Try to avoid calculation mistake

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ESE 2023 : 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 ☐		
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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	32
Q.2	44
Q.3	
Q.4	47
Section-B	
Q.5	34
Q.6	
Q.7	32
Q.8	
Total Marks Obtained	189

Signature of Evaluator: Sourabh kumar

Cross Checked by: ....

IMPORTANT INSTRUCTIONS

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

DONT'S

1. Do not write your name or registration number anywhere inside this Question-cum-Answer Booklet (QCAB).
2. Do not write anything other than the actual answers to the questions anywhere inside your QCAB.
3. Do not tear off any leaves from your QCAB, if you find any page missing do not fail to notify the supervisor/invigilator.
4. Do not leave behind your QCAB on your table unattended, it should be handed over to the invigilator after conclusion of the exam.

DO'S

1. Read the Instructions on the cover page and strictly follow them.
2. Write your registration number and other particulars, in the space provided on the cover of QCAB.
3. Write legibly and neatly.
4. For rough notes or calculation, the last two blank pages of this booklet should be used. The rough notes should be crossed through afterwards.
5. If you wish to cancel any work, draw your pen through it or write "Cancelled" across it, otherwise it may be evaluated.
6. Handover your QCAB personally to the invigilator before leaving the examination hall.

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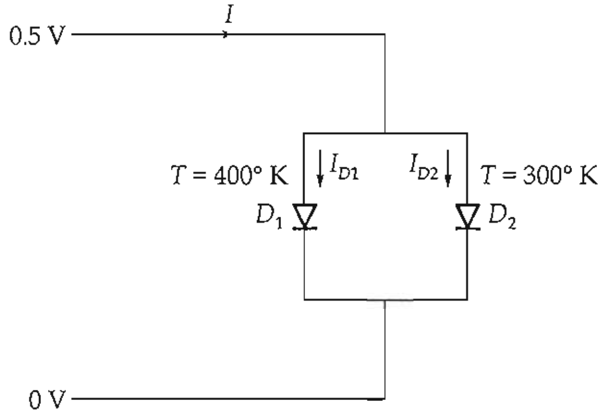
Section A : Basic Electronics Engineering + Analog Electronics + Electrical Materials

Q.1 (a) For the circuit shown in figure below, the two identical Si PN junction diodes are connected in parallel and a 0.5 V of forward bias is applied. Diode D_1 is heated to 400°K temperature and diode D_2 was kept at 300°K temperature. Calculate the ratio between the current flowing through diode D_1 and diode D_2. (Ideality factor of Si = 2).



[12 marks]

Across D_1

$V_{D1} = 0.5$ V

$V_{T_1} = \frac{T}{11600} = \frac{400}{11600} = 34.48$ mV

Across D_2

$V_{D2} = 0.5$ V

$V_{T_2} = 25$ mV (at T = 300k).

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$I_{D1} = I_s [e^{V_{D1}/\eta V_{T_1}} - 1]$.

$I_{D2} = I_s [e^{V_{D2}/\eta V_{T_2}} - 1]$ {By shockley eqn}

Dividing

$$\frac{I_{D1}}{I_{D2}} = \frac{e^{\frac{0.5}{2 \times 34.48m}} - 1}{e^{\frac{0.5}{2 \times 25m}} - 1}$$

$= 0.06392$

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Q.1 (b) The average magnetic moment along the field direction per spin in Bohr magnetron when a paramagnetic spin system is subjected to a uniform magnetic field is 3.2×10^{-4} Bohr magnetron. Calculate the uniform magnetic field applied if the temperature is 27°C. (1 Bohr magnetron = 9.27×10^{-24} A/m²).

[12 marks]

Let the total magnetic moment caused by ~~spin only~~

~~$p_s = \pm g \times \frac{h}{2\pi} \times \frac{e}{m}$~~

$p_0 = \frac{e^2 r^2 B}{4m}$

$p_s = \pm g \times \frac{h}{2\pi} \times \frac{e}{m} = \pm p_B$

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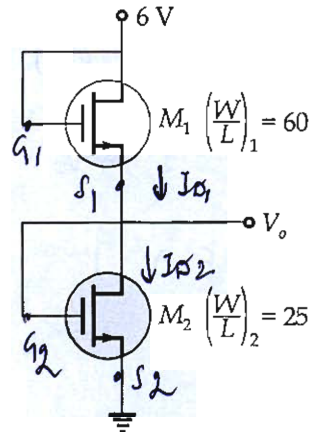
Incomplete Solution

Q.1 (c) 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.

[12 marks]

since Drain & Gate shorted Both works in saturation region

$V_{G1} = 6$ | $V_{G2} = V_0$

$V_{S1} = V_0$ | $V_{S2} = 0$

$V_{GS1} = 6 - V_0$ | $V_{GS2} = V_0$

$I_{D1} = I_{D2}$

$$60\left[V_{GS1} - V_T\right]^2 = 25\left[V_{GS2} - V_T\right]^2$$

$\left(\because\ I_D = \mu_n C_{ox}\left(\frac{W}{L}\right)(V_{GS} - V_T)^2\right)$.

So,

$$\frac{60}{25} = \left(\frac{V_0 - 0.9}{6 - V_0 - 0.9}\right)^2$$

$$[2.4]^{1/2} = \frac{V_0 - 0.9}{5.1 - V_0}$$

$$1.55\,(5.1 - V_0) = V_0 - 0.9$$

$$7.91 - 1.55\,V_0 = V_0 - 0.9$$

$$8.81 = 2.55\,V_0$$

$$\boxed{V_0 = 3.455\ \text{V}}$$

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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 :-

→ Here large specimens are brought up & are divided upon nanometer level either in all directions, one direction, two directions, three directions.

→ The methods used here are attrition, grinding etc.

→ carbon nano tubes are formed using above Techniques.

→ Lots of wastes produced.

Bottom-up Technique :-

→ small micrometer particles are piled & attached to get the large material.

→ colloidal dispersion is one of the method used here.

→ Graphene is one of the nano material made by using above method.

→ wastes formed are minimal.

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Q.1 (e) The Hall coefficient of a certain silicon specimen was found to be -8.25×10^{-5} m^3/C at 300° K. If the conductivity is 2.50 ℧/cm, then find :

(i) type of semiconductor

(ii) density of charge carrier

(iii) mobility of charge carrier

[12 marks]

