• Write all steps

• Improve presentation

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	49
Q.2	
Q.3	32
Q.4	46
Section-B	
Q.5	36
Q.6	
Q.7	
Q.8	32
Total Marks Obtained	195

Signature of Evaluator: Good Approach ....

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]

As we know.

$E_i = E + \frac{\gamma P}{\epsilon_0}$ [when γ factor = 1/3 constant]

↓ internal field.

$E_i = E + \frac{P}{3\epsilon_0}$ —— (1) [E = Electric field, P = Polarization.]

Now as we know $P = \epsilon_0(\epsilon_r - 1)E$.

put in the eqn (1)

$E_i = E + \frac{\epsilon_0(\epsilon_r - 1)E}{3\epsilon_0}$

$E_i = E\left[\frac{3 + \epsilon_r - 1}{3}\right]$

$E_i = E\left[\frac{\epsilon_r + 2}{3}\right]$ —— (2)

as $P = Np$ (p dipole moment)

$P = N\alpha E_i$ [$p = \alpha E$] ↳ polarizability

put E_i from eq (2)

$P = N\alpha E\left[\frac{\epsilon_r + 2}{3}\right]$

$(\epsilon_r - 1)\epsilon_0 E = N\alpha E\left[\frac{\epsilon_r + 2}{3}\right]$

$P = N\alpha$
$P = Np$.

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

Hence proved

$P = (\epsilon_r - 1)\epsilon_0 E_i$	$P = Np$	$p = \alpha E$

eqn used. where,

$\epsilon_r \rightarrow$ permitivity.

$p \rightarrow$ dipole moment.

α = polarizabity.

E_i = Electric field.

P = Polarization.

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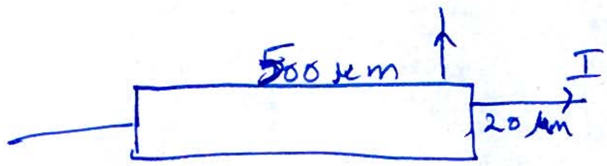
Good Approach

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]



$I = 3\,mA$

$B = 10^{-4}\ wb/cm^2.$

$V = 3.2\,mV$

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

As we know.

$V_H = R_H \frac{B \times I}{t}$

I^{st} case $3.2 \times 10^{-3} = R_H \frac{10^{-4} \times 10^{4} \times 3 \times 10^{-3}}{20 \times 10^{-6}}.$

$R_H = \frac{1}{ne} = \frac{3 \times 10^{-3}}{20 \times 10^{-6}}.$

$n = \frac{20 \times 10^{-6}}{3 \times 10^{-3} \times 1.6 \times 10^{-19}} = 4.16 \times 10^{16}\ /m^3$

Hole Concentration = $4.16 \times 10^{16}\ /m^3$

(3)

Wrong value calculated

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]

$V_H = \frac{R_H}{} \frac{B \times I}{t}$ [when $R_H = \frac{1}{ne}$

B = field density

& I = current

t = thickness.

as we know conductivity is given by

$\sigma = \mu \times n \times e$

↓ mobility. ↓ Concentration ↓ Charge

$\sigma = 700 \times 10^{-4} \times 10^{17} \times 10^{6} \times 1.6 \times 10^{-19}$

$\sigma = 1120$ Ωm

Now ρ (resistivity) $= \frac{1}{\sigma} = 8.92 \times 10^{-4}\ \Omega^{-1} m^{-1}$

$\rho = 8.92 \times 10^{-4}\ \Omega^{-1} m^{-1}$ * Ans

$R = \rho \frac{l}{A}$

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Good Approach

Now $R_H = \frac{1}{ne} = \frac{\mu}{\sigma}$

$R_H = \frac{700 \times 10^{-4}\ m^2/V.s}{1120\ \Omega m} = 6.25 \times 10^{-05}$

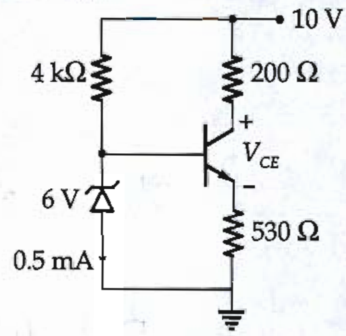
$V_H = R_H \frac{10^{-5} \times 10^{4} \times 1 \times 10^{-3}}{100 \times 10^{-6}}$

* Ans $V_H = 62.5\,\mu V$

$= \frac{6.25 \times 10^{-5} \times 10^{-5} \times 10^{4} \times 10^{-3}}{10^{-4}} = 62.5\,\mu V$

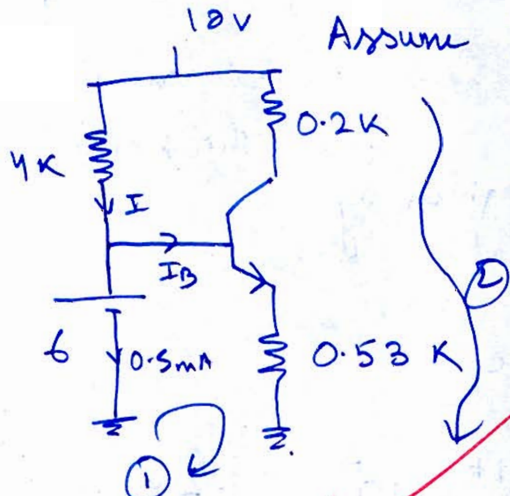
Do not write in this margin

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



[12 marks]

Assume zener in breakdown.
$V_Z = 6$.



$I = I_B + 0.5\text{mA}$

$I = \frac{10-6}{4} = \frac{4}{4} = 1\text{mA}$

$I_B = 0.5\text{mA}$

Now using KVL in loop ① $\{I_E = (1+\beta)I_B\}$

$6 - 0.7 - 0.53 \times (1+\beta) I_B = 0.$

As $I_B = 0.5\text{mA}$ put in eqn.

$5.3 - 0.53 \times 0.5\,(1+\beta) = 0$

$1+\beta = 20$ $\beta = 19$

$I_C = 9.5\text{mA}$ $I_E = 10\text{mA}$

using KVL in loop ②

$10 - 0.2 \times 9.5 - V_{CE} - 0.53 \times 10 = 0$

$V_{CE} = 2.8\text{ V}$ $\beta = 19$

Ans

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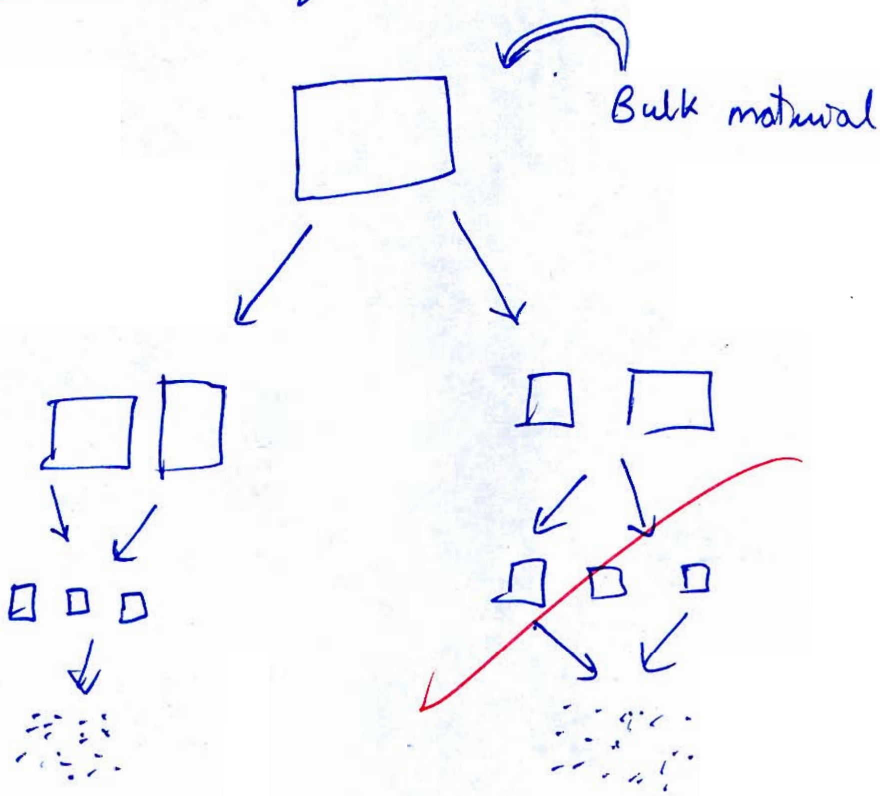
Good Approach

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

[12 marks]

Top down technique



→ In the Top down technique which is used in nano material synthesis we use a bulk material → make smaller material.

