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ESE 2019 : 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 : KINJALK SHUKLA

Roll No : E E 1 9 M T D L A 6 7 3

Test Centres					Student's Signature
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Instructions for Candidates

1. Do furnish the appropriate details in the answer sheet (viz. Name & Roll No).
2. Answer must be written in English only.
3. Use only black/blue pen.
4. 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.
5. Any page or portion of the page left blank in the Question Cum Answer Booklet must be clearly struck off.
6. Last two pages of this booklet are provided for rough work. Strike off these two pages after completion of the examination.

FOR OFFICE USE

Question No.	Marks Obtained
Section-A	
Q.1	47
Q.2	45
Q.3	
Q.4	53
Section-B	
Q.5	34
Q.6	
Q.7	
Q.8	32
Total Marks Obtained	211

Signature of Evaluator .... Cross Checked by K. Sudharshan

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Section A : Basic Electronics Engg. + Analog Electronics + Electrical Materials

1 (a) A conducting bar of 20 μm length, 2 μm wide and 1 μm thick is taken. Find the resistance of the bar if it is

(i) n-doped Silicon with $N_D = 10^8/\text{cm}^3$.

(ii) p-doped Silicon with $N_A = 10^{10}/\text{cm}^3$.

take $\mu_n = 2.5\,\mu_p = 1200\ \text{cm}^2/\text{Vs}$ and n_i for Silicon is $1.5 \times 10^{10}/\text{cm}^3$.

[12 marks]

Given

length = 20 μm
width = 2 μm thickness = 1 μm.

$\mu_n = 2.5\ \mu_p = 1200$ $n_i = 1.5 \times 10^{10}/cm^3$.

(i) n doped Si $N_D = 10^8$.

we know, by neutrality of a semiconductor

$$\boxed{N_A + n = p + N_D}$$

∵ given ~~N_D~~ n is doped with N_D $N_A \simeq 0$

$n = p + N_D$

∴ By law of mass action $\boxed{np = n_i^2}$

$(p+N_D)p = (1.5 \times 10^{10})^2$.

$p^2 + N_D p - (1.5 \times 10^{10})^2 = 0$

$p^2 + 10^8 p - (1.5 \times 10^{10})^2 = 0$

$$\boxed{p = 1.495 \times 10^{10}/cm^3} \quad \boxed{n = 1.505 \times 10^{10}}$$

$\sigma = (\mu_n n + \mu_p p)q = (2.5 \times 1.505 \times 10^{10} + 1200 \times 1.495 \times 10^{10}) \times 1.6 \times 10^{-19}$

$$\boxed{\sigma = 2.876 \times 10^{-6}}$$

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

$A = (2 \times 10^{-6} \times 1 \times 10^{-6})m^2$

$$\boxed{A = 2 \times 10^{-8} cm^2}$$

$\boxed{R = 3.477 \times 10^{10}\,\Omega}$

(iii) p doped $N_A = 10^{10}$

$\boxed{n + N_A = p}$ by mass law action

$(n + N_A)n = n_i^2 \Rightarrow n^2 + N_A n - n_i^2 = 0$

$\boxed{n = 1.081 \times 10^{10}}$ $\quad p = (2.081 \times 10^{10})$

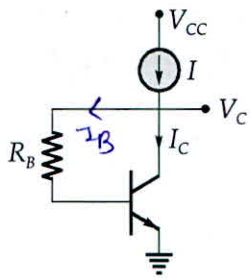
$\sigma = (1.081 \times 2.5 + 1200 \times 2.081) \times 10^{10} \times 1.6 \times 10^{-19}$

$\boxed{\sigma = 4 \times 10^{-6}}$

$R = \frac{\rho l}{A} = \frac{l}{\sigma A} = \frac{20 \times 10^{-4}}{4 \times 10^{-6} \times 2 \times 10^{-8}}$ — 10

$\boxed{R = 2.5 \times 10^{10}\,\Omega}$

Q.1 (b) A circuit that can provide a very large voltage gain for a high resistance load is shown in figure below. Find the value of current I and R_B to bias the BJT at $I_C = 3$ mA and $V_C = 1.5$ V for $\beta = 90$.



[12 marks]

Given,

$I_C = 3mA \quad V_C = 1.5V \quad \beta = 90$

To find – I and R_B

applying KVL in Base loop.

$V_C - R_B I_B - 0.7 = 0$

$1.5 - 0.7 = R_B I_B = 0.8$ — (1)

$I = I_B + I_C$ — (2)

Now we know $\boxed{I_C = \beta I_B}$

$I_B = \frac{I_C}{\beta} \Rightarrow I_B = \frac{3 \times 10^{-3}}{90}$

$$\boxed{I_B = 3.333 \times 10^{-5} A} \quad \text{—(3)}$$

putting (3) in eqn(1)

$$R_B \times 3.333 \times 10^{-5} = 0.8$$

$$\boxed{R_B = 24.0024\ k\Omega}$$

$$I = I_C + I_B$$

$$= 3 \times 10^{-3} + 3.333 \times 10^{-5}$$

$$= 3.0333 \times 10^{-3}$$

$$\boxed{I = 3.0333\ mA}$$

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Q.1 (c) A material with magnetic property such that when it was placed in a magnetic field, $B = 4\ Wb/m^2$, magnetic field intensity was found to be 4800 A/m. If $\vec{H}$ is reduced to 640 A/m and $B = 1.8\ Wb/m^2$, then calculate the percentage change in magnetization M of the material.

[12 marks]

Given $B = 4\ wb/m^2$
$H = 4800\ A/m$

Case 2 → $H = 640\ A/m$
$B = 1.8\ wb/m^2$

To find → percentage change in magnetisation M.

we know

$$B = \mu_0 [H + M]$$

$$\therefore \frac{B}{\mu_0} = H + m \qquad \boxed{m = \frac{B}{\mu_0} - H}$$

Case 1

$$M_1 = \frac{B_1}{\mu_0} - H = \frac{4}{4\pi \times 10^{-7}} - 4800$$

$$M_1 = 3.1783 \times 10^6 \quad \text{—(1)}$$

Case 2

$$M_2 = \frac{B_2}{\mu_0} - H = \frac{1.8}{4\pi \times 10^{-7}} - 640$$

$$M_2 = 1.4318 \times 10^6 \quad \text{—(2)}$$

$$\% \text{ change} = \frac{|M_1 - M_2|}{M_1} \times 100$$

$$= \frac{3.1783 - 1.4318}{3.1783} \times 100$$

$$\boxed{\% \text{ change} = 54.951 \%}$$

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.1 (d) 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]

Magnetic dipoles are randomly distributed in any direction in magnetic materials seperated by magnetic domains. These magnetic dipoles on application of external magnetic field cause magnetization of the magnetic materials by showing field strength in the direction of application of magnetic field.

Magnetic dipoles are ~~magn~~ mathematically represented by

$$\boxed{\text{magnetic dipoles} = I \cdot A} \; A \cdot m^2$$

Now the magnetic dipoles per unit volume are defined as the magnetisation

i.e

$$M = \frac{\text{magnetic dipoles}}{\text{Volume}}$$

Or the magnetisation is defined as product of no of dipoles with magnetic dipole

$$\boxed{M = n \times \text{magnetic dipole}}$$

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Q.1 (e) What are type-I and type-II superconductors? Draw the magnetization versus magnetic field characteristic for type-I and type-II superconductors. Why superconductivity is observed for signals upto radio frequencies?

[4 + 4 + 4 marks]

There are two types of superconductors -

(1) Type I superconductors

(1) They follow exactly Meissener's rule and Silsbee's rule.

(2) They have sharp transition temperature.

(3) They have lower transition temp.

