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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	50
Q.2	39
Q.3	
Q.4	24
Section-B	
Q.5	42
Q.6	
Q.7	
Q.8	46
Total Marks Obtained	201

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 : 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]

Polarization of a dielectric material is defined as no. of electric dipoles per unit volume.

Let $N \rightarrow$ No. of atoms per unit volume.

so $P = N\vec{p}$ where $\vec{p} = q \cdot d$

C/m^2

and $D = \epsilon_0 \epsilon_r \vec{E}$

The total field experienced by dielectric material is due to:

1) Applied Electric field

2) Polarisation.

$D = \epsilon_0 E + P$

but $D = \epsilon_0 \epsilon_r E$

$\Rightarrow \boxed{P = \epsilon_0 \chi_e E}$ —①

→ Now Polarisability (α) of a dielectric is defined as dipole moment per unit electric field.

so $\alpha = \dfrac{\vec{p}}{E}$

$\Rightarrow \vec{p} = \alpha E$

but $P = N\vec{p}$

so $\boxed{P = N\alpha E}$ —②

equating ① & ②

$\Rightarrow \epsilon_0(\epsilon_r - 1)E = N\alpha E$

$\Rightarrow \boxed{\alpha = \dfrac{\epsilon_0(\epsilon_r - 1)}{E}}$

→ In case of solids and liquids atoms are packed very close to each other. Hence net field experienced by them is:

$$E_i = E + \frac{\gamma P}{\epsilon_0}$$ where $\gamma \rightarrow$ internal field const.

Now

$$P = N\alpha E_i = N\alpha\left[E + \frac{\gamma P}{\epsilon_0}\right]$$

$$P = N\alpha E + \frac{N\alpha\gamma P}{\epsilon_0}$$ & $\gamma = \frac{1}{3}$

but $P = \epsilon_0(\epsilon_r - 1)E$ — ③

$$\Rightarrow P\left(1 - \frac{N\alpha}{3\epsilon_0}\right) = N\alpha E$$

$$P = \frac{N\alpha E}{1 - \frac{N\alpha}{3\epsilon_0}}$$

substituting ③

$$\Rightarrow \epsilon_r - 1 = \frac{N\alpha/\epsilon_0}{1 - \frac{N\alpha}{3\epsilon_0}} \quad — ④$$

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Good Approach

add +3 on both sides

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

$$\epsilon_r + 2 = \frac{3}{1 - \frac{N\alpha}{3\epsilon_0}} \quad — ⑤$$

eqn ④ ÷ ⑤

$$\Rightarrow \boxed{\frac{\epsilon_r - 1}{\epsilon_r + 2} = \frac{N\alpha}{3\epsilon_0}}$$ → is the classical Mossati equation.

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/cm^2 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]

width $= 500 \times 10^{-6}$ m

thickness $= w = 20 \times 10^{-6}$ m

$d = 2 \times 10^{-6}$ m

$I = 3$ mA

$B = 10^{-4}$ Wb/cm^2 $= \frac{10^{-4}}{10^{-4}}$ Wb/m^2

$B = 1$ Wb/m^2

$V_H = 3.2$ mV

by Hall effect we know that

$V_H = \frac{BI}{\rho_v w}$ where $w \to$ thickness

$\rho_v = nq$

as P-type semiconductor, $q = 1.6 \times 10^{-19}$ C

so Hall coeff. $R_H = \frac{1}{\rho_v} = \frac{1}{nq}$

is positive

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$\Rightarrow \rho_v = \frac{BI}{V_H w} = \frac{1 \times 3 \times 10^{-3}}{3.2 \times 10^{-3} \times 20 \times 10^{-6}}$

$\rho_v = nq = 46.875 \times 10^3$

now when field direction is reversed

$V_H = 2.8$ mV

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]

as Phosphorous used ⟹ N-type doping [Majority carriers]

$N_D = 10^{17}$ atoms/cm^3

$\rho = ?$ if $\mu_n = 700$ cm^2/V-s

$w = 100 \times 10^{-6}$ m $= 100 \times 10^{-4}$ cm

$I_x = 1$ mA and $B_z = 10^{-5}$ Wb/cm^2

as $n = N_D$

$\sigma = nq\mu_n$ and $\sigma = \frac{1}{\rho}$

$\Rightarrow \rho = \frac{1}{nq\mu_n}$

$= \frac{1}{1.6 \times 10^{-19} \times 10^{17} \times 700}$

$\boxed{\rho = 89.285}$ ohm-cm

and

$V_H = \frac{BI}{\rho_v w} = \frac{1 \times 10^{-3} \times 10^{-5}}{10^{17} \times 1.6 \times 10^{-19} \times 100 \times 10^{-4}}$

$\boxed{V_H = 0.625 \text{ mV}}$

— 62.5 μV

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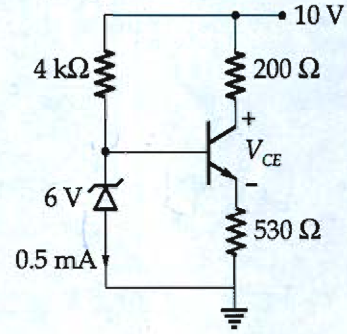
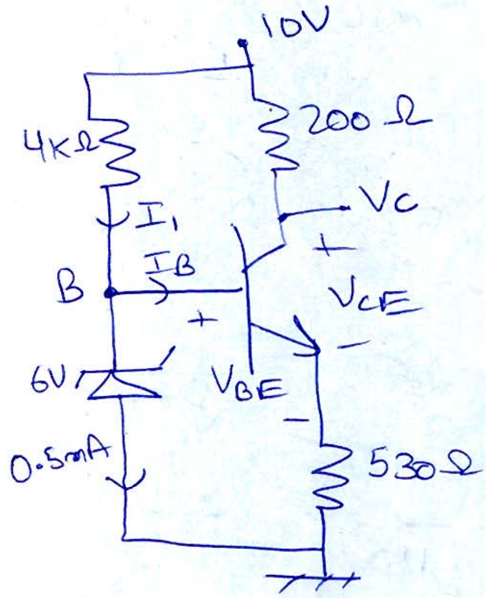
Do not write in this margin

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



[12 marks]



considering zener diode in breakdown

ie $V_Z = 6V$

$V_B = V_Z = 6V$

$V_{BE} = V_B - V_E = 0.7V$

$\Rightarrow V_E = 6 - 0.7 = 5.3V$

so $I_E = \frac{5.3}{530\,\Omega} = 10\,mA$

and $I_1 = \frac{10 - V_Z}{4K} = \frac{10-6}{4} = 1\,mA$

by KCL at point B:

$I_1 = I_B + I_Z$

$\Rightarrow I_B = 1 - 0.5 = 0.5\,mA$

also $I_E = I_C + I_B$

$\Rightarrow I_C = 10 - 0.5 = 9.5\,mA$

and by KVL: $V_C = 10 - I_C R_C$

$= 10 - 9.5\times10^{-3}\times200$

Do not write in this margin

$V_C = 8.1V$

so $V_{CE} = V_C - V_E = 8.1 - 5.3$

$V_{CE} = 2.8V > V_{CE\,sat}$

$\Rightarrow$ Active mode only.

now $I_C = \beta I_B$

$\Rightarrow \beta = \frac{I_C}{I_B} = \frac{9.5\times10^{-3}}{0.5\times10^{-3}}$

$\boxed{\beta = 19}$

and $\boxed{V_{CE} = 2.8V}$

(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]

→ In nanomaterials synthesis two major techniques are used:

1) <u>Top-down Approach:</u>

→ In this atom nanomaterials are made by breaking bigger materials.

→ This approach is not suitable for bulk production of nanomaterials

→ with this approach nanomaterials of uniform shape and size can not be synthesized.

→ The biggest drawback of this approach is that synthesised nano materials have different surface properties.

→ It involves physical processes such as : 1) Grinding
2) Crushing & milling using attrition mills.

→ Lithographic Technique used:

→ Photolithography.

2) Bottom Up Approach:

→ In this approach nanomaterials are made from base ie atom by atom, molecule by molecule, block by block and cluster by cluster.