→ after several cycles we can obtain the nano material

→ This technique is use in making of integrated circuits.

→ There are several process or methods from which this Top → down technique can be synthesize.

→ ① Cutting ② Mechanical sputtering . etc.

→ It is comparatively easier than bottom up approch.

② bottom up technique

- In this technique we use smaller particles i.e atomic size or nanoparticle from starting to make the nano materials.
- There are several methods which is used in bottom up synthesis.

① PVD (Physical vapour deposition)

② CVD (chemical vapour deposition)

③ Sputtering.

- These technique is very much used in making of wafer which is highly used in semiconductor industry.

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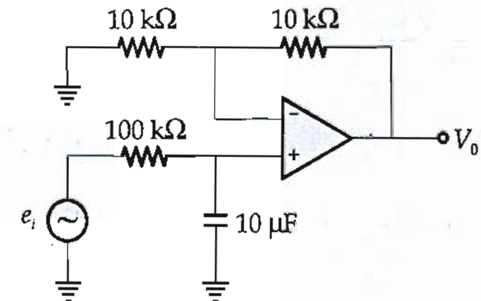
Elaborate it more

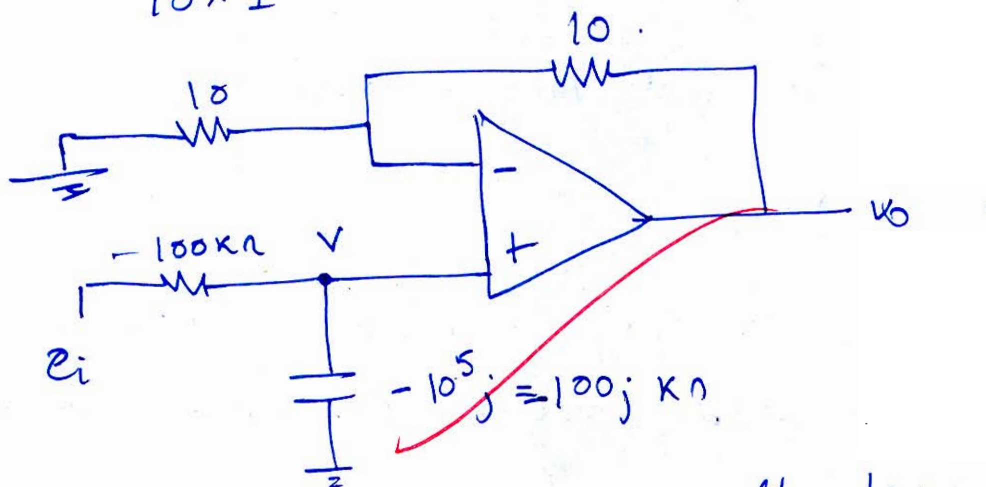
Q.1 (e) In the circuit shown in figure below, if $e_i = \sin t$, find the voltage V_0.



[12 marks]

$e_i = \sin t \qquad \omega = 1$

$X_C = \dfrac{10^6}{10 \times 1} = \dfrac{-j}{\omega}10^5 = -100j \text{ k}\Omega$



using voltage division rule

$V = \dfrac{-100j}{100 + (-100j)} e_i$

$= \dfrac{-100j}{100 - 100j} e_i = \dfrac{-j}{1-j}$

$V = 0.707 \angle -45 \times e_i$

Now $V_0 = \left(1 + \dfrac{10}{10}\right) V$

$V_0 = 2V$ (as -ve feedback)

$V_o = 2 \times 0.707 \angle -45 \; e_i$

$V_o = 1.414 \angle -45 \; e_i$

$e_i = \sin t$

* $V_o = 1.414 \sin(t - 45) \, v$ Ans

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Good Approach

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]

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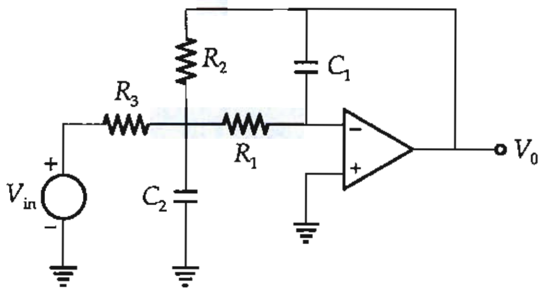
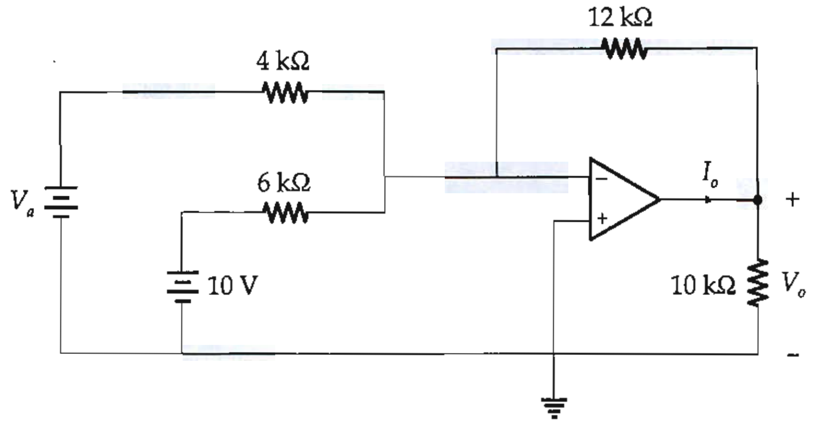
Q.2 (b) For the circuit shown below, find $A_v = \dfrac{V_0}{V_{in}}$, the damping factor and cutoff frequency.



[20 marks]

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

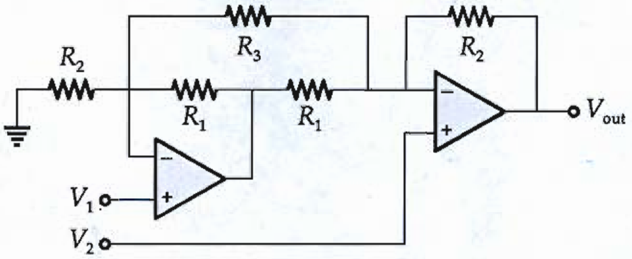


(i) For an input voltage $V_a = 4$ V, find the output voltage V_o and current I_o.