(4) Used for soft magnets

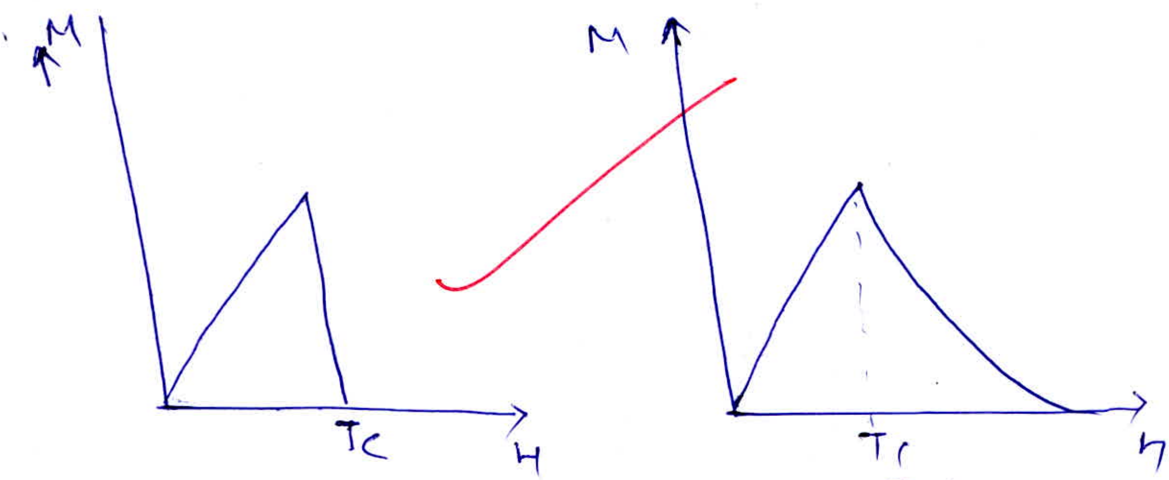
(2) Type II superconductors

(1) They do not exactly follow Meissener's and Silsbee's rule.

(2) They ~~have~~ do not have sharp transitions but include intermediate temp.

(3) They have higher transition temp.

(4) Used for Hard magnets.



Type I superconductor Type II superconductor

Superconductivity is observed for signals upto radio frequencies because superconductivity is inversely proportional to the frequency hence as frequency increases superconductivity decreases and after radio frequency it completely vanishes.

2

.2 (a) The copper crystal has FCC unit cell configuration. If radius of Cu atom is 0.148 nm and atomic mass of Cu is 63.5 gm mol^{-1} then calculate atomic packing fraction (APF), the atomic concentration in a unit cell and density of Cu atom in gcm^{-3}.
(Take Avogadro number : 6.023×10^{23} mol^{-1})

[20 marks]

Given

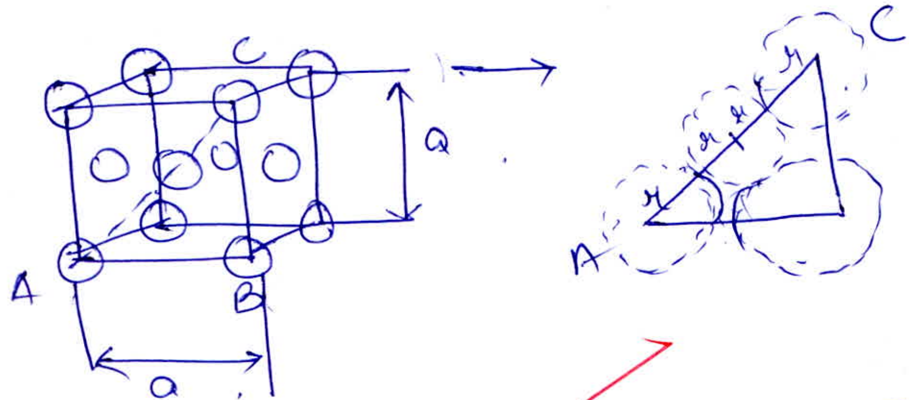
copper crystal = FCC configuration

radius of Cu atom = 0.148 nm

atomic mass = 63.5 gm/mol

$N_A = 6.023 \times 10^{23}$ mol^{-1}

For atomic packing fraction



∴ from diagram $AC = \sqrt{a^2 + a^2}$ & $AC = 4r$

$= \sqrt{2}a$.

∴ $\boxed{\sqrt{2}a = 4r}$ —(1) $a = \frac{4}{\sqrt{2}} r$

Now $\boxed{APF = \frac{\text{no. of atoms} \times \text{volume of each atom}}{\text{volume of cell}}}$

No of atoms in a cell $= \cancel{8} \times \frac{1}{\cancel{8}} + \cancel{6}^{3} \times \frac{1}{\cancel{2}}$

$= 1 + 3$

$= 4$

$$APF = \frac{4 \times \frac{4}{3}\pi r^3}{a^3} = \frac{16\pi}{3a^3} \times \left(\frac{\sqrt{2}}{4} a\right)^3$$

$$\boxed{APF = 0.74}$$

Now, atomic concentration

$$= \frac{N_A}{volume} \quad \text{— (2)}.$$

or. $n \times volume = no\ of\ atoms = 4$

$$n \times a^3 = 4$$

$$n = \frac{4}{a^3} = \frac{4}{\left(\frac{4}{\sqrt{2}} r\right)^3} = 5.453 \times 10^{28}$$

$$\boxed{n = 5.453 \times 10^{28}}$$ unit?

$$Density = \frac{Mass}{Volume}$$

from eqn (2).

$$Volume = \frac{6.023 \times 10^{23}}{5.453 \times 10^{28}} = \cancel{1.1}05 \times 10^{-5}\ m^3$$

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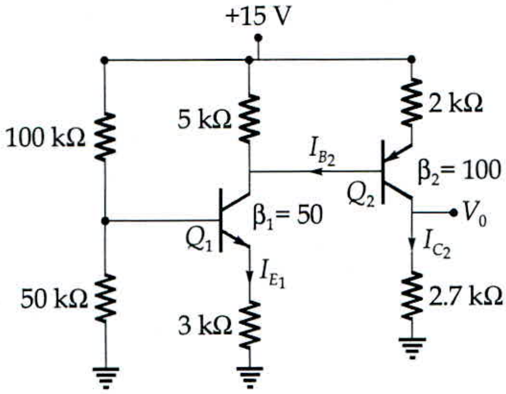
$$\therefore density = \frac{63.5 \cancel{\times 10^{3}}}{1.105 \times 10^{-5}}$$

$$= \cancel{5746.64}$$

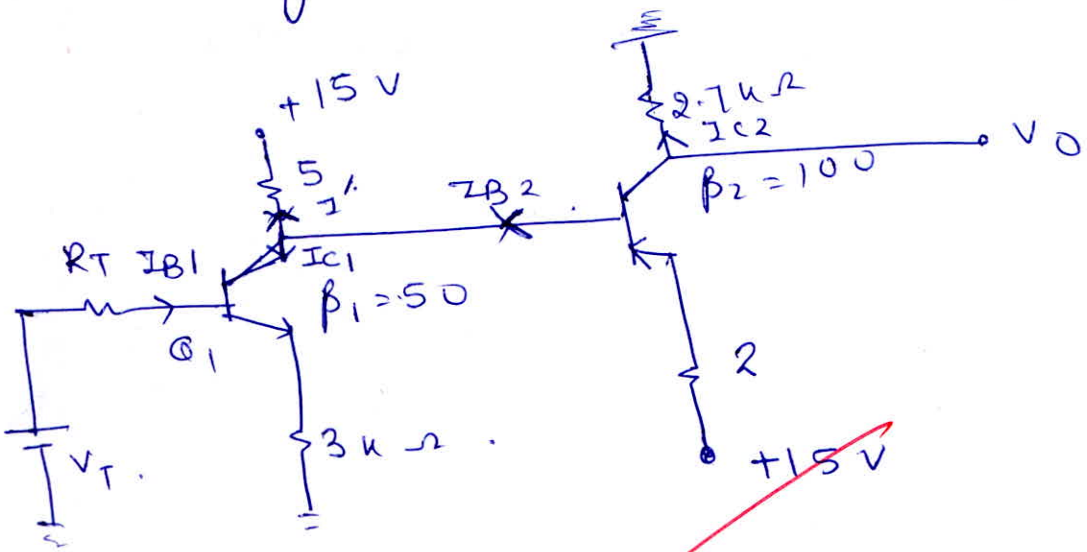
$$\boxed{Density = 5.7466\ gm/cm^3}$$

.2 (b) In the below configuration, calculate the values of I_{B_2}, I_{C_2}, I_{E_1} and V_0.



