candidate should write the answer in the space provided

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ESE 2024 : 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 : RAJAN KUMAR

Roll No : EE24MTDLA011

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Student's Signature

Rajan Kumar

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	47
Q.2	
Q.3	47
Q.4	50
Section-B	
Q.5	44
Q.6	
Q.7	53
Q.8	
Total Marks Obtained	241

Signature of Evaluator: Sourabh Kumar

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IMPORTANT INSTRUCTIONS

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

DONT'S

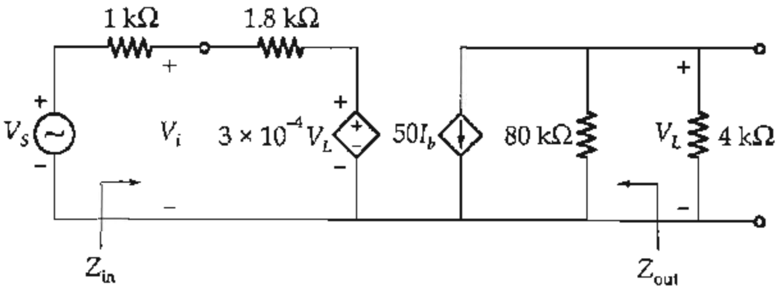
1. Do not write your name or registration number anywhere inside this Question-cum-Answer Booklet (QCAB).
2. Do not write anything other than the actual answers to the questions anywhere inside your QCAB.
3. Do not tear off any leaves from your QCAB, if you find any page missing do not fail to notify 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 : Basic Electronics Engineering + Analog Electronics + Electrical Materials

Q.1 (a) The small signal h-parameter ac equivalent circuit of a certain transistor connected in CE configuration is as shown in figure:



Calculate:

(i) Current gain.

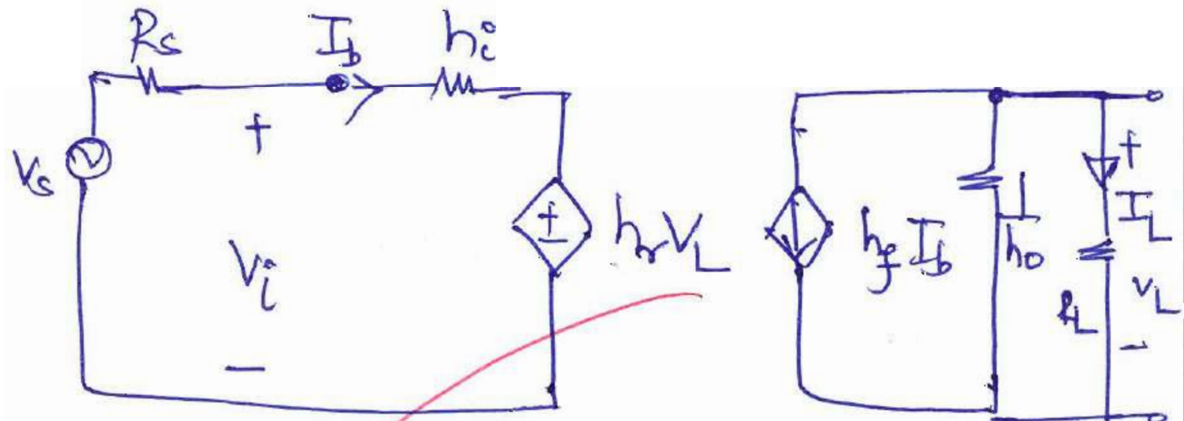
(ii) Voltage gain $\frac{V_L}{V_S}$.

(iii) Input impedance Z_{in}.

(iv) Output impedance Z_{out}.

[12 marks]

Drawing the circuit in Symbol,



① Current gain,

$$\frac{I_L}{I_b} = \frac{-h_f I_b \cdot \frac{\frac{1}{h_o}}{\frac{1}{h_o} + R_L}}{I_b}$$

$$= \frac{-50 I_b \cdot \frac{80}{80+4}}{I_b}$$

$$= -47.619$$

(II) voltage gain :—

$\frac{V_L}{V_S} = $

$V_L = -50 I_b (R_L \parallel \frac{1}{h_o})$

$= -50 I_b (4 \parallel 80)$

$= -190.476 I_b$

Also, $V_s = 2.8 I_b + 3\times10^{-4} V_L$

$\Rightarrow \frac{V_s}{V_L} = 2.8 \frac{I_b}{V_L} + 3\times10^{-4}$

$= 2.8 \left(\frac{-1}{190.476}\right) + 3\times10^{-4}$

$\Rightarrow \frac{V_L}{V_S} = -69.997 \ V/V$

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Good Approach

(I) $Z_{in} = \frac{V_i}{I_b} = \frac{1.8 I_b + 3\times10^{-4} V_L}{I_b}$

$= 1.8 + 3\times10^{-4} \frac{V_L}{I_b}$

$= 1.8 + 3\times10^{-4} \times (-190.476)$

$= 1.7428 \ K\Omega$

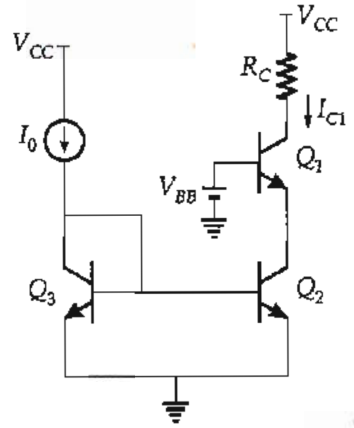
(IV) $Z_{out} = \frac{V_L}{\frac{V_L}{80} + 50 I_b} = \frac{1}{\frac{1}{80} + 50 \frac{I_b}{V_L}}$ — (1)

excluding (4K)

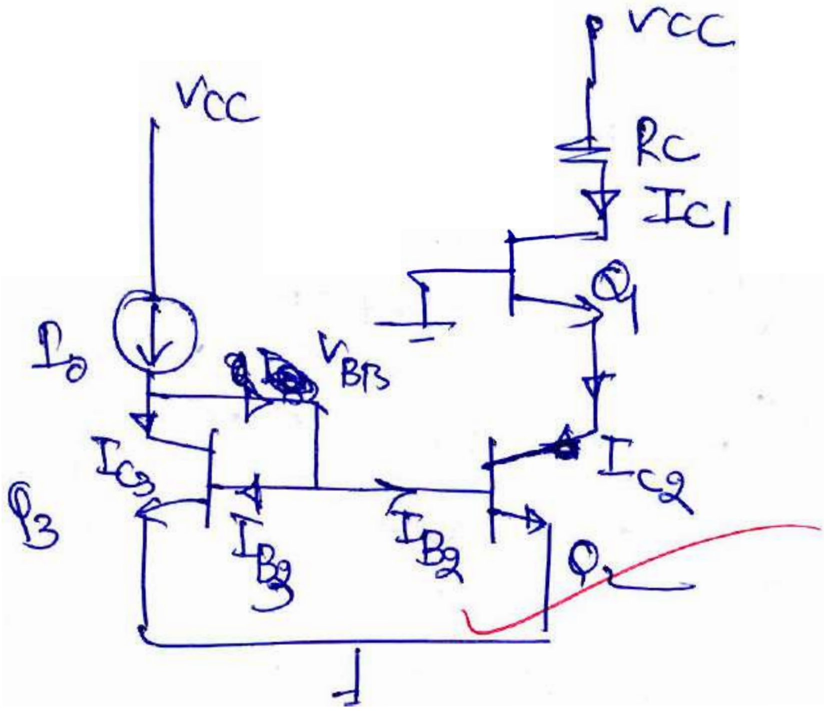
$V_S = 0 \Rightarrow 2.8 I_b + 3\times10^{-4} V_L = 0$ — (2)

using $Z_{out} = 140 \ K\Omega$

Q.1 (b) Determine the stability factor $S'' = \frac{\partial I_{C1}}{\partial \beta}$ for the collector current of Q_1 in figure given below. Assume the current source to be ideal, all transistors to be identical and $I_C = \beta I_B$. Also, $\beta = 100$ and $I_0 = 1$ mA.



[12 marks]



we have,

$$I_0 = I_{C3} + I_{B3} + I_{B2}$$

$$= I_{C3} + 2 I_{B3} \quad [I_{B2} = I_{B3}]$$

$$= (\beta + 2) I_{B3}$$

hence

$$I_{C1} = \beta \, I_{B1}$$

$$= \frac{\beta}{\beta+1} I_{E1}$$

$$= \frac{\beta}{\beta+1} I_{C2}$$

$$= \frac{\beta}{\beta+1} \beta \frac{I_{B2}}{\beta}$$

$$= \frac{\beta^2}{\beta+1} \frac{I_0}{\beta+2}$$

$$= I_0 \left(\frac{\beta^2}{(\beta+1)(\beta+2)} \right) = \left(\frac{\beta^2}{\beta^2 + 3\beta + 2} \right) I_0$$

$$\frac{\partial I_{C1}}{\partial \beta} = I_0 \left(\frac{2\beta(\beta^2 + 3\beta + 2) - \beta^2(2\beta + 3)}{(\beta^2 + 3\beta + 2)^2} \right)$$

$$= 1 \left(\frac{200(100^2 + 300 + 2) - 100^2(200+3)}{(100^2 + 300 + 2)^2} \right)$$

$$= 2.8643 \times 10^{-9} \text{ mA}$$

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Good Approach

Do not write in this margin

Q.1 (c) A copper conductor has a resistance of 17.5 Ω at 0° C. Find its percentage conductivity at 16° C. Assume the temperature coefficient of copper as 0.00428 per °C at 0° C.

[12 marks]

The resistance varies as,

$$R = R_0 (1 + \alpha T)$$

$$= 17.5 (1 + 0.00428T)$$

where α is temperature coefficient of resistance.