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

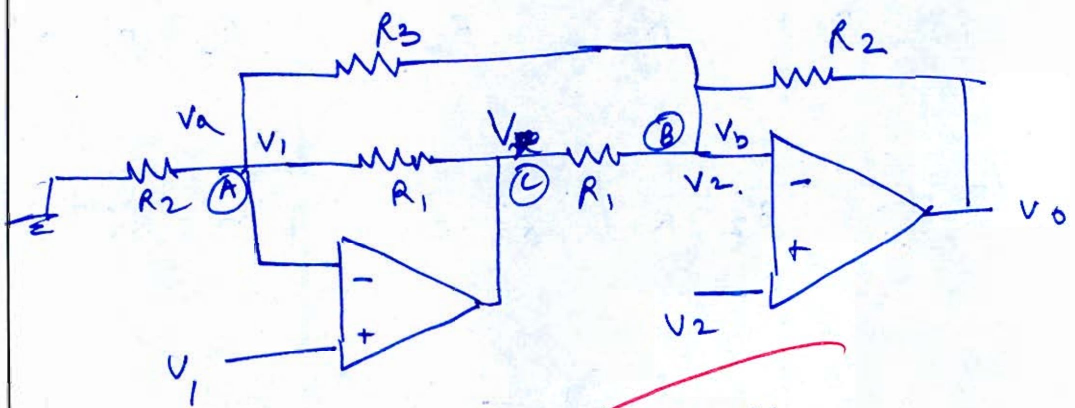
[20 marks]

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]



$V_a = V_1$ $\quad V_b = V_2$

~~due to~~

~~KCL~~ node analysis at node (A)

$$\frac{V_1}{R_2} + \frac{V_1 - V_x}{R_1} + \frac{V_1 - V_2}{R_3} = 0.$$

$$V_1\left(\frac{1}{R_2} + \frac{1}{R_1} + \frac{1}{R_3}\right) = \frac{V_x}{R_1} + \frac{V_2}{R_3} \quad \text{—— (1)}$$

now at node (B)

$$\frac{V_2 - V_0}{R_2} + \frac{V_2 - V_x}{R_1} + \frac{V_2 - V_1}{R_3} = 0.$$

$$V_2\left(\frac{1}{R_2} + \frac{1}{R_1} + \frac{1}{R_3}\right) = \frac{V_0}{R_2} + \frac{V_x}{R_1} + \frac{V_1}{R_3} \quad \text{—— (2)}$$

finding value of $\frac{V_x}{R_1}$ from ①

$$V_1\left[\frac{1}{R_3}+\frac{1}{R_2}+\frac{1}{R_1}\right]-\frac{V_2}{R_3}=\frac{V_x}{R_1}$$

put in ③

$$V_2\left[\frac{1}{R_3}+\frac{1}{R_2}+\frac{1}{R_1}\right]-\frac{V_1}{R_3}=\frac{V_0}{R_2}+V_1\left[\frac{1}{R_3}+\frac{1}{R_2}+\frac{1}{R_1}\right]-\frac{V_2}{R_3}$$

$$\frac{V_0}{R_2}=V_2\left[\frac{1}{R_3}+\frac{1}{R_2}+\frac{1}{R_1}\right]+\frac{V_2}{R_3}-V_1\left[\frac{1}{R_3}+\frac{1}{R_3}+\frac{1}{R_2}+\frac{1}{R_1}\right]$$

$$\frac{V_0}{R_2}=V_2\left[\frac{2}{R_3}+\frac{1}{R_2}+\frac{1}{R_1}\right]-V_1\left[\frac{2}{R_3}+\frac{1}{R_2}+\frac{1}{R_1}\right]$$

$$\boxed{\frac{V_0}{V_2-V_1}=R_2\left[\frac{2}{R_3}+\frac{1}{R_2}+\frac{1}{R_1}\right]}$$

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

$$\boxed{\frac{V_0}{V_2-V_1}=1+\frac{2R_2}{R_3}+\frac{R_2}{R_1}}$$

(11)

Good Approach

Do not write in this margin

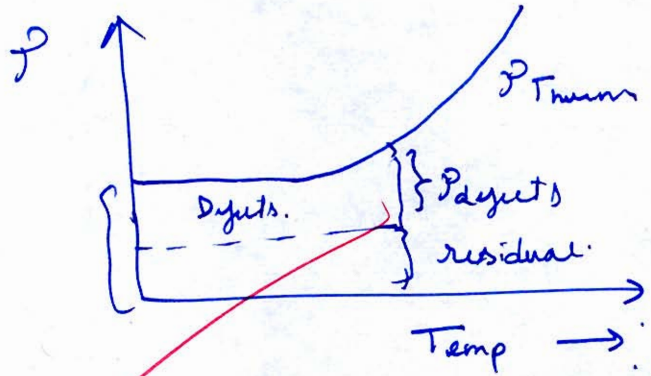
Q.3 (a) (ii) Discuss Matthiessen's rule and explain the influence of the factors affecting resistivity of metals.

[8 marks]

→ Mathiessen' rule give the resistivity of the metals.

→ It said that resistivity of metals is sum of various factor for - Temp, defects, Alloying, & residual Resistivity.

$$\rho = \rho_d + \rho_T + \rho_r.$$



factor affecting resistivity.

① Alloying → on mixing the two metal ρ ↑.

② Temp → on increasing the Temp the ρ ↑ because of increase in lattice vibration.

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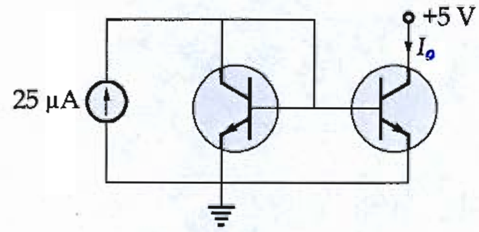
③ defects → defects causes hindrance in the flow of charge carriers (e^-)

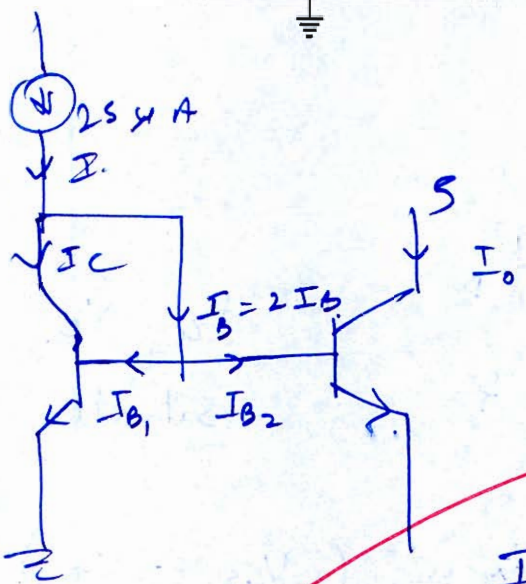
④ cold working → increases the ρ of the metal because of the structure change of atom.

⑤ mechanical stress

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]



$I_{B_1} = I_{B_2} = I_B$

$I_B = 25$

$I_o = \dfrac{25}{1 + \frac{2}{\beta}} = \dfrac{25}{1 + \frac{2}{25}}$

$\boxed{I_o = 23.148\ \mu A}$

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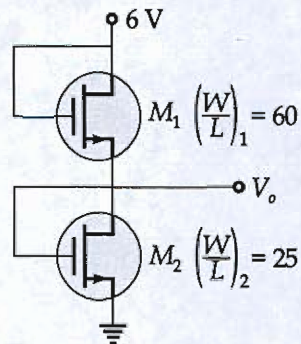
Improve presentation

$I_B = I_C + 2I_B$

$I = \beta I_B + 2I_B = I_B(2 + \beta) = I$

$\boxed{I_o = \dfrac{I}{1 + \frac{2}{\beta}}}$ Proved

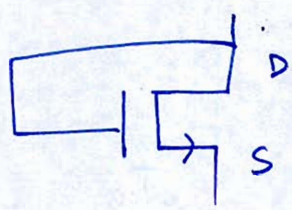
Q.3 (b) **(ii)** Consider the circuit shown in figure below :



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]

M1



$V_G = V_D$.

Saturation

$I_D = \frac{1}{2} \mu_n C_{ox} \frac{W}{L} (V_{GS} - V_{th})^2$ — ①

$V_{GS} = V_G - V_O = 6 - V_O$.

In M1

$I_D = \frac{1}{2} \mu_n C_{ox} \frac{W}{L} (6 - V_O - 0.9)^2$

In M2 $\quad$ $\boxed{V_S = 0}$ in M2.