[20 marks]

Redrawing the above circuit diagram



$$V_T = \frac{50}{50+100} \times 15 = 5V.$$

$$R_T = \frac{50 \times 100}{50 + 100} = 33.33\,k\Omega.$$

Apply KVL in Base loop of Q1

$$V_T - R_T I_{B1} - 0.7 - 3\times10^3 I_E = 0$$

$$5 - 0.7 = 33.33\times10^3 I_{B1} + 3\times10^3 (1+\beta) I_{B1}$$

$$4.3 = (33.33 + (3\times51)) I_{B1}$$

$$\boxed{I_{B1} = 23.077\,\mu A.}$$

$I_{C1} = \beta I_{B1} = 1.154\ mA.$

$I_{E1} = (1+\beta) I_{B1} \Rightarrow \boxed{I_E = 1.176\ mA}$

Applying KVL in Base of Q2

$\cancel{15} - 2 I_{E2} - 0.7 - 5\times10^3 I' \cancel{-15} = 0$

$\cancel{-2I_E}$

$-2\times10^3 I_{E2} - 5\times10^3 I' = 0.7$

$-2\times10^3(1+\beta_2) I_{B2} - 5\times10^3 (I_{B2} - I_{C1}) = 0.7$

$-2\times101\, I_{B2} - 5 I_{B2} + 5 I_{C1} = 0.7$

$-207 I_{B2} + 5.77 = 0.7$

$I_{B2} = \frac{-5.07}{-207}$ $\boxed{I_{B2} = 24.493\ \mu A}$

$I_{C2} = \beta_2 I_{B2}$

$\boxed{I_{C2} = 2.449\ mA}$

$V_0 = 2.7\times10^3 \times I_{C2}$

$\boxed{V_0 = 6.6123\ V}$

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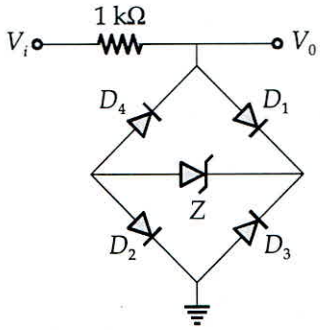
Q.2 (c) Sketch the transfer characteristics of the circuit given below for $-20\text{ V} \le V_i \le 20\text{ V}$. Assume that diodes can be represented by a piece-wise linear model with $V_{D0} = 0.65$ V and $r_D = 20\ \Omega$. Assuming that the specified zener voltage at a current of 10 mA is 8.2 V and $r_Z = 20\ \Omega$. Represent the Zener by a piece-wise linear model.



[20 marks]

Given, diodes are represented by $V_{D0} = 0.65$ & $r_d = 20$.

& for zener

$V_Z = V_{Z0} + I r_Z$

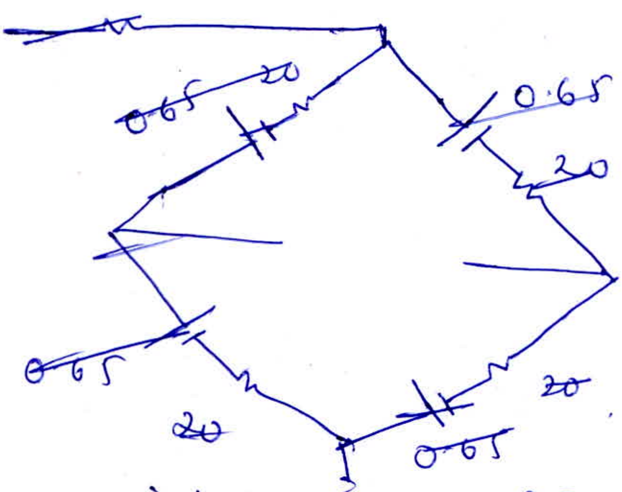
$8.2 = V_{Z0} + 10 \times 10^{-3} \times 20$

$\boxed{8 = V_{Z0}}$ $\boxed{r_Z = 20\ \Omega}$

~~On re drawing circuit diagram~~

characteristics to be drawn for

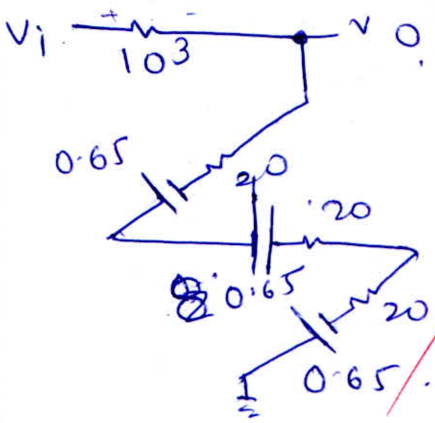
$-20 \le V_i \le 20$



~~When the input is $-20 \le V_i$.~~

Let us take the case when D_4 and D_3 are ON and zener diode is at ~~-ve~~ zener mode.

Takin zener as normal diode



∴ Diodes will be ON when $V_0 > 0.65 + 0.65 + 8$ ~~-065~~

$$\boxed{V_0 > -0.65}$$

V_0 ~~> -9.3~~

$\boxed{\cancel{V_0 < -9.3}}$

ON $I = \frac{V_i + \cancel{9.3} \cancel{+9.5} 0.65}{1060}$.

$V_0 = V_i - 10^3 \frac{V_i + \cancel{9.95} 0.613}{1060} = V_i - 0.943$ ~~-8.774~~ ~~1.839~~ 0.613

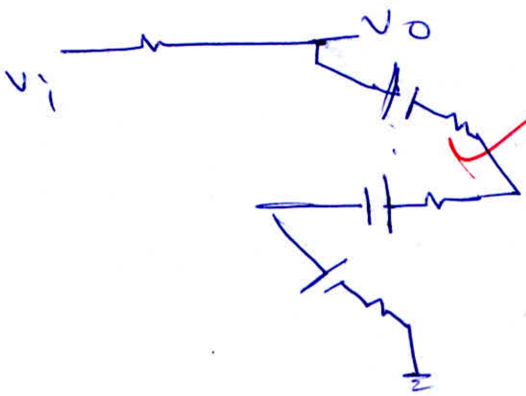
$$\boxed{V_0 = 0.057 V_i - \cancel{8.774} \cancel{1.839}\ 0.613}$$

& when Diodes are OFF $\boxed{V_i = V_0}$

Now, when

D_1 D_2 & zener act. $V_0 < 9.3$

10

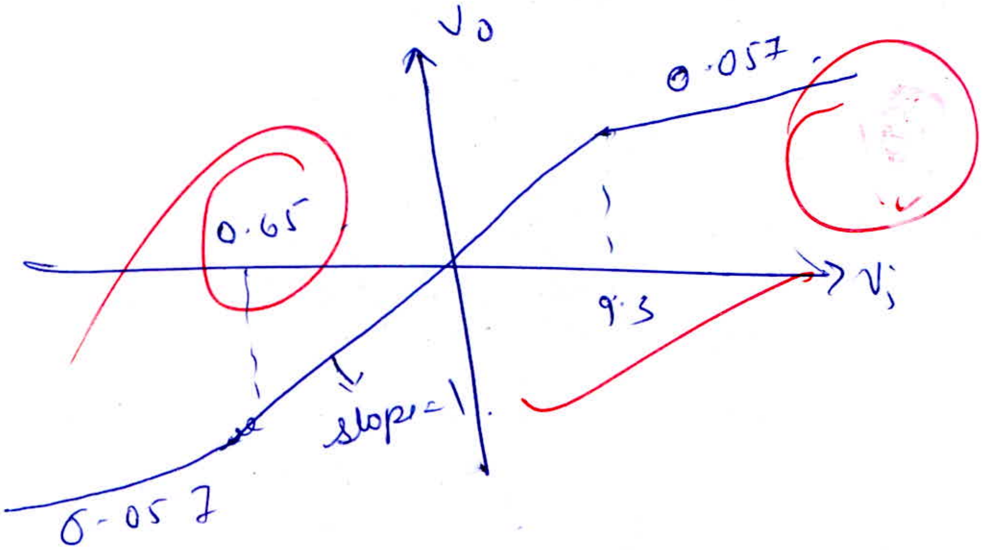


ON $I = \frac{V_i - 0.65 - 8 - 0.65}{1060}$

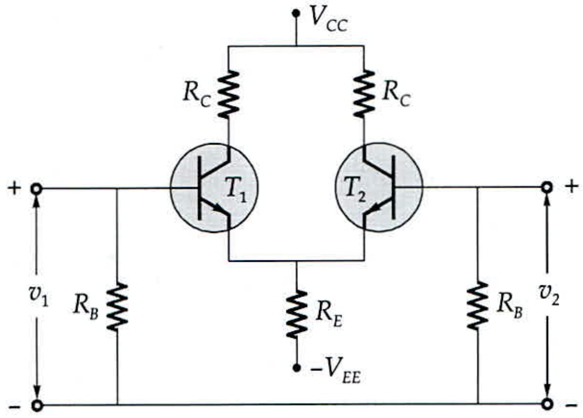
$I = \frac{V_i - 9.3}{1060}$

$$\boxed{V_0 = 0.057 V_i - 8.774}$$

diodes OFF $V_i = V_0$



Q.3 (a) (i) The BJT in the differential amplifier circuit shown below have negligible leakage current and $\beta_1 = \beta_2 = 60$. Also $R_C = 6.8\ \text{k}\Omega$, $R_B = 10\ \text{k}\Omega$ and $V_{CC} = V_{EE} = 15$ V. Find the value of R_E needed to bias the amplifier such that $V_{CEQ_1} = V_{CEQ_2} = 8$ V.