At $T = 0°c$, $R_0 = 17.5 \Omega$

~~At~~ $T = 16°c$, $R = 17.5 (1 + 0.00428 \times 16)$

$$= 18.6987 \ \Omega$$

Conductivity is inversely proportional to R.

$$\sigma \propto \frac{1}{R} \Rightarrow \sigma = \frac{K}{R}$$

At $16°c$,

The conductivity is $\frac{K}{R} = \frac{K}{18.6987}$

At $0°c$,

The conductivity is $\frac{K}{R_0} = \frac{K}{17.5}$

The % Conductivity at 16°C is,

$$\% = \frac{\sigma_{16^\circ C}}{\sigma_{0^\circ C}} \times 100$$

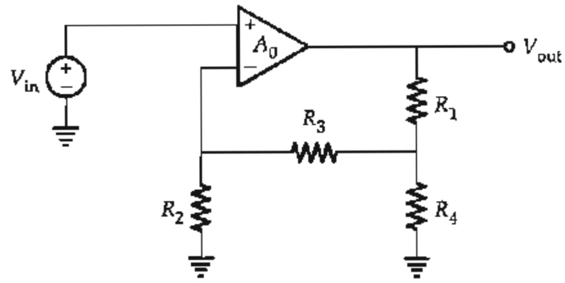
$$= \frac{\frac{K}{18.06984}}{\frac{K}{17.5}} \times 100$$

$$= 93.59\,\%$$

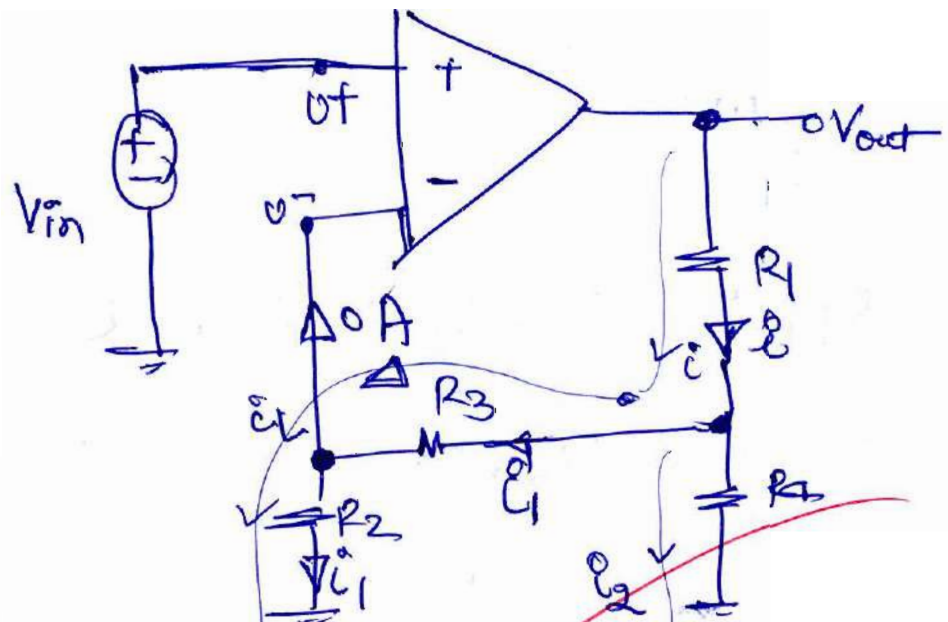
11

Good Approach

Q.1 (d) For a non-inverting amplifier circuit shown below with $A_o = \infty$, calculate the closed loop gain. What happens to the result when $R_1 \to 0$ and $R_3 \to 0$?



[12 marks]



using virtual short,

$$v^+ = v^- = v_{in}$$

$$i = \frac{V_{out}}{R_1 + \frac{(R_2+R_3)R_4}{R_2+R_3+R_4}}$$

using current division rule,

$$i_1 = \frac{V_{out}}{R_1 + \frac{(R_2+R_3)R_4}{R_2+R_3+R_4}} \cdot \frac{R_4}{R_2+R_3+R_4}$$

$$i_1 = \frac{V_{out} \cdot R_4}{R_1(R_2+R_3+R_4)+(R_2+R_3)R_4}$$

Thus closed loop gain,

$$A_c = \frac{V_{out}}{V_i}$$

$$= \frac{V_{out}}{i_1 R_2}$$

$$= \frac{R_1(R_2+R_3+R_4)+(R_2+R_3)R_4}{R_2 R_4}$$

As $R_1 \to 0$ and $R_3 \to 0$

$$A_c = \frac{R_2 R_4}{R_2 R_4} = 1$$

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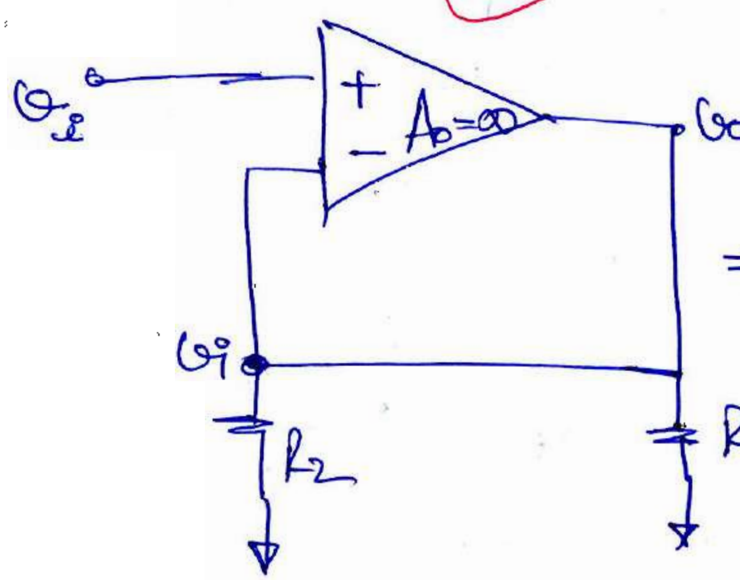
From the circuit



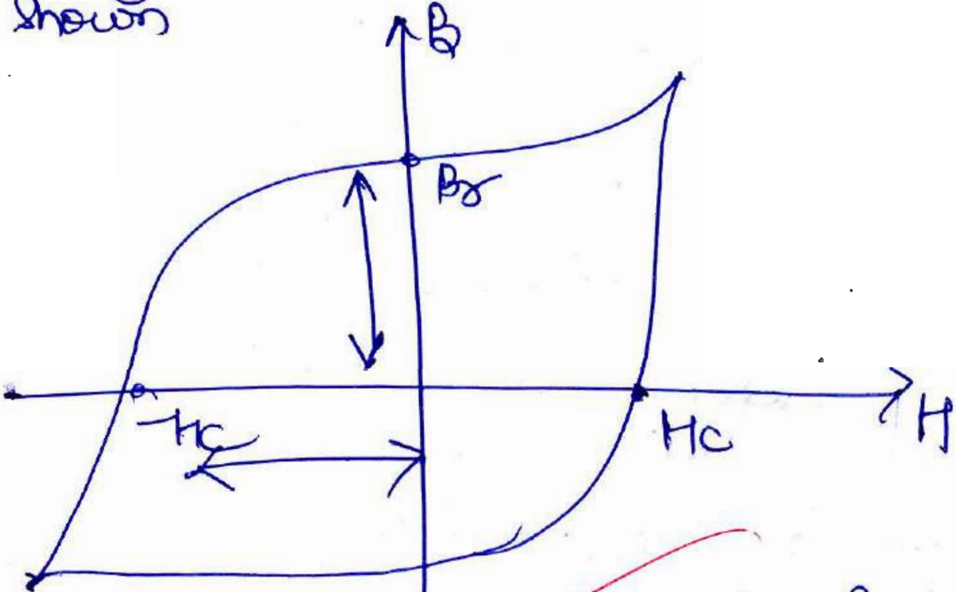
$V_o = V_i$

$$\Rightarrow \frac{V_o}{V_i} = 1$$

Q.1 (e) Explain how ferrimagnetic materials are special class of ferromagnetic materials. Give electric and magnetic characteristics of ferrites.

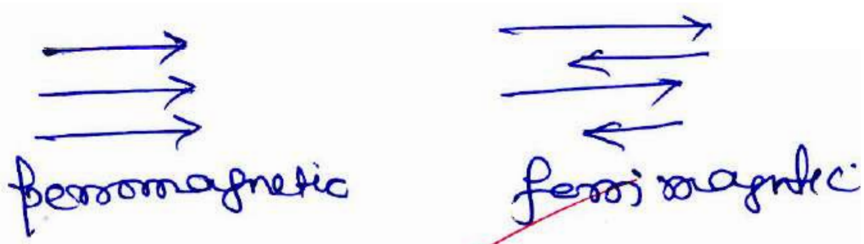
[12 marks]

Ferrimagnetic has hysteris loop as shown



It has very wide hysteris loop and even rectangular (in some case) that permits them to have higher permeability. The high frequency application of ferrimagnetic is due to its enhanced electrical resistivity.

The ferrimagnetec material has net moment which are opposite to each other but does not cancel each other



Electric properties

(a) High resistivity
(b) High dielectric strength
(c) Lower loss tangent.

Magnetic properties.

(a) wide hysteresis loop.
(b) reduced eddy current loss.
(c) High frequency application.

Example :- Ni – Zn ferrite
Mg – Mn ferrite

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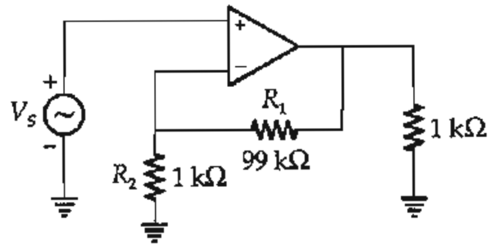
Q.2 (a) (i) For a specimen of $V_3\,Ga$, the critical fields are respectively 0.176 T and 0.528 T for 14 K and 13 K respectively. Calculate the transition temperatures and critical field at 0 K and 4.2 K.

[10 marks]

Do not write in this margin

Q.2 (a) (ii) An op-amp has gain, $A = 100000$, $Z_{in} = 1\ M\Omega$ and $Z_{out} = 300\ \Omega$. Calculate A_f, $Z_{in\,f}$ and $Z_{out\,f}$ for the circuit shown in figure. What happen to these parameters if $R_1 = 0$ and $R_2 = \infty$?



