Draw all diagram properly

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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 ☐ Pune ☐ Kolkata ☐ Bhubaneswar ☐ Hyderabad ☐	

Instructions for Candidates

1. Do furnish the appropriate details in the answer sheet (viz. Name & Roll No).
2. There are Eight questions divided in TWO sections.
3. Candidate has to attempt FIVE questions in all in English only.
4. Question no. 1 and 5 are compulsory and out of the remaining THREE are to be attempted choosing at least ONE question from each section.
5. Use only black/blue pen.
6. The space limit for every part of the question is specified in this Question Cum Answer Booklet. Candidate should write the answer in the space provided.
7. Any page or portion of the page left blank in the Question Cum Answer Booklet must be clearly struck off.
8. There are few rough work sheets at the end of this booklet. Strike off these pages after completion of the examination.

FOR OFFICE USE

Question No.	Marks Obtained
Section-A	
Q.1	42
Q.2	
Q.3	38
Q.4	46
Section-B	
Q.5	38
Q.6	
Q.7	38
Q.8	
Total Marks Obtained	202

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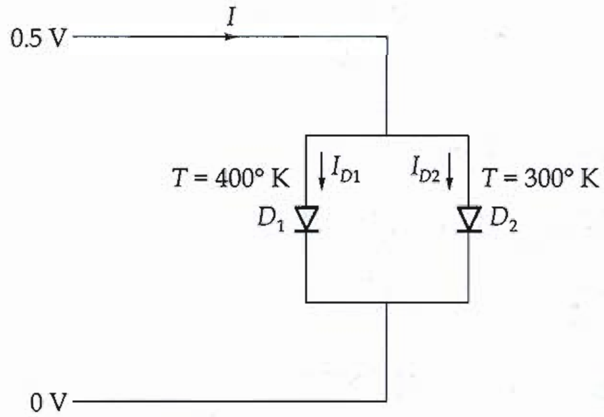
Section A : Basic Electronics Engineering + Analog Electronics + Electrical Materials

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]

Using Diode V-I Relation,

$$I_D = I_s\left(e^{\frac{V_D}{nV_T}} - 1\right)$$

Where, I_s : Reverse Saturation current which is same for both sides.

For Diode D_1,

$$I_{D1} = I_s\left(e^{\frac{V_D}{nV_{T1}}} - 1\right) \quad —(1)$$

For Diode D_2,

$$I_{D2} = I_s\left(e^{\frac{V_D}{nV_{T2}}} - 1\right) \quad —(2)$$

eq (1) ÷ eq (2)

$$\frac{I_{D1}}{I_{D2}} = \frac{e^{\frac{V_D}{nV_{T1}}} - 1}{e^{\frac{V_D}{nV_{T2}}} - 1}$$

V_T : Thermal voltage $= \frac{KT}{q}$

i.e
$$\frac{I_{D1}}{I_{D2}} = \frac{e^{\frac{V_D}{\eta \frac{KT_1}{q}}} - 1}{e^{\frac{V_D}{\eta \frac{KT_2}{q}}} - 1}$$

Putting $V_D = 0.5V$

$T_1 = 400K$

$T_2 = 300K$

$K = 1.38 \times 10^{-23} \frac{J}{K}$

We get,

$$\frac{I_{D1}}{I_{D2}} = \frac{e^{\frac{0.5}{2 \times \frac{1.38 \times 10^{-23} \times 400}{1.6 \times 10^{-19}}}} - 1}{e^{\frac{0.5}{2 \times \frac{1.38 \times 10^{-23} \times 300}{1.6 \times 10^{-19}}}} - 1}$$

$$= \frac{1402.01}{15705.91}$$

$= 0.089$

11

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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/m^2).