[10 marks]

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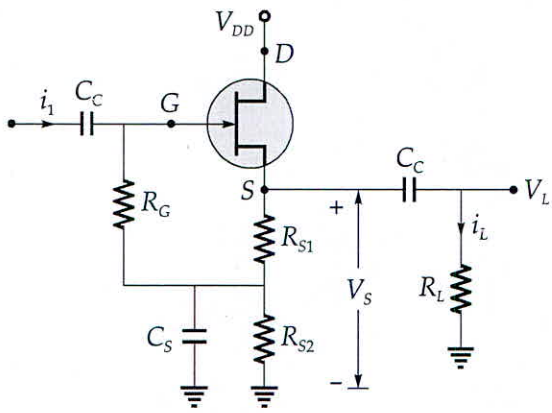
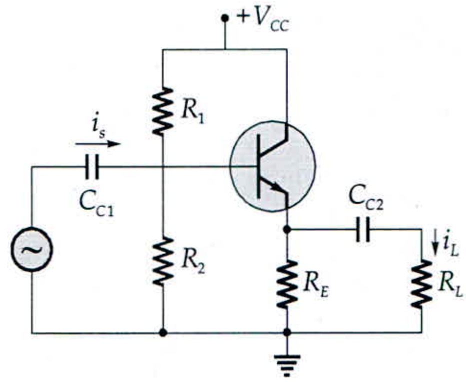
Q.3 (a) **(ii)** In the circuit shown below $R_G >> R_{S1}, R_{S2}$. The JFET is described by $I_{DSS} = 10$ mA, $V_P = 4$ V, $V_{DD} = 15$ V, $V_{DSQ} = 10$ V and $V_{GSQ} = -2$ V. Find the value of R_{S1} and R_{S2} to set amplifier at above Q-point and also find the value of V_S.



[10 marks]

Q.3 (b) Consider the amplifier circuit shown below:



The parameters of BJT and the circuit are, $\beta = 80$, $V_{CC} = 10$ V, $V_{CEQ} = 5$ V, $V_{BE\,(on)} = 0.7$ V and $R_E = R_L = 500\ \Omega$. Design the values of R_1 and R_2 such that the mid-band current gain $A_i = \dfrac{i_L}{i_S} = 8$. Assume that $V_T = 26$ mV.

[20 marks]

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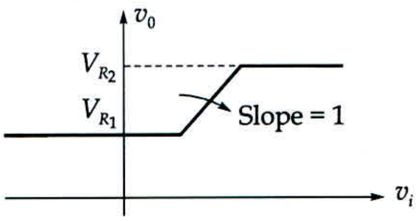
Q.3 (c) (i) Design a clipper circuit for the characteristics curve given below:



[10 marks]

Q.3 (c) **(ii)** Define the 'mobility' of electrons in conductive materials and derive relation showing components of random velocity and average drift velocity to deduce expression for electron mobility.

(iii) If a conductor material has following data as shown below:

Density : 9.40 gram/cc

Resistivity : 1.72×10^{-8} ohm-m

Atomic weight : 63.5

Compute the mobility and the average time of collision of electrons in the conductors if valance electron for each conductor material atom is 1.

[10 marks]

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Q.4 (a) **(i)** Consider a diode with mean lifetime of holes to be 10 nsec and $\eta = 1$. If a forward current of 0.1 mA is flowing in diode then determine the diffusion capacitance. (Assume room temperature to be 300 K).

[5 marks]

Given $\tau = 10\,ns$.

$\eta = 1$.

$I_D = 0.1\,mA$

To find C_D

we know, $\boxed{C_D = \frac{I \times \tau}{\eta V_T}}$

$$V_T = \frac{T}{11600} = \frac{300}{11600} = 25.862\,mV$$

$$C_D = \frac{0.1 \times 10^{-3} \times 10 \times 10^{-9}}{1 \times 25.862 \times 10^{-3}}$$

$$C_D = 3.8666 \times 10^{-11}$$

$$\boxed{C_D = 38.666\,pF.}$$

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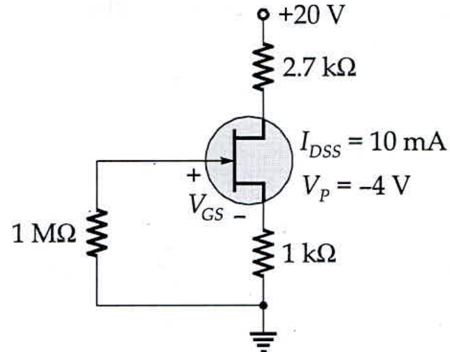
Q.4 (a) (ii) Determine V_{GSQ}, I_{DQ} and V_{DS} for the self bias circuit shown in figure below.



[15 marks]

Given

$I_{DSS} = 10\,mA \qquad V_P = -4\,V.$

To find

V_{GSQ}, I_{DQ} and V_{DS}.

we know,

$$I_D = I_{DSS}\left[1 - \frac{V_{GS}}{V_P}\right]^2 \quad \text{—(1)}$$

and we know $I_g = 0$

∴ Applying KVL in gate - source loop.

$$-V_{GS} - 1\times10^3 I_D = 0$$

$$V_{GS} = -10^3 I_D \qquad \boxed{I_D = -\frac{V_{GS}}{10^3}} \text{—(2)}$$

putting (2) in (1)

$$\cancel{-\frac{V_{GS}\times10^{-3}}{10^3}} = \cancel{10\times10^{-3}}\left[\cancel{1 + \frac{V_{GS}}{+4}}\right]^2$$

$$\cancel{-\frac{V_{GS}}{10}} = \left[\cancel{1 + \frac{V_{GS}}{4}}\right]^2.$$

$$-V_{GS}\times10^{-3} = 10\times10^{-3}\left[1 - \frac{V_{GS}}{(-4)}\right]^2$$

$$-\frac{V_{GS}}{10} = \left[1 + \frac{V_{GS}}{4}\right]^2$$

$$-\frac{V_{GS}}{10} = \left[\frac{4 + V_{GS}}{4}\right]^2 = \frac{(4 + V_{GS})^2}{16}$$

$$-\frac{16}{10} V_{GS} = (4 + V_{GS})^2 = 16 + V_{GS}^2 + 2 \times 4 \times V_{GS}$$

$$-1.6 V_{GS} = 16 + V_{GS}^2 + 8 V_{GS}$$

$$V_{GS}^2 + 9.6 V_{GS} + 16 = 0$$

$$\boxed{V_{GS} = -2.1467 \text{ or } -7.4533}$$

Now $\because V_{GS} > V_p$.

$$\therefore \boxed{V_{GS} = -2.1467}$$

$$I_D = \frac{-V_{GS}}{10^3} = \frac{-(-2.1467)}{10^3}$$

$$\boxed{I_D = 2.1467 \text{mA}}$$

for V_{DS} applying KVL in ~~a~~ DS loop

$$20 - 2.7 \times 10^3 I_D - V_{DS} - 1 \times 10^3 I_D = 0$$

$$20 - 3.7 \times 10^3 I_D = V_{DS}$$

$$V_{DS} = 20 - 3.7 \times 10^3 \times 2.1467 \times 10^{-3}$$

$$\boxed{V_{DS} = 12.0572 \text{ V}}$$

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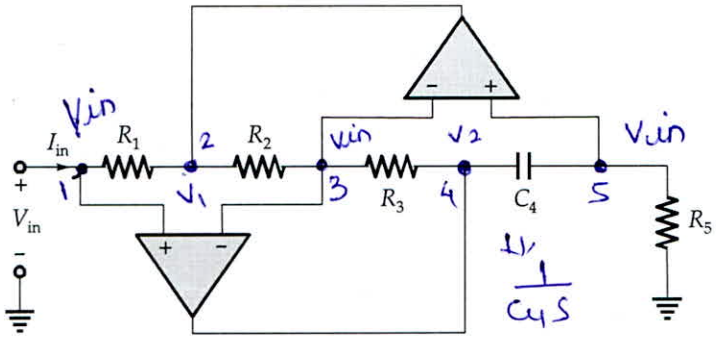
Q.4 (b) Consider the circuit with ideal op-amps, shown in the figure below:



Calculate the input impedance $Z_{in}(s) = \dfrac{V_{in}(s)}{I_{in}(s)}$ and comment on the result obtained.