[10 marks]

Q.2 (b) (i) Explain the Silsbee's rule briefly. How is it related to critical magnetic field? Determine the amount of current a lead wire of 1 mm in diameter can carry in super conducting state at 4.2 K. [Given, $B_C(4.2\text{ K}) = 0.0548$ T]

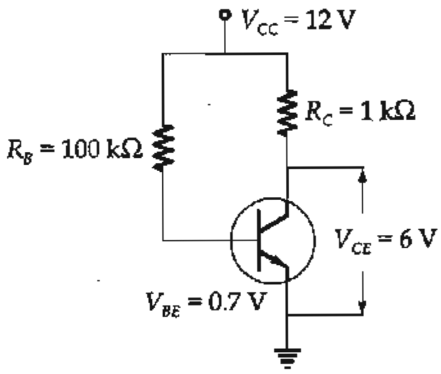
(ii) A material behaves as a superconductor at a temperature of $T_C = 7.26$ K. If the value of the critical magnetic field of material at $T = 0$ K is 7×10^5 A/m then calculate the critical magnetic field of the material at 4 K.

[12 + 8 marks]

Q.2 (c) (i) Derive the expression for the stability factor $S = \dfrac{\Delta I_C}{\Delta I_{CBO}}$ of a fixed bias circuit.

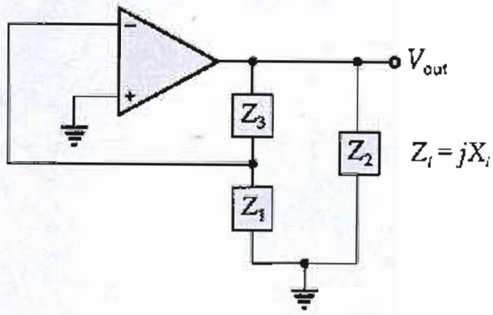
[10 marks]

Q.2 (c) (ii) Calculate the stability factor S for the circuit shown in figure,



[10 marks]

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

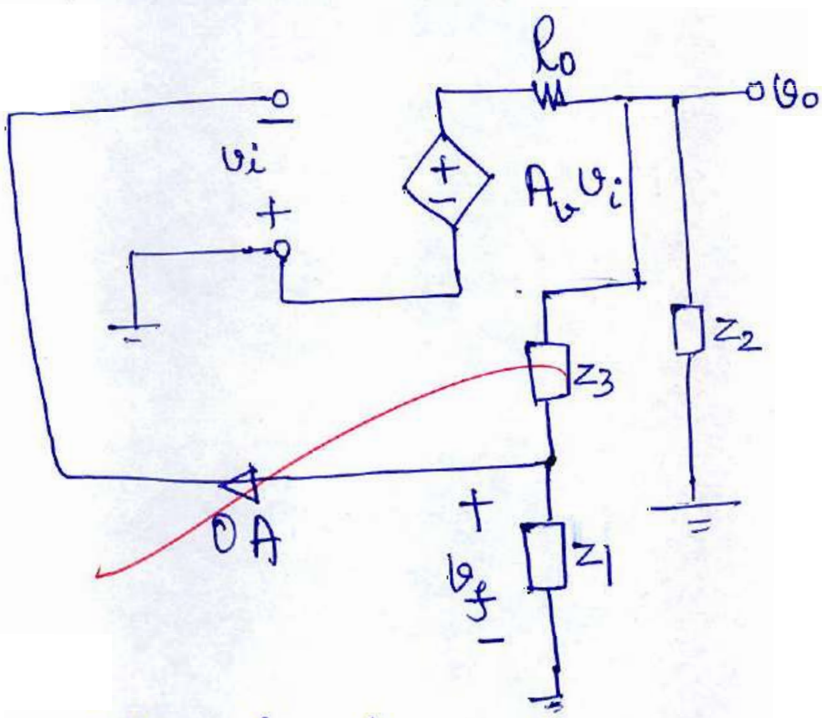


The op-amp in the circuit has a finite open loop gain (A_v), finite output resistance ($R_0 > 0$) and it is ideal in all other aspects. Z_1, Z_2 and Z_3 are purely reactive elements with magnitudes $|X_1|$, $|X_2|$ and $|X_3|$.

Prove that X_1 and X_2 must be of the same type of reactance (i.e., both must be either capacitive or inductive) to produce sustained oscillations.

[20 marks]

The equivalent circuit is,



The amplifier gain is,

$$A = \frac{v_o}{v_i} = \frac{A_v \cdot \dfrac{Z_2(Z_1+Z_3)}{Z_2+Z_1+Z_3}}{R_o + \dfrac{Z_2(Z_1+Z_3)}{Z_2+Z_1+Z_3}}$$

$$= A_v \frac{Z_2(Z_1+Z_3)}{R_o(Z_1+Z_2+Z_3)+Z_L(Z_1+Z_3)}$$

The feedback factor is.

$$\beta = \frac{v_f}{v_o}$$

$$= \frac{Z_1}{Z_1+Z_2}$$

The open loop gain,

$$A\beta = A_v \frac{Z_2(Z_1+Z_3)}{R_o(Z_1+Z_2+Z_3)+Z_L(Z_1+Z_3)} \cdot \frac{Z_1}{Z_1+Z_2}$$

$$= A_v \frac{Z_2}{R_o\left(1+\frac{Z_2}{Z_1+Z_3}\right)+Z_L} \cdot \frac{Z_1}{Z_1+Z_2}$$

Let us assume

$$Z_i = jX_i$$

$$A\beta = A_v \frac{jX_2}{R_o\left(1+\frac{X_2}{X_1+X_3}\right)+jX_L} \cdot \frac{X_1}{X_1+X_2}$$

$$= A_v \frac{1}{R_o\left(-j \pm \frac{jX_2}{X_1+X_3}\right)+X_L} \cdot \frac{X_1X_2}{X_1+X_2}$$

According to Bar Kausen criterion for oscillation

$\angle A\beta = 0^\circ$ or 360°

$\Rightarrow R_0\left(-j - \dfrac{jX_2}{X_1+X_3}\right) = 0$

$\Rightarrow \cancel{0} - 1 - \dfrac{X_2}{X_1+X_3} = 0$

$\Rightarrow X_1 + X_2 + X_3 = 0$ — (i)

under such condition,

$A\beta = A_v \cdot \dfrac{1}{X_2} \cdot \dfrac{X_1 X_2}{X_1+X_2} = \dfrac{A_v X_1}{X_1+X_2}$

But $A\beta = 1$

$\dfrac{A_v X_1}{X_1+X_2} = 1$

$A_v X_1 = X_1 + X_2$

$\Rightarrow A_v = 1 + \dfrac{X_2}{X_1}$

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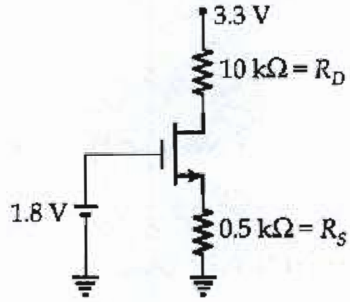
Since $A_v >> 1$ thus X_2 and X_1 must have same sign. (say inductive)

to satisfy (i), X_3 must be of negative sign. (say capacitive).

Do not write in this margin

Q.3 (b) (i) The transistor shown in the figure below has $V_T = 1$ V, and $\mu_n C_{ox}\left(\frac{W}{L}\right) = 2\ \text{mA/V}^2$.

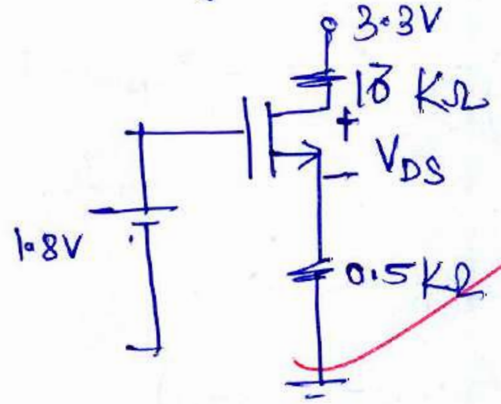
Determine the drain voltage.



(ii) Define transconductance, dynamic drain resistance and amplification factor of JFET.

[14 + 6 marks]

(i) Assuming the transistor to be in saturation,



$\Rightarrow \frac{1}{2}\mu_n C_{ox}\frac{W}{L}\left(V_{GS}-V_T\right)^2 = \frac{1.8-V_{GS}}{0.5}$

$\Rightarrow \left(V_{GS}-1\right)^2 = \frac{1.8-V_{GS}}{0.5}$

$\Rightarrow V_{GS}^2 - 2.6 = 0 \Rightarrow V_{GS} = \sqrt{2.6}$
$= 1.6124$ V

Let us check for saturation :-

$V_{DS} \geq V_{GS} - V_T$

$\Rightarrow 3.3 - (10+0.5)\, I_D \geq 1.6124 - 1$

$$\Rightarrow \quad 3.3 - 10.5 \times \left(\frac{1.8 - 1.6127}{0.5}\right) \geq 0.6127$$

$$\Rightarrow \quad -0.6396 \geq 0.6127$$

(which is false)

Assuming the transistor in triode region,

$$\mu_n C_{ox} \frac{W}{L}\left[(V_{GS}-V_T)V_{DS} - \frac{V_{DS}^2}{2}\right] = \frac{1.8 - V_{GS}}{0.5}$$

$$\Rightarrow 2\left((V_{GS}-1)\,V_{DS} - \frac{V_{DS}^2}{2}\right) = 3.6 - 2V_{GS} \quad \text{—} (1)$$

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Also,

$$V_{DS} = 3.3 - 10.5\,I_D$$

$$V_{DS} = 3.3 - 10.5\left(3.6 - 2V_{GS}\right)$$

$$= -34.5 + 21\,V_{GS} \quad \text{———} (2)$$

Putting in eq (i)

$$2\left[(V_{GS}-1)(-34.5+21V_{GS}) - \frac{(-34.5+21V_{GS})^2}{2}\right] = 3.6 - 2V_{GS}$$