[12 marks]

Net magnetic moment

$= 3.2 \times 10^{-4} \times 9.27 \times 10^{-24} \frac{A}{m^2}$

$= 2.9664 \times 10^{-27} \frac{A}{m^2}$

1

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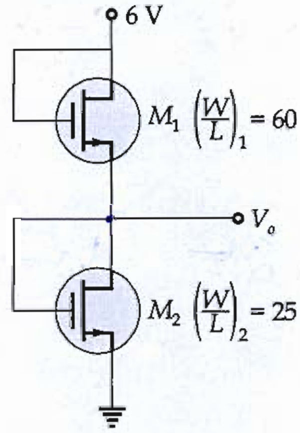
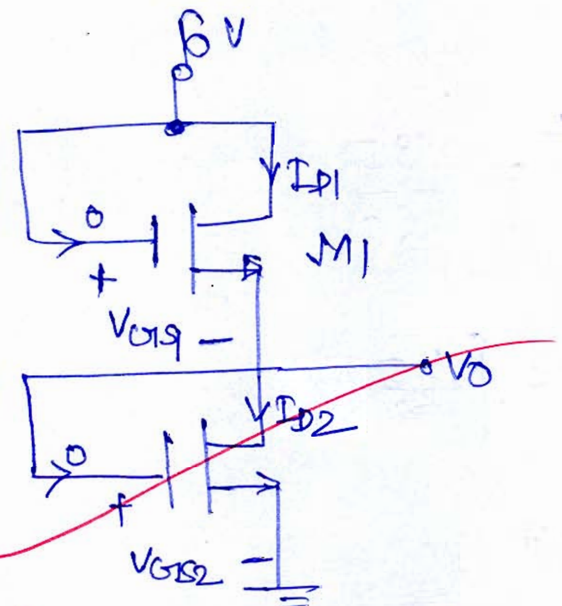
Q.1 (c) Consider the circuit shown in figure below :



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]



We have $V_{GS2} = V_O$

$V_{GS1} = 6 - V_O$

As Mosfet are drain to gate shorted so they are in saturation region.

Apply current Balance

$I_{D1} = I_{D2}$

Where

$I_{D1} = \frac{1}{2} \mu_n C_{ox} \left(\frac{W}{L}\right)_1 \left[V_{GS_1} - V_{TH}\right]^2$

we get

$$I_{D1} = \frac{1}{2} \times 40 \times 60 \left(6 - V_0 - 0.9\right)^2$$

Similarly

$$I_{D2} = \frac{1}{2} \times 40 \times 25 \left(V_0 - 0.9\right)^2$$

As $I_{D1} = I_{D2}$

$$\frac{1}{2} \times 40 \times 60 \times \left(6 - V_0 - 0.9\right)^2 = \frac{1}{2} \times 40 \times 25 \left(V_0 - 0.9\right)^2$$

$$\Rightarrow \left(\frac{5.1 - V_0}{V_0 - 0.9}\right)^2 = \frac{25}{60}$$

$$\Rightarrow \frac{5.1 - V_0}{V_0 - 0.9} = \sqrt{\frac{25}{60}}$$

Solving we get

$$\boxed{V_0 = 3.452 \text{ volt}}$$

For Saturation V_0 should be ~~go~~ positive so only positive root calculated.

11

Good approach

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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

In this technique nanomaterials are formed from big size materials after breaking them using various methods.
example of such method are
Ball milling

Bottom up technique

In this technique, nanomaterials are formed from small size particles after vaporization.

Examples of such methods
(i) Vapour deposition
(ii) Sputtering

(8)

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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) For a n-type semiconductor hall coefficient is negative. Thus semiconductor is n-type.

(ii) As Hall coefficient,

$$R_H = \frac{1}{\rho} \quad [\rho : \text{charge density}]$$

$$= \frac{1}{nq} \quad [n : \text{electron concentration}]$$

we get density of charge carrier,

$$n = \frac{1}{R_H q}$$

$$= \frac{-1}{8.25 \times 10^{-5} \times 1.6 \times 10^{-19}} \ /m^3$$

$$= 1.32 \times 10^{-23} \ /m^3$$

(iii) Further we have

conductivity, $\sigma = q n \mu_n$

where μ_n = mobility of carrier

$$qn = \rho = \frac{1}{R_H}$$

$$\sigma = \frac{\mu_n}{R_H}$$

we get $\mu_n = \sigma R_H$

$$= 2.50 \times 10^{2} \frac{V}{m} \times -8.25 \times 10^{-5} \frac{m^3}{C}$$

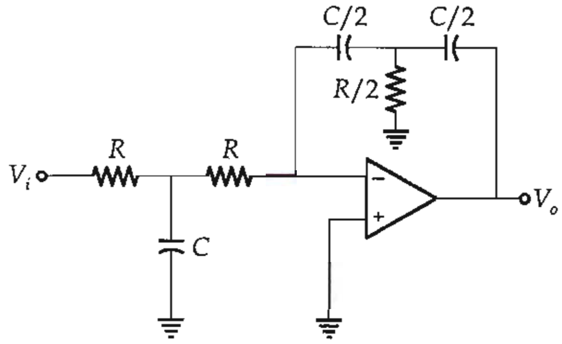
$$= -0.020625 \frac{m^2}{V sec}$$

$$\boxed{\mu_n = -206.25 \frac{cm^2}{V sec}}$$

i.e mobility is $206.25 \frac{cm^2}{V sec}$

11

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]