(i) $R_h = -8.25 \times 10^{-5}$

since it is negative. It is N-type extrinsic semiconductor

(ii) density of charge carrier

$= \frac{1}{R_h} = 12121.21$

≈ 12122

(iii) $\sigma = nq\mu_n$

$2.5 = 12122 \times \mu_n$

$\mu_n = 2.0625 \times 10^{-4}$ cm²/V-s

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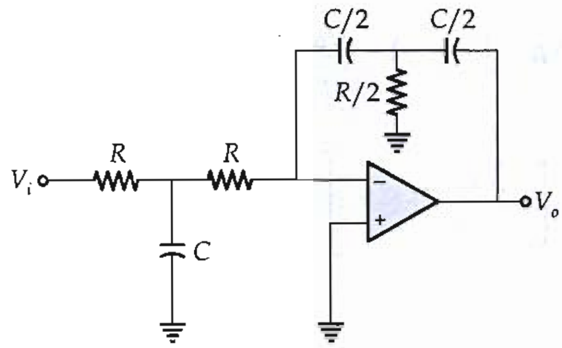
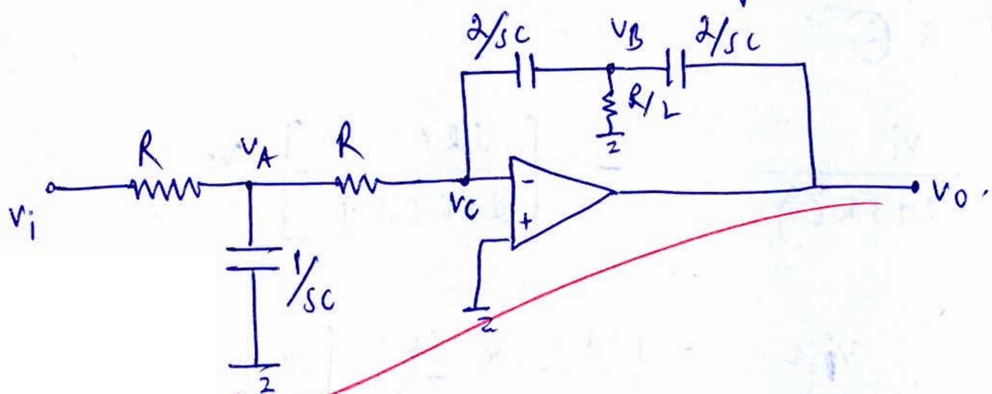
Q.2 (a) Consider the circuit shown in figure



Find the relation between input V_i and output V_o. (Assume the op-amp is ideal).

[20 marks]

Let us make above circuit in Laplace domain



$$V_C = V^{(-)} = V^{(+)} = 0 \text{ (virtual ground)}$$

By nodal at V_B.

$$\frac{2V_B}{R} + \frac{V_B}{2}sC + \frac{(V_B - V_0)}{2}sC = 0.$$

$$V_B\left[\frac{2}{R} + \frac{sC}{2} + \frac{sC}{2}\right] = V_0\left[\frac{sC}{2}\right].$$

$$V_B = \frac{V_0\left[sC/2\right]}{\left[sC + 2/R\right]}$$

$$V_B \Rightarrow V_0\left[\frac{sRC}{2sRC + 4}\right] \text{ ——— (1)}$$

By nodal at V_A

$$\frac{V_i - V_A}{R} = V_A\, sC + \frac{V_A}{R}$$

$$\frac{V_i}{R} = V_A\left[\frac{2}{R} + sC\right] \Rightarrow V_A = \frac{V_i}{2 + sRC} \quad \text{—(2)}$$

By nodal at V_C

$$\frac{V_A}{R} = -V_B\left[\frac{sC}{2}\right]$$

using (1) & (2)

$$\frac{2}{sRC} \times \frac{V_i}{(2+sRC)} = -\left[\frac{sRC}{2sRC+4}\right] V_0$$

$$V_i = -\left[\frac{sRC}{2} \times \frac{sRC}{2}\right] V_0$$

$$\boxed{V_0 = \frac{-4}{s^2R^2C^2}\, V_i}$$

(18)

Q.2 (b) Zirconium has an HCP crystal structure and a density of 6.51 g/cm^3.

(i) Calculate the volume of its unit cell in cubic meters if the atomic weight of Zirconium is 91.2 g/mol.

(ii) If c/a ratio is 1.593, then compute the values of c and a.

[20 marks]

(i)

$$\rho = \frac{Z \times m_A}{V \times N_A}$$

For HCP, $Z = 6$.

$$V = \frac{6 \times 91.2}{6.51 \times 6.02 \times 10^{23} \times 6.51}$$

$$V = 2.145 \times 10^{-23} \text{ cm}^3 \quad \text{—— (1)}$$

(ii)

$$\frac{c}{a} = 1.593$$

volume of Hexagon $= 6 \times 6 \times \frac{\sqrt{3}}{4} a^2$

~~value~~

$$= 1.593 \times 6 \times \frac{\sqrt{3}}{4} \times a^3 \quad \text{—— (2)}$$

thus,

equating (1) & (2)

$$1.593 \times 6 \times \frac{\sqrt{3}}{4} \cdot a^3 = 2.145 \times 10^{-23}$$

$$a = 1.731 \times 10^{-8} \text{ cm}$$

$$a = 1.731 \text{ Å}$$

then,

$c = 1.593a = \underline{2.758\ \text{Å}}$

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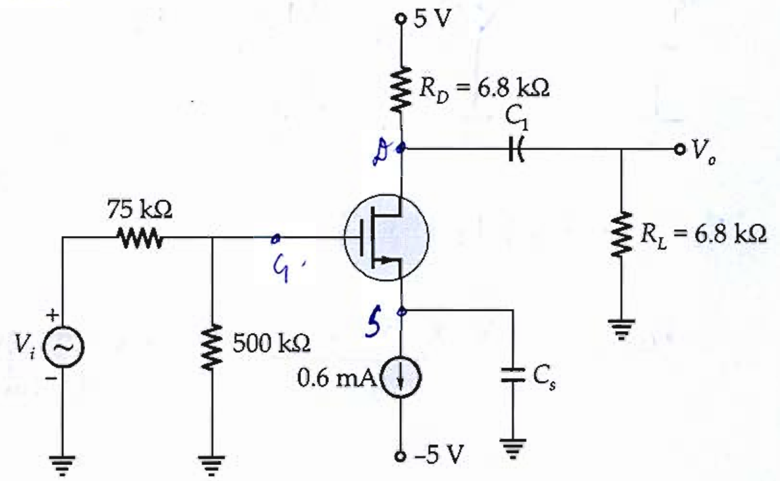
Q.2 (c) Determine the small signal voltage gain of the circuit shown in below figure having parameters $V_T = 0.8$ V, $k = \frac{\mu_n C_{ox} W}{2L} = 1.2$ mA/V², $\lambda = 0$. Also calculation gate-to-source voltage (V_{GSQ}).

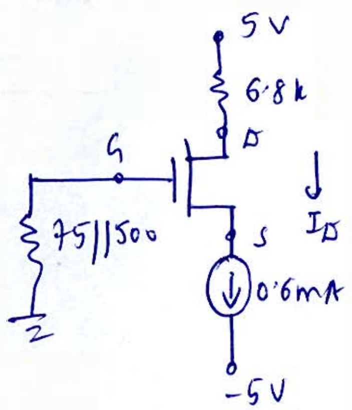


[20 marks]

DC - analysis :-

All ac small signal voltage source → short
All capacitors open.

$I_D = 0.6$ mA



From circuit $V_G = 0$

$V_D = 5 - I_D \times 6.8$
$= 0.92$ V

Now,

$I_D = k\,[V_{GS} - V_T]^2$ (saturation)

$0.6 = 1.2\,[V_{GS} - 0.8]^2$

$(V_{GS})_Q = 1.51$ V

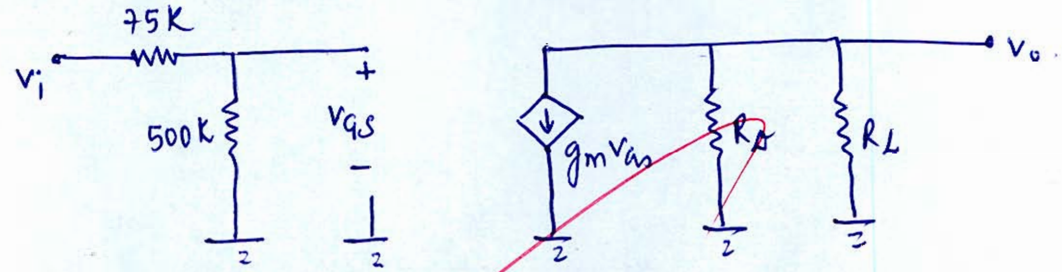
Here

$g_m = 2k\,[V_{GS} - V_T]$

$= 2 \times 1.2 \times (1.51 - 0.8)$.