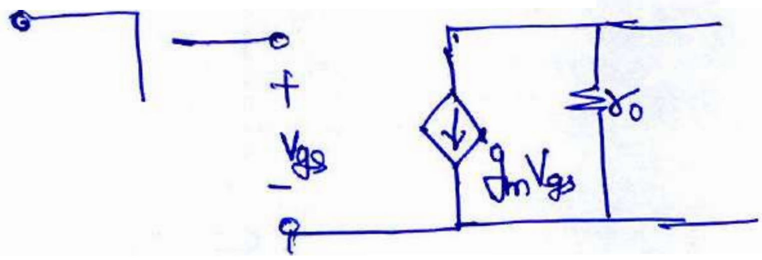
$$\Rightarrow \quad V_{GS} = 1.656\,V \Longrightarrow \cancel{V_{DS} = 0.276V}$$

Drain voltage

$$\Rightarrow V_D = 3.3 - 10\left[\frac{1.8-1.656}{0.5}\right] = \cancel{0.42\,V}$$

~~(triode region)~~

(ii). Consider the ac model of JFET



Transconductance :- It is the rate of change of drain current wrt gate to source voltage.

$$g_m = \frac{\partial I_D}{\partial V_{GS}}$$

Dynamic drain resistance — The rate of change of V_{DS} wrt I_D.

$$r_d = \frac{\partial V_{DS}}{\partial I_D}$$

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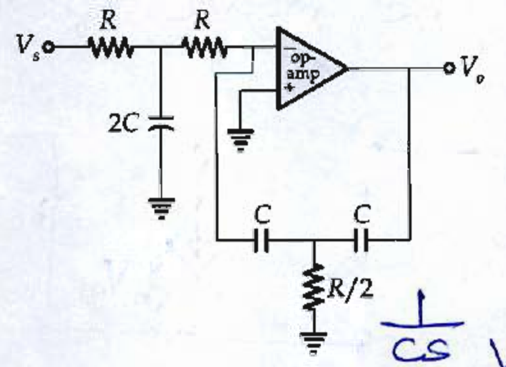
Amplification factor —

It is the ratio of incremental output voltage (ΔV_{DS}) to incremental gate-source voltage (ΔV_{GS})

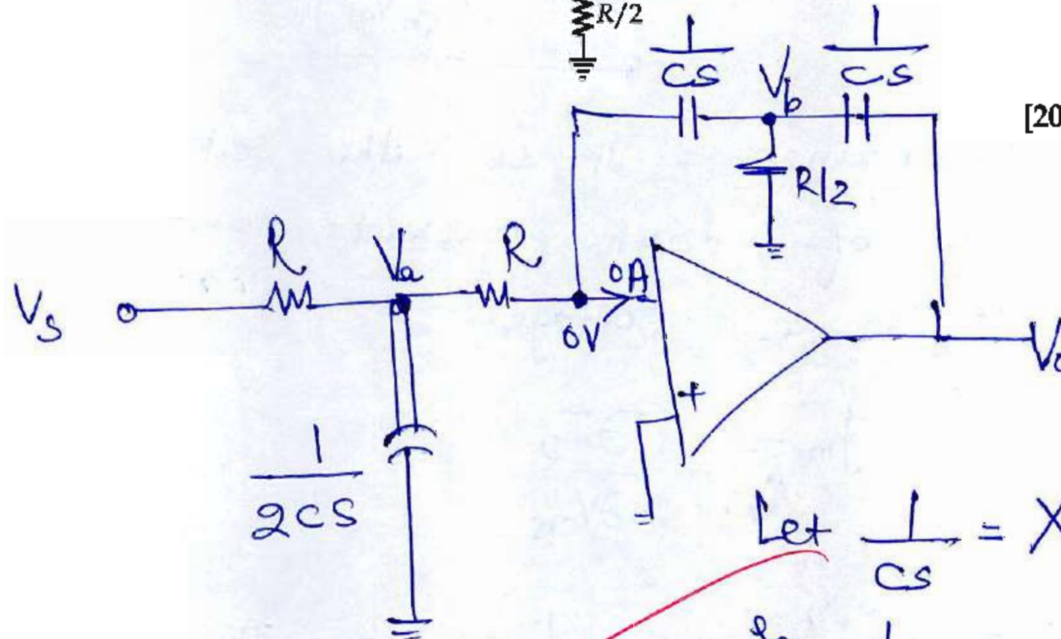
$$A_o = \frac{\partial V_{DS}}{\partial V_{GS}} = \frac{\partial I_D}{\partial V_{GS}} \cdot \frac{\partial V_{DS}}{\partial I_D}$$

$$\Rightarrow A_v = g_m R_D$$

Q.3 (c) Prove that the circuit shown in figure is a double integrator. Assume that the op-amp is ideal.



[20 marks]



Let $\frac{1}{Cs} = X$

So 1

Assuming ideal opamp,

KCL at node V_a,

$$\frac{V_a - V_s}{R} + 2Cs\,V_a + \frac{V_a}{R} = 0$$

$$\Rightarrow V_a\left[\frac{2}{R} + 2CS\right] = \frac{V_s}{R}$$

$$\Rightarrow \frac{V_a}{V_s} = \frac{1}{2(1+RCS)} \quad \text{—(1)}$$

Appyeng KCL at node b:—

$$V_b\left(2CS + \frac{2}{R}\right) = V_0 CS$$

$$\Rightarrow \frac{V_0}{V_b} = \frac{2(1+RCS)}{RCS} \quad \text{—— (2)}$$

Due to enverteng design,

$$\frac{V_b}{V_a} = -\frac{1}{RCS} \quad \text{—— (3)}$$

Thus

$$\frac{V_0}{V_s} = \frac{V_0}{V_b} \times \frac{V_b}{V_a} \times \frac{V_a}{V_s}$$

$$= \frac{2(1+RCS)}{RCS} \cdot \frac{-1}{RCS} \cdot \frac{1}{2(1+RCS)}$$

$$\frac{V_0}{V_s} = -\frac{1}{(RCS)^2}$$

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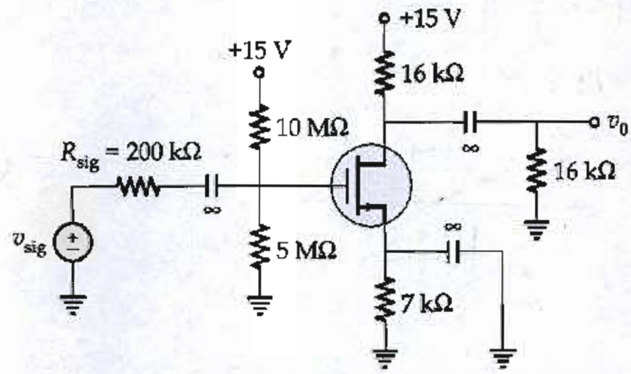
taking enverse Laplace,

$$v_0(t) = -\int_{-\infty}^{t}\frac{1}{RC}\int_{-\infty}^{t'}\frac{1}{RC}\, v_s(t)\, dt$$

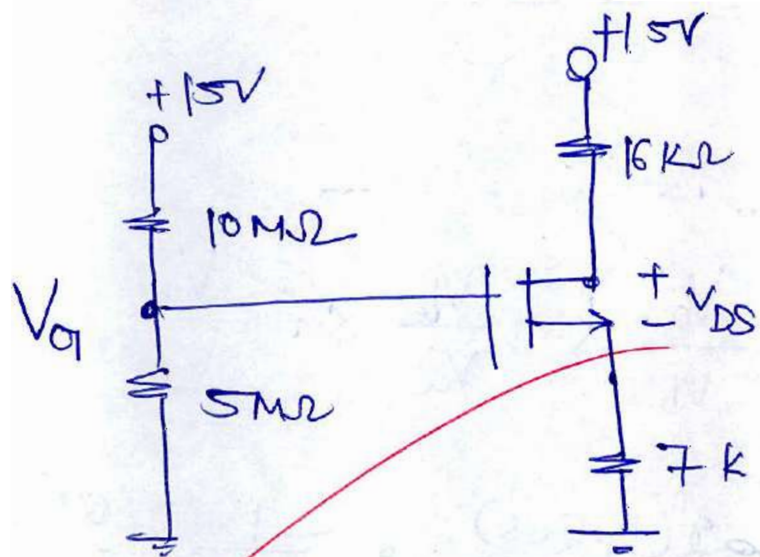
Thus it is an double integrator.

Q.4 (a) In the MOSFET amplifier shown below, the ac source signal is v_{sig} and the output ac voltage is v_o. Verify that the MOSFET is operating in saturation mode if $V_T = 1$ V and $\mu_n C_{ox}\left(\frac{W}{L}\right) = 4\ \text{mA/V}^2$ and $V_A = 100$ V. Determine the voltage gain $A_V = \frac{v_0}{v_{sig}}$.



[20 marks]

Dc analysis :—



$V_G = 5$ V (using voltage division)

using current equation, (for saturation)