→ This approach is suitable for bulk production.

→ With this approach nanomaterials of uniform shape & size can be synthesized.

→ With this approach ultra fine nanoparticles can be synthesized.

→ It uses a combination of physical & chemical methods.

Physical Methods:
1) Evaporation
2) Physical Vapour Deposition
3) Sputtering
4) Plasma Arcing

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Chemical methods:
1) Chemical vapour deposition
2) Electrolysis
3) Pyrolsis
4) Sol-Gel method.

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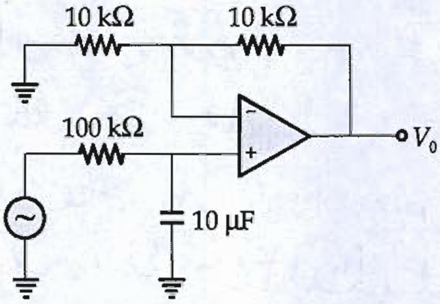
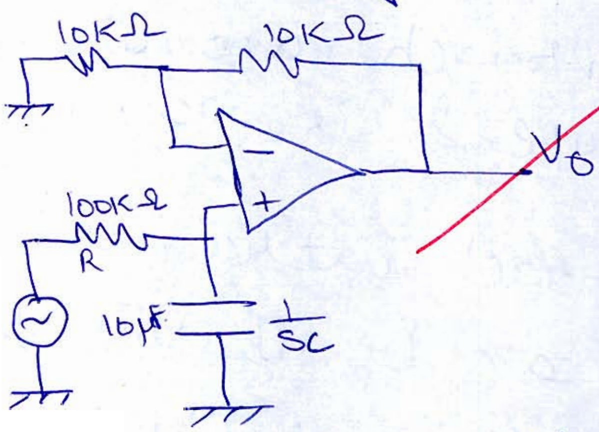
Q.1 (e) In the circuit shown in figure below, if $e_i = \sin t$, find the voltage V_0.



[12 marks]

converting to s-domain



so

$$V_o = \cancel{-10V}\left(1+\frac{10K}{10K}\right)V^+$$

$$\boxed{V_o = 2V^+}$$

and by voltage division rule

$$V^+ = \frac{\frac{1}{SC}\times V_i}{R+\frac{1}{SC}} = \frac{V_i}{1+SCR}$$

$$\Rightarrow V_o = 2V^+ = \frac{2V_i}{1+SCR}$$

$V_i = \sin t \quad \omega = 1$

substitute $s = j\omega$

so $SCR = j\omega CR = j\,10\times10^{-6}\times100\times10^3$

$= j$

so

$$V_o = \frac{\sin t}{1+j}$$

$$\Rightarrow \boxed{V_o = 0.707 \sin(t - 45^\circ)} \text{ volts.}$$

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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) $v = ?$

$\epsilon_r = 5.5$

$$v_{ligh} = \frac{1}{\sqrt{\epsilon_0 \epsilon_r \mu_0 \mu_r}} = \frac{\frac{1}{\sqrt{\epsilon_0 \mu_0}}}{\sqrt{\mu_0 \mu_r}}$$

and $\frac{1}{\sqrt{\epsilon_0 \mu_0}} = 3 \times 10^8$ m/s $= c$

given $\epsilon_r = 5.5$ & $\chi_m = -2.17 \times 10^{-5}$

also $\chi_m = \mu_r - 1 \Rightarrow \mu_r = 1 - 2.17 \times 10^{-5}$
$= 0.9999787$

so

$$v_{light} = \frac{3 \times 10^8}{\sqrt{5.5 \times 0.9999787}} = 1.28 \times 10^8 \text{ m/s}$$

$\Rightarrow$ $\boxed{v_{light} = 1.28 \times 10^8 \text{ m/s}}$

ii) Given: $I = 10A$, $l = 0.2m$ &
$N = 200$

1) $H = \frac{NI}{l} = \frac{200 \times 10}{0.2} = 10^4$ AT/m

2) now $B = \mu_0 \mu_r H$

given vacuum $\mu_r = 1$

$\Rightarrow B = 4\pi \times 10^{-7} \times 10^4$

$$B = 12.566 \ mWb/m^2$$

3) flux density $= B$ — ? inside titanium bar

$\chi_m = 1.81 \times 10^{-4}$ as $\chi_m = \mu_r - 1$

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

$\mu_r = 1.000181$

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

$$\Rightarrow B = 12.568 \ mWb/m^2$$

4) Magnetization is defined as magnetic dipole moment per unit volume.

$M = N \vec{P}_m$

or

$B = \mu_0 (H + M)$

but $B = \mu_0 \mu_r H$

$\Rightarrow M = \chi_m H$

for Ti bar case:

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

$$\Rightarrow M = 1.81 \ A/m$$

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Good Approach

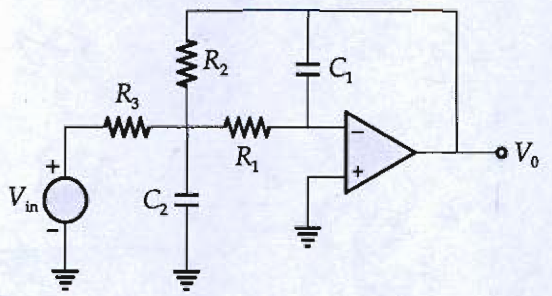
for vaccum case:

$\mu_r = 1$

$\Rightarrow \chi_m = \mu_r - 1 = 0$ when material ~~when~~ ~~kept~~ ~~as~~ vaccum.

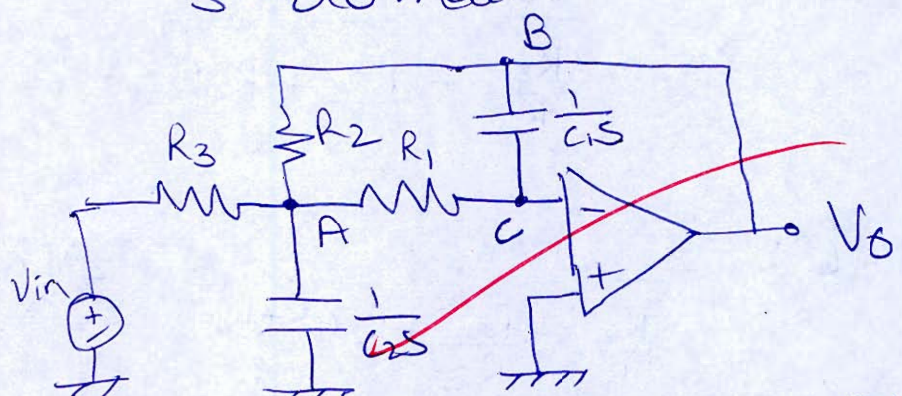
$\Rightarrow \boxed{M = 0}$

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



[20 marks]

converting the circuit into s-domain



by using virtual GND concept

$$V^- = V^+ = 0$$

now KCL at node A:

$$\frac{V_A - 0}{R_1} + \frac{V_A - V_{in}}{R_3} + \frac{V_A}{\frac{1}{C_2 S}} + \frac{V_A - V_O}{R_2} = 0$$

$$\Rightarrow V_A\left(\frac{1}{R_1} + \frac{1}{R_3} + C_2 S + \frac{1}{R_2}\right) = \frac{V_{in}}{R_3} + \frac{V_O}{R_2} \rightarrow (1)$$

~~Using KCL at node B:~~

~~$$\frac{V_O - V_A}{R_2} + \frac{V_O}{1/C_1 S} = 0$$~~

$$\Rightarrow V_o\left(\frac{1}{R_2} + C_1 s\right) = \frac{V_A}{R_2} \quad -(2)$$

using eq^n (1) in eq^n (2)

$$V_o\left(1 + R_2 C_1 s\right) = \frac{\frac{V_{in}}{R_3} + \frac{V_o}{R_2}}{\frac{1}{R_1} + \frac{1}{R_3} + C_2 s + \frac{1}{R_2}}$$

$$V_o\left(1 + R_2 C_1 S\right) = \frac{\frac{R_2 V_{in}}{R_3} + V_o}{\frac{R_2}{R_1} + \frac{R_2}{R_3} + R_2 C_2 S + 1} \quad -2x$$