$= 1.704$ m℧

small signal model :-



$$v_o = -g_m (R_D \| R_L)\, v_{gs}$$

&

$$v_{gs} = v_i \times \frac{500}{575} \quad \text{(by voltage division)}.$$

we get,

$$\frac{v_o}{v_i} = -g_m [R_D \| R_L] \times \frac{500}{575}$$

$$A_v = \frac{v_o}{v_i} = -5.04$$

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Good Approach

Q.3 (a) The electron mobility of Indium (In) is measured to be 7.5 cm^2/V-s and the resistivity of In is 9.43×10^{-6} Ω-m at room temperature (27°C).

(i) Calculate the number of free electrons donated by each In atom in crystal.

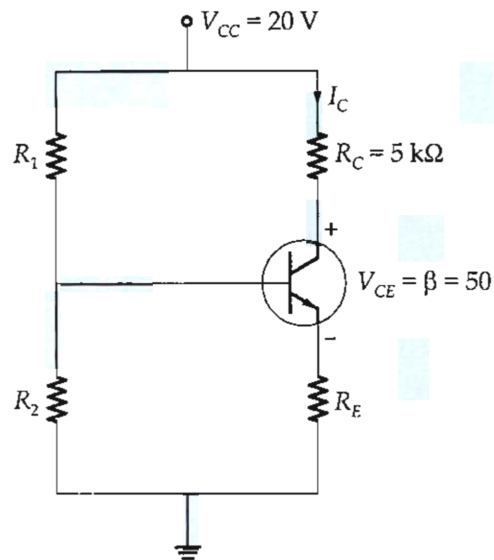
(ii) If the mean free path of electrons in In is 8.2 nm then calculate the mean speed of electrons in In.

(iii) Calculate the thermal conductivity of In at room temperature.

(Assume atomic mass of In = 115 g/mol and density = 7.3 g/cm^3]

[20 marks]

Q.3 (b) A silicon transistor with $\beta = 50$ is used in a self bias circuit as shown in figure below.



The operating point is $Q(11.5\text{ V}, 1.5\text{ mA})$. For stability factor $S \leq 2$, determine the values of R_1, R_2 and R_E.

[20 marks]

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Q.3 (c) (i) An amplifier has a mid-frequency gain of 800. Its upper and lower cut-off frequency f_U and f_L are 16 kHz and 40 Hz respectively. Determine the bandwidth of the amplifier. What will be the bandwidth if 2% of the output signal is given as a negative feedback?

(ii) Define superconductivity. What are the condition required for superconductor? Also briefly discuss the properties of superconductor.

[10 + 10 marks]

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Q.4 (a) (i) A crystal oscillator has the following parameters :

$L_s = 0.33$ H, $C_s = 0.065$ pF, $C_P = 1$ pF, $R_s = 5.5$ kΩ

(a) Calculate the series-resonant frequency.

(b) By what percentage does the parallel-resonant frequency exceed the series resonant frequency?

(c) Calculate the quality factor Q of the crystal at series and parallel resonant frequencies.

(ii) A solid specimen of dielectric has $\varepsilon_r = 4.1$ and $\tan\delta = 0.001$ at a frequency of 60 Hz. If it is subjected to an alternating field of 45 kV/cm then calculate the heat generated in the specimen due to the dielectric loss.

[15 + 5 marks]

(i)

(a)

$$w_s = \frac{1}{\sqrt{L_s C_s}}$$

$$f_s = \frac{1}{2\pi\sqrt{L_s C_s}}$$

$$= \frac{1}{2\pi\sqrt{0.33 \times 0.065 \times 10^{-12}}} = 1.09 \text{ MHz}$$

(b)

$$w_p = \frac{1}{\sqrt{L_s C_{eq}}}$$

$$c_{eq} = \frac{C_s C_p}{C_s + C_p} = 0.061033 \text{ pF}$$

$$f_p = \frac{w_p}{2\pi} = \frac{1}{2\pi\sqrt{0.33 \times 0.061033 \times 10^{-12}}}$$

$$= 1.121 \text{ MHz}$$

$$\% \text{ change} = \frac{(f_p - f_s) \times 100}{f_s} = 2.844\ \%$$

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(c)

$$(Q)_{series} = \frac{\omega_s L}{R}$$

$$= \frac{2\pi \times 1.09 \times 10^6 \times 0.33}{5.5 \times 10^3}$$

$$(Q)_{series} = 410.92$$

$$(Q)_{parallel} = \omega_p R C_{eq}$$

$$= 1.121 \times 10^6 \times 5.5 \times 10^3 \times 0.061033 \times 10^{-12}$$

$$= 3.763 \times 10^{-4}$$

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(ii)

$$w_f = \frac{(E_{rms})^2 \times f \times \epsilon_r''}{1.8 \times 10^{12}} \quad (watt/cm^3)$$

$$w_f = \frac{(45)^2 \times 60 \times (4.1) \times \tan\delta \times 10^6}{1.8 \times 10^{12}}$$

$$= \frac{(45)^2 \times 60 \times 4.1 \times 0.001 \times 10^6}{1.8 \times 10^{12}} \quad watt/cm^3$$

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$$w_f = 2.7675 \times 10^{-4} \text{ watt/cm}^3$$

or

$$w_f = 276.75 \text{ watt/m}^3$$

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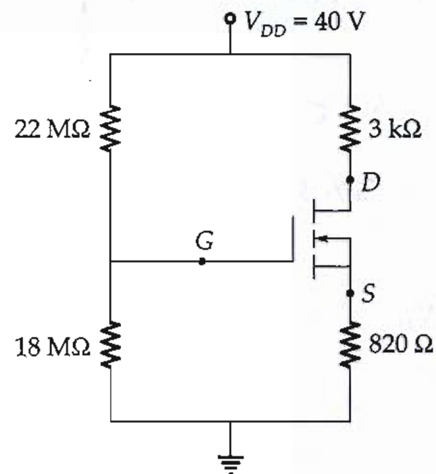
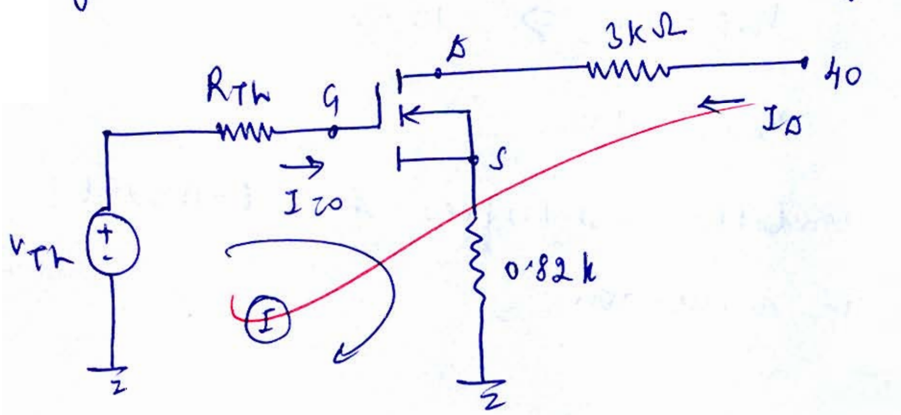
Q.4 (b) Consider the circuit shown below :



If $V_{GS(TH)}$ = 5 V, $I_{D(ON)}$ = 3 mA at $V_{GS(ON)}$ = 10 V, then determine I_{DQ}, V_{GSQ} and V_{DS}.