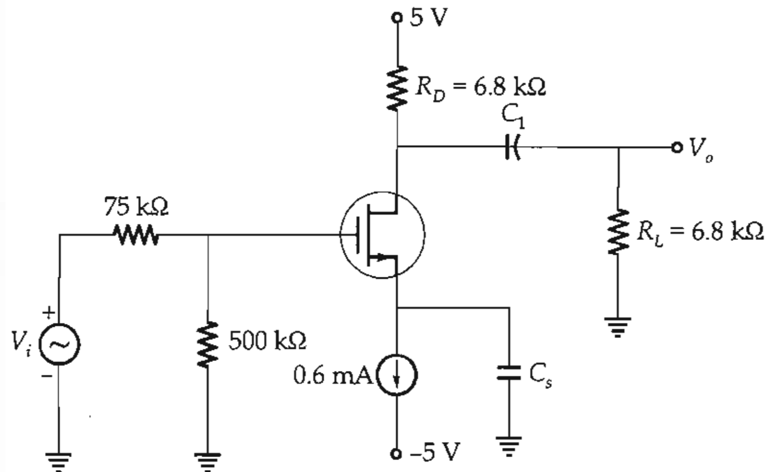
Q.2 (b) Zirconium has an HCP crystal structure and a density of 6.51 g/cm^3.

(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]

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/V^2, $\lambda = 0$. Also calculation gate-to-source voltage (V_{GSQ}).



[20 marks]

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Q.3 (a) The electron mobility of Indium (In) is measured to be 7.5 $cm^2/V\text{-}s$ 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]

(i) As Conductivity $\sigma = \frac{1}{\rho} = n\mu q$

electron Concentration,

$$n = \frac{1}{\rho \mu q}$$

$$= \frac{1}{7.5 \frac{cm^2}{Vsec} \times 1.6\times10^{-19}\,C \times 9.43\times10^{-6}\times10^{2}\,\Omega\text{-}cm}$$

$$= 8.837 \times 10^{20} \frac{1}{cm^3}$$

Atomic density of Indium

$$= \frac{N_A \times density}{Atomic\ mass}$$

$$= \frac{6.022\times10^{23} \times 7.3 \frac{g}{cm^3}}{115 \frac{g}{mole}}$$

$$= 3.8226\times10^{22} /cm^3$$

no of free e- donated by each In atom

$$= \frac{8.837\times10^{20}}{3.8226\times10^{22}} = 0.023$$

(8)

Incomplete solution

(ii)

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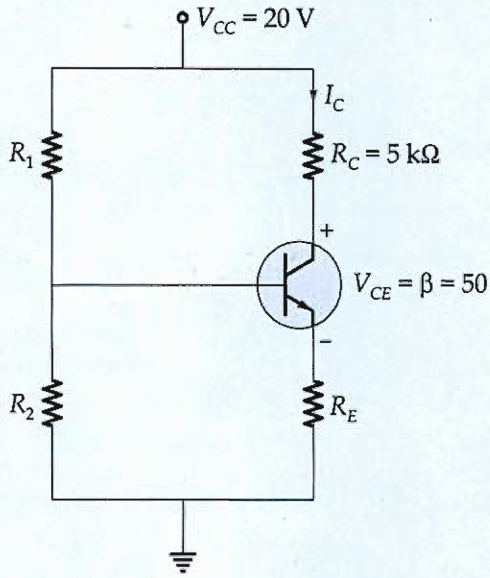
Q.3 (b) A silicon transistor with $\beta = 50$ is used in a self bias circuit as shown in figure below.