Try to avoid overwriting

$$\Rightarrow V_o\left(1 + R_2 C_1 S - \frac{1}{\frac{R_2}{R_1} + \frac{R_2}{R_3} + R_2 C_2 S + 1}\right) = \frac{R_2 V_{in}}{R_3 \; 2x}$$

---

using KCL at node C

$$\frac{V_A}{R_1} = \frac{-V_o}{\frac{1}{C_1 S}}$$

$$\Rightarrow \boxed{-V_o R_1 C_1 S = V_A} \quad -(2)$$

using equation (2) in eq^n (1)

$$(-V_o R_1 C_1 S)\left(\frac{1}{R_1} + \frac{1}{R_3} + C_2 S + \frac{1}{R_2}\right) = \frac{V_{in}}{R_3} + \frac{V_o}{R_2}$$

$$V_o\left\{C_1 S + \frac{R_1}{R_3} C_1 S + S^2 R_1 C_1 + \frac{R_1}{R_2} C_1 S + \frac{1}{R_2}\right) = -\frac{V_{in}}{R_3}$$

$$\Rightarrow V_o\left\{ sC_1\left(1 + \frac{R_1}{R_3}\right) + \frac{R_1}{R_2} C_1 S + S^2 R_1 C_1 + \frac{1}{R_2}\right) = -V_{in}/R_3$$

Do not write in this margin

$$\Rightarrow V_o\left\{C_1 s\left(1+\frac{R_1}{R_3}+\frac{R_1}{R_2}\right)+s^2R_1C_1+\frac{1}{R_2}\right\}=-\frac{V_{in}}{R_3}$$

$$\Rightarrow \frac{V_o}{V_{in}}=\frac{-\frac{1}{R_3}}{s^2R_1C_1+C_1s\left(1+\frac{R_1}{R_3}+\frac{R_1}{R_2}\right)+\frac{1}{R_2}}$$

$$\boxed{\frac{V_o}{V_{in}}=\frac{-\frac{1}{R_1R_3C_1}}{s^2+s\left(\frac{1}{R_1}+\frac{1}{R_2}+\frac{1}{R_3}\right)+\frac{1}{R_2R_1C_1}}}$$

$\downarrow$ Av

comparing with std. 2nd order equation $\frac{K\omega_n^2}{s^2+2\xi\omega_n s+\omega_n^2}$

$$\Rightarrow \boxed{\omega_n=\frac{1}{\sqrt{R_1R_2C_1}}} \rightarrow \text{cutoff freq.}$$

&

$$2\xi\omega_n=\frac{1}{R_1}+\frac{1}{R_2}+\frac{1}{R_3}$$

$\Rightarrow$ damping factor $\alpha=\xi\omega_n=\frac{1}{2}\left\{\frac{1}{R_1}+\frac{1}{R_2}+\frac{1}{R_3}\right\}$

and

damping ratio $\rightarrow$ $\boxed{\xi=\frac{\frac{1}{2}\left\{\frac{1}{R_1}+\frac{1}{R_2}+\frac{1}{R_3}\right\}}{\frac{1}{\sqrt{R_1R_2C_1}}}}$

(10)

(11)

Go through the made easy solution

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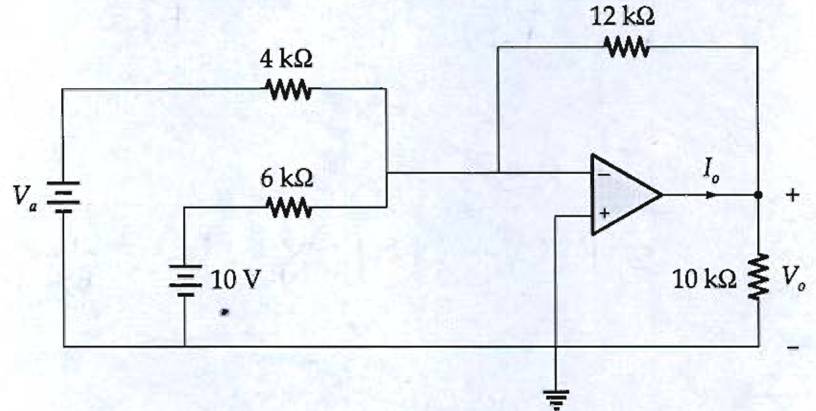
Q.2 (c) For the circuit shown below, the op-amp is considered to be ideal.



(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]

(i) $V_a = 4V$

~~so by superposition~~

~~$V^- = \frac{4 \times 6 + 10 \times 4}{4+6} = \frac{24+40}{10}$~~

~~= 6.4 V~~

as opamp is ideal

so by virtual ground concept.

$V^- = V^+ = 0$

$\Rightarrow I_T = I_1 + I_2 = \frac{4}{4K} + \frac{10}{6K}$

$= 2.667 \text{ mA}$

and $V_o = -I_T \times 12K$

$\boxed{V_o = -32V}$

and $I_L = \frac{V_o}{10K} = -3.2 \text{ mA}$

so by KCL: $I_T + I_o = I_L$

Do not write in this margin

$\Rightarrow I_o = -3.2 - 2.667$

$|I_o| = 5.867\ mA$

ii) $V_{sat} = \pm 12V$

so by superposition principle

$V^- = \frac{V_a \times 6 + 10 \times 4}{4+6} = \frac{6V_a + 40}{10K}$

$\Rightarrow V^- = 0.6V_a + 4$

and $V^+ = 0V$

so in case of non linear operation

if $V^- < V^+$

$\Rightarrow V_o = +V_{sat} = +12V$

ie $0.6V_a + 4 < 0$

$\Rightarrow V_a < \frac{-4 \times 10^2}{0.6}$

$V_a < -6.67V$

if $V^- > V^+ \Rightarrow V_o = -V_{sat}$

$\Rightarrow 0.6V_a + 4 > 0$

$\Rightarrow V_a > -6.67V$

for linear operation

V_o should lie between $\pm V_{sat}$ is $\pm 12V$

so solving for extreme limits.

when $V_o = +V_{sat} = +12V$

[$I_o = 0$ considering no current goes into OPAMP]

$I_L = I_T = \frac{12}{10} = 1.2mA$

& $I_T = \frac{V^- - V_o}{12K}$

$\Rightarrow \frac{0.6V_a + 4 - 12}{12} = 1.2$

$\Rightarrow$ $V_a = 37.33V$

so if $V_a > 37.33V \Rightarrow$ Non linear operation.

Case 2: when $V_o = -V_{sat} = -12V$

$\Rightarrow I_L = I_T = -1.2V$

so $\frac{0.6V_a + 4 - (-12)}{12} = -1.2$

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$0.6V_a + 16 = -14.4$

$\Rightarrow$ $V_a = -50.67V$

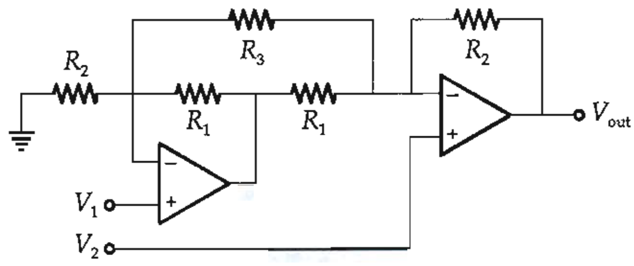
so output is non linear if $V_a < -50.67V$

so limits for V_a:

$-50.67V < V_a < 37.33V$

Go through the made easy solution

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]

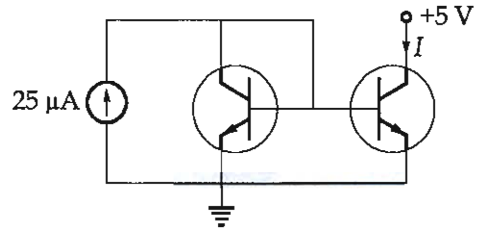
Do not write in this margin

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

[8 marks]

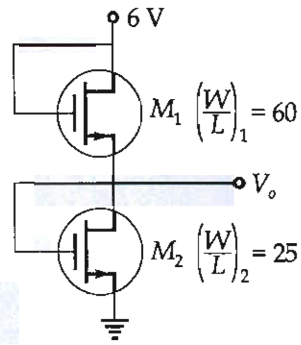
Do not write in this margin

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]

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]

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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]

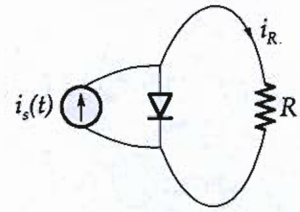
Q.3 (c) A parallel plate capacitor has an area of 25 cm^2 and the separation between the plates is 0.3 mm. The space between the plates is filled with a dielectric having the real part of dielectric constant $\varepsilon_r' = 3$ when subjected to the frequency of 1.5 MHz. The loss tangent at this frequency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

(i) Parallel R-C circuit.