[20 marks]

To calculate $Zin(s) = \dfrac{Vin(s)}{Iin(s)}$

By virtual ground the vtg at the & -ve terminal of opAmp are same as marked in figure.

Applying KCL at node 5

$$\frac{Vin}{R5} + \frac{Vin - V2}{1/C_4 s} = 0$$

$$\frac{Vin}{R5} + C_4 s\,[Vin - V_2] = 0 \Rightarrow Vin\left[\frac{1}{R5} + C_4 s\right] = V_2 C_4 s$$

$$Vin\left[\frac{1 + R_5 C_4 s}{R_5}\right] = V_2 C_4 s \Rightarrow \boxed{V_2 = Vin\left[\frac{1 + R_5 C_4 s}{R_5 C_4 s}\right]} \quad -(1)$$

Applying KCL at Node 3

$$\frac{Vin - V_2}{R3} + \frac{Vin - V_1}{R_2} = 0$$

$$Vin\left[\frac{1}{R_3} + \frac{1}{R_2}\right] - \frac{V2}{R3} = \frac{V_1}{R2}$$

putting from (1) we have

$$V_{in}\left[\frac{1}{R_2}+\frac{1}{R_3}\right]-\frac{1}{R_3}\left[V_{in}\frac{[1+R_5C_4s]}{R_5C_4s}\right]=\frac{V_1}{R_2}$$

$$V_{in}\left[\frac{1}{R_2}+\cancel{\frac{1}{R_3}}-\frac{1}{R_3R_5C_4s}-\cancel{\frac{R_5C_4s}{R_3R_5C_4s}}\right]=\frac{V_1}{R_2}.$$

$$V_{in}\left[\frac{1}{R_2}-\frac{1}{R_3R_5C_4s}\right]=\frac{V_1}{R_2}$$

$$\boxed{V_{in}\left[\frac{R_3R_5C_4s-R_2}{\cancel{R_2}R_3R_5C_4s}\right]=\frac{V_1}{\cancel{R_2}}}\text{ — (2)}$$

Now, $I_{in}=\dfrac{V_{in}-V_1}{R_1}$

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$$I_{in}=\cancel{V_t}\frac{1}{R_1}\left[V_{in}-V_{in}\left[\frac{R_3R_5C_4s-R_2}{R_3R_5C_4s}\right]\right]$$

$$=\frac{V_{in}}{R_1}\left[1-\frac{(R_3R_5C_4s-R_2)}{R_3R_5C_4s}\right]$$

$$=\frac{V_{in}}{R_1}\left[\frac{\cancel{R_3R_5C_4s}-\cancel{R_3R_5C_4s}+R_2}{R_3R_5C_4s}\right]$$

$$I_{in}=\frac{V_{in}R_2}{R_1R_3R_5C_4s}$$

$$\therefore\ \boxed{\frac{V_{in}}{I_{in}}=\frac{R_1R_3R_5C_4s}{R_2}}$$

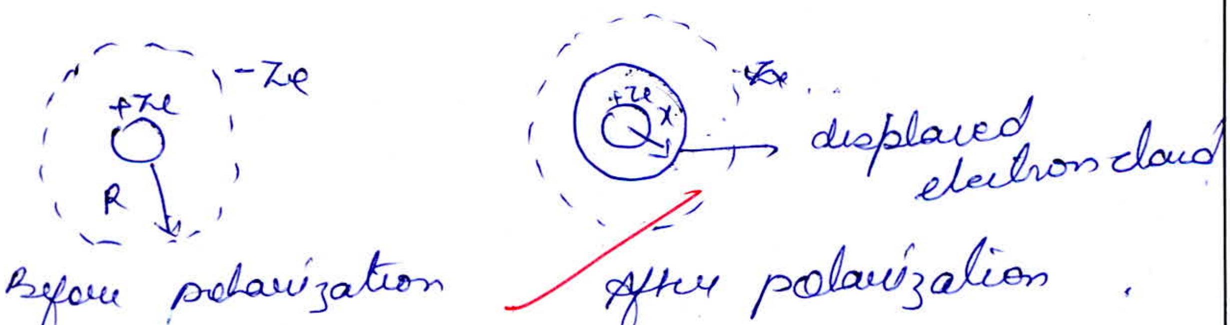
comment ??

Q.4 (c) Explain briefly the polarization occurring in dielectric materials. What are different types of polarization occurring in dielectric material?
If a dielectric material contains 3.2×10^{19} polar molecules/m^3 and the relative permittivity of material is $\epsilon_r = 2.4$ with applied external electric field $\vec{E} = 10^4 \vec{a_x}$ V/m, then calculate the value of polarization and dipole moment in each molecule. (Consider all molecules have same dipole moment).

[20 marks]

* In dielectric materials if no external field is applied to the materials the positive charge is centered at the nucleus of the atom & the negative charge is in the form of charge electron cloud at radius R shown below.

* Now, if external field is applied to the material it causes shift in the negative electron cloud by some distance (say x) which leads to the polarization in the dielectric material.



The different types of polarization occurring in the dielectric materials are.

(1) Electronic → shift of electron cloud.
(2) Ionic → shift of the +ve & -ve ions in ionic Bond
(3) Oriental → shift of the permanent angular displacement
(4) Space charge → In multiphase ~~mote~~ materials

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Only oriental polarization depends on temperature.

(ii) Given $N = 3.2 \times 10^{19}$ $\varepsilon_r = 2.4$
$\vec{E} = 10^4 \, a_x \, V/m.$

• To find polarization & dipole moment

we know

$$\boxed{\varepsilon_r = 1 + 4\pi \varepsilon_0 N R^3} \quad (1)$$

$$\cancel{\varepsilon_r - 1 = 4\pi \varepsilon_0 R^3 = 2.4 - 1 = 1.4} \quad (1)$$

& Polarization $= N\alpha E$.
where $N\alpha = 4\pi \varepsilon_0 N R^3$. from (1)

$$\frac{\varepsilon_r - 1}{4\pi N} = R^3 = \frac{2.4 - 1}{4\pi \times 3.2 \times 10^{19}} =$$

$$\boxed{R = 1.5156 \times 10^{-7} m}$$

$$P = N\alpha E$$
$$= N \times 4\pi \varepsilon_0 R^3 \times 10^4.$$
$$= 3.2 \times 10^{19} \times 4\pi \times 8.85 \times 10^{-12} \times (1.5156 \times 10^{-7})^3 \times 10^4$$

$$= \cancel{3.2 \times 10^{19}} \times \cancel{4\pi} \varepsilon_0 \times \frac{1.4}{\cancel{4\pi} \times \cancel{3.2 \times 10^{19}}} \times 10^4$$

$$= 1.4 \times 10^4 \times 8.85 \times 10^{-12}$$

$$\boxed{P = 1.239 \times 10^{-7} \, C/m}$$

$$\boxed{p = \text{dipole} = \frac{P}{N} = 3.872 \times 10^{-27} \, C\text{-}m}$$

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

Q.5 (a) Draw the reactance diagram of the system whose bus admittance matrix is given below. First, second, third and fourth rows refer to buses 1, 2, 3 and 4 respectively.

$$Y_{bus} = j\begin{bmatrix} -3.78 & 1.25 & 2.5 & 0 \\ 1.25 & -3.42 & 1.11 & 1.0 \\ 2.5 & 1.11 & -4.89 & 1.25 \\ 0 & 1.0 & 1.25 & -2.31 \end{bmatrix}$$

[12 marks]

Given

$$Y_{bus} = j\begin{bmatrix} -3.78 & 1.25 & 2.5 & 0 \\ 1.25 & -3.42 & 1.11 & 1.0 \\ 2.5 & 1.11 & -4.89 & 1.25 \\ 0 & 1.0 & 1.25 & -2.31 \end{bmatrix}$$

