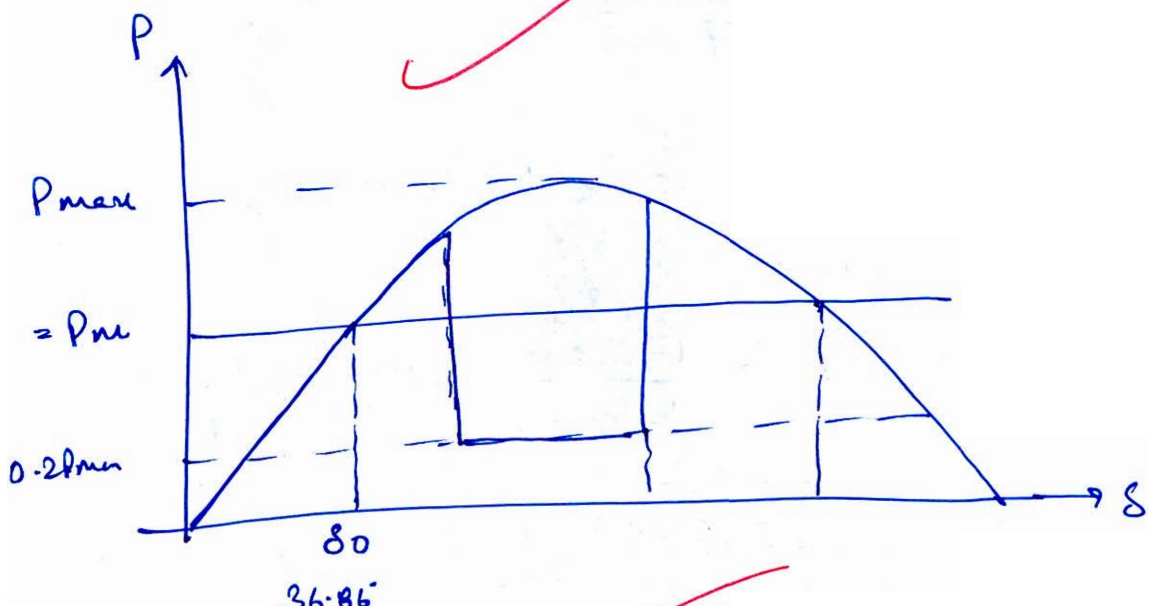
$\delta_1 = \sin^{-1} 0.2$

So $P_{m2} = \frac{EV}{X_2} = \frac{EV}{5X_1} = 0.2 P_{max} = 0.2$

$P_{m3} = P_{max} \sin \delta_{m3} = 0.8 P_{m} = 0.8 \times 0.6 P_{max}$

$\sin \delta_{m3} = 0.48$

$\delta_{max} = \pi - \delta_{m3} = 126.86$



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

$= \cos^{-1}\left[\frac{1(126.86 - 36.86) + 0.8\cos 126.86 - 0.2\cos 36.86}{0.8 - 0.2}\right.$

$= \cos^{-1}\left[\frac{1.57 - 0.479 - 0.16}{0.6}\right.$

15

Simplify your answer

Q.8 (c) A 3-phase, 400 V, 50 Hz, star-connected induction motor gave the following test results:

No load: 400 V, 7.5 A, 0.135 power factor.

Block rotor: 150 V, 35 A, 0.44 power factor.

The ratio of standstill reactance of stator and rotor is estimated as 2. If the motor is running at a speed of 960 rpm, determine:

(i) net mechanical power output,

(ii) the net torque and

(iii) efficiency of the motor

Assume stator and rotor copper losses to be equal.

[20 marks]

$$Z_{NL} = \frac{V_{NL}}{I_{NL}} = \frac{400/\sqrt{3}}{7.5} \angle 82.24 = 30.79 \angle 82.24^\circ$$

$$Z_{SC} = \frac{V_{SC}}{I_{SC}} = \frac{150/\sqrt{3}}{35} \angle 63.89 = 2.474 \angle 63.89^\circ$$

$$\frac{X_S}{X_r} = 2$$

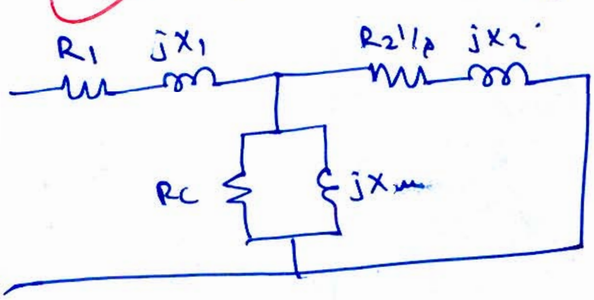
If $N_r = 960$ rpm

$N_s = 1000$ rpm

$$s = \frac{N_s - N_r}{N_s} = \frac{40}{1000} = 0.04 = 4\%$$

$$Z_{NL} = R_{NL} + jX_{NL} = 3.837 + 30.54i$$

$$Z_{SC} = R_{SC} + jX_{SC} = 1.088 + j2.221$$



(6)

Incomplete solution

OOOO

Space for Rough Work

Space for Rough Work

1 a
4a –(ii)
5 a
5d
8a
8b
8c