(ii) Series R-C circuit.

[20 marks]

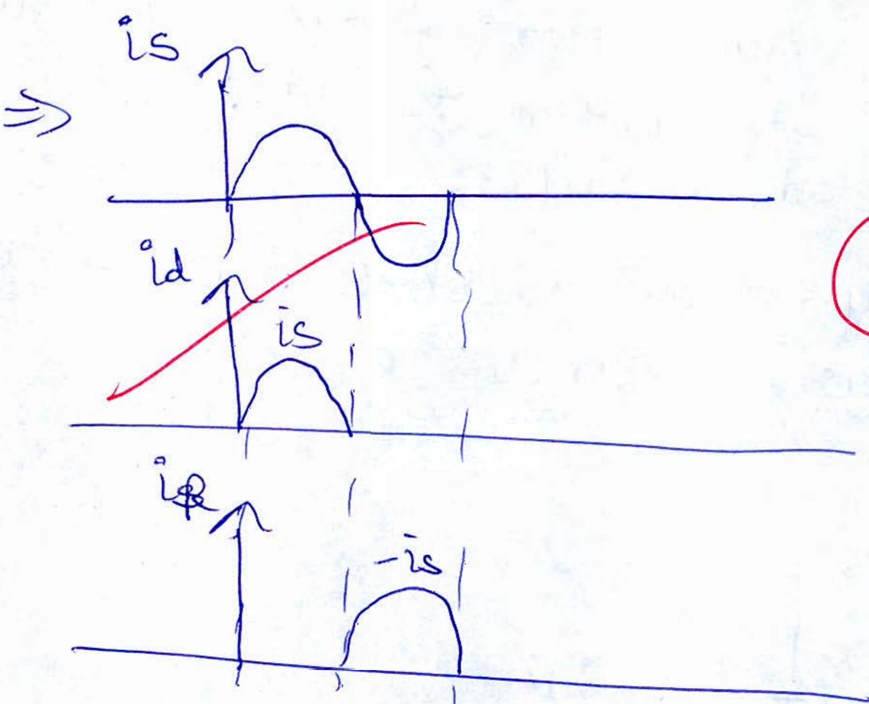
Q.4 (a) (i) The diode in the circuit is ideal. The current sources $i_s(t) = \pi \sin(3000\pi t)$mA. Find the magnitude of the average current flowing through the resistor R.



[10 marks]

as Ideal diode so in Positive half cycle Diode → ON
and $i_R = 0$
in negative half cycle $i \to -ve$
so Diode → OFF
so $i_R = -i_s$

⇒



3

so it behaves like half wave rectifier. $i_{Ravg} = -\frac{I_m}{T} = -\frac{\pi}{2\pi/\omega}$

⇒ $i_{Ravg} = \frac{I_m}{2\pi} = \frac{\pi}{2\pi} = -0.5A$

~~$I_{Ravg} = 0.514A$~~

$i_{Ravg} = -4712.38A$ ⇒ $i_{Ravg} = -4712.38A$

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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]

Type - I Superconductors:

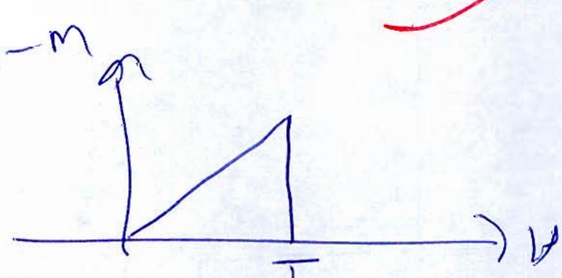
→ are also called as ideal or soft superconductors.

→ they have a low value of critical temperature and magnetic field.

→ They can not be used for high freq. applications.

→ The transition from superconducting state to normal state is ~~grad~~ abrupt.

→ They obey silsbee rule and show Meisner's effect.



Type-II superconductors:

→ also called as non-ideal or hard superconductors.

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→ they have a higher value of critical magnetic field and temperature.

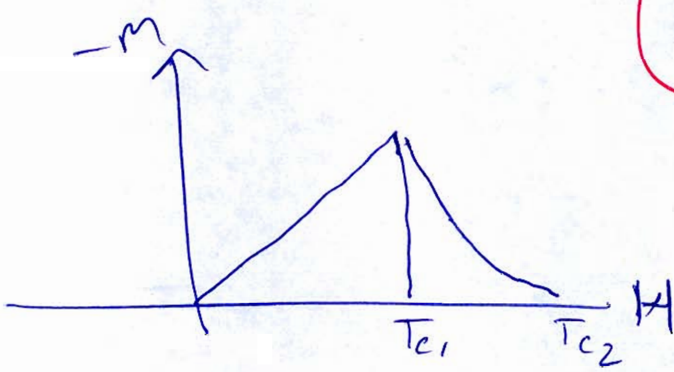
→ They can be used for high freq. application.

→ The transition from superconducting state to normal state is gradual.

→ The do not obey silsbee rule & show incomplete Meissner's effect.

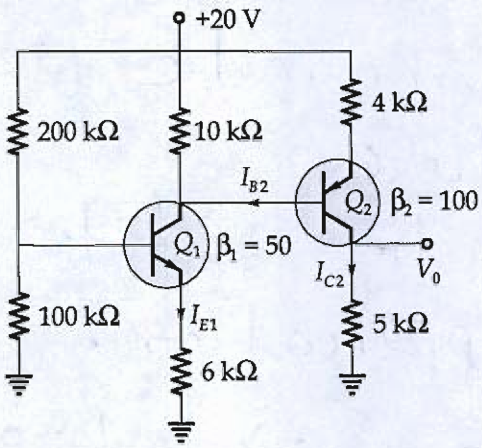
eg: Nb_3Sn

7



Improve presentation

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]

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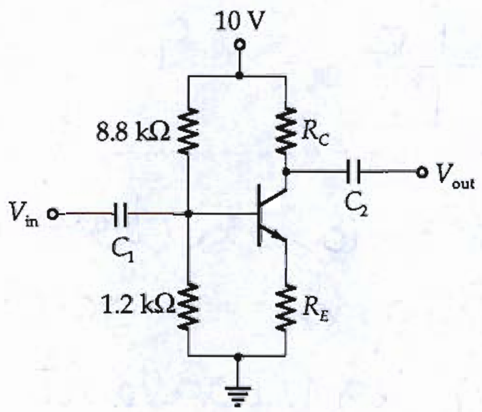
Q.4 (c) In the amplifier circuit shown below, assume $V_{BE} = 0.7$ V and the β of the transistor and the values of C_1 and C_2 are extremely high. If the amplifier is designed such that at the quiescent point its $V_{CE} = V_{CC}/2$, where V_{CC} is the power supply voltage, find its small signal voltage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

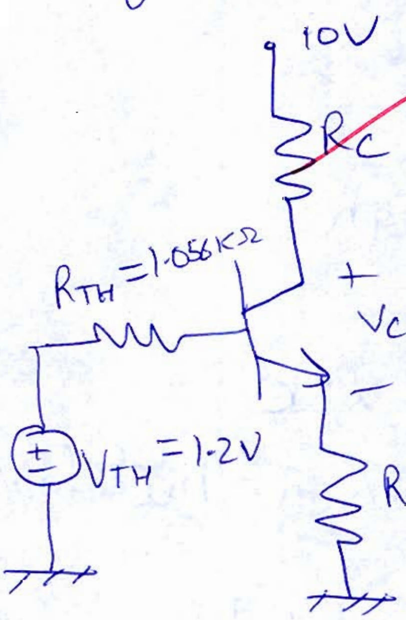


[20 marks]

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

<u>DC Analysis :</u> C → open ckt

equiv. ckt.