To check for shunt admittances

Row 1 = $(-3.78 + 1.25 + 2.5 + 0)j = -0.03j$

Row 2 = $(1.25 - 3.42 + 1.11 + 1)j = -0.06j$

Row 3 = $(2.5 + 1.11 - 4.89 + 1.25)j = -0.03j$

Row 4 = $(1 + 1.25 - 2.31)j = -0.06j$

Shunt reactance

Bus 1 = $\dfrac{1}{-0.03j} = 33.33i$ $\quad$ Bus 2 = $\dfrac{1}{-0.06j} = 16.667j$

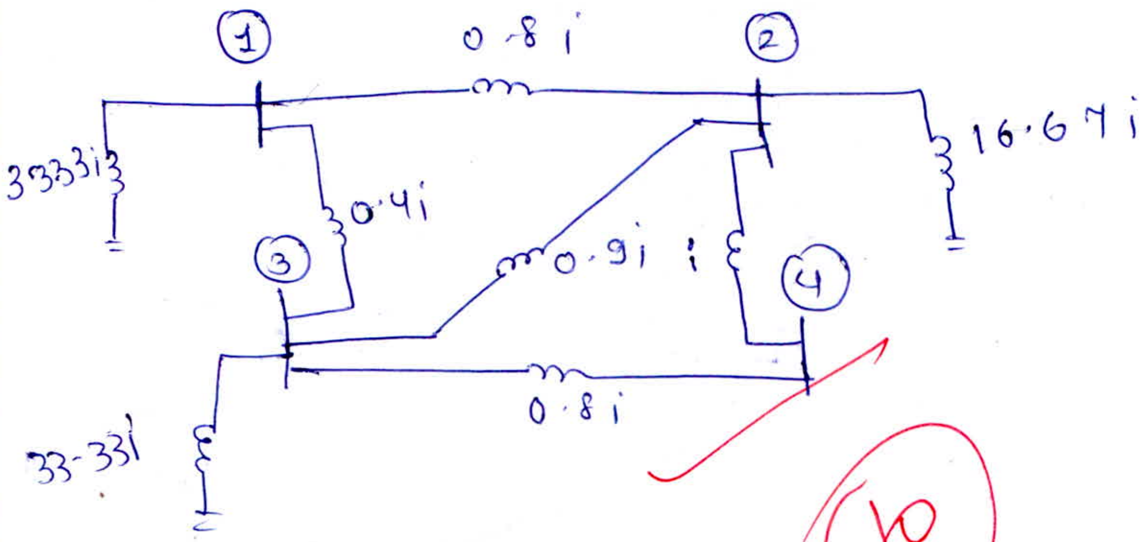
Bus 3 = $\dfrac{1}{-0.03j} = 33.33i$ $\quad$ Bus 4 = $\dfrac{1}{-0.06j} = 16.667j$

Now b/w 1 & 2 = $\dfrac{-1}{1.25j} = 0.8i = 2 \& 1$

Bus 1 & 3 = $\dfrac{-1}{2.5i} = 0.4i = 3 \& 1$ | Bus 1 & 4 = 0

Bus 2 & 3 = 3 & 2 = $\dfrac{-1}{1.11j} = 0.9i$ | Bus 2 & 4 = $\dfrac{-1}{j} = i$

Bus 3 & 4 = $\dfrac{-1}{1.25i} = 0.8i$



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Q.5 (b) A voltage of (200 sinωt – 50 sin 3ωt), 50 Hz is applied to a 250 turn transformer winding having negligible resistance and leakage reactance. Deduce an expression for flux and find its maximum value. By what percentage will eddy current loss in the iron core be reduced if the applied voltage is altered to 200 sin ωt?

[12 marks]

Given vtg = (200 sinωt − 50 sin 3ωt)

N = 250

To find ϕ and ϕ_m.

we know, ~~$v = -N\frac{d\phi}{dt}$~~

$$v = -N\frac{d\phi}{dt}$$

so putting values

$$200 \sin\omega t - 50 \sin 3\omega t = 250 \frac{d\phi}{dt}.$$

$$-\frac{1}{250}\left[\int (200 \sin\omega t - 50 \sin 3\omega t]\,dt\right] = \int d\phi$$

$$\phi = \frac{1}{250}\left[\int 200 \sin \omega t \, dt - \int 50 \sin 3\omega t \, dt\right]$$

$$\phi = \frac{-1}{250}\left[\frac{200}{\omega}[-\cos\omega t] + 50\frac{\cos 3\omega t}{3\omega}\right]$$

$$= \frac{-1}{250}\left[\frac{50}{3\omega}\cos 3\omega t - \frac{200}{\omega}\cos \omega t\right]$$

$\omega = 2 \times \pi \times 50 = 314.159$

$$\boxed{\phi = -2.122\times10^{-4}\cos 3\omega t + 2.546\times10^{-3}\cos\omega t}$$

wb

~~ϕ_m~~ = For eddy current
we know. eddy current loss $\propto V^2$.

so case 1. $V_{rms} = \sqrt{\left(\frac{200}{\sqrt{2}}\right)^2 + \left(\frac{50}{\sqrt{2}}\right)^2}$

$= 145.774 V$

case 2 → $V_{rms} = \frac{200}{\sqrt{2}} = 141.421 V$.

$$\therefore \frac{\text{eddy c. loss}_2 - \text{eddy c. loss}_1}{\text{eddy c loss}_1} = \frac{(141.421)^2 - (145.774)^2}{(145.774)^2}$$

$= -0.0588 \times 100$

$= -5.883\%$

∴ % reduction in eddy current loss $= 5.883\%$

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$$\phi_{max} = \sqrt{\left(\frac{2.122\times10^{-4}}{\cancel{\sqrt{2}}}\right)^2 + \left(\frac{2.546\times10^{-3}}{\cancel{\sqrt{2}}}\right)^2}$$

$\phi_m = 2.555\times10^{-3}$ wb

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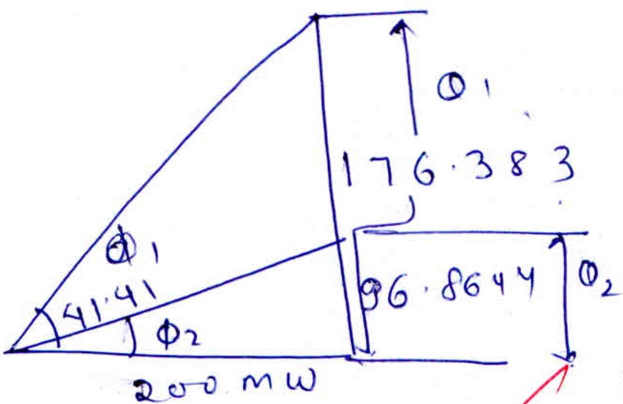
Q.5 (c) An industry load of 200 kW at 0.75 p.f. lagging is fed from the 3-ϕ, 11 kV distribution feeders. It is required to maintain the 0.9 p.f. lag at the drawl point. Find the rating of capacitor installed at industrial drawl point.

[12 marks]

Given load = 200 kW at 0.75 pf.
fed from 11 kV.
New p.f = 0.9
To find Rating of capacitor



Case 1

$\phi_1 = \cos^{-1} 0.75$
$= 41.41$

$Q_1 = P_1 \tan \phi_1$
$= 200 \tan 41.41$
$Q_1 = 176.383$ MVAR

Case 2

$\phi_2 = \cos^{-1} 0.9 = 25.842$

$Q_2 = P_1 \tan \phi_2 = 200 \tan 25.842$
$= 96.8644$

$\therefore$ Installed capacity of capacitor $= 176.383 - 96.8644$

$$\boxed{Q_c = 79.518 \text{ MVAR}}$$

4

Q.5 (d) A 2-wire DC distributor cable AB is 2.2 km long and supplies loads of 25 A, 50 A, 75 A at 0.4 km, 1 km and 1.6 km from the point A. Each conductor has a resistance of 0.05 Ω/km. Calculate the potential difference at each point if potential difference of 400 volts is maintained at point A.