$V_{GS} = V_O - 0 = V_O$

$I_D = \frac{1}{2} \mu_n C_{ox} \frac{W}{L} (V_O - 0.9)^2$ — ②

Do not write in this margin

$1 = (2)$

$\frac{1}{2} \times 60 (5.1 - V_0)^2 = \frac{1}{2} \times 25 (V - 0.9)^2.$

$1.55 = \frac{V - 0.9}{5.1 - V_0}$

$7.9 - 1.55V = V - 0.9.$

$7.9 + 0.9 = V + 1.55V$

$8.8 = 2.55V$

$\boxed{V = 3.45 V}$

(6)

Good Approach

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.

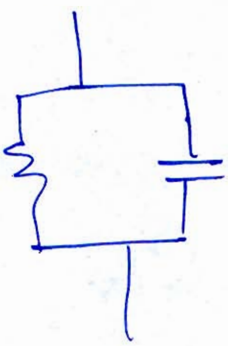
[20 marks]

$A = 25\ cm^2 \qquad d = 0.3\ mm. \qquad \epsilon_r' = 3$

$f = 1.5\ MHz \qquad \tan\delta = 3.8 \times 10^{-4}$

$\tan\delta = \dfrac{\epsilon_r''}{\epsilon_r'} \qquad \epsilon_r'' = 3.8 \times 10^{-4} \times 3$

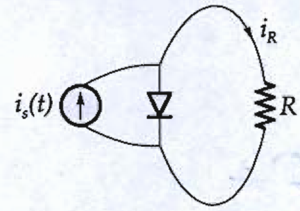
$\epsilon_r'' = 1.14 \times 10^{-3}$



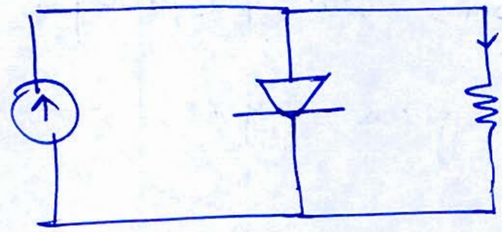
(2)

In complete solution.

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.



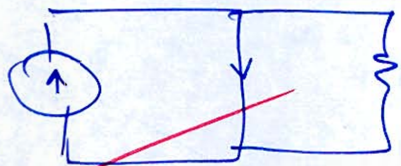
[10 marks]



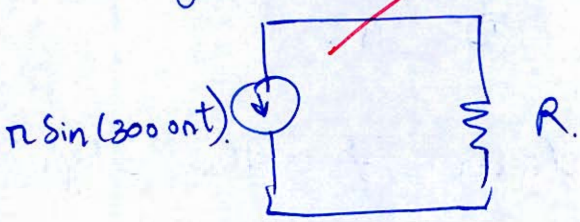
$R = \frac{V_D}{\eta V_T}$

in +ve half cycle. Diode on.

$i_R = 0$



in -ve cycle



Now

$$I_{avg} = \frac{1}{2\pi}\int_0^{T} 0 + \int_{T}^{2T} -I_m$$

$$= -\frac{I_m}{\pi}.$$

$$\text{magnut} = \left(\frac{-I_m}{\pi}\right) = \frac{\pi}{\pi} = 1\ mA$$

$$|i_{R_{avg}}| = 1\ mA$$

Improve presentation

9

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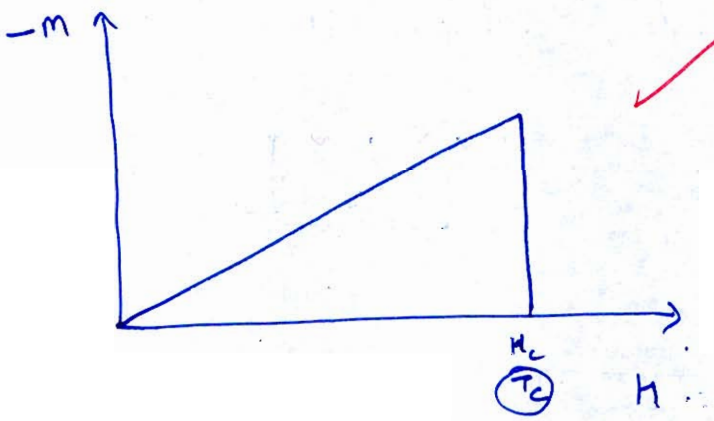
Q.4 (a) (ii) With the help of magnetization characteristics (M vs H curves) explain the difference between Type-I and Type-II superconductors.

[10 marks]

Type 1 super conductors -

also known as soft conductors they follow seilbi's & Meissin's law property.

The m v/s H curve given by.



as the graph is linear. & the slope of H v/s -m is +ve i.e..

$\frac{-M}{H} = 1$ $\frac{M}{H} = -1$ $M = -H$.

as we know $\chi H = M$

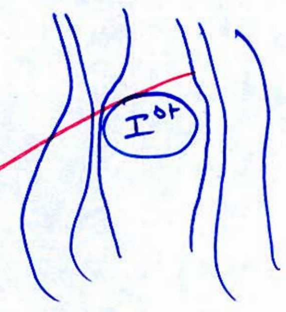
on comparing

$\chi = -1$ (when χ susactibility). $\mu_r - 1 = \chi$

$\mu_r - 1 = -1$ $\boxed{\mu_r = 0}$

Permeability is $= 0$

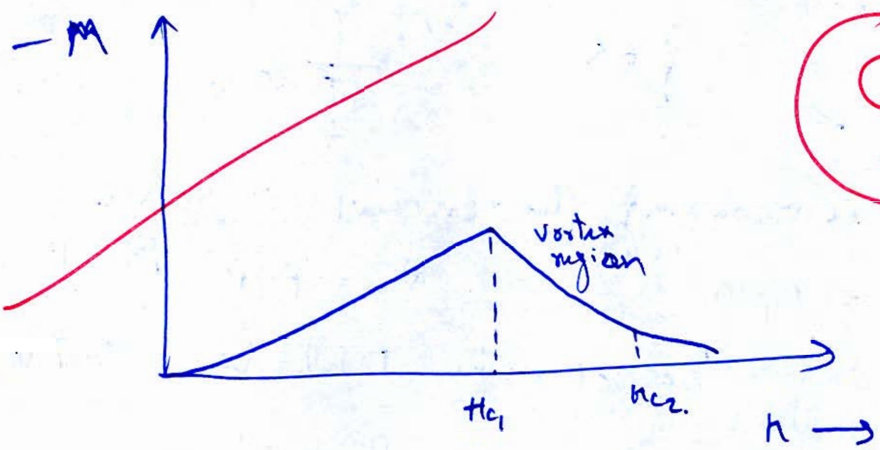
That means the Type I superconductors show perfectly diamagnetic behaviour. as compare to II" type.



Ex Hg, Al etc

Type-II also called as Hard superconductors.

they follow silsbi & Meissner's effect upto some extent but not perfectly.
so they show diamagnetic behaviour but changes according to change in H (field intensity.



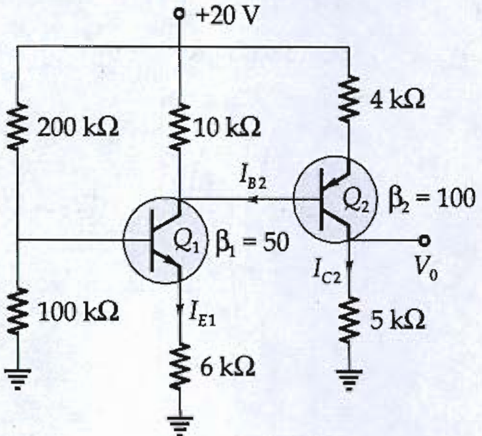
(9)

here the change in magnetic field lines are not abruptly as in type I st conductors

Ex V_3Si V_3Ge etc.