[20 marks]

By Thevenin equivalent about G & ground



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since $I = 0$

$V_G = V_{Th}$

& $V_{Th} = \frac{40 \times 18}{18 + 22} = 18$ V

& $R_{Th} = 22 \| 18 = 9.9$ MΩ

So, $V_G = 18$ V

with $V_{GS} = 10$

thus $V_S = 8$ V .

from circuit we can also say that

$$V_D = 40 - 3I_D$$
$$= 40 - 3\times3 = 31\,V.$$

$$\therefore \quad V_{DS} = V_D - V_S = 23\,V$$

<u>checking for saturation</u>

$$V_{DS} > V_{GS} - V_T$$

here $V_{GS} - V_T \Rightarrow 10 - 5 = 5V$

& $V_{DS} = 23\,V$

thus, condition satisfies & E-MOSFET operating in saturation.

or

$$I_D = K(V_{GS} - V_T)^2 \quad \text{——— (A)}$$

$$K = \frac{3}{(5)^2} = 0.12\ mA/V^2$$

<u>operating condn case</u> :-

By KVL in (I).

$$-V_{Th} + V_{GS} + 0.82\,I_D = 0.$$

$$V_{GS} = 18 - 0.82\,I_D \quad \text{——— (1)}.$$

or $$I_D = \left[\frac{18 - V_{GS}}{0.82}\right].$$

By (A),

$$\frac{18 - V_{GS}}{0.82} = (V_{GS} - 5)^2 \times K$$

$$\frac{18 - V_{GS}}{0.82} = (V_{GS}^2 + 25 - 10V_{GS})\, 0.12$$

$$0.12\, V_{GS}^2 + 0.0195\, V_{GS} - 18.951 = 0$$

$$V_{GS} = 12.49\ ,\ -12.65$$

From (1)

$$I_D = 6.72\ mA$$

Hence,

$$V_D = 40 - 3I_D$$
$$= 19.84\ V$$

Also,

$$V_S = 0.82\, I_D = 5.51\ V$$

$$V_{DS} = V_D - V_S = 14.33$$

So,

$$V_{DS} > V_{GS} - V_T \quad \text{(saturation)}.$$

Thus we can say that,

$$(I_D)_Q = 6.72\ mA$$
$$V_{DS} = 14.33\ V$$
$$(V_{GS})_Q = 12.49\ V$$

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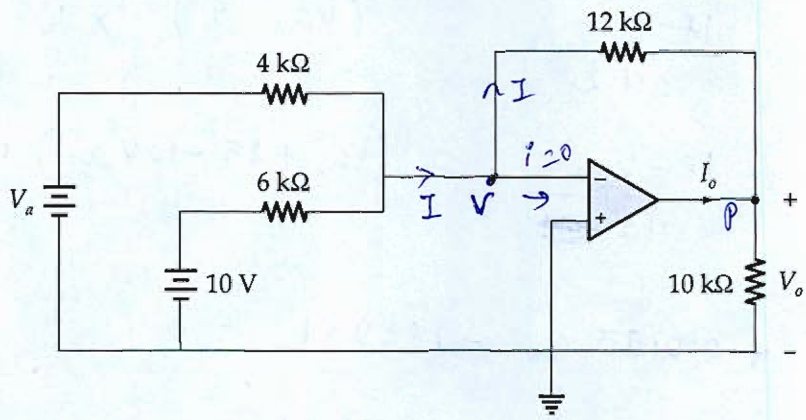
Q.4 (c) For the circuit shown below, the op-amp is considered to be ideal.



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

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

[20 marks]

(i) $V = V^{(-)} = V^{(+)} = 0$ (virtual ground).

thus,

$$I = \left[\frac{V_a}{4} + \frac{10}{6}\right] \quad \text{—— (1)}$$

For $V_a = 4$

$$I = 2.67 \text{ mA}$$

Also,

$$\frac{0 - V_o}{12} = I. \quad \text{— (2)} \ (i = 0 \Rightarrow \text{ideal opamp})$$

$$V_o = -5.34 \text{ V}$$

At P by KCL

$$I_o + I = \frac{V_o}{10}$$

$$I_o + 2.67 = \frac{-5.34}{10}$$

$$I_o = -3.204 \text{ mA}$$

(ii) using ① & ②.

$$V_0 = -12\left[\frac{V_a}{4} + \frac{10}{6}\right].$$

For $V_{sat} = +12\ V$

$$12 = -12\left[\frac{V_a}{4} + \frac{10}{6}\right].$$

$$\boxed{V_a = -10.67}$$

For $V_{sat} = -12\ V$

$$-12 = -12\left[\frac{V_a}{4} + \frac{10}{6}\right].$$

$$\boxed{V_a = -2.67}$$

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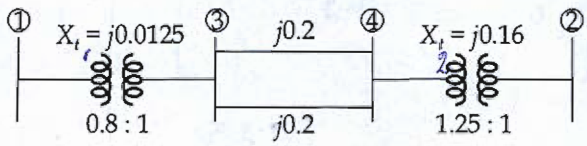
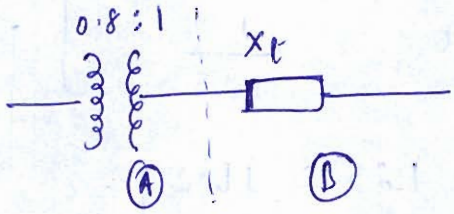
Section B : Electrical Machine-1 + Power Systems-2

Q.5 (a) The single line diagram of a 4-bus power system is shown in figure. Reactances are given in per unit on a common MVA base. The transformer T_1 and T_2 have tap settings of 0.8 : 1 and 1.25 : 1 respectively. Obtain the bus admittance matrix of the system.



[12 marks]



Transmission Parameter for (A)

$$[T]_A = \begin{bmatrix} 0.8 & 0 \\ 0 & \frac{1}{0.8} \end{bmatrix}$$

similarly for (B)

$$[T]_B = \begin{bmatrix} 1 & X_t \\ 0 & 1 \end{bmatrix}.$$

$$[T]_{eq} = [T_A][T]_B = \begin{bmatrix} 0.8 & 0 \\ 0 & \frac{1}{0.8} \end{bmatrix} \begin{bmatrix} 1 & jX_t \\ 0 & 1 \end{bmatrix}$$

$$\begin{bmatrix} V_1 \\ I_1 \end{bmatrix} \Rightarrow \begin{bmatrix} 0.8 & j0.8X_{t_1} \\ 0 & \frac{1}{0.8} \end{bmatrix} \begin{bmatrix} V_3 \\ I_3 \end{bmatrix}.$$

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similarly.