β → very high

so $I_C \approx I_E$

and $I_B = 0$

so $V_B = 1.2V$

and $V_{BE} = V_B - V_E = 0.7V$

$\Rightarrow \boxed{V_E = 0.5V}$

$\Rightarrow I_E = \frac{0.5}{R_E}$

and $V_{CE} = V_C - V_E = 5$

$\Rightarrow V_C = 5.5V$

so $I_C = \frac{10 - 5.5}{R_C} = \frac{4.5}{R_C}$

as $I_E = I_C$

$$\Rightarrow \frac{0.5}{R_E} = \frac{4.5}{R_C}$$

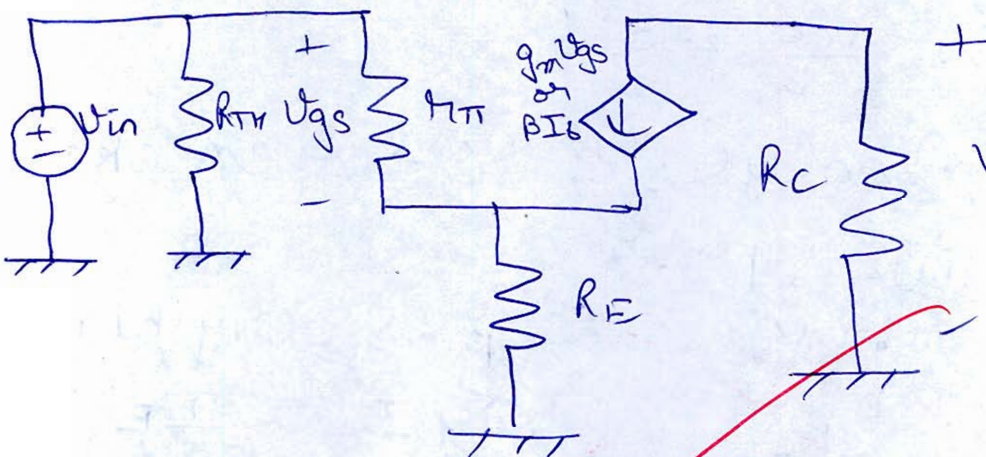
$$\Rightarrow \boxed{\frac{R_E}{R_E} = 9}$$

& $r_\pi = \frac{\beta}{g_m}$

$\Rightarrow r_\pi \to$ very high

replacing transistor with small signal model and drawing equivalent ckt.

$r_\pi \to \infty$



as $\beta \to$ very high

so, $r_\pi \to \infty$

$V_o = -g_m V_{gs} \times R_E$

and by KVL in input loop

$V_{in} = V_{gs} + g_m V_{gs} R_E$

$$\Rightarrow V_{gs} = \frac{V_{in}}{1 + g_m R_E}$$

$$\Rightarrow V_o = \frac{-g_m V_{in} R_C}{1 + g_m R_E}$$

$$\Rightarrow A_V = \frac{V_o}{V_{in}} = \frac{-g_m R_C}{1 + g_m R_E}$$

and $g_m = \frac{I_C}{V_T} = \frac{4.5}{R_C V_T}$

taking V_T as 25 mV

$$\Rightarrow |A_V| = \frac{\frac{4.5 R_C}{R_C V_T}}{1 + \frac{4.5}{R_C V_T} \times R_E} = \frac{\frac{4.5}{25 \times 10^{-3}}}{1 + \frac{4.5}{25 \times 10^{-3}} \times \frac{1}{9}}$$

$$\Rightarrow \boxed{|A_V| = 8.571}$$

(14)

Go through the made easy solution

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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]

6 pulse rectifier

$V_o = 400\,KV$ and $\alpha = 15°$

for 6-pulse rectifies

$$V_o = \frac{3V_{mL}}{\pi}\cos\alpha - \Delta V_o$$

assuming continuous conduction

where

$$\Delta V_o = \frac{V_{do}}{2}\left[\cos\alpha - \cos(\alpha+\mu)\right]$$

where μ is commutation angle.

$$V_{do} = \frac{3V_{mL}}{\pi}$$

so

$$V_o' = \frac{3V_{mL}}{\pi}\cos\alpha$$

given AC side: 3-ϕ, 50Hz, 400KV

so $V_{mL} = \frac{400\times\sqrt{2}}{\cancel{3}}KV$

(i) comm^n resistance = R

$$V_o = \frac{3V_{mL}}{\pi}\cos\alpha - \Delta V_{do} - 2I_oR$$

ii) so $V_o' = \frac{3 \times 400\sqrt{2} \times \cos 15}{\pi \times \sqrt{2}} = 2\sout{60.89}V$

$V_o' = 521.783\ KV$

$\Rightarrow \Delta V_{do} = 521.783 - 400$

$\boxed{\Delta V_{do} = 121.783\ KV}$

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

$\Rightarrow \mu + 15 = \cos^{-1}\left(\frac{139.10}{260.89}\right) = 57.78°$

$\Rightarrow \boxed{\mu = 42.78°}$ is the commuttation angle.

(i) $R = \frac{V_o}{I_o} = \frac{400 \times 10^3}{1000} = 400\ \Omega$

iii) if $V_s = 200\ KV \Rightarrow V_{mL} = 200\sqrt{2}\ KV$

$\mu = ?$, $I_o \rightarrow$ const. $\alpha = 15°$

so $V_o \rightarrow$ const.

$V_o' = \frac{3 \times 200\sqrt{2}}{\pi} \cos\alpha = 260.89$

$\Rightarrow \Delta V_o = 400 - 260.89 = 139.108\ KV$

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

9

$\Rightarrow \alpha + \mu = 93.67°$

$\Rightarrow \boxed{\mu = 78.67°}$

Go through the made easy solution

Do not write in this margin

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]

Shaft load ie output = 45 KW

& $\eta = \frac{O/P}{I/P} \times 100$

$\Rightarrow$ Input $= \frac{45}{0.9} = 50$ KW

so losses = Input − Output = 50 − 45
= 5 KW

Given:
Stator Cu loss = Rotor Cu loss = Iron loss

Mech. loss = $\frac{1}{3^{rd}}$ No load loss

No load loss = Iron loss

let iron loss = x

Total loss = Stator Cu loss + Rotor Cu loss + Iron loss + Mech. loss = 5 KW

$\Rightarrow x + x + x + \frac{x}{3} = 5$ KW

$\frac{10x}{3} = 5$ KW

$x = 1.5$ KW

$\Rightarrow$ Iron loss = 1.5 KW
and Stator Cu loss = 1.5 KW

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so

Air gap Power = Input − core loss − stator cu loss

$= 50 - 1.5 - 1.5$

AGP $= 47$ KW

and Rotor cu loss = s AGP = 1.5 KW

$\Rightarrow s = \frac{RCL}{AGP} = \frac{1.5}{47}$

$s = 0.032$

$\Rightarrow$ s = 3.2 %
slip

(10)

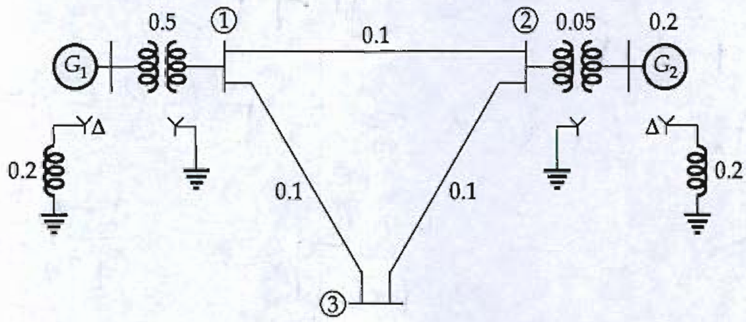
Improve presentation

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)