[12 marks]

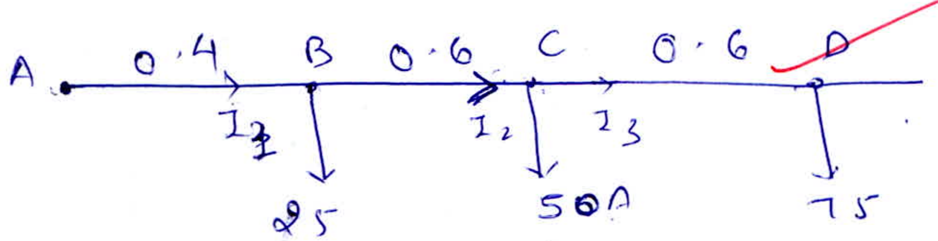
Given 2 wire DC distributor

$AB = 2.2$ km

total resistance of ~~co~~ conductors $= 2r$

$= 2 \times 0.05\ \Omega/\text{km}$

$r' = 0.1\ \Omega/\text{km}$



$I_3 = 75\text{A}$. $I_2 = 50 + 75 = 125$. $I_1 = 25 + I_2 = 150\text{A}$

$\therefore V_B = V_A - 0.4 \times r' \times I_1$

$= 400 - 0.4 \times 0.1 \times 0.4 \times 150$

$\boxed{V_B = 397.6\ \text{V}}$

$V_C = V_B - 0.6 \times 0.1 \times I_2$,

$= 397.6 - 0.6 \times 0.1 \times 125$

$\boxed{V_C = 390.1\ \text{V}}$

$V_D = V_C - 0.6 \times 0.1 \times I_3$

$=$ ~~$V_C - 0$~~ $390.1 - (0.6 \times 0.1 \times 75)$

$\boxed{V_D = 385.6\ \text{V}}$

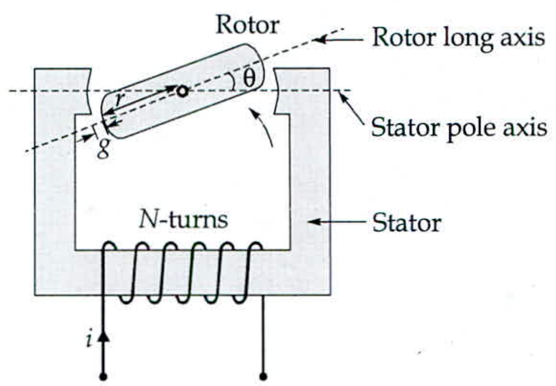
4

Q.5 (e) For the electro-mechanical configuration shown in figure, assume all the field energy is present in the overlapping regions. Radius is r and the airgap length is g. Calculate the magnitude of torque, when the maximum flux density in the airgap is limited to 2.2 T. The other data are as follows:

Radius, r = 50 mm,

Gap length, g = 2 mm,

Length normal to radius is l = 10 mm.



[12 marks]

Given radius $r = 50\,mm$

airgap length $= g = 2\,mm$

$B_{max} = 2.2\,T$

$l = 10\,mm$

we know torque $= F \times d$

$= F\, d \sin\theta$

$= B\, i\, l\, d \sin\theta$

Do not write in this margin

$$= 2.2 \times l \times 10 \times 10^{-3} \sin \theta.$$

$NI = \phi \times \text{reluctance}.$

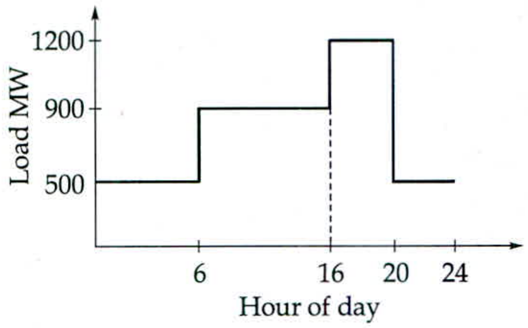
$$\text{reluctance} = \frac{l}{\mu_0 \mu_r A}.$$

Q.6 (a) 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.6 (b) **(i)** The incremental fuel costs for two units of a plant are $\lambda_1 = \dfrac{df_1}{dP_{g1}} = 0.012P_{g1} + 8.0$; $\lambda_2 = \dfrac{df_2}{dP_{g2}} = 0.008\,P_{g2} + 9.6$ where f is in (Rs/hour) and P_g is in megawatts (MW). If both units operate at all times and maximum and minimum loads on each unit are 550 and 100 MW respectively then find λ of the plant in Rs/MWh versus plant output in MW for economic dispatch as total load varies from 200 to 1100 MW.

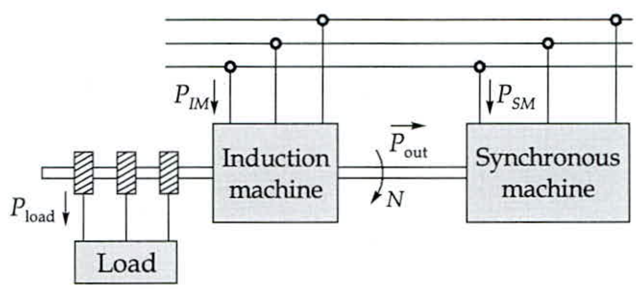
(ii) Find the saving in Rs/hour for economic dispatch of load between the units of part (i) compared with their sharing the output equally when the total plant output is 600 MW.

[20 marks]

Q.6 (c) A 3-ϕ wound-rotor induction machine is mechanically coupled to a 3-ϕ synchronous machine as shown in figure. The synchronous machine has 4-poles and the induction machine has 6-poles. The stator of the two machines are connected to a 3-ϕ , 50 Hz supply. The rotor of the induction machine is connected to a 3-ϕ resistive load. Neglect rotational losses and stator resistance losses. The load power is 1 p.u. The synchronous machine rotates at the synchronous speed.

(i) The rotor rotates in the direction of the stator rotating field of the induction machine. Determine the speed, frequency of the current in the resistive load, and power taken by the synchronous machine and by the induction machine from the source.

(ii) Repeat part (i) if the phase sequence of the stator of the induction machine is reversed.



[20 marks]

Q.7 (a) 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]

Given primary : sec : tertiary

11 kV 6 MVA : 3.3 kV 3 MVA : 400 V 3 MVA

Y : Y : Δ

Q.7 (b) A 4-pole, 50-Hz turbo-alternator is rated at 45 MW, 0.8 pf lag and has an inertia of 25000 kg-m^2. It is connected via a transmission system to another set whose corresponding data is 2-pole, 50 Hz, 60 MW, 0.75 lag, 9000 kg-m^2. Calculate the inertia constant of each set on its own rating and that of the single equivalent set connected to an infinite bus-bar and on a base rating of 100 MVA.

[20 marks]

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Do not write in this margin

Q.7 (c) The following test results are obtained for a 3-ϕ, 280 V, 60 Hz, 6.5 A induction machine.

Block-rotor test : 44 V, 60 Hz, 25 A, 1250 W

No load test : 208 V, 60 Hz, 6.5 A, 500 W

The average resistance measured between two stator terminals is 0.27 Ω.

Determine:

(i) the no load rotational loss.

(ii) the output power in horse power (hp) at $s = 0.1$.

(iii) the efficiency.

(Take 1 hp = 746 W) **[20 marks]**

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.8 (a) Figure below shows the single line diagram of a sample 3-bus power system. Data for this system are given in table-1 and table-2.

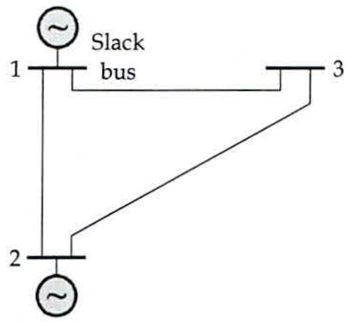

Table 1: Scheduled generation and loads and assumed bus voltage

Bus code i	Assumed Bus voltage	Generation		Load	
		MW	MVAr	MW	MVAr
1 (slack bus)	$1.05 + j0.0$	–	–	0	0
2	$1 + j0.0$	50	30	305.6	140.2
3	$1 + j0.0$	0	0	138.6	45.2

Base MVA = 100

Table 2: Line impedance

Bus code $i - k$	Impedance Z_{ik} (p.u.)
1 - 2	$0.02 + j0.04$
1 - 3	$0.01 + j0.03$
2 - 3	$0.0125 + j0.025$

Using the Gauss-Seidel method, determine the phasor values of voltages at buses 2 and 3. Perform one iteration only.