$$T_{34} = \begin{bmatrix} 1 & 0.2j \\ 0 & 1 \end{bmatrix}.$$

Also,

$$T_{(42)} = \begin{bmatrix} 1.25 & j1.25X_{t2} \\ 0 & \frac{1}{1.25} \end{bmatrix}.$$

overall Parameter

$$[T] = \begin{bmatrix} 0.8 & j0.8 \times 0.0125 \\ 0 & 1.25 \end{bmatrix} \begin{bmatrix} 1 & 0.2j \\ 0 & 1 \end{bmatrix}$$

$$\begin{bmatrix} 1.25 & j\,1.25 \times 0.16 \\ 0 & \frac{1}{1.25} \end{bmatrix}.$$

$$[T] = \begin{bmatrix} 0.8 & 0.17i \\ 0 & 1.25 \end{bmatrix} \begin{bmatrix} 1.25 & j0.2 \\ 0 & 0.8 \end{bmatrix}.$$

$$[T] = \begin{bmatrix} 1 & 0.296j \\ 0 & 1 \end{bmatrix}$$

$$\begin{bmatrix} V_1 \\ I_1 \end{bmatrix} = \begin{bmatrix} 1 & 0.296j \\ 0 & 1 \end{bmatrix} \begin{bmatrix} V_2 \\ I_2 \end{bmatrix}.$$

$$V_1 = V_2 + 0.296j\, I_2$$

$$I_1 = I_2,$$

so, $I_1 = I_2 = \frac{-1}{0.296j} V_2 + \frac{1}{0.296j} V_1$

or

$$\begin{bmatrix} I_1 \\ I_2 \end{bmatrix} = \begin{bmatrix} \frac{1}{0.296j} & \frac{-1}{0.296j} \\ \frac{+1}{0.296j} & \frac{-1}{0.296j} \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \end{bmatrix}$$

$$Y = -j \begin{bmatrix} 3.38 & -3.38 \\ 3.38 & -3.38 \end{bmatrix}_{2\times 2}$$

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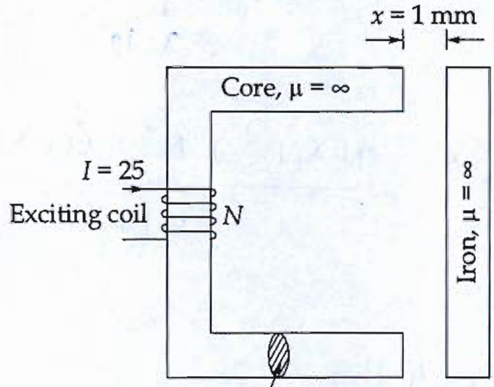
Q.5 (b) An electromagnet, shown in figure, is required to exert a 500 N force on the iron at an airgap of 1 mm, while the exciting coil is carrying 25 A dc. The cross-section at the air gap is 600 mm^2 in area. Calculate the required number of turns in the exciting coil.



Area of cross-section, 600 mm^2

[12 marks]

coenergy, $W_f' = \frac{1}{2} L(x) i^2$

Here $\mathcal{R}(x) = \frac{2x}{\mu_0 A}$

$\mathcal{R}(x)\Big|_{at\ x = 1mm} = \frac{2 \times 10^{-3}}{4\pi \times 10^{-7} \times 600 \times 10^{-6}}$

So, $L(x) = \frac{N^2}{\mathcal{R}(x)} = \frac{\mu_0 N^2 A}{2x}$.

we know, $F = \frac{\partial W_f'}{\partial x}\Big|_{i = const}$

$F = \frac{1}{2} \frac{\partial L(x)}{\partial x} i^2$

$F = -\frac{1}{2} \times \frac{\mu_0 N^2 A}{2x^2} \times i^2$

substituting the values on next page

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$$500 = \frac{1}{2} \times \left. \frac{\mu_0 N^2 A}{2x^2} \right|_{x=10^{-3}} \times I^2$$

$$500 = \frac{1}{2} \times \frac{4\pi \times 10^{-7} \times N^2 \times 600 \times 10^{-6}}{2 \times 10^{-6}} \times 625$$

$$N^2 = 4244.132$$

$$N = 65.147$$

or $N \approx 66$ turns

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Q.5 (c) A 3-ϕ, squirrel cage induction motor is designed to restrict the maximum starting line current drawn from 400 V, 3-ϕ supply to 120 A. If starting current of motor is six times the full load current. What is the maximum permissible full KVA rating of motor when

(i) it is directly connected to the supply mains?

(ii) it is connected through an auto-transformer with a tapping of 60%?

(iii) it is designed for the use with star-delta starter?

[12 marks]

$$I_{st} = 6 I_{fl}$$

(i) With direct connection :-

$$6 I_{fl} = 120$$

$$I_{fl} = 20 \text{ A}$$

$$\text{KVA rating} = \sqrt{3} \times V_L \times I_{fL}$$

$$= \sqrt{3} \times 400 \times 20 = 13.86 \text{ KVA}$$

5

(ii) With tapping of 60%.

$$x = 0.6$$

so,

$$x^2 I_{st} = 6 I_{fl}$$

$$I_{fl} = \frac{(0.6)^2 \times 120}{6} = 7.2$$

$$\text{KVA rating} = \sqrt{3} \times (V_L) \times I_{fL}$$

$$= \sqrt{3} \times 400 \times 7.2 = 4.99 \text{ KVA}$$

(iii) With star-delta starter

$$I'_{st} = \frac{I_{st}}{\sqrt{3}} = 6 I_{fl}$$

$$I_{fl} = \frac{120}{\sqrt{3} \times 6} = 11.55\ A$$

$$(kVA)\ rating = \sqrt{3} \times V_L \times I_{fl}$$

$$= \sqrt{3} \times 400 \times 11.55$$

$$= 8.0021\ kVA$$

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Q.5 (d) A 230 V, 20 hp, 60 Hz, 6 pole, 3-ϕ induction motor driving a constant torque load of rated frequency, rated voltage and rated hp, has a speed of 1175 rpm and an efficiency of 92.10%. Determine the new operating speed if a system disturbance causes 10% drop in voltage and 6% drop in frequency. Assuming the friction, windage and stray power loss remain constant.

[12 marks]

Torque → constant

$\frac{P_g}{\omega_{sm}}$ → constant.

Let initially the slip be 's', voltage be 'V'
& frequency be 'f'

$P_g = P_{in} = \frac{P_{out}}{\eta} = \frac{20\,hp}{\eta} = \frac{20 \times 746}{0.921} = 16.2\,kW$

with 1175 rpm,

$s = 0.02083$

4

So,

$\left(\frac{P_g}{\omega_{sm}}\right)_1 = \frac{3V^2}{r_2 \times (\omega_{sm})_1}$

where $(\omega_{sm})_1 \propto f$

$P_g = I_2^2 \times r_2/s$

$P_g = \frac{3 \times V^2}{\left[(r_2^2 + x_2^2)^{1/2}\right]^2} \times r_2/s$

$P_g = \frac{3V^2}{\left[1 + \left(\frac{x_2}{r_2}\right)^2\right]} \times 1/s \Rightarrow T_g = \frac{P_g}{\omega_{sm}}$

substituting values

$x_2 = 12.48\, r_2$ at $f = 60\,Hz$

at $f' = 56.4$

$$\frac{(x_2') \propto f'}{(x_2) \propto f}$$

$$(x_2') = (12.48)\, r_2 \times \frac{56.4}{60}.$$

$$\boxed{x_2' = 11.73\, r_2}$$

$$P_g' = \frac{3 \times (0.9V)^2}{[r_2^2 + (11.73\, r_2)^2]} \times \frac{r_2}{s'}$$

(with droop of 10% voltage & 6% in f).

$$T_g' = \frac{3 \times (0.9V)^2}{[r_2^2 + (11.73\, r_2)^2]} \times \frac{r_2}{s'} \times \frac{1}{(\omega'_{sm})}$$

with constant torque

$$T_g = T_g'$$

$$\frac{1}{\omega_{sm}} \times \frac{3 \times V^2}{[r_2^2 + (12.48\, r_2)^2]} \times \frac{r_2}{s} = \frac{3 \times (0.9V)^2}{[r_2^2 + (11.73\, r_2)^2]} \times \frac{r_2}{s'(\omega'_{sm})}$$

$$s' = 0.0191$$

thus

$$(N)_{new} = N_s(1 - s')$$

$$= 1177 \text{ rpm}$$

Q.5 (e) Consider the Y_{bus} of a 4-bus power system,

$$Y_{bus} = \begin{bmatrix} -6 & 2 & 2.5 & 0 \\ 2 & -10 & 2.5 & 4 \\ 2.5 & 2.5 & -9 & 4 \\ 0 & 4 & 4 & -8 \end{bmatrix}$$

where first, second, third and fourth row refers to bus 1, 2, 3 and 4 respectively and all the given entries in matrix are in per unit. Draw the reactance diagram of given power system.