Improve presentation

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



Determine:

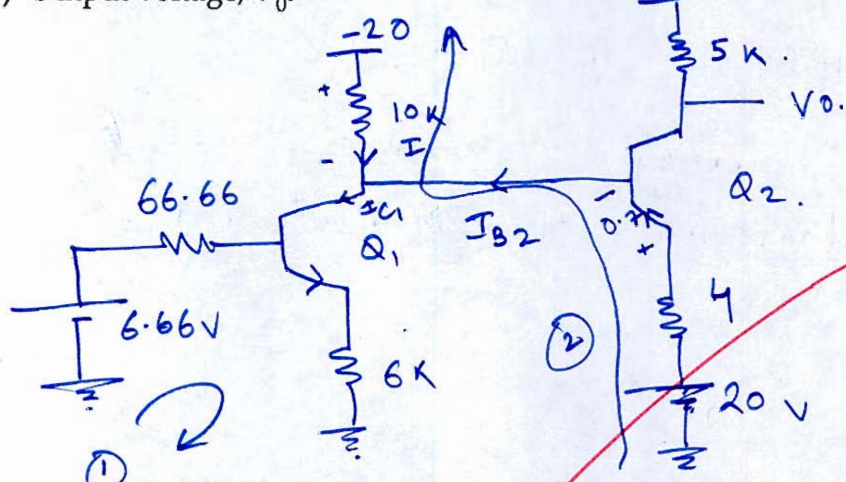
(i) Base current of transistor, Q_2.

(ii) Collector current of transistor, Q_2.

(iii) Emitter current of transistor, Q_1.

(iv) Output voltage, V_0.

[20 marks]



rearranging the circuit to solve.

$Q_1 \rightarrow npn$ & $Q_2 = pnp$ BJT

Assuming V_{BE} of both BJT to $= 0.7$ V.

$\beta_1 = 50$ $\beta_2 = 100$

In loop ①

$6.66 - 66.66 \times I_{B_1} - 0.7 - 6 \times 51 \times I_{B_1} = 0$

$(I_{E_1} = (1+\beta) I_{B_1} = 51 I_{B_1})$

$I_{B_1} = 0.0159$ mA

$I_{E_1} = 51 \times 0.0159$

$I_{E_1} = 0.811$ mA

Now $I_{C_1} = 50 \times 0.159$

$I_{C_1} = 0.795\ mA.$

In loop ② $\quad I + I_{B_2} = I_{C_1}$

$I = I_{C_1} - I_{B_2}.$

$20 - 4 \times 101\ I_{B_2} + I \times 10 - 20 - 0.7 = 0.$

$0.7 = -4 \times 101\ I_{B_2} + (0.795 - I_{B_2}) \times 10$

$0.7 = -404 I_{B_2} + (0.795 - I_{B_2})10.$

$0.7 = -404\ I_{B_2} + 7.95 - 10\ I_{B_2}.$

$(10 + 404) I_{B_2} = 7.95 - 0.7$

$\boxed{I_{B_2} = 0.0175\ mA}$ *

$I_{C_2} = 100 \times 0.0175\ mA$

$\boxed{I_{C_2} = 1.751\ mA}$ *

$V_0 = I_{C_2} \times 5$

$\boxed{V_0 = 8.75\ V}$

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Good Approach

(i) $I_{B2} = 0.0175\ mA$

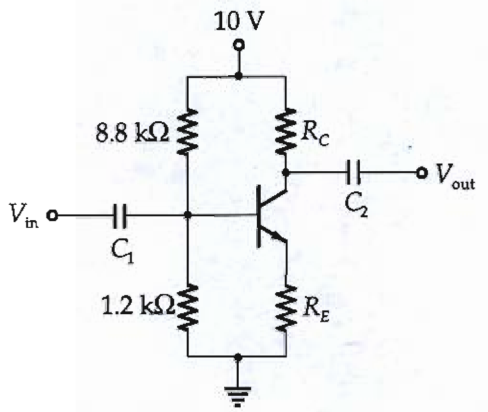
(ii) $I_{C2} = 1.751\ mA$

(iii) $I_{E1} = 0.811\ mA$

(iv) $V_0 = 8.75\ V$

Ans

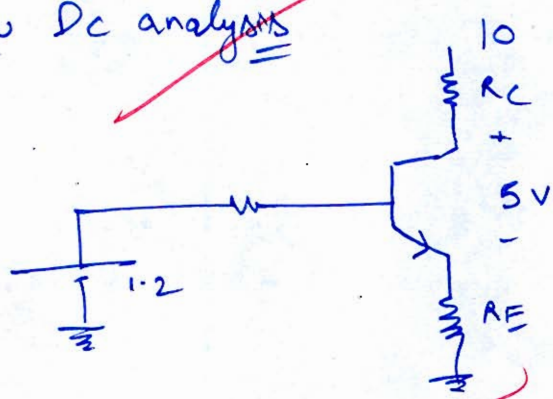
Q.4 (c) In the amplifier circuit shown below, assume $V_{BE} = 0.7$ V and the β of the transistor and the values of C_1 and C_2 are extremely high. If the amplifier is designed such that at the quiescent point its $V_{CE} = V_{CC}/2$, where V_{CC} is the power supply voltage, find its small signal voltage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



[20 marks]

$\beta = \infty$ $\quad V_{CE} = \frac{V_{cc}}{2} = \frac{10}{2} = 5$ V

Now Dc analysis



$I_B = 0$

$V_{BE} = 0.7$.

$1.2 - 0.7 - R_E I = 0$. $\quad$ $I R_E = 0.5$ v

KVL $\quad 10 - IR_c - 5 - IR_E = 0$.

$5 - 0.5 = IR_c$. $\quad IR_c = 4.5$ v

Now as $V_{BE} = 0.7$ & $V_B = 1.2$ v.

$1.2 - V_E = 0.7$

$V_E = 0.5$.

$V_{CE} = 5$ $\quad V_c - 0.5 = 5$

$V_c = 5.5$.

$I = \frac{10 - 5.5}{R_c}$

Do not write in this margin

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

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

10

Incomplete solution

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]

It is 6 pulse rectifier.

(i) $\Delta V_0 = 6 \times I \times f \times L$ (decrease in o/p voltage due to Source Inductance.)

$\Delta V = 6 \times 1000 \times 50 \times L$

$V_d = \left(\frac{6 V_m}{\pi}\right.$

$V_0 = 400\,kV = \frac{V_d}{2}\left(\cos(\alpha + \mu) + \cos\alpha\right)$

$400 \times 10^3 = \frac{6\ 400}{\sqrt{3}} \times \frac{\sqrt{2} \times 10^3}{2}\left(\cos(15 + \mu) + \cos 15\right]$

$\frac{\sqrt{2} \times \sqrt{3}}{6} - \cos 15 = \cos(15 + \mu)$

$\boxed{\mu = 108.88°}$ Commutation angle is

3

(iii) If AC voltage reduced = 200 kV.

$400 = \frac{200 \times 10^3 \times \sqrt{2}}{\sqrt{3} \times 2} \times 6 \left(\cos(15 + \mu) + \cos 15\right)$

Incomplete 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 $1/3^{rd}$ of the no load losses. Neglect ohmic losses at no load, and calculate the slip.

[12 marks]

$\eta = 0.9$ efficiency $\quad P_{shaft} = 45\,kW$

$P_{stator\ cu\ loss} = P_{rotor\ cu\ loss} = P_{iron\ loss}$ ——— (1)

$P_{mechanical\ loss} = \frac{1}{3}\left[P_{iron\ loss} + P_{mech\ loss}\right]$ (No load loss.)