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

[20 marks]

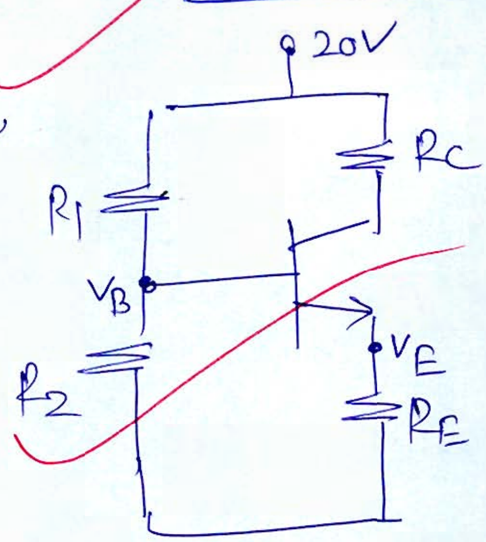
Applying KVL

$$V_{CC} - V_{CE} = I_C R_C + I_E R_E$$

$$\Rightarrow 20 - 11.5 = 1.5 \times 5 + \left(\frac{1.5 \times 51}{50}\right) \times R_E$$

we get, $\boxed{R_E = 0.6536\ \text{k}\Omega}$

As,



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$$V_E = I_E R_E = \left(1.5 \times \frac{51}{50}\right) mA \times 0.6536 k\Omega$$

$$= 1 \text{ Volt}$$

$$V_B = V_E + V_{BE} = 1 + 0.7 = 1.7 \text{ Volt}$$

Applying voltage Division,

$$V_B = V_{CC} \frac{R_2}{R_1 + R_2}$$

$$\Rightarrow 1.7 = 20 \times \frac{R_2}{R_1 + R_2}$$

we get,

$$\boxed{\frac{R_1}{R_2} = 10.76} \quad \text{—— (1)}$$

As Stability factor

$$S = \frac{1 + \beta}{1 + \beta\left(\frac{R_E}{R_E + R_{TH}}\right)}$$

$$= \frac{1 + 50}{1 + 50\left(\frac{0.6536}{0.6536 + R_{TH}}\right)}$$

$$= \frac{51}{1 + \left(\frac{32.68}{R_{TH} + 0.6536}\right)}$$

As $S \leq 2$

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$$\frac{51}{1+\frac{32.68}{R_{TH}+0.6536}} \leq 2$$

$$\Rightarrow 1+\frac{32.68}{R_{TH}+0.6536} \geq 25.5$$

$$\Rightarrow R_{TH} \leq 0.68\ k\Omega$$

Let us take $R_{TH} = 0.60\ k\Omega$

$$R_1 \parallel R_2 = 0.60\ k\Omega$$

$$\Rightarrow \frac{R_1 R_2}{R_1+R_2} = 0.60$$

and $\frac{R_1}{R_2} = 10.76$

Solving for R_1 and R_2

we get,

7.9

$$R_1 = 7.056\ k\Omega$$
$$R_2 = 0.6557\ k\Omega$$

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calculation mistake

0.744

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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]

(i) Bandwidth of Above Amplifier

$= f_U - f_L$

$= 16 \text{ KHZ} - 0.040 \text{ KHZ}$

$= 15.96 \text{ KHZ}.$

With feedback factor of 2%.

$\beta = 0.02$

$\text{Sensitivity} = \frac{1}{1+A\beta} = \frac{1}{1+800\times0.02} = \frac{1}{17}$

Desensitivity = 17

With negative feedback,

new Bandwidth $= 15.96 \text{ KHZ} \times 17$

$= 271.32 \text{ KHZ}$

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(ii)
SuperConductivity :- SuperConductivity is a property of material in which it shows zero resistivity below a certain temperature.
A material undergoes transition from normal state to superconducting state at a temperature called transition temperature.

Conditions required for Superconductivity

① It should show zero resistivity
② It should be perfect diagmagnetic.

A superconducting material like mercury for which transistion temperature is 4.2 K.

Properties of SuperConductors.

① It has infinite Conductivity (ideally)
② It shows perfect diamagnetic behaviour.

③ It obey's Silsbee Rule.

④ It expels magnetic field lines.