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

$\Rightarrow 2 (V_{GS} - 1)^2 = \frac{V_G - V_{GS}}{7}$

$\Rightarrow 2 (V_{GS} - 1)^2 = \frac{5 - V_{GS}}{7}$

which yields, $V_{GS} = 1.5$ Volt

Thus for saturation,

$$V_{DS} \geq V_{GS} - V_T$$

$$\Rightarrow 15 - (16+7)\, I_D \geq 1.5 - 1$$

$$\Rightarrow 15 - 23 \times \left(\frac{5-1.5}{7}\right) \geq 0.5$$

$$\Rightarrow 3.5 \geq 0.5 \quad [\text{holds true}]$$

→ Small-signal parameters :-

$$g_m = \mu_n C_{ox} \frac{W}{L} (V_{GS} - V_T)$$

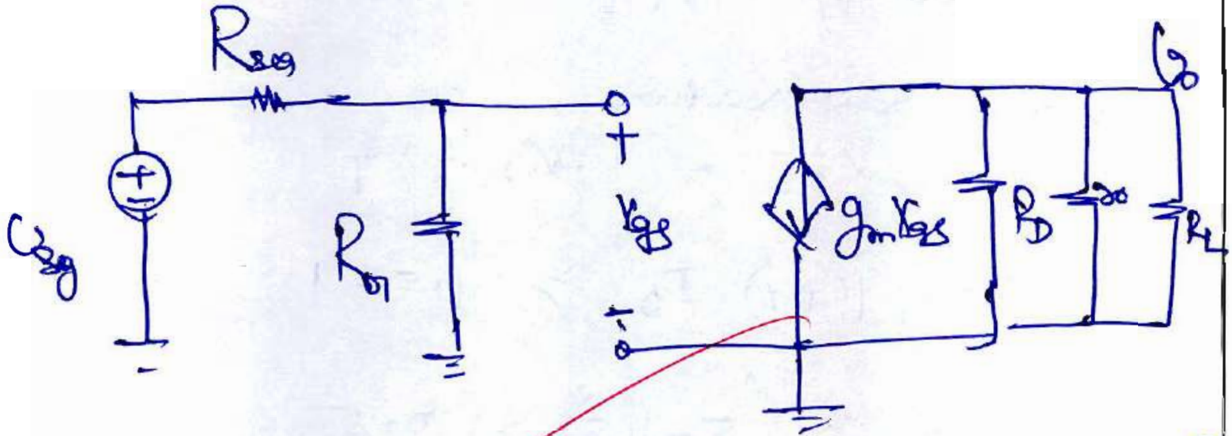
$$= 4 \times (1.5 - 1) = 2 \frac{mA}{V}$$

$$r_o = \frac{V_A}{I_D} = \frac{100}{0.5} = 200 \text{ K}\Omega$$

$[I_D = 0.5 \text{ mA}]$

To find $A_v = \frac{v_o}{v_{sig}}$ we have

the small-signal equivalent circuit,



$$v_o = -g_m V_{gs} R_L' \qquad \left[\frac{1}{R_L'} = \frac{1}{R_L} + \frac{1}{R_D} + \frac{1}{r_o}\right]$$

$$= \frac{1}{16} + \frac{1}{16} + \frac{1}{200}$$

$$\frac{v_{gs}}{v_{sig}} = \frac{R_G}{R_{sig} + R_G}$$

$$R_L' = \frac{100}{13}\ k\Omega$$

$$R_G = 5M \parallel 10M = \frac{10}{3}\ M\Omega$$

Thus,

$$\frac{v_o}{v_{sig}} = \frac{v_o}{v_{gs}} \times \frac{v_{gs}}{v_{sig}}$$

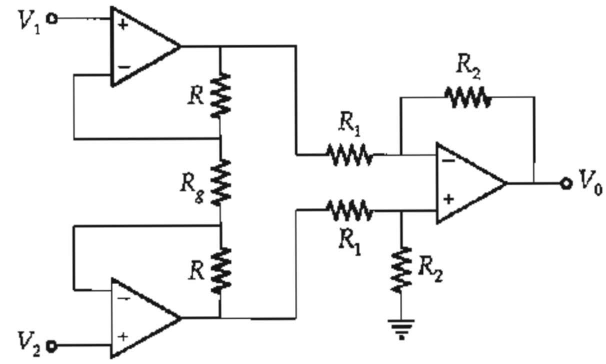
$$= \frac{R_G}{R_{sig}+R_G} \times -g_m R_L'$$

$$= \frac{\frac{10000}{3}}{200 + \frac{10,000}{3}} \times -2 \times \frac{100}{13}$$

$$= -14.51\ V/V$$

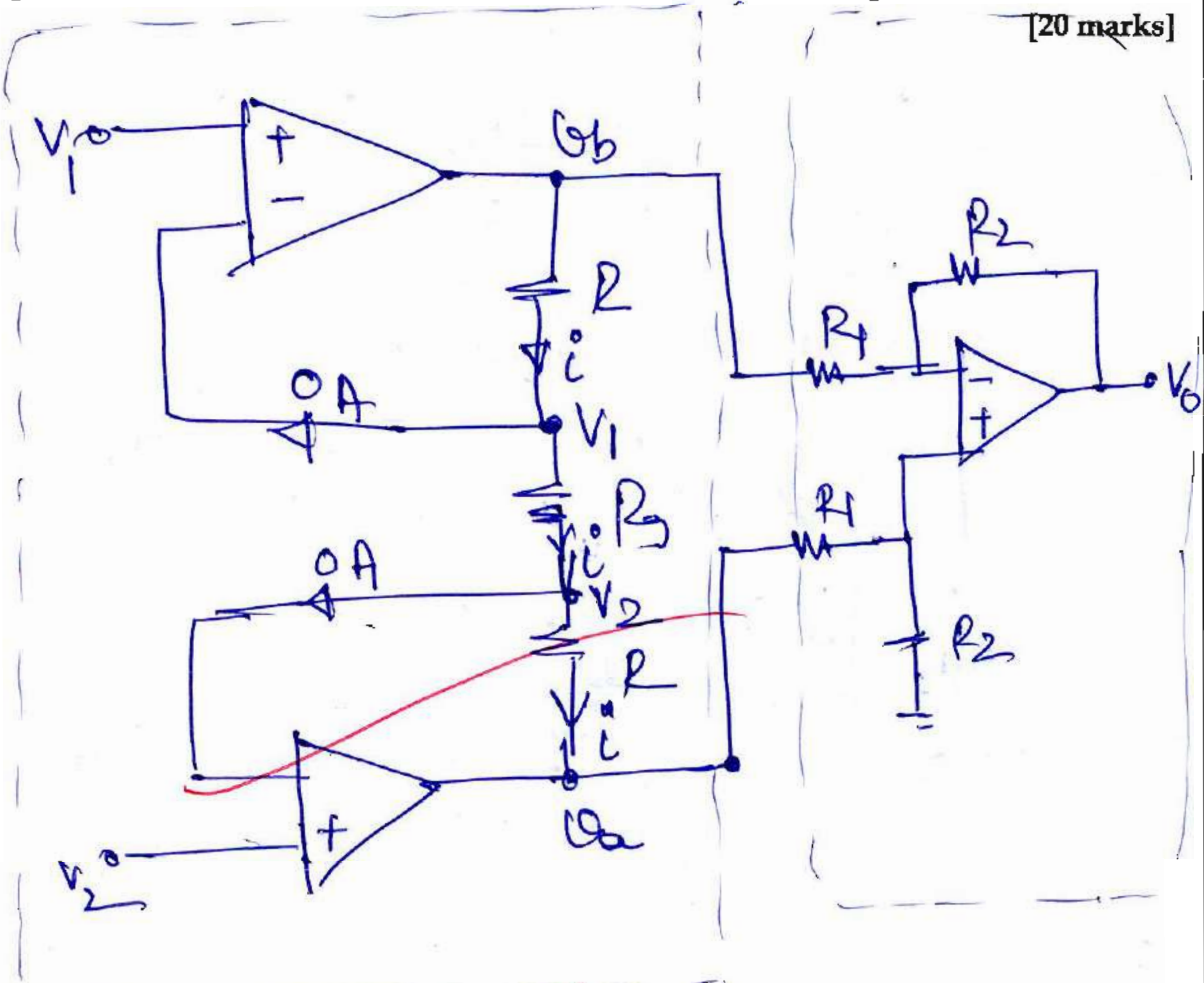
18

Q.4(b) The circuit shown below is made by three identical operational amplifiers.



If $V_1 = 5$ V, $V_2 = 5.05$ V and $V_0 = 5$ V, then find the ratio of R/R_g and R_2/R_1 when overall gain is divided in the ratio of 10 : 1 between first and second stage of circuit.

[20 marks]



For the difference amplifier stage-1,

$$(v_b - v_a) = (R + R_g + R)\, i$$

$$= (R + R_g + R)\left(\frac{V_1 - V_2}{R_g}\right)$$

$$= \left(1+2\frac{R}{R_g}\right)\left(v_1 - v_2\right)$$

The second-stage is also an ideal difference amplifier,

So $v_o = \frac{R_2}{R_1}\left(v_a - v_b\right)$

$$= \underbrace{\frac{R_2}{R_1}}_{\text{second-stage}} \underbrace{\left(1+\frac{2R}{R_g}\right)}_{\text{first stage}} \left(V_2 - V_1\right)$$

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Overall gain $= \frac{V_o}{V_2 - V_1} = \frac{5}{5.05-5} = 100$

$$\left[G_{stg1}\right]\left[G_{stg2}\right] = 100$$

$$\Rightarrow (G_1)\left(\frac{G_1}{10}\right) = 100 \Rightarrow \begin{cases} G_1 = \sqrt{1000} \\ G_2 = \sqrt{10} \end{cases}$$

Thus,

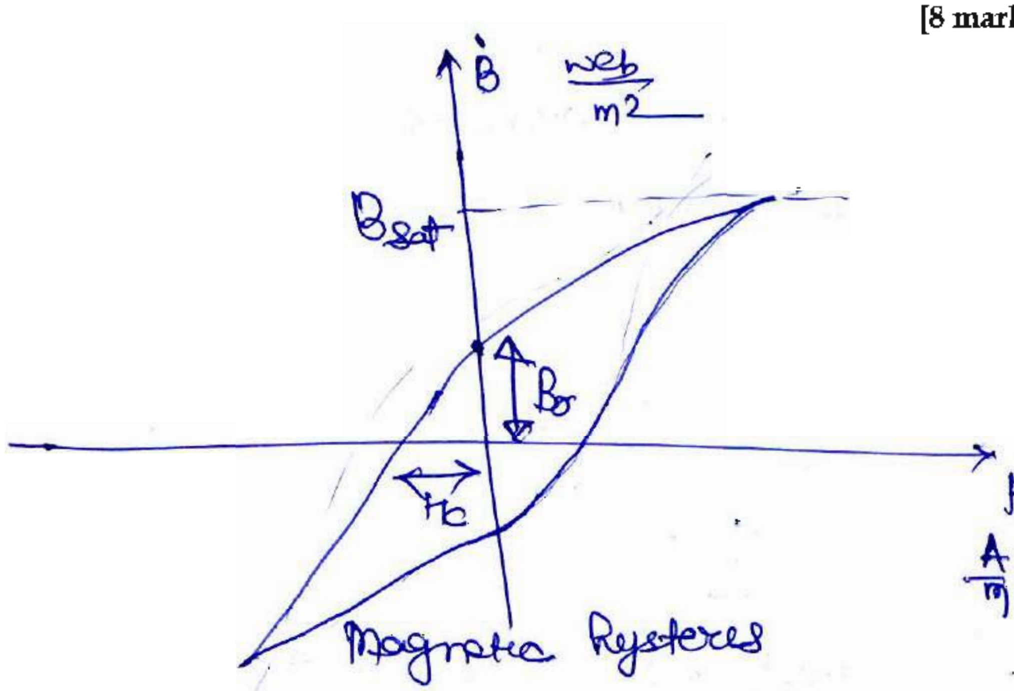
$$1 + \frac{2R}{R_g} = G_1 \Rightarrow \frac{R}{R_g} = \frac{G_1 - 1}{2} = \frac{\sqrt{1000}-1}{2} = 15.31$$

and,

$$\frac{R_2}{R_1} = G_2 \Rightarrow \frac{R_2}{R_1} = \sqrt{10}$$

Q.4 (c) (i) What are soft magnetic materials? What are the characteristic of soft magnetic materials? Explain with the help of example and their applications.