Total losses in Motor $= P_{i/p} - P_{o/p}$

$= \frac{45}{0.9} - 45 = 5\,kW = \text{Losses}$

$5000 = P_i + P_{st\,cu} + P_{rt\,cu} + P_{mech}$ ——— (2)

$P_m = \frac{1}{3}P_i + \frac{1}{3}P_m \qquad P_m\left[1-\frac{1}{3}\right] = \frac{1}{3}P_i$

$P_m\left[\frac{2}{3}\right] = \frac{1}{3}P_i$

$$\boxed{P_m = \frac{P_i}{2}}$$ ——— (3)

from eq (1) & (3) put in eq^n (2)

$5000 = P_i + P_i + P_i + \frac{P_i}{2}$

$5000 = 3.5P_i \qquad P_i = 1428.57\,W = P_{rt\,cu\,loss}$

Now finding air gap power.

$$P_{ag} = P_{i/p} - P_{st\ cu\ loss} - P_{iron\ loss}.$$

$$= 50 - 1.4285 - 1.4285$$

$$P_{ag} = 47.143.$$

as we know $P_{rt\ cu\ loss} = S \times P_{ag}.$

$$S = \frac{P_{rt\ cu\ loss}}{P_{ag}} = \frac{1.428}{47.143}$$

$$\boxed{S = 0.0302}$$ Ans

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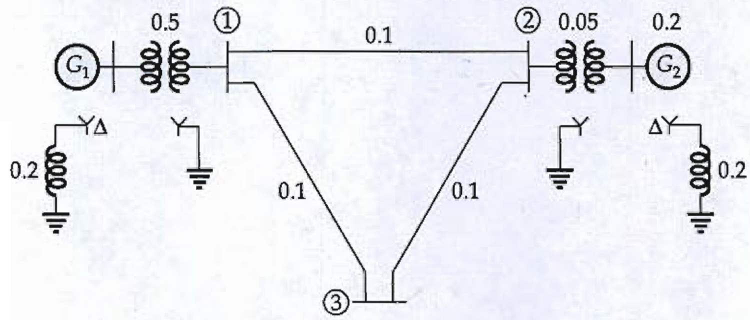
Good Approach

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) Fault current. as fault is on bus ③

$I_F = \frac{V_3}{Z_{33}}$ $[V_3 = 1\angle 0 \text{ pu}]$

$Z_{33} = 0.1750$ pu. $I_F = \frac{1}{j0.1750}$

$I_F = 5.714\angle -90$ pu

(ii) $V_1^f = V_{1\,\text{prefault}} - I_F \times Z_{13}$

$= 1 - 5.714\angle -90 \times 0.1250\angle 90$

* $V_{1\,\text{post fault}}^f = 0.285$ pu ← Ans

$V_2^f = V_{2\,\text{prefault}} - I_F \times Z_{23}$

$= 1 - 5.714 \times 0.1250$

* Ans $V_2^f = 0.285$ pu

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

$I_{12}^f = \dfrac{0.285 - 0.285}{Z_{12}} = 0 \text{ pu}$

$\boxed{I_{12} = 0}$

$I_{13}^f = \dfrac{0.285 - 0}{0.1250} = \dfrac{V_1^f - V_3^f}{Z_{13}}$ $\quad (V_3^f = 0$

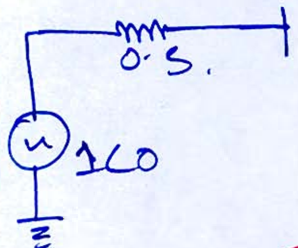
* $\boxed{I_{13f} = 2.28\angle -90}$ * $\boxed{I_{12} = 0}$

$I_{23f} = \dfrac{V_2^f - V_3^f}{Z_{23}} = \dfrac{0.285 - 0}{0.1250} = 2.28\angle -90$

$\boxed{I_{13f} = I_{2f} = 2.28\angle -90}$ $\boxed{I_{12} = 0}$ Ans

(iv) I_{G1}^f

$V_1^f = 0.285 \text{ pu}$



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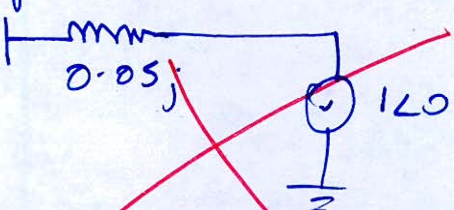
$I_{G1f} = \dfrac{1\angle 0 - 0.285\angle 0}{0.5j} = 1.43\angle -90$ Ans

* $\boxed{I_{G1f} = 1.43\angle -90}$

$I_{G2f} =$



$I_{G2f} = \dfrac{1 - 0.285}{0.05j}$

* $\boxed{I_{G2f} = 14.3\angle -90 \text{ pu}}$ 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]

efficiency of motor = 0.86.

p.f of motor = 0.7.

with delta connected Capacitor Bank p.f to improved to = 0.9 lag.

So we have to find the (Q) Reactive Power supplied by the Cap. bank to improve p.f.

→ $P_{i/p}$ of ind. motor $= \frac{P_{o/p}}{\eta} = \frac{500}{0.86}$

$P_{i/p} = 581.39$ kW.

$Q_{difference}$ (supplied of Cap bank) = $Q_{\text{without Cap bank}} - Q_{\text{with improved p.f.}}$

$= P_{i/p}\,(\tan\cos^{-1}0.7 - \tan\cos^{-1}0.9)$

$$\boxed{Q_{3ph} = 311.556 \text{ KVAR.}}$$

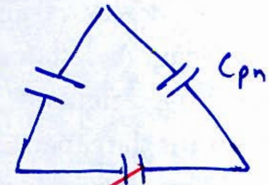
<u>Now</u> $Q_{3ph} = 3 \times (V_{ph})^2\,\omega C.$

$\Delta \quad V_{ph} = V_L = 420.$

$311.556 = 3 \times (420)^2 \times 314 \times C$

$$\boxed{C = 1.87 \text{ mF}}$$

Now $C_{eq} =$



$C = 3 \times 1.87$

each unit

$C_{each\ unit} = 5.61\ \mu F$ | $C_{pn} = 1.87\ mF$

energy saving.

$S_1 = P_1 + jQ_1$

$= j593.136 + 581.39$

$S_1 = 830.55\ KVA$

Now

Now after cap-bank.

$Q = 581.39 - 311.556$

$Q_{new} = 269.834$

(6)

$830.55 = \sqrt{P^2 + 269.83^2}$

$P_{new} = 785.49$

Saving $\Rightarrow = \frac{785.49 - 581.39}{581.39} \times 100$

$S_{aving} = 35.1\ \%$ Ans

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) $f = 50\,Hz$

$p.f = 0.2 \Rightarrow$ $I = 30$ $f = 50$

$V = 16$.

$P_L = 30 \times 0.2 \times 16 = 96 = $ Loss (Cu)

$I^2 R = 96$ $\boxed{R = 0.106\,\Omega}$

Now $Z = \frac{16}{30} = 0.533\,\Omega$.

$Z^2 = R^2 + X^2$

$X_{50} = \sqrt{Z^2 - R^2}$

$X_{50} = 0.5223\,\Omega$

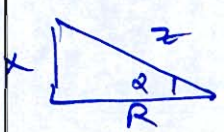
(ii) $f = 25\,Hz$

Now at 25 Hz. $X \propto f$.

$\frac{0.5223}{X_{25}} = \frac{50}{25}\ 2$ $\boxed{X_{25} = 0.2611\,\Omega}$

Now ~~R = 0.160~~ $\boxed{R = 0.106\,\Omega}$ $\boxed{X_{25} = 0.2611\,\Omega}$

$\boxed{Z = 0.281\,\Omega}$



$\cos = \frac{R}{Z}$

$= \frac{0.106}{0.281} = 0.376$

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* $\boxed{p.f = 0.376 \text{ lag}}$

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

Good approach

$I = \frac{16}{0.281}$ * $\boxed{I = 57\,A}$ Ans

$\boxed{p.f = 0.376 \text{ lag}}$

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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.