[12 marks]

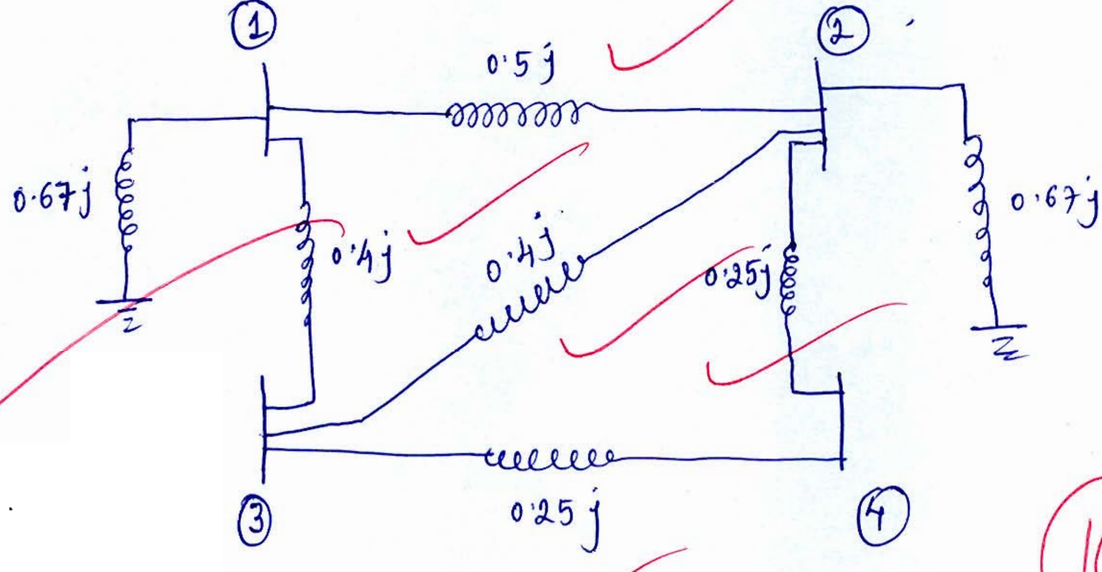
$y_{21} = y_{12} = -2j$; $y_{13} = -2.5j = y_{31}$; $y_{41} = y_{14} = 0$

$y_{23} = y_{32} = -2.5j$; $y_{24} = y_{42} = -4j$

$y_{34} = y_{43} = -4j$

Also, $y_{11} = -1.5j$; $y_{22} = -1.5j$

$y_{33} = 0$; $y_{44} = 0$



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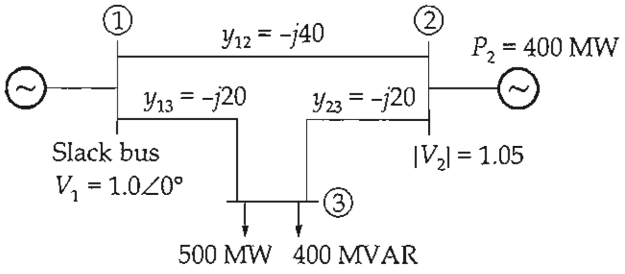
Q.6 (a) The figure shows the single line diagram of a simple three-bus power system with generation at bus-(1) and bus-(2). The voltage at bus-(1) is $V = 1.0\angle 0°$ pu. The voltage magnitude at bus-(2) is fixed at 1.05 pu with real power generation of 400 MW. A load consisting of 500 MW and 400 MVAR is taken from bus-(3). Line admittances are marked in per unit on a 100 MVA base. The line resistances and line charging susceptances are neglected.



Using Newton-Raphson method, start with the initial guess of $V_2^{(0)} = 1.05 + j0$ and $V_3^{(0)} = 1.0 + j0$ and keeping $|V_2| = 1.05$ pu, determine the phasor values of V_2 and V_3 after one iteration.

[20 marks]

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Q.6 (b) (i) The fuel inputs for two plants are given as :

$$F_1 = 0.005P_1^2 + 2P_1 + 10 \text{ Rs/hr}$$
$$F_2 = 0.005P_2^2 + 0.75P_2 + 15 \text{ Rs/hr}$$

The loss coefficients are $B_{11} = 0.0015$, $B_{22} = 0.0025$ and $B_{12} = -0.0005$. The cost of power received by each plant is 2.6 Rs/MWhr, then calculate the generating schedule and the load received by the system.

(ii) A generating station having a capacity of 200 MW and it is supplying 600×10^6 units in a year, the load factor of the unit is 0.60. Find plant utilization factor, plant capacity factor and reserve capacity of the plant.

[14 + 6 marks]

.6 (c) The following test data were taken as a 7.5 hp, 4-pole, 208 V, 60 Hz, Y-connected induction motor having a rated current of 28 A.

DC test : $V_{dc} = 9.07$ V, $I_{dc} = 28.0$ A

No-load test : $V_t = 208$ V; $f = 60$ Hz; $P_{in} = 420$ W

$I_a = 8.12$ A; $I_b = 8.20$ A and $I_c = 8.18$ A

Blocked rotor test :

$V_t = 25$ V, $f = 15$ Hz, $P_{in} = 920$ W

$I_a = 28.1$ A, $I_B = 28.0$ A, $I_c = 27.6$ A

(i) Draw the equivalent circuit of motor and find its parameters. Assume the stator and rotor are equal reactances.

(ii) Find the slip at the pull-out torque and find the value of the pull-out torque.

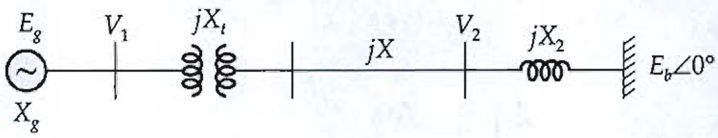
(Consider AC resistance to be 1.5 times of DC resistance)

[20 marks]

.7 (a) 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).



[10 + 10 marks]

(i) steady state stability limit

$$S^3L = \frac{E_g E_b}{X_g + X_t + X + X_2}$$

$$= \frac{1}{0.9} = 1.111$$

Thus, $P_e = 1.11 \sin\delta$.

5

Initially supplying $P_e = 1$ pu

so, $\delta_0 = \sin^{-1}\left[\frac{1}{1.11}\right] = 64.28°$.