[8 marks]



Magnetic Hysteresis

Soft magnetic materials can be magnetized and demagnetized easily due to applied field.

characteristics :—

(a) Have low retentivity (Br).

(b) Needs low Coercive force. (Hc).

(c) Have high permeability and taller and narrower hysteresis loop.

(d) low hysteresis loss.

(e) High saturation magnetization.

Example :— Permalloy, Soft-Fe etc.

Applications :—

These find application low frequency transformer and inductor core.

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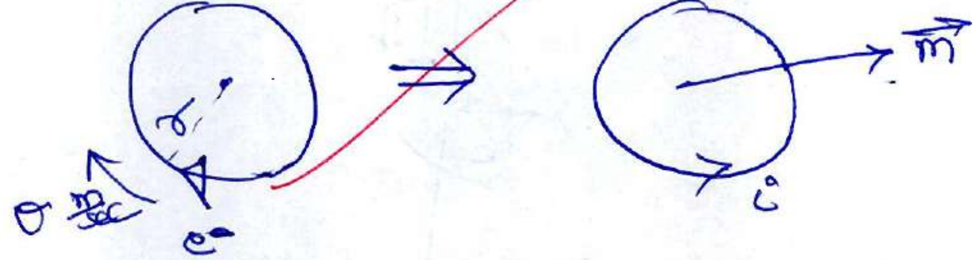
Q.4 (c) (ii) What is the significance of 'Magnetic dipole' and 'Magnetization' phenomena in magnetic materials? Explain clearly with the help of definition and mathematical derivation. How are above two phenomena related to each other?

[12 marks]

Origin of magnetic dipole lies in rotating electron inside an atom.



As viewed is a current circulating in a wire of area πr^2.

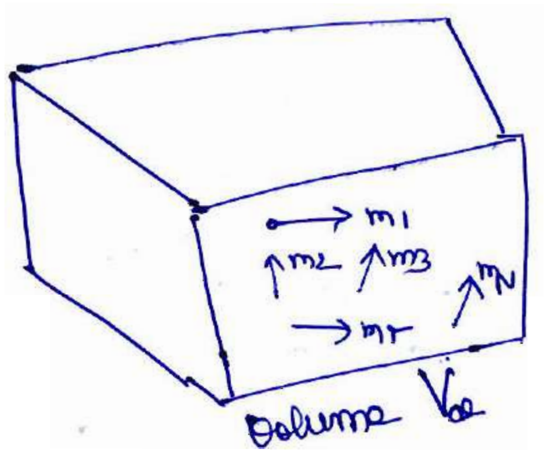
We define magnetic moment as

$$\vec{m} = i \pi r^2 \hat{a_z}.$$

Inside a material every atom have some magnetic moment. On the bulk level we define magnetization $\vec{M}$, which is total magnetic moment per unit volume.

Or, $$\vec{M} = \frac{\sum_{n=i}^{N} m_i}{V} = N m$$

Where N is ~~[illegible]~~ no of magnetic moments per unit volume.



Magnetic moment is added vectorily to get total magnetic moment.

$$\vec{M}_{tot} = \sum_{i=1}^{N} \vec{m_i}$$

Let N is the no of magnetic moment per unit volume, then magnetisation is

$$\vec{M} = \frac{\text{Total magnetic moment}}{\text{Total volume}}$$

$$= \frac{\sum_{i=1}^{N} \vec{m_i}}{V_{ol}}$$

$$= \frac{N\vec{m}}{V_{ol}} \qquad \left[\text{Let } \vec{m_1} = \vec{m_2} = \cdots \vec{m}\right]$$

$$= n\vec{m}$$

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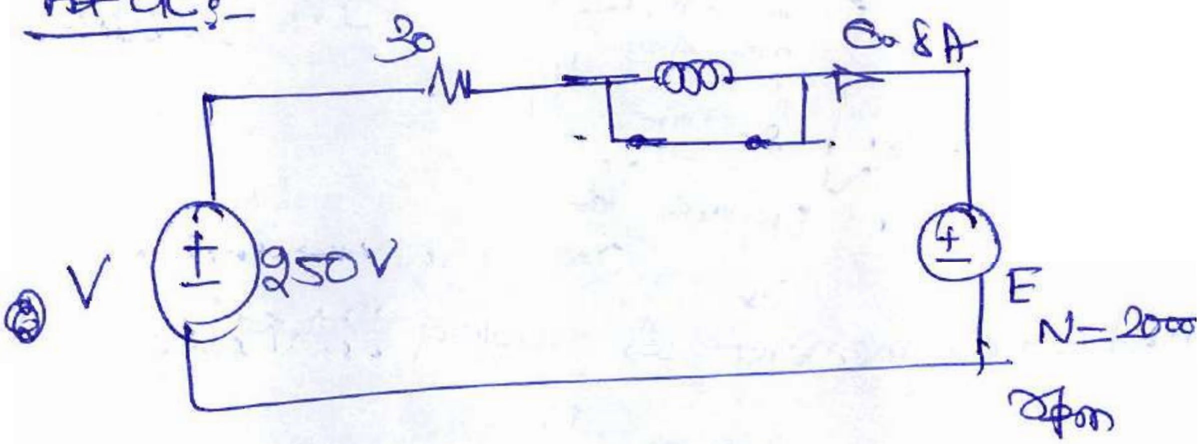
Section B : Electrical Machine-1 + Power Systems-2

Q.5 (a) A universal series motor has a resistance of 30 Ω and an inductance of 0.5 H. When connected to a 250 V dc supply and loaded to take 0.8 A it runs at 2000 rpm. Calculate the speed, torque and power factor, when connected to a 250 V, 50 Hz ac supply and loaded to take the same current.

[12 marks]

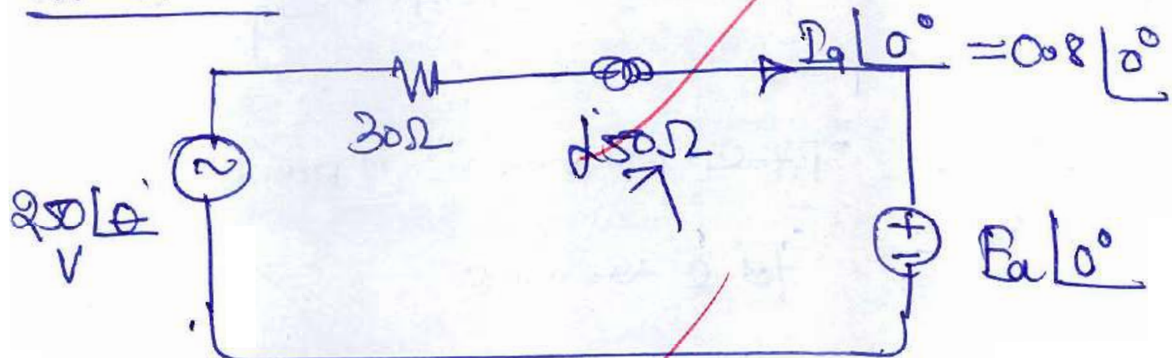
At dc:-



The motor constant is,

$$K = \frac{V - 30I}{N} = \frac{250 - 30 \times 0.8}{2000} = \frac{113}{1000} \frac{V}{rpm}$$

At AC:-



Since I_a and E_a are in phase

$$250 \angle 0 = (30 + j50) \times 0.8 + E_a \angle 0^\circ$$

$$\Rightarrow 250^2 = (E_a + 24)^2 + (40)^2$$

$E_a = \cancel{222.78}$ Volt
192.12

Thus speed $= \dfrac{222.78}{(113/1000)} = \cancel{1971.49\ rpm}$
1700.2 rpm

The angle θ is,

$V\angle\theta = (30 + j50) \times 0.8 \angle 0^\circ + \cancel{222.78}\angle 0^\circ$
192.12

$= 250 \angle 30.176^\circ$

Power factor $= \cos 30.176^\circ$ lag
$= 0.8644$ lag

Torque $= K_a \phi I_a$

$= \dfrac{K_a \phi \omega I_a}{\omega}$

$= \dfrac{E_a I_a}{\omega}$

$= \dfrac{192.12 \times 0.8}{\left(\dfrac{1700.2}{60} \times 2\pi\right)}$

$= 0.8635$ Nm

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Q.5 (b) Explain DC transmission advantage over AC transmission.

[12 marks]

DC transmission is advantageous to AC transmission over certain things

(i) For long distance high power transmission DC is more economical than AC.

(ii) Power carrying conductor of DC conductor is longer than that of AC.

eg:– Bipolar DC can carry as much power as 3 ϕ - single circuit line.

(III) Skin effect is not present in DC transmission.

(IV) Charging current is less

(V) Radio interference and corona is less.

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(vi) Less ~~Risht~~ of way required

(vii)

8

Elaborate it more

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Q.5 (c) A single phase transformer has voltage regulation of 6% and 6.6% for lagging power factor of 0.8 and 0.6 respectively. Full load ohmic losses is equal to iron loss. Calculate the lagging power factor at which full load voltage regulation is maximum and the full load efficiency at unity power factor.