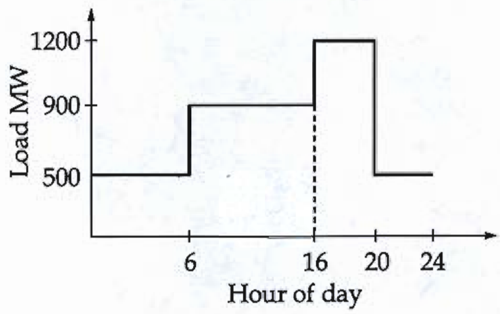
[20 marks]

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

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

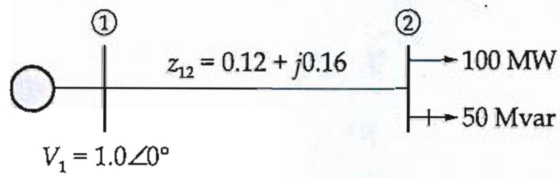
$$C_2 = 2500 + 15P_2 + 0.05 P_2^2 \text{ Rs./hour}$$

The limit of generation for the two units are $200 \leq P \leq 800$ 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.

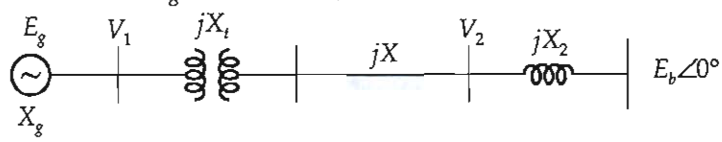
[10 marks]

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]

Do not write in this margin

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

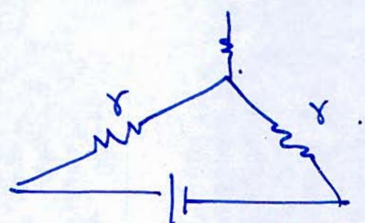
I_C = 27.6 A

(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]

DC test



$\frac{13.6}{28} = 2r$

$r_{pn} = 0.242\ \Omega$

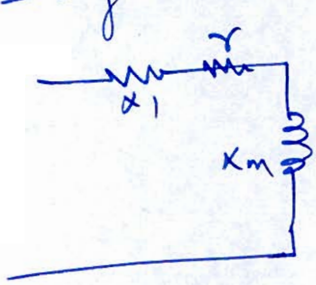
$r_{ac} = 1.2 \times 0.242$

$r_{ac\,pn} = 0.291\ \Omega$

No load test

$I_{avg} = 8.166$ A

$P_{i/p} = 420$ W



$V_{pn} = 120$ V

$Z = \frac{120}{8.166} = 14.7\ \Omega$

$14.7 = Z = \sqrt{r_1^2 + (x_1 + x_m)^2}$

$\sqrt{14.7^2 - 0.291^2} = (x_1 + x_m)$

$x_1 + x_m = 14.697\ \Omega$ (1)

Now Block rotor test

$$I_{avg} = \frac{28.1 + 28 + 27.6}{3} = 27.9\,A$$

$$Z = \frac{25}{27.9\sqrt{3}} = 0.517^2 = r^2 + x_1^2.$$

where

$r_1 = 0.291\,\Omega$

$X_1 = 0.8474$ at $f = 15$

at $f = 60$

$X_1 = 3.389\,\Omega$

put in eq ①

$X_m = 11.308\,\Omega$

Try to avoid

Now rotor per phase.

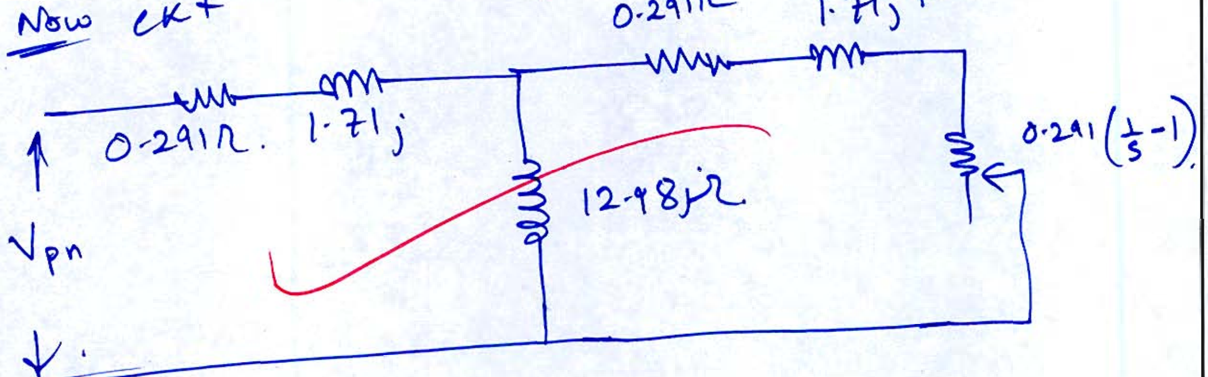
$X_1 = 0.427$ at $f = 15$

$X_1 = 1.71$ at $f = 60$

put in eq ①

$X_m = 12.98\,\Omega$

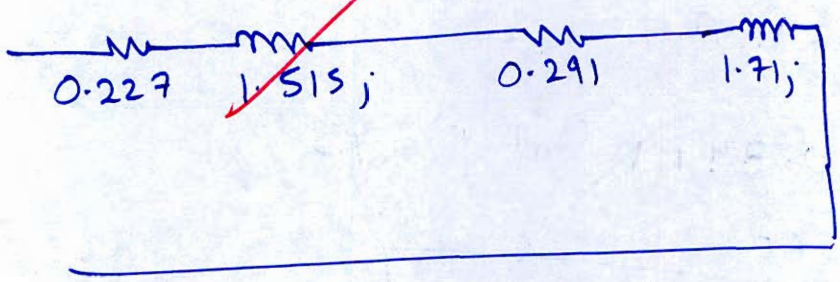
Now ckt



Sm

$(0.291 + 1.71j) \parallel 12.98j$

$$\frac{(0.291 + 1.71j) \times 12.98j}{0.291 + 1.71j + 12.98j}$$



$$S_m = \frac{R_2}{\sqrt{R_1^2 + (X_1 + X_2)^2}}$$

$S_m = 0.09$

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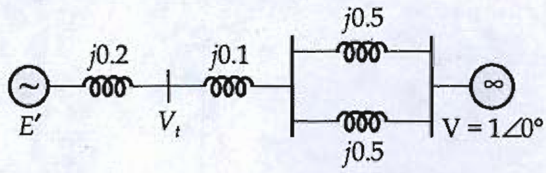
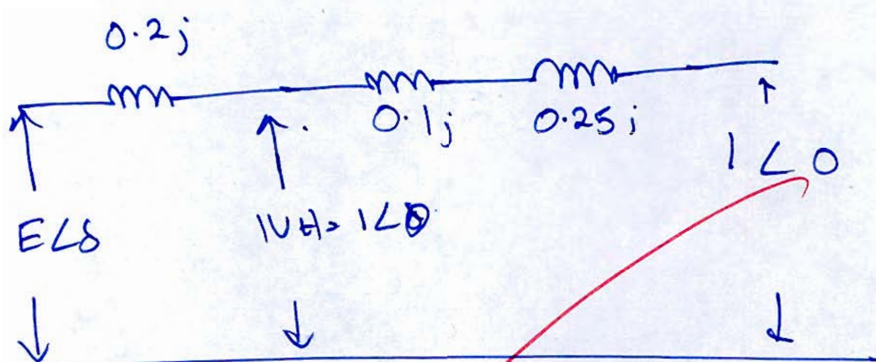
Q.8 (b) (i) Consider the power system shown below. With parallel transmission impedance of $j0.5\Omega$ and delivered power is 0.8 p.u. when both the terminal voltage of the machine and the voltage of the infinite bus is 1 p.u. Determine the power angle equation of the system during above specified conditions.