[20 marks]

Given $Z_{12} = 0.02 + j0.04$

$$y_{12} = \frac{1}{0.02 + j0.04} = 10 - 20i$$

$$Z_{13} = 0.01 + j0.03 \qquad y_{13} = \frac{1}{0.01 + j0.03} = 10 - 30i$$

$$Z_{23} = 0.0125 + j0.025 \qquad y_{23} = \frac{1}{0.0125 + j0.025} = 16 - 32j$$

$$Y_{bus} = \begin{bmatrix} 20 - 50i & -(10 - 20i) & -(10 - 30i) \\ -(10 - 20i) & 26 - 52i & -(16 - 32i) \\ -(10 - 30i) & -(16 - 32i) & 26 - 62i \end{bmatrix}$$

Now given

$\cancel{P_1 = 10}$ $V_1 = 1.05$.

$V_2 = 1\angle 0$ $V_3 = 1\angle 0$.

$P_{G_1} = 50$. $Q_G = 30$. $P_D = 305.6$
$Q_D = 140.2$.

$P_2 = P_{G_1} - P_D = (50 + j30) - (305.6 + j140.2)$

$P_2 = -255.6 - 110.2i$

$P_3 = P_{G_3} - P_{D_3} = (0 + j0) - (138.6 + 45.2i)$

$P_3 = -138.6 - 45.2i$

Now, By Gauss Seidal

$$V_2 = \frac{1}{y_{22}}\left[\frac{P_2 - jQ_2}{V_2} - \sum_{\substack{i=1 \\ i\neq 2}}^{3} y_{i2} V_i V_2\right]$$

$$= \frac{1}{26-52i}\left[\frac{-255.6 + 110.2i}{1.} - [y_{12} V_1 V_2] - [y_{13} V_3 V_2]\right]$$

$$= \frac{1}{26-52i}\left[-255.6 + 110.2i - [(-10+20i) \times 1.05 \times 1] - (-10+30i) \times 1 \times 1\right]$$

$$= \frac{1}{26-52i}\left[-255.6 + 110.2i + 10.5 - 21i + 10 - 30i\right]$$

$$= \frac{1}{26-52i}\left[-235.1 + 59.2i\right]$$

$$V_2 = 4.17 \angle -130.698$$

$$V_3 = \frac{1}{y_{33}}\left[\frac{P_3 - jQ_3}{V_3} - \sum_{\substack{i=1 \\ i \neq 3}}^{2} y_{i3} V_3 V_i\right]$$

$$= \frac{1}{26-62i}\left[\frac{-138.6+45.2i}{1} - [(-10+30i) \times 1 \times 1.05) - [(-16+32i) \times 1 \times 1)\right]$$

$$= \frac{1}{26-62i}\left[-138.6+45.2i + 10.5 - 31.5i + 16 - 32i\right]$$

$$= \frac{1}{26-62i}\left[-112.1 - 18.3i\right]$$

$$\boxed{V_3 = 1.689 \angle -103.48}$$

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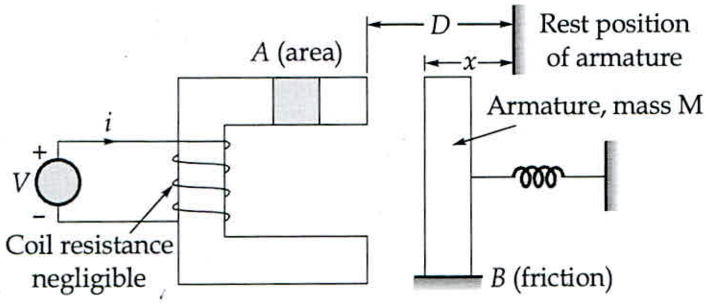
8 (b) For the electromechanical system shown in figure, the area of cross-section of core is A and the air-gap flux density under steady operating condition is $B(t) = B_m \sin\omega t$.

Find:

(i) the coil voltage.

(ii) the force of field origin as a function of time.

(iii) the displacement of armature as a function of time.



[20 marks]

(i) coil voltage $= \dfrac{d\phi}{dt}$

$= \dfrac{d}{dt}(B_m \sin\omega t \cdot A)$

$= A B_m \omega \cos\omega t$

3

(ii) $f = \dfrac{v}{d} = \dfrac{A B_m \omega \cos\omega t}{D.}$

(iii) displacement =

Q.8 (c) A 1-ϕ 10 kVA, 2400/240 V, 50 Hz distribution transformer has the following characteristics.

Core loss at rated voltage = 100 W
Copper loss at half load = 60 W

(i) Determine the per unit rating at which the transformer efficiency is maximum. Also determine this efficiency if the load power factor is 0.9 (lag).

(ii) The transformer has the following load cycles

no load for 6 hours.
70% full load for 10 hours at 0.8 p.f.
90% full load for 8 hours at 0.9 p.f.

Determine the all-day efficiency of the transformer:

(iii) If the above transformer is connected as autotransformer then, determine the maximum kVA rating and for this rating determine the efficiency when delivering full load at 0.8 power factor lagging.

[20 marks]

Given core loss at rated vtg = 100 W
copper loss at half load = 60 W
copper loss at full load
$= 60 \times 2^2$
$= 240 W$

(i). pu rating for max. efficiency

$$\frac{S_{max}}{S_{rated}} = \sqrt{\frac{P_i}{P_{cu}}} = \sqrt{\frac{100}{240}} = 0.6455$$

Now $\boxed{pu = 0.6455}$

$S_{max} = 0.6455 \times 10$
$= 6.455$ kVA

$\therefore \eta_{max} = \frac{S_{max} \times 0.9}{S_{max} \times 0.9 + 2P_i}$

Because at η_{max} $P_i = P_{cu}$

$$\eta_{max} = \frac{6.455 \times 0.9}{6.455 \times 0.9 + 2 \times 0.1} \times 100$$

$$= 96.672\%$$

(ii) All day efficiency

$$O/P = (0.7 \times 10 \times 10 \times 0.8) + (0.9 \times 10 \times 8 \times 0.9) \text{ kWh}$$

$$= 56 + 64.8$$

$$= 120.8 \text{ kWhr}.$$

Now, $P_{core\ loss} = 24 \times 100$
$= 2.4 \text{ kWhr}$

$$P_{copper} = (0.7)^2 \times 10 \times P_{cufl} + (0.9)^2 \times 8 \times P_{cufl}.$$

$$= 11.38 \times P_{cufl}$$

$$= 11.38 \times 240$$

$$= 2.7312 \text{ kW}$$

$$\therefore \eta = \frac{120.8}{120.8 + 2.4 + 2.7312} \times 100$$

$$\boxed{\eta = 95.93\%}$$

(iii) KVA max

$$= \left[1 + \frac{1}{a}\right] S_{2\,wind\ xmer}$$

$$= \left[\cancel{1 + \frac{1}{\left(\frac{2400}{240}\right)} \times 10}\right] \cancel{\times 10}$$

$$= \cancel{1.1 \times 10}$$

$$= \left[1 + \frac{1}{\frac{240}{2400}}\right] \times 10$$

$$= (1+10) \times 10 = 110 \text{ kVA}$$

$$\eta = \frac{110 \times 0.8}{110 \times 0.8 + 0.100 + 0.24}$$

$$\boxed{\eta = 99.615\%}$$

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Space for Rough Work

$(\varepsilon_r - 1)\, 4\pi \varepsilon_0 \cancel{N} R^3$

$\varepsilon_0 \cancel{\varepsilon_r} \chi \cancel{E} = 4\pi \varepsilon_0 N R^3 \cancel{E}$

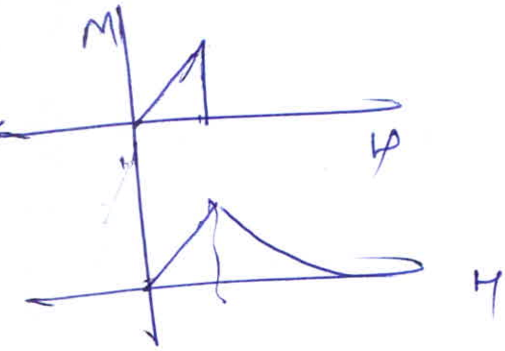
$= N \alpha E$

$\varepsilon_r - 1 = 4\pi N R^3$

$\varepsilon_r = 1 + 4\pi N R^3$

$4\pi \varepsilon_0 \cancel{N} R^3 \cancel{E} = \cancel{N} \alpha \cancel{E}$

$\boxed{\alpha = 4\pi \varepsilon_0 R^3}$



$200 \tan(\cos^{-1} 0.75) - 200 \tan \cos^{-1} 0.9$

$Q = 79.5189$