8

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

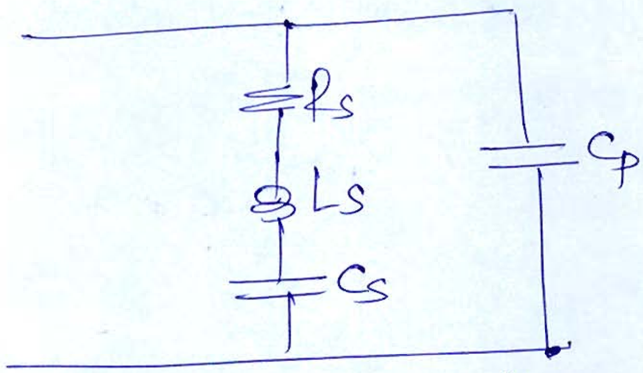
(a) Calculate the series-resonant frequency.

(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]



$$Y_{net} = \frac{1}{R_s + jX_s} + \frac{j}{X_p}$$

Where $X_s = \omega L_s - \frac{1}{\omega C_s}$

$X_p = \frac{1}{\omega C_p}$

$$Y_{Real} = \frac{R_s}{R_s^2 + X_s^2}$$

$$Y_{imag} = \frac{1}{X_p} - \frac{X_s}{R_s^2 + X_s^2} = 0$$

$$\Rightarrow X_s X_p = R_s^2 + X_s^2$$

Neglecting R_s

$$X_s(X_s - X_p) = 0$$

At Series Resonance,

$$X_s = 0$$

$$\Rightarrow \omega L_s - \frac{1}{\omega C_s} = 0$$

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

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$Y_{net} = \frac{1}{R}$

Quality factor $Q_{series} = \frac{\omega L_s}{R}$

At parall

$X_s = X_p$

$\Rightarrow \omega L_s - \frac{1}{\omega C_s} = \frac{1}{\omega C_p}$

$\omega_p = \frac{1}{\sqrt{L C_{eq}}}$; $\frac{1}{C_{eq}} = \frac{1}{C_s} + \frac{1}{C_p}$

Quality factor,

$Q_{parallel} = \frac{1}{\omega_p R_s C_p}$

(a) $f_{series} = \frac{1}{2\pi\sqrt{L_s C_s}}$

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

$= 1086.69$ KHZ

(b) $\frac{1}{C_{eq}} = \frac{1}{0.065} + \frac{1}{1} \Rightarrow C_{eq} = 0.061$ PF

$f_{parallel} = \frac{1}{2\pi\sqrt{L_s C_{eq}}}$

$= \frac{1}{2\pi\sqrt{0.33 \times 0.061 \times 10^{-12}}}$

$= 1121.45$ KHZ

% by which fparallel exceeds $= \frac{1121.45 - 1086.69}{1086.69} \times 100$

$= 3.198\%$

(c) At Series Resonance,

$$Q_{series} = \frac{\omega_s L_s}{R_s}$$

$$= \frac{2\pi(1086.69 \times 10^3) \times 0.33}{5.5 \times 10^3} = 409.67$$

$$Q_{parallel} = \frac{1}{\omega_p R_s C_p} = \frac{1}{2\pi \times 1145.21 \times 10^3 \times 5.5 \times 10^3 \times 10^{-12}}$$

$$= 25.26$$

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(ii) Heat generated in $\left(\frac{Watt}{m^3}\right)$

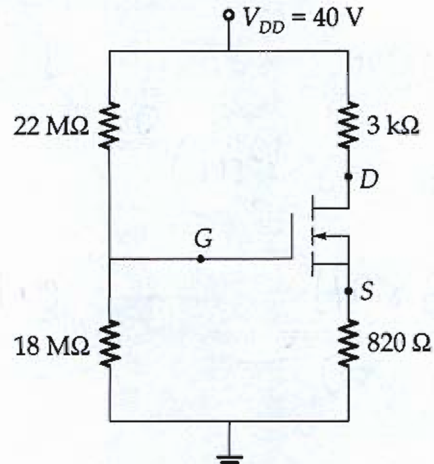
$$= 2\pi f \epsilon_0 \epsilon_r \tan\delta \, E_{rms}^2$$

$$= 2\pi \times 60 \times 8.85 \times 10^{-12} \times 4.1 \times 0.001 \times (45 \times 10^5)^2$$