[12 marks]

using the formula

$$\epsilon = R_{pu}\cos\phi \pm X_{pu}\sin\phi$$

we have

6% at 0.8 (lagging)

$$6 = 0.8R + 0.6X \quad \text{— (1)}$$

6.6% at 0.6 (lag)

$$6.6 = 0.6R + 0.8X \quad \text{— (2)}$$

Solving (1) and (2)

$R = 3\%$

$X = 6\%$

Maximum voltage regulation :—

$$\epsilon = 3\cos\phi + 6\sin\phi$$

(diff.)

$$\frac{d\epsilon}{d\phi} = -3\sin\phi + 6\cos\phi$$

$\Rightarrow 0 = -3\sin\phi + 6\cos\phi$

$\Rightarrow \tan\phi = 2$

$\phi = 63.43^\circ$ (lagging)

pf = $\cos\phi = 0.4472$ (lagging)

Full load efficiency :—

$$\eta = \frac{x S\cos\phi}{x S\cos\phi + P_i + x^2 P_{cu,fl}}$$

At full load, $x = 1$

At upf, $\cos\phi = 1$

$P_i = P_{cu\text{-}fl}$ (given)

we know, $P_{i(pu)} = R_{(pu)} = 0.03$

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Good Approach

Thus efficiency,

$$\eta = \frac{1\times1\times1}{1\times1\times1 + 0.03 + 1^2\times0.03}$$

$= 94.339\ \%$

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Q.5 (d) A transformer has its maximum efficiency 0.98 at 20 kVA at unity power factor. During the day it is loaded as follows:

12 hours : 2 kW at power factor 0.6

6 hours : 10 kW at power factor 0.8

6 hours : 20 kW at power factor 0.9

Find the 'all-day' efficiency of the transformer.

[12 marks]

Total KWhr for day is :-

$12\text{ hr} \rightarrow 12 \times 2 = 24$

$6\text{ hr} \rightarrow 6 \times 10 = 60$

$6\text{ hr} \rightarrow 6 \times 20 = 120$

$P_o = 204\text{ kWh}$

Iron loss of machine is,

$$\eta_{max} = \frac{xS\cos\phi}{xS\cos\phi + 2P_c}$$

$$\Rightarrow 0.98 = \frac{1 \times 20 \times 1}{1 \times 20 \times 1 + 2P_c} \qquad [\text{let } x = 1]$$

$P_c = 0.2041\text{ kW}$

Total iron loss $P_{iron} = 24 \times 0.2041$

$= 4.898\text{ kWh}$

Total copper loss in one day

time	$S_{machine}$	S_{rated}	x
12 hrs	$\frac{2}{0.6} = 10/3$ kVA	20 kVA	$\frac{S_{machine}}{S_{rated}}$
6 hrs	$\frac{10}{0.8} = 12.5$ kVA	20 kVA	
6 hrs	$\frac{20}{0.9} = \frac{200}{9}$ kVA	20 kVA	

Total copper loss =

$P_{cu} = \sum x^2 \, P_{cu,fl}$ +

$$= \left[\left(\frac{10/3}{20}\right)^2 \times 12 + \left(\frac{12.5}{20}\right)^2 \times 6 + \left(\frac{200/9}{20}\right)^2 \times 6\right] \times 0.244$$

$= 2.058$ kWh

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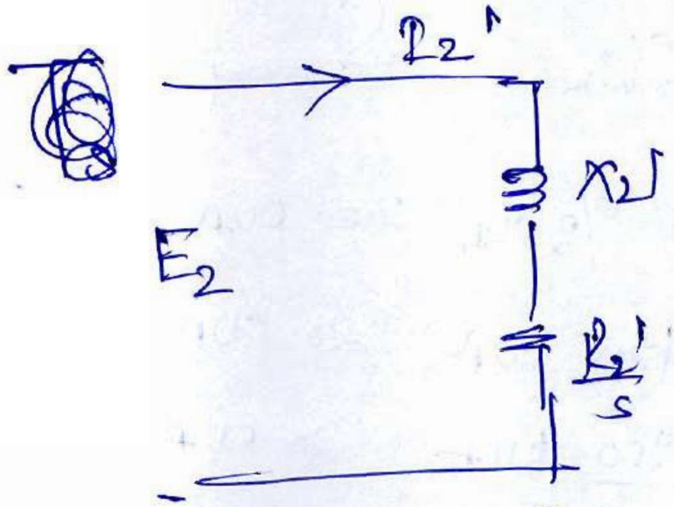
$$\eta_{all\text{-}day} = \frac{209}{209 + 4.898 + 2.058}$$

$= 96.702\%$

Q.5 (e) A 4-pole, 3-phase, 400 V, 50 Hz induction motor develops 1.6 times its full-load torque at stating. The ratio of maximum torque to full-load torque is 2 . Calculate the speed of the motor when it is developing maximum torque. Also, calculate its full-load speed.

[12 marks]



$$T = \frac{3}{\omega_s} \cdot \frac{E_2^2}{\left(\frac{R_2'}{s}\right)^2 + X_2'^2} \cdot \frac{R_2'}{s}$$

$$T_{st} = \frac{3}{\omega_s} \frac{E_2^2 \cdot R_2'}{R_2'^2 + X_2'^2}$$

$$T_{max} = \frac{3}{2\omega_s} \frac{E_2^2}{X_2'}$$

3

$$\frac{T_e}{T_{max}} = \frac{R_2}{s} \frac{X_2'}{\left(\frac{R_2'}{s}\right)^2 + X_2'^2}$$

$$= \frac{2}{\frac{s}{s_{max}} + \frac{s_{max}}{s}}$$

$$\left[s_{max} = \frac{R_2'}{X_2'} \right]$$

Given,

$$\frac{T_{st}}{T_{fl}} = 1.6 \text{ and } \frac{T_{max}}{T_{fl}} = 2$$

$$\frac{T_{max}}{T_{st}} = \frac{2}{1.6} = \frac{2}{\frac{1}{S_{max}} + \frac{S_{max}}{1}}$$

$$\Rightarrow S_{max} + \frac{1}{S_{max}} = 1.6$$

$$\Rightarrow S_{max} =$$

In complete solution

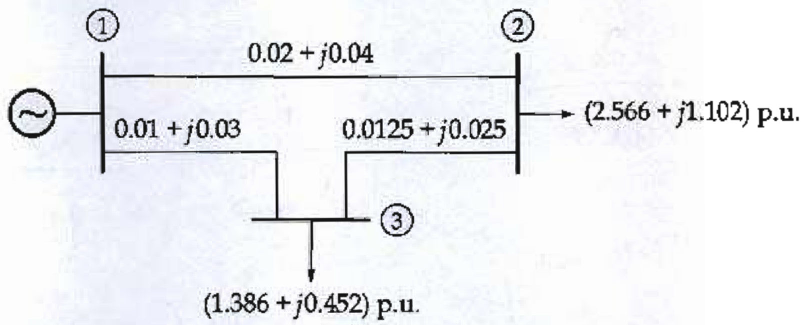
Q.6 (a) The single line diagram of a simple three-bus power system with generator at bus-1 is given in figure below. The line impedances are marked in per unit on 100 MVA base. The voltages obtained by performing load flows are :

$$V_1 = 1.05\angle 0° \text{ p.u.};$$
$$V_2 = 0.98183\angle -3.5035° \text{ p.u.};$$
$$V_3 = 1.00125\angle -2.8624° \text{ p.u.};$$

Calculate:

(i) slack bus power,

(ii) complex power flow from line-1 to line-2.



[20 marks]

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Q.6 (b) A 3-phase bank consisting of three single-phase, 3-winding transformers connected in star-delta-star is used to step down the voltage of a 3-phase, 220 kV transmission line. The data pertaining to one of the transformers is as follows:

Ratings

Primary-1 : 25 MVA, 220 kV

Secondary-2 : 12.5 MVA, 33 kV

Tertiary-3 : 12.5 MVA, 11 kV

Short-circuit reactances on 12.5 MVA base:

$X_{12} = 0.2$ p.u., $X_{23} = 0.15$ p.u., $X_{13} = 0.3$ p.u.

Transformer resistances are neglected. The delta-connected secondaries supply their rated current to a balanced load at 0.8 p.f. lagging. The tertiaries deliver the rated current to a balanced load at unity power factor.

(i) Calculate the primary line-to-line voltage to maintain rated voltage at the secondary terminals.

(ii) For the condition in part (i) find the line voltage at the tertiary terminals.

(iii) If the primary voltage found in part (i) is held fixed, to what value the tertiary voltage rises if the secondary load is reduced to zero?

[20 marks]

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Q.6 (c) A 1000 V, 24 pole, 50 Hz, 3-phase star connected induction motor has a slip ring rotor having a resistance of 0.02 Ω and standstill reactance of 0.3 Ω per phase. The motor develops full-load torque at a speed of 245 rpm.

Find:

(i) Full load torque.

(ii) Speed at maximum torque and

(iii) Maximum torque.

(Neglect stator impedance. The ratio of stator to rotor turns is 2).

[20 marks]

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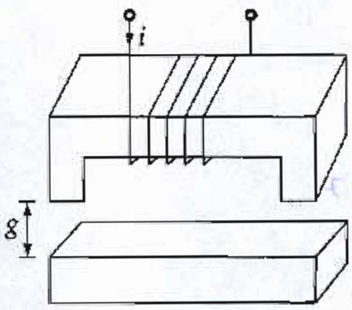
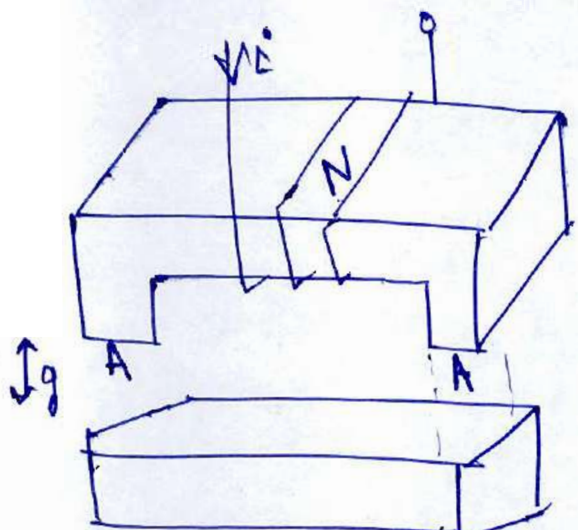
Q.7 (a) A lifting magnetic system shown in figure has a square cross-section $6 \times 6\ \text{cm}^2$. The coil has 300 turns and resistance of $6\ \Omega$. Neglect the reluctance of magnetic core and field fringing in the air gap.