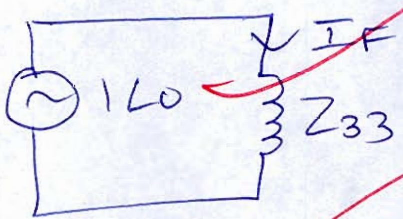
Z_{Bus} for the above system, $Z_{Bus} = j\begin{bmatrix} 0.1397 & 0.1103 & 0.1250 \\ 0.1103 & 0.1397 & 0.1250 \\ 0.1250 & 0.1250 & 0.1750 \end{bmatrix}$

[12 marks]

3 phase fault occurs at bus ③
initial no load rated v condition

let at bus 3 : $V_{pre\,fault} = 1\angle 0°$

i)



so $I_F = \dfrac{1\angle 0}{j0.1750}$

$\boxed{I_F = -j5.714 \text{ PU}}$

ii) V_1^f and V_2^f

so $V_1^f = V_{pf}' - I_F Z_{13}$

$= 1 - (-j5.714) \times j0.1250$

$\boxed{V_1^f = 0.2857}$ PU

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and $V_2^f = V_{pf}^2 - I_F Z_{23}$

$= 1 - (-j5.714) \times j0.1250$

$V_2^f = 0.2857$ PU

iii) I_{12}^f, I_{13}^f and I_{23}^f

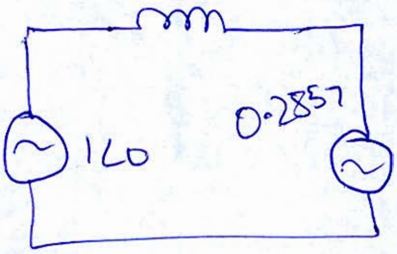
as $V_1^f = V_2^f \Rightarrow$ $I_{12}^f = 0$

and $I_{13}^f = \dfrac{0.2857 - 1}{j0.1250}$

$I_{13}^f = 5.714j$

and $I_{23}^f = \dfrac{0.2857 - 1}{j0.1250} = 5.714j$

iv) I_{G1}^f and I_{G2}^f



$\Rightarrow I_{G1}^f = \dfrac{1 - 0.2857}{j0.5}$

$I_{G1}^f = -j1.4286$ PU

8

||ly

$I_{G2}^f = \dfrac{1 - 0.2857}{j0.05} = -14.286j$

Ans

Go through the made easy solution

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]

η of (M) = 0.86

so Motor Input = $\frac{500\,KW}{0.86}$

= 581.4 KW

KVA = $\frac{~~500~~\ 581.4}{0.7}$

⇒ ~~S =~~ KVS$_{I/P}$ = 830.57

pf = 0.7 lag

⇒ $\Phi_1 = \cos^{-1}(0.7)$
= 45.57

and reqd. pf = 0.9 lag

⇒ $\Phi_2 = \cos^{-1}(0.9) = 25.84$

as capacitor bank only provides Q.

so

$Q_c = P(\tan\Phi_1 - \tan\Phi_2)$

$= 581.4(\tan 45.57 - \tan 25.84)$

$\boxed{Q_c = 208.514 \text{ KVAR}}$

as capacitance is delta connected

$Q_{c_{1phase}} = \frac{Q_c}{3} = 69.505$ KVAR

& $Q_{c_{1phase}} = \frac{V^2}{X_c} = V^2\omega C_{ph}$

$\Rightarrow C_{ph} = \frac{69.505\times 10^3}{420\times 420\times 2\times\pi\times 50} = 1.25\text{ mF}$

$\Rightarrow$ $\boxed{C_{ph} = 1.254\ mF}$

So

$S_{I/p\ new} = 581.4 + j(384.57)$ KVA

4

Incomplete solution

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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]

$I_{sc} = 30A$ @ 0.2 Pf lag
from 16V, 50Hz source

$I_{sc} = ?$, Pf
when energized from 16V, 25Hz source

as ~~Isc~~ $Z = \frac{V}{I} = \frac{16}{30}$

$Z = 0.533 \angle \cos^{-1}(0.2)$

$Z_1 = R + jX_1 = 0.1066 + j0.522$

now as f changes
R → remains same
and $X_1 \propto f$

(11)

$\Rightarrow X_2 = \frac{f_2}{f_1} \times X_1 = \frac{25}{50} \times j0.522$

Good Approach

$X_2 = j0.2611$

so

$Z_2 = R + jX_2 = 0.1066 + j0.2611$

$\Rightarrow I_{sc} = \frac{V}{Z_2} = \frac{16}{0.1066 + j0.2611}$

$I_{sc} = 56.733 \angle -67.79°$

$\Rightarrow$ $I_{sc} = 56.733A$

Ans: $PF = \cos 67.79 = 0.378$ lagg.

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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.

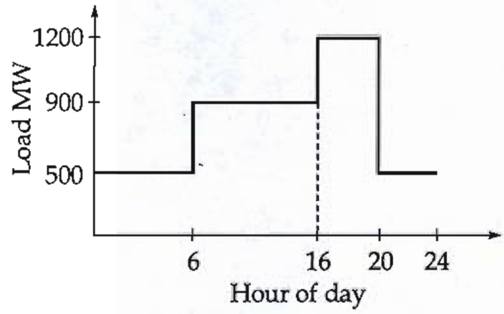
[20 marks]

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

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

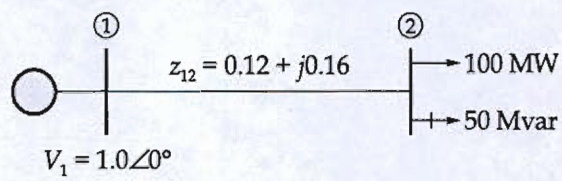
$$C_2 = 2500 + 15P_2 + 0.05 P_2^2 \text{ Rs./hour}$$

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]

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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]

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]

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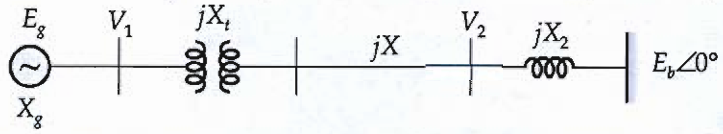
Q.7 (c) A single machine is connected to a load centre through a transmission line as shown in figure. The load centre is represented by a reactance connected to an infinite bus. The generator is initially operating with $P_e = 1.0$ pu and the magnitudes of voltages V_1 and V_2 are 1.0 pu. Assume $X_g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

i) so $R_1 = 1.5 \frac{V_{DC}}{I_{DC}} = 1.5 \times \frac{13.6}{28}$

$= 0.7285\ \Omega$

No load test:

$I_L = \frac{I_A + I_B + I_C}{3} = \frac{8.12 + 8.20 + 8.18}{3}$

$I_{NL} = 8.167$ A

$Z_{NL} = \frac{V_{NL}}{I_{NL}} = \frac{208/\sqrt{3}}{8.167} = 14.7\ \Omega$

and $I_{NL}^2 R_{NL} = P_{in} = 420$

$\Rightarrow R_{NL} = \frac{420}{8.167^2} = 6.296\ \Omega$

$\Rightarrow X_{NL} = X_1 + X_m = \sqrt{Z_{NL}^2 - R_{NL}^2}$

$\Rightarrow \boxed{X_{NL} = 13.283\ \Omega}$

Blocked rotor test:

$$I_{BR} = \frac{I_A + I_B + I_C}{3} = \frac{28.1 + 28 + 27.6}{3}$$

$$I_{BR} = 27.9\ A$$

so $Z_{BR} = \frac{V_T/\sqrt{3}}{I_{BR}} = \frac{25/\sqrt{3}}{27.9} = 0.5173$

and $I_{BR}^2 R_{BR} = 920$

$$\Rightarrow R_{BR} = \frac{920}{27.9^2} = 1.18\ \Omega$$

as $R_2' = R_{BR} - R_1 = 1.18 - 0.7285$

$$\Rightarrow \boxed{R_2' = 0.453\ \Omega}$$

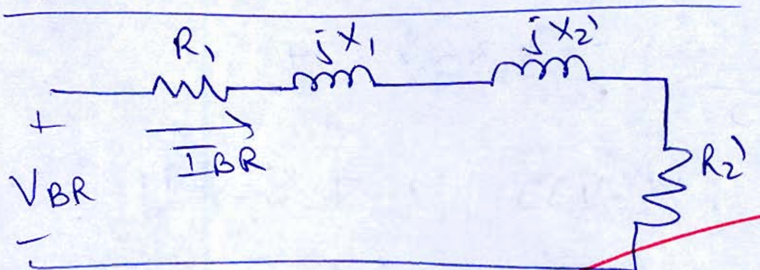
now $Z_{BR} \rightarrow$ is at 15 Hz

$= R_{BR} + X_{BR}j$

and $X \propto f$

and $X_1 = X_2' = \frac{X_{BR}}{2}$

locked rotor test ckt:



at $f = 60Hz$

$V_T = \frac{V}{f}$ remain const.