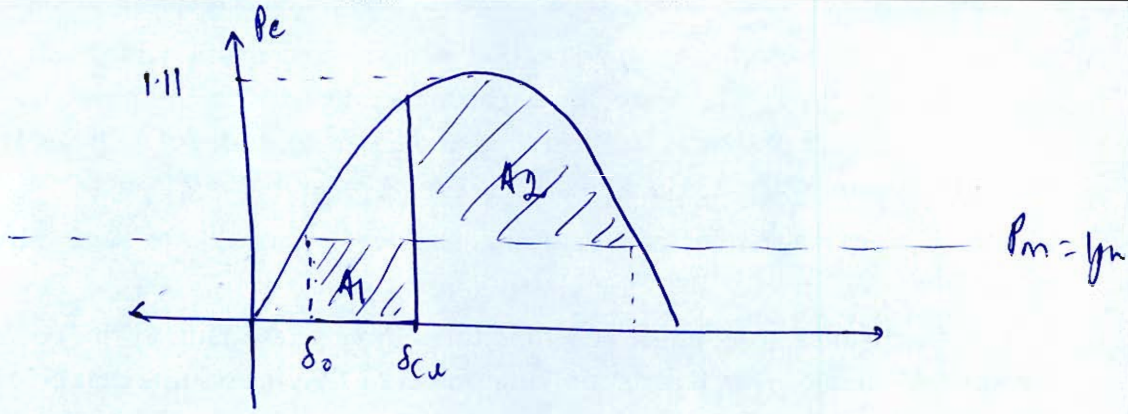
$$S_p = \frac{dP_e}{d\delta} = 1.11\cos\delta.$$

$1.11\cos\delta > 0$.

or $\delta < \pi/2$.

then, $(P_{max})_{mech} = P_e = 1.11$ pu

(ii)



By equal area criteria

$$A_1 = A_2$$

$$\int_{\delta_0}^{\delta_{cr}} P_m \cdot d\delta = \int_{\delta_{cr}}^{\pi-\delta_0} (1.11 \sin\delta - 1)\, d\delta$$

$$P_m(\delta_{cr} - \delta_0) = 1.11(\cos\delta_{cr} + \cos\delta_0) - (\pi - \delta_0 - \delta_{cr}).$$

$$\delta_{cr} - \delta_0 = 1.11(\cos\delta_{cr} + \cos\delta_0) - \pi + \delta_0 + \delta_{cr}$$

$$2\delta_0 = \pi - 1.11[\cos(\delta_{cr}) + \cos\delta_0]$$

$$\boxed{\delta_{cr} = 67.98^\circ}$$

By swing equation

$$\frac{2H}{2\pi \times 50} \frac{d^2\delta}{dt^2} = 1.$$

$$\frac{d^2\delta}{dt^2} = \frac{2\pi \times 50}{2 \times 4}.$$

$$\frac{d^2\delta}{dt^2} = 39.27$$

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$$\frac{d\delta}{dt} = 39.27\, t$$

$$\delta = \frac{39.27\, t^2}{2} + \delta_0.$$

for $\delta = \delta_{cr}$

$$\frac{(\delta_{cr} - \delta_0) \times 2}{39.27} = t^2$$

$$t_{cr} = 0.0571 \text{ seconds}$$

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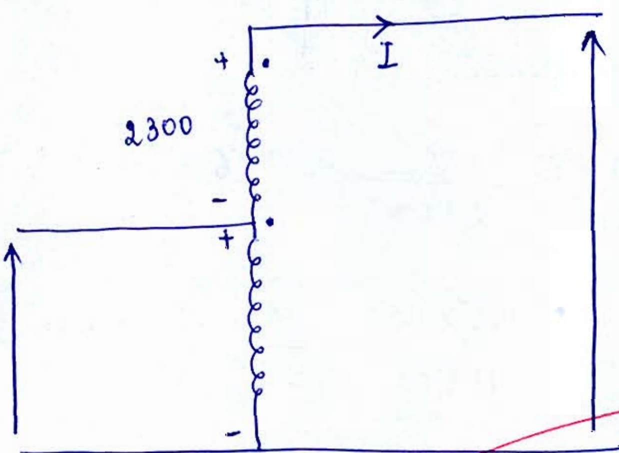
7 (b) (i) An 11500/2300 V transformer is rated at 100 kVA as a 2-winding transformer. If the windings are connected in series to form an auto-transformer, what will be the possible voltage ratios and output? Also calculate the power transferred through conduction and induction and percentage saving in conductor material.

(ii) Write any four applications of auto-transformers.

[16 + 4 marks]

(A) cumulative addition :-

(a)



$(\because kVA = V \times I)$. $I = \dfrac{100 \times 10^3}{2300} = 43.48\,A$

$S = (kVA)$ rating $= V_s I = 600.024$ kVA

$S_{cond} = \dfrac{S}{a} = \dfrac{600.024}{a}$

Here $a = \dfrac{13800}{11500} = 1.2$

thus,

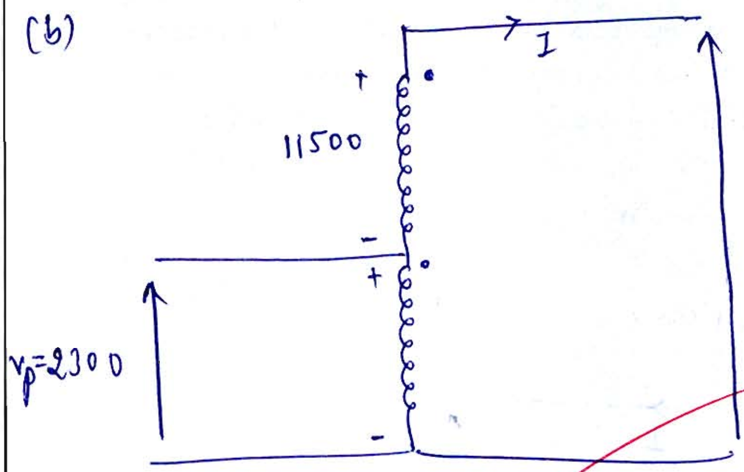
$S_{cond} = \dfrac{600.024}{1.2} = 500.02$ kVA

$S_{Induction} = S - S_{cond} = 100.004$ kVA

% saving in conductor material $= \dfrac{100}{a}$

$= 83.33\,\%$

(b)



$V_s = 11500 + 2300$
$= 13800$

$a = \frac{13800}{2300} = 6.$

$I = \frac{100 \times 10^3}{11500} = 8.696$ A

$S =$ (kVA) rating $= V_s I = 120$ kVA

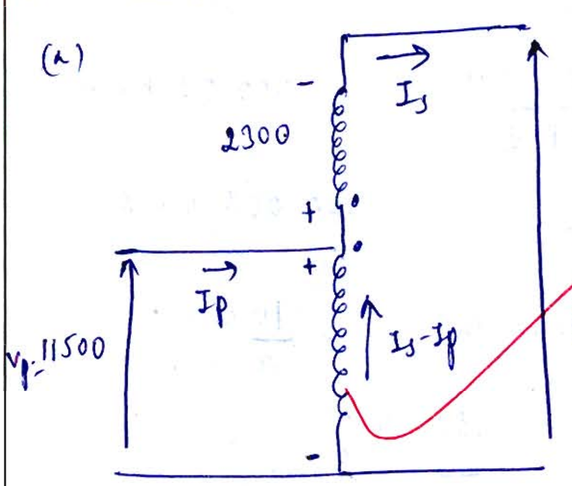
$S_{cond} = \frac{S}{a} = 20$ kVA

$S_{Ind} = S - S/a = 100$ kVA

% saving $= \frac{100}{a} = 16.67$ %

(B) Differential cascading addn :-

(a)



$V_s = 9200$ V (11500 − 2300)