(i) The airgap is initially held at 5 mm and dc source of 120 V is connected to the coil. Determine the stored field energy and lifting force.

(ii) The airgap is again held at 5 mm but now an ac source of 120 V at 60 Hz is connected to the coil. Determine the average value of the lifting force.

[20 marks]



The total reluctance of the air gap $= \underset{Q}{} \quad \dfrac{2g}{\mu_0 A}$

The flux, $\phi = \dfrac{Ni}{Q} = \dfrac{N\mu_0 A i}{2g}$

Inductance of air gap, $L = \dfrac{N\phi}{i}$

$= \dfrac{N^2 \mu_0 A}{2g}$

The Coenergy of the system is,

$$W_f' = \frac{1}{2} L i^2$$

$$= \frac{N^2 \mu_0 A}{4g} i^2$$

The lifting force in newton is,

$$F = \frac{\partial W_f'}{\partial g} = -\frac{N^2 \mu_0 A}{4g^2} i^2$$

(i) Stored field energy, $(W_f = W_f')$

$$W_f' = \frac{N^2 \mu_0 A}{4g} i^2 \qquad \left[i = \frac{120}{6} = 20A\right]$$

$$= \frac{300^2 \times 4\pi \times 10^{-7} \times 6 \times 6 \times 10^{-4} \times 20^2}{4 \times 5 \times 10^{-3}}$$

$$= 8.143 \text{ J}$$

Lefting force,

$$F = -\frac{N^2 \mu_0 A}{4g} i^2$$

$$= -\frac{W_f'}{g} = \frac{-8.143 \text{ J}}{05 \times 10^{-3} \text{ m}} = -1628.6 \text{ N}$$

(11) Lifting force

$$F_{(t)} = -\frac{N^2 \mu_0 A}{4g^2} \, i^2(t)$$

Average value of lifting force

$$F_{avg} = -\frac{N^2 \mu_0 A}{4g^2} \left| I_{rms} \right|^2$$

where,

$$i(t) = \frac{120\sqrt{2}}{Z} \cos(\omega t - \phi)$$

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where,

$$Z = R + j2\pi f L$$

$$= R + j2\pi f \frac{N^2 \mu_0 A}{2g}$$

$$= 6 + j\,120\pi \times \frac{300^2 \times 4\pi \times 10^{-7} \times 6 \times 6 \times 10^{-4}}{2 \times 5 \times 10^{-3}}$$

$$= 6 + j\,15.349\ \Omega$$

$$|Z| = 16.48\ \Omega$$

$$|I_{rms}| = \frac{120}{|Z|} = \frac{120}{16.48}\ A$$

$$F_{avg} = (-)\frac{300^2 \times 4\pi \times 10^{-7} \times 6 \times 6 \times 10^{-4}}{4 \times (5 \times 10^{-3})^2} \times \left(\frac{120}{16.48}\right)^2$$

$$= \cancel{215.875}\ \cancel{1.8758} \; -215.875\,N$$

Do not write in this margin

Q.7 (b) A 3-phase, 3-winding delta/delta/star, 33000/1100/400 V, 200 kVA transformer has a secondary load of 150 kVA at 0.8 p.f. lagging and a tertiary load of 50 kVA at 0.9 p.f. lagging. The magnetizing current is 4% of rated load, the iron loss being 1 kW. Calculate the value of the primary current when the other two windings are delivering the above loads.

[20 marks]

$\Delta \quad \Delta \quad Y$

33 KV $\quad$ 1.1 KV $\quad$ 0.4 KV $\quad$ [200 KVA]

$S_2 = 150$ KVA @ 0.8 pf lagging

$= 150 \angle + \cos^{-1} 0.8$

$= 150 \angle +36.87^\circ$ KVA

Similarly.

$S_3 = 50 \angle + \cos^{-1} 0.9 = 50 \angle 25.84^\circ$ KVA

$S_m = 4\%$ of 200 KVA $= 8 \angle 90^\circ$ KVA

$S_i = 1 \angle 0^\circ$ KW

Applying the equation,

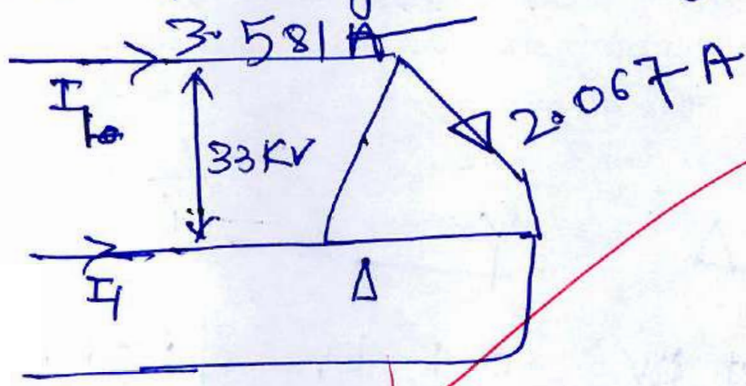
$S_1 = S_0 + S_2 + S_3$

$= (S_i + S_m) + S_2 + S_3$

$= (1 \angle 0^\circ + 8 \angle 90^\circ) + 150 \angle 36.87 + 50 \angle 25.84$

$= 204.711 \angle 35.816^\circ$ KVA

The primary side voltage



$$I_1 = \frac{|S_1|}{\sqrt{3}\, V_L}$$

$$= \frac{204.711}{\sqrt{3} \times 33}$$

$$= 3.581 \text{ A}$$

The value of primary current (line) is 3.581 A.

The phase current $= \frac{3.581}{\sqrt{3}} = 2.0677\text{ A}$

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7 (c) A 60 Hz, 4-pole turbo-generator rated 100 MVA, 13.8 kV has an inertia constant of 10 MJ/MVA:

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

(ii) If the input to the generator is suddenly raised to 60 MW for an electrical load of 50 MW, find rotor acceleration in rpm/sec.

(iii) If the rotor acceleration calculated in part (ii) is maintained for 12 cycles, find the change in torque angle and rotor speed in rpm at the end of this period.

[20 marks]

(i) At synchronous speed,

the stored energy $= HS$

$$= 10 \frac{MJ}{MVA} \times 100\,MVA$$

$$= 1000\ MJ$$

(ii) Refer to swing equation

$$\frac{2HS}{\omega_s}\frac{d^2\delta}{dt^2} = P_m - P_e$$

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

$$= \frac{(60-50)\,120\pi}{2 \times 1000}$$

$$= \frac{3\pi}{5} \frac{rad^e}{sec^2}$$

$$= \frac{3\pi}{10} \frac{rad^m}{sec^2} \qquad \left[\theta_m = \frac{2}{P}\theta_e\right]$$

$$= \frac{3\pi}{10} \times \frac{60}{2\pi} \frac{rpm}{sec}$$

$$= 18 \frac{rpm}{sec}$$

(ii) Finding change in δ:-

$$\frac{d^2\delta}{dt^2} = \frac{3\pi}{5}\ \frac{\text{rad}^e}{\text{sec}^2}$$

$$\frac{d^2\delta}{dt^2} = 108\ \frac{\text{deg}^e}{\text{sec}^2}$$

$$\delta = \delta_0 + 54t^2$$

At t = 12 cycle $= \frac{12}{f} = \frac{12}{60}$ sec

change $= \Delta\delta = \delta - \delta_0 = 54 \times \left(\frac{12}{60}\right)^2$

$= 2.16^\circ$ (electrical)

(iii) As we have calculated,

$$\frac{d^2\delta}{dt^2} = 18\ \frac{\text{rpm}}{\text{sec}}$$

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which means every sec speed increases by 18 rpm.

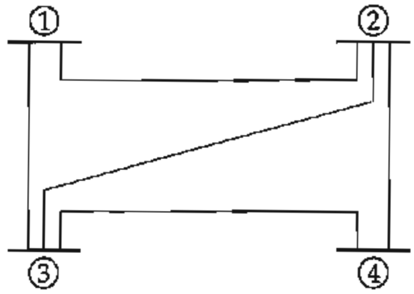
Initial speed $= \frac{120f}{P} = \frac{120 \times 60}{4} = 1800$ rpm.

At $t = \frac{12}{60}$ sec later,

speed (final) $= 1800 + \frac{12}{60} \times 18$

$= 1803.6$ rpm

3 (a) Solve the four bus power system by Gauss-Seidel method. The line data and bus data are given in tables. Calculate the bus voltages at the end of one iteration.



Line Data

Line	R, Pu	X, Pu
1-2	0.05	0.15
1-3	0.1	0.3
2-3	0.15	0.45
2-4	0.1	0.3
3-4	0.05	0.15

Bus Data

Bus	P_i (Pu)	Q_i (Pu)	V_i (Pu)
1-Slack	–	–	$1.04\angle 0°$
2-PQ	0.5	–0.2	
3-PQ	–1.0	0.5	
4-PQ	0.3	–0.1	

[20 marks]

Q.8 (b) A 400 V, 1450 rpm, 4-pole, 50 Hz wound-rotor induction motor has the following circuit model parameters.

$$R_1 = 0.3\ \Omega, \qquad R_2' = 0.25\ \Omega$$

$$X_1 = X_2' = 0.6\ \Omega \quad X_m = 35\ \Omega$$

$$\text{Rotational loss} = 1500\ \text{W}$$

(i) Calculate the starting torque and current when the motor is started directly on full voltage.

(ii) Calculate the full-load current, power factor and net torque. Also find internal efficiency and overall efficiency.

(iii) Find the slip for maximum torque and the value of maximum torque.

[20 marks]

3 (c) A 6-pole, 50 Hz, 3-phase induction motor has rotor resistance and reactance per phase of 0.02 Ω and 0.1 Ω respectively. At what speed is the torque maximum? What must be the value of the external rotor resistance per phase to produce two-third of the maximum torque at starting?

[20 marks]

Space for Rough Work

Space for Rough Work