$$\Rightarrow V_T = 100V \text{ @ } 60Hz$$

so $Z_{BRactual} = \frac{100/\sqrt{3}}{27.9} = 2.069\ \Omega$

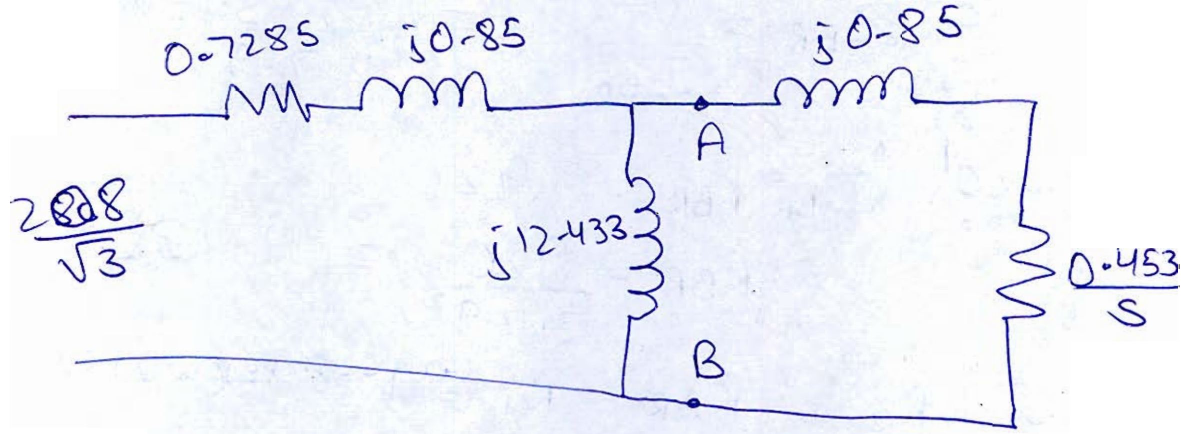
so $X_{BR} = \sqrt{Z_{BR}^2 - R_{BR}^2} = 1.7$

$$\Rightarrow \boxed{X_1 = X_2' = \frac{1.7}{2} = j0.85\ \Omega}$$

& $X_1 + X_m = 13.283\ \Omega$

$\Rightarrow$ $X_m = j\,12.433\ \Omega$

so equivalent circuit:



ii) Pull out torque is the maximum torque.

Finding equiv. ckt seen from AB terminals:

$$V_{AB} = \frac{j\,12.433}{0.7285 + j0.85 + j12.433} \times 208/\sqrt{3}$$

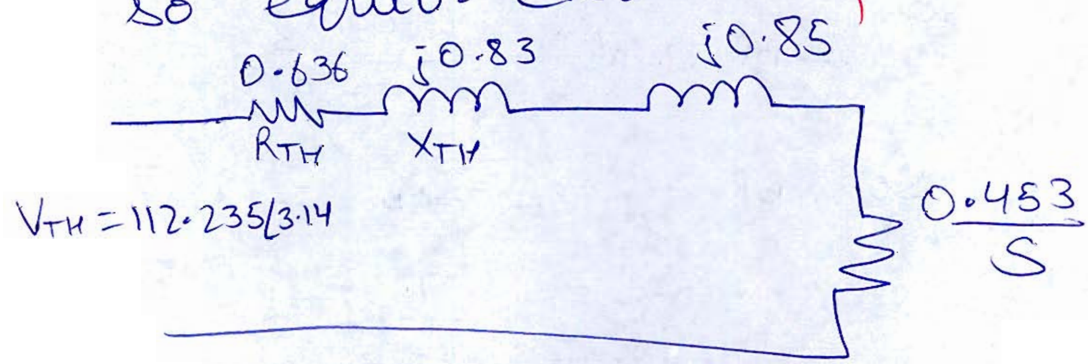
$$= 112.235 \angle 3.14^\circ$$

and

$$Z_{AB} = j\,12.433 \,||\, (0.7285 + j0.85)$$

$$= 0.636 + j\,0.83$$

so equiv. ckt



for slip at maximum torque:

$$\frac{R_2'}{S_m} = \sqrt{(R_{TH})^2 + (X_{TH} + X_2')^2}$$

$$\frac{0.453}{S_m} = \sqrt{(0.636)^2 + (0.83 + 0.85)^2}$$

$$\Rightarrow \boxed{S_m = 0.252}$$

so $\frac{R_2'}{S_m} = \frac{0.453}{0.252} = 1.796\ \Omega$

so $I_{mx} = \frac{112.235\angle 3.14}{1.796 + 0.636 + j(0.83 + 0.85)} = 37.97\angle -31.5°$

so $T_{max} = \frac{3 \times 60}{2\pi N_s} I_{mx}^2 \times \frac{R_2'}{S}$

$$= \frac{3 \times 60}{2\pi\, 1800} \times 37.97^2 \times 1.796$$

$$\boxed{T_{max} = 41.21\ Nm}$$

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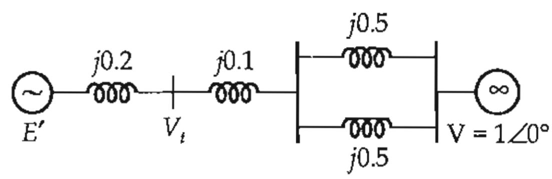
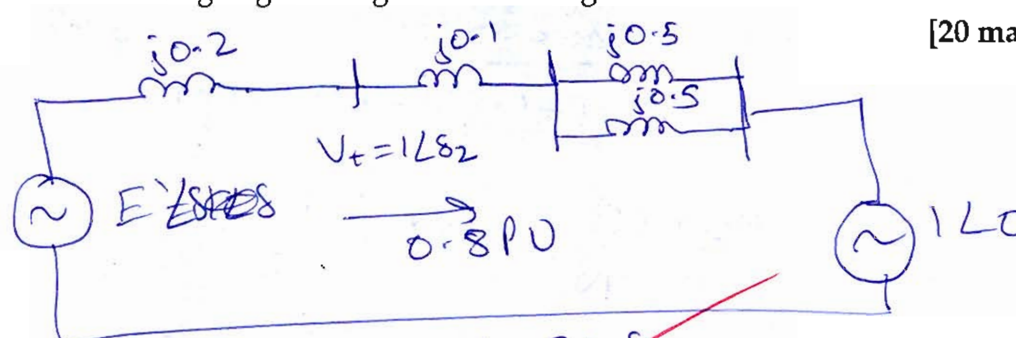
Q.8 (b) (i) Consider the power system shown below. With parallel transmission impedance of $j0.5\Omega$ and delivered power is 0.8 p.u. when both the terminal voltage of the machine and the voltage of the infinite bus is 1 p.u. Determine the power angle equation of the system during above specified conditions.