(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]



$P = 0.8$ $\qquad$ $P = \frac{V_t \times V_\infty}{X_T} \sin\theta$

$0.8 = \frac{1 \times 1}{0.35} \sin\theta$ $\qquad$ $\boxed{\theta = 16.26}$

$I = \frac{1\angle 16.26 - 1\angle 0}{0.35j}$

$I = 0.808\angle 8.13$

$E_g\angle\delta = 1\angle 16.26 + 0.808\angle 8.13 \times 0.2\angle 90$

$\boxed{E_g\angle\delta = 1.035\angle 25.15}$ *

$$P = \frac{E_f \times V_\infty}{X_g + X_T} \sin\delta.$$

$$P = \frac{1.035 \times 1}{0.55} \sin 25.15 \simeq 0.8$$

iii) pre fault condition.

$P_m = 0.6\ P_{max}$

~~after~~ during fault.

$$P'_{max} = \frac{P_{max}}{4} = 0.25 P_{max}.$$

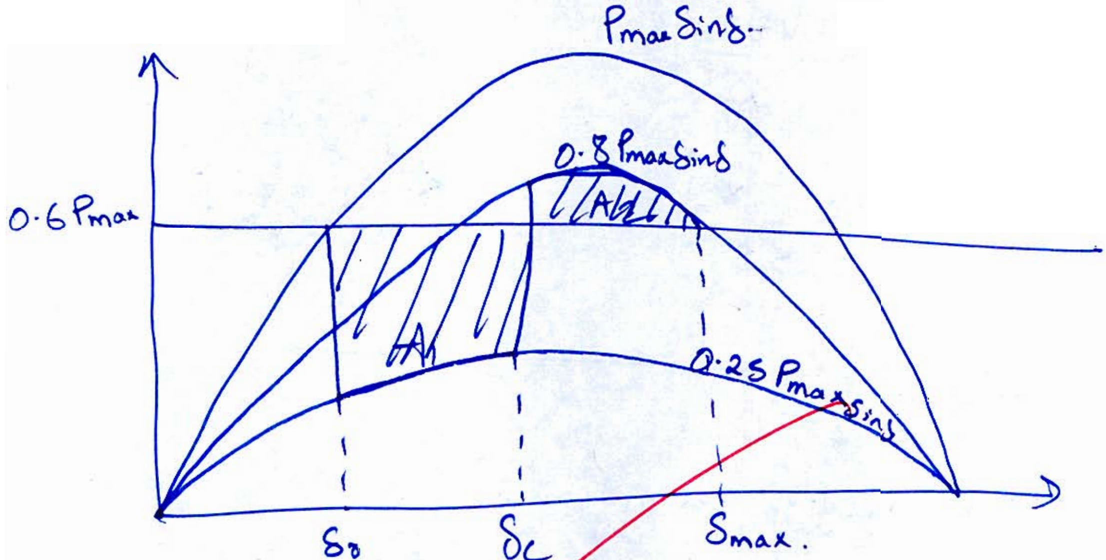
after fault $P''_{max} = 0.8 P_{max}$.

Making ~~graph~~

using equal area criteria to solve the question.

(8)

Incomplete solution



$\delta_0 \Rightarrow \quad 0.6 P_{max} = P_{max} \sin\delta$

$\delta_0 = 36.86$

$0.6 P_m = 0.8 P_m \sin\delta_2$

$\delta_{max} = 180 - \delta_2 = 131.4^\circ$

Now $\quad A_1 = A_2$ for stability.

$$\int_{\delta_0}^{\delta_c} 0.6 P_m - 0.25 P_m \sin\delta = \int_{\delta_c}^{\delta_{max}} 0.8 P_m \sin\delta - 0.6 P_m$$

$$0.6(\delta_c - \delta_0) + 0.25 [\cos\delta]_{\delta_0}^{\delta_c} = 0.8 [\cos\delta]_{\delta_{max}}^{\delta_c} - 0.6\delta_m + 0.6\delta_c$$

$$-0.6\delta_0 + 0.25\cos\delta_c - 0.25\cos\delta_0$$

$$= 0.8\cos\delta_c - 0.8\cos\delta_m - 0.6\delta_m.$$

$$0.6(\delta_m - \delta_0) + 0.8\cos\delta_m - 0.25\cos\delta_0 = 0.8\cos\delta_c - 0.25\cos\delta_c$$

$$\frac{0.9895 - 0.729}{(0.8-0.25)} = \cos\delta.$$

$$\boxed{\delta_c = 61.74^\circ}$$

Ans

16

Improve presentation

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

$V_{pn} = \frac{400}{\sqrt{3}} = 231.\ V$

$P_{pn} = 233.82 = I^2 r_{pn}.$

$r_{pn} = 4.156\ \Omega$

$Z = \sqrt{30.8^2 - 4.156^2} = X_1 + X_m$

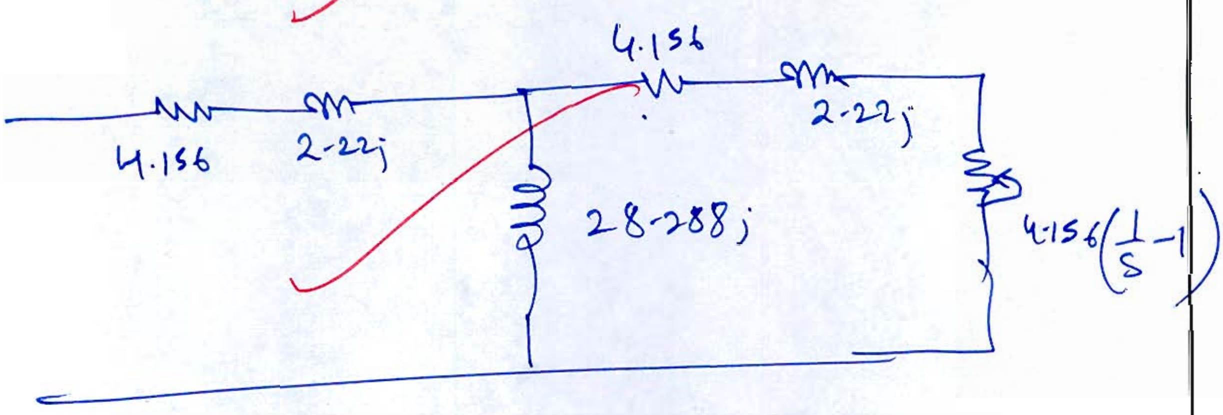
$X_1 + X_m = 30.51\Omega$

Blocked $V_{pn} = 86.6\ V$

$Z = 2.474 = \quad r_{pn} = 1.088\ pu.\ \Omega$

$X_{pn} = 2.22\ \Omega$

$X_m = 28.288\ \Omega.$



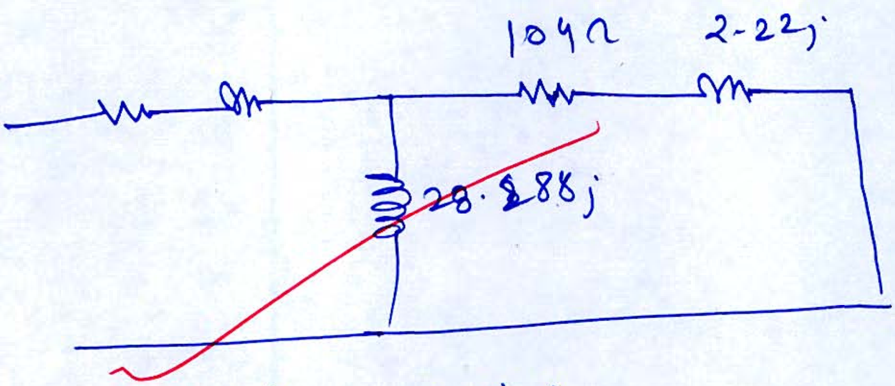
$S = \frac{1000 - 960}{1000} = S = 0.04$

P_{core} loss $= 701.46$ W.

$P_{rotor\ cu}$ loss $= 4001.03$ W

~~$P_{\phi} = \sqrt{3} \times 400 \times$~~

$S = 0.04$



$(104 + 2.22j)$?

9

Incomplete solution

OOOO

$N\alpha E$

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

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

Space for Rough Work