$a = \frac{9200}{11500} = 0.8$

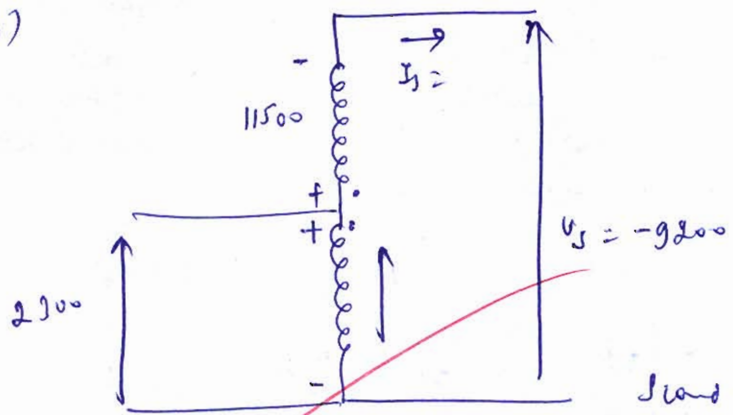
$I_s = \frac{100 \times 10^3}{2300}$
$= 43.48$

$S =$ (kVA) rating $= V_s I_s$
$= 400.02$ kVA

$S_{cond} = S/a = 500.025$ kVA, $S_{ind} = -100.005$ kVA

% saving = $\frac{100}{a} = \frac{100}{0.8} = 125\%$

(b)



$a = \left|\frac{-9200}{2300}\right| = 4$

$I_s = 8.696$ A

$S = V_s I = -800.032$ kVA

$S_{load} = -200.008$ kVA

$S_{Ind} = -600.024$ kVA

% saving = 25% $\left(\frac{100}{a}\right)$

14

(ii) Applications of Autotransformers :-

① To connect two power systems as their voltage ratio will be near to 2.

② In the starting of induction motor to limit the starting current.

③ Insulation works Autotransformers are used like insulating with voltage constant.

④ It can be used as booster transformer in Traction system.

4

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Q.7 (c) (i) For a 3-ϕ, induction motor, maximum torque is twice the full load torque and starting torque is 1.6 times the full load torque. In order to get a full load slip of 5%, determine the percentage reduction in rotor resistance. Neglect the stator impedance.

(ii) Two generating units rated 300 MW and 400 MW have governor speed regulation of 6% and 4% respectively from no load to full load. Both the generating units are operating in parallel to share a load of 600 MW. Assuming free governor action, determine the load shared by both units and frequency of operation. (Assume no-load frequency to be 50 Hz).

[10 + 10 marks]

(i)

$$T_{max} = 2T_{fl}$$

$$T_{st} = 1.6\,T_{fl} \quad \Rightarrow \quad \frac{T_{st}}{T_{max}} = 0.8$$

we know that,

$$\frac{T_{fl}}{T_{max}} = \frac{2}{\frac{s_{max}}{s_{fl}} + \frac{s_{fl}}{s_{max}}}$$

$$0.5 = \frac{2}{\frac{s_{max}}{0.05} + \frac{0.05}{s_{max}}}$$

5

$$[(s_{max})^2 + (0.05)^2] \times 0.5 = 2 \times 0.05 \times s_{max}.$$

$$0.5\,(s_{max})^2 - 2 \times 0.05\,s_{max} + 0.5 \times (0.05)^2 = 0.$$

$$s_{max} = 0.187\,,\ 0.0134$$

. s_{max} for (s_{fl}) of 5%

Now,

$$\frac{T_{st}}{T_{max}} = \frac{2}{(s_{max})' + \frac{1}{(s_{max})'}}$$

$$0.8 = \frac{2\,(s_{max})'}{(s_{max}')^2 + 1}$$

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$(s_{max}')^2 - 2(s_{max})' + 0.8 = 0$

$(s_{max})' = 0.553$

we know,

$(s_{max})_{T_{max}} = \frac{r_2}{x_2}$

with $(s_{max})'$ let rotor resistance be r &

x_2 be K.

so, $r = 0.553\,K$

For $(s_{fl}) = 0.05$

rotor resistance, $r' = 0.187\,k$

$\%$ reduction $= \frac{0.187k - 0.553k}{0.553k} = -66.184\%$

(ii) Let for first unit, load sharing be P, second unit would be $600 - P$.

In steady state operating frequency for both units should be same.

4

$f_{NL} - \frac{0.06}{300} \times P = f_{NL} - \frac{0.04}{400} \times (600 - P)$

$\frac{6}{3} P = \frac{4}{4} (600 - P)$.

$2P = 600 - P$

$\boxed{P = 200} \longrightarrow 1^{st}$ unit

2nd unit, $600 - P \Rightarrow$ 400 MW.

frequency at which Pload = 600 MW is delivered is.

$$f = f_{NL} - \frac{0.04}{400} \times (600 - 8)$$

$$f = 50 - 0.04$$

$$f = 49.96\ Hz$$

(a) A 600 kVA, 1-ϕ transformer with 0.012 pu resistance and 0.06 pu reactance is connected in parallel with a 300 kVA transformer with 0.014 pu resistance and 0.045 pu reactance to share a load of 800 kVA at 0.8 pf lagging. Find the load shared by each transformer when :

(i) both the secondary voltages are 440 V.

(ii) the open circuit voltages are respectively 445 V and 455 V. (Also comment on the results).

[20 marks]

Q.8 (b) **(i)** Explain the advantages of HVDC power transmission in detail.

(ii) A d.c. link has a loop resistance of 10 Ω and is connected to transformer giving secondary voltage of 120 kV at each end.

The bridge connected converters operates as follows :

Rectifier : $\alpha = 15°$, $X = 15\ \Omega$

Inverter : $\delta_0 = 10°$, $\gamma = 15°$, $X = 15\ \Omega$. Allow 5° margin on δ_0 for δ.

Calculate the direct current delivered if inverter operates on constant β control.

[14 + 6 marks]

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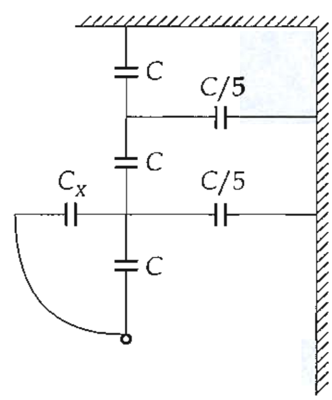
(c) (i) A 250 MVA, 60 Hz, two-pole synchronous generator with inertia constant H of 5.4 MJ/MVA. Assume the machine is running steadily at synchronous speed with a shaft input of 331, 100 hp. The electrical power developed suddenly changes from its normal value to a value of 200 MW. Determine the acceleration or deceleration of rotor. If acceleration computed for the generator is constant for a period of 9 cycles, determine the change in the power angle in that period, frequency of system and speed of generator at the end of 9 cycles.

(ii) In a transmission line each conductor is at 20 kV and supported by a string of 3 suspension insulators. The air capacitance between each cap-pin junction and tower is one fifth of the capacitance C of each insulation unit. A guard ring, effective only over the line-end insulator unit is fitted so that the voltages on two units nearest to line-end are equal.



Calculate the voltage on line-end unit and the value of capacitance C_X.

[10 + 10 marks]

OOOO

Space for Rough Work

Space for Rough Work

Space for Rough Work

Space for Rough Work

Space for Rough Work

$$I_D = \frac{k_n}{2}(V_{GS} - V_T)^2$$

$$\frac{\partial I_D}{\partial V_{GS}} = k_n(V_{GS} - V_T) = k_n\sqrt{\frac{2 I_D}{k_n}} = \sqrt{2 k_n I_D}$$

$$\frac{2k(V_{GS} - V_T)}{2X}$$