(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)



$$P = 0.8 = \frac{V_t \times V_\infty}{X} \sin\delta_2$$

$$\Rightarrow 0.8 = \frac{1 \times 1}{0.1 + 0.25} \sin\delta_2$$

$$\Rightarrow \boxed{\delta_2 = 16.26^\circ}$$

$$\Rightarrow I = \frac{1\angle 16.26 - 1\angle 0}{j0.35} = 0.808\angle 8.13^\circ$$

$$\Rightarrow E' = V_t + I\,j0.2$$

$$\boxed{E' = 1.035\angle 25.15^\circ}$$

so

$$P_{emax} = \frac{1.035 \times 1}{0.2 + 0.1 + 0.25} = 1.88 \text{ PU}$$

so by Swing equation

$$\frac{2H}{\omega_s}\frac{d^2\delta}{dt^2} = 0.8 - 1.88 \sin\delta$$

and Power equation:

$$P_e = P_{em} \sin\delta$$

$$\boxed{P_e = 1.88 \sin\delta} \quad PU$$

ii) $P_m = 0.6\, P_{em1}$

after fault $X_{new} = 4 X_{old}$

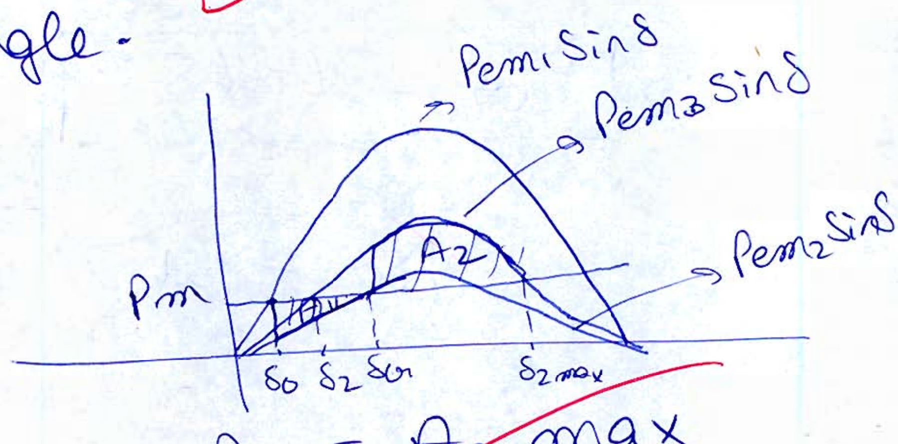
so during fault

$$P_{em2} = \frac{P_{em}}{4} = 0.25 P_{em1}$$

<u>after fault cleared:</u>

$$P_{em3} = 0.8\, P_{em1}$$

Let δ_{cr} be critical clearing angle.



$$A_1 = A_2 \max$$

so

$$\cos\delta_{cr} = \frac{(\delta_{2max} - \delta_0) P_m + P_{em3}\cos\delta_{2max} - P_{em2}\cos\delta_0}{P_{em3} - P_{em2}}$$

now $\delta_0 = \sin^{-1}\left(\frac{P_m}{P_{em1}}\right) = \sin^{-1}(0.6)$

$$\delta_0 = 36.87^\circ = 0.643 \text{ rad.}$$

$$\delta_{2max} = \pi - \sin^{-1}\left(\frac{P_m}{P_{em3}}\right) = \pi - \sin^{-1}\left(\frac{0.6 P_{em1}}{0.8 P_{em1}}\right)$$

$\Rightarrow \delta_{2max} = \pi - \sin^{-1}\left(\frac{0.6}{0.8}\right)$

$= 131.41^\circ = 2.293$ rad.

so

$$\cos\delta_{cr} = \frac{(2.293 - 0.643)\times 0.6 P_{em1} + 0.8 P_{em1}\cos 131.41 - 0.25 P_{em1}\cos 36.87}{0.8 P_{em1} - 0.25 P_{em1}}$$

$$= \frac{0.99 - 0.7291}{0.55}$$

$$\Rightarrow \delta_{cr} = \cos^{-1}\left(\frac{0.2609}{0.55}\right)$$

$$\Rightarrow \boxed{\delta_{cr} = 61.68^\circ}$$

ie $\boxed{\delta_{cr} = 61.7^\circ}$

(18)

Good Approach

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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]

No load test:

$$\cancel{R_{BR}} = Z_{BR} = \frac{400/\sqrt{3}}{7.5} = 30.792$$

$$R_{BR} = Z_{BR} \cos\phi_0 = 4.157$$

$$X_{BR} = Z_{BR} \sin\phi_0 = 30.51$$

$$\Rightarrow X_{NL} = X_1 + X_m$$

No load loss $= \sqrt{3} \times 400 \times 7.5 \times 0.135 = 701.48 W$

Blocked rotor test: considering $R_1 = R_2' = \frac{R_{BR}}{2}$

$$Z_{BR} = \frac{150/\sqrt{3}}{35} = 2.474$$

$$R_{BR} = Z_{BR} \cos\phi_{BR} = 1.088$$

$$\Rightarrow R_1 = R_2' = \frac{R_{BR}}{2} = 0.544 \Omega$$

$$X_{BR} = Z_{BR} \sin\phi_{BR} = 2.221$$

given $\frac{X_1}{X_2'} = 2 \Rightarrow X_1 = 2X_2'$

$$\Rightarrow X_1 + X_2' = X_{BR} \Rightarrow 3X_2' = X_{BR}$$

$$X_2' = \frac{X_{BR}}{3} = \frac{2.221}{3}$$

$$\Rightarrow X_2' = j0.47 \ \& \ X_1 = j1.48$$

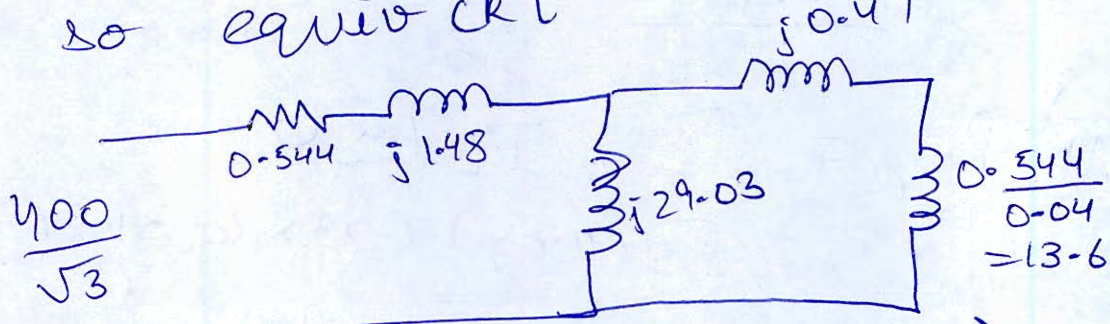
and $X_m = 30.51 - 1.48$

$X_m = j\,29.03\ \Omega$

$N_s = 1000$ rpm

$S = \frac{1000 - 960}{1000} = 0.04$

so equiv ckt



so $Z_f = j29.03 \parallel (j0.47 + 13.6)$

$= 10.86 + j\,5.47$ (R_f, X_f)

so

$I_L = \frac{400/\sqrt{3}}{0.544 + j1.48 + 10.86 + j5.47}$

$I_L = 17.29\angle{-31.36^\circ}$

so $AGP = 3 I_L^2 R_f = 3 \times 17.29^2 \times 10.86$

$= 9739.50\,W$

so

Rotor Output $= AGP(1-S)$

$= 9350.01\,W$

↓

Net Output

so Shaft Output = Rotor O/P − No load loss

$= 9350.01 - 701.48$

$= 8848.53\,W$

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ii) Net torque $= \frac{60}{2\pi N}$ Rotor O/P

$= \frac{60}{2\pi 960} \times 9350$

$T_{net} = 93 \text{ Nm}$

iii) $P_{I/P} = \sqrt{3} V_2 I_2 \cos\phi$

$= \sqrt{3} \times 400 \times 17.29 \times \cos 31.36$

$= 10228.92 \text{ W}$

so

$\eta = \frac{O/P}{I/P} \times 100$

$= \frac{8648.53}{10228.92} \times 100$

$\Rightarrow \eta = 84.55\%$

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Improve presentation

Space for Rough Work

Space for Rough Work

$\frac{VA}{R1} = \frac{VO}{1/C1S}$