1

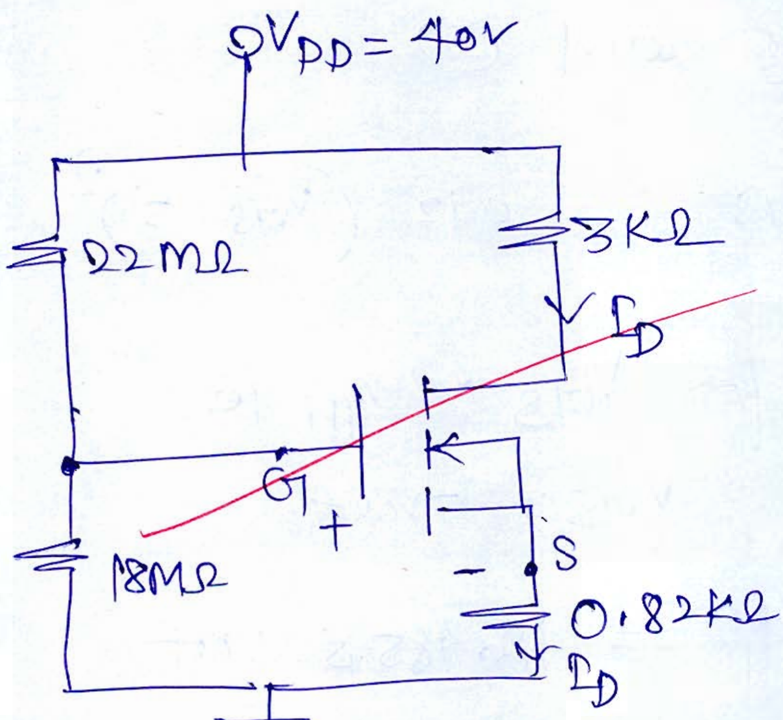
$$= 297.27 \frac{Watt}{m^3}$$

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]



$V_G = 40 \times \frac{18}{18+22} = 18$ Volt

$V_S = V_G - V_{GS} = 18 - V_{GS}$

$I_D = \frac{18 - V_{GS}}{0.820}$ mA —— (1)

using current equation

$I_D = K_n (V_{GS} - V_{TH})^2$

For $V_{GS} = 10V$, $I_D = 3mA$, K_n

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We get,

$$K_n = \frac{I_{D(ON)}}{(V_{GS(ON)} - V_{TH})^2}$$

$$= \frac{3\,mA}{(10-5)^2} = 0.12\,\frac{mA}{V^2}$$

So $I_D = 0.12\,(V_{GS} - 5)^2$ —— (2)

Equating (1) and (2)

$$\frac{18 - V_{GS}}{0.82} = 0.12\,(V_{GS} - 5)^2$$

Solving for $V_{GS} > V_{TH}$ ie
$V_{GS} > 5$ volt

We get $V_{GS} = 12.4858$ volt

Then $\boxed{V_{GSQ} = 12.4858 \text{ volt}}$

from eq (1)

$$I_D = \frac{18 - 12.4858}{0.82}$$

$\boxed{I_{DQ} = 6.7246\,mA}$

$V_{DS_Q} = V_{DD} - 3 I_D - 0.82 I_D$

$= 40 - 3.82 \times 6.7246$

$V_{DS_Q} = 14.311$ volt

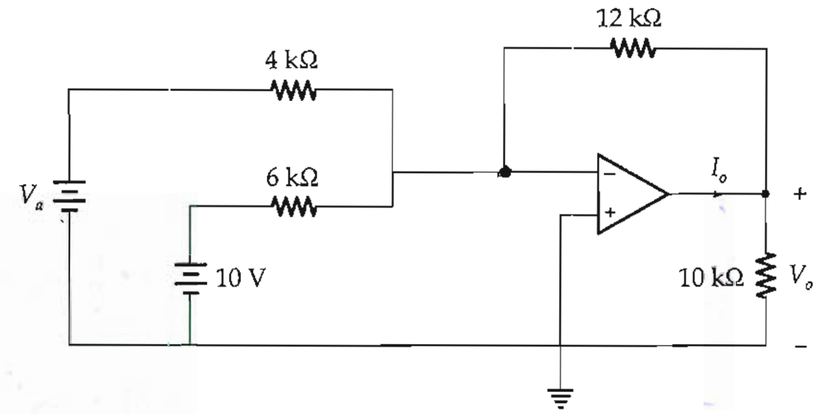
As $V_{DS_Q} \geq V_{GS_Q} - V_T$ Satisfied

So given mosfet is working in Saturation.

(18)

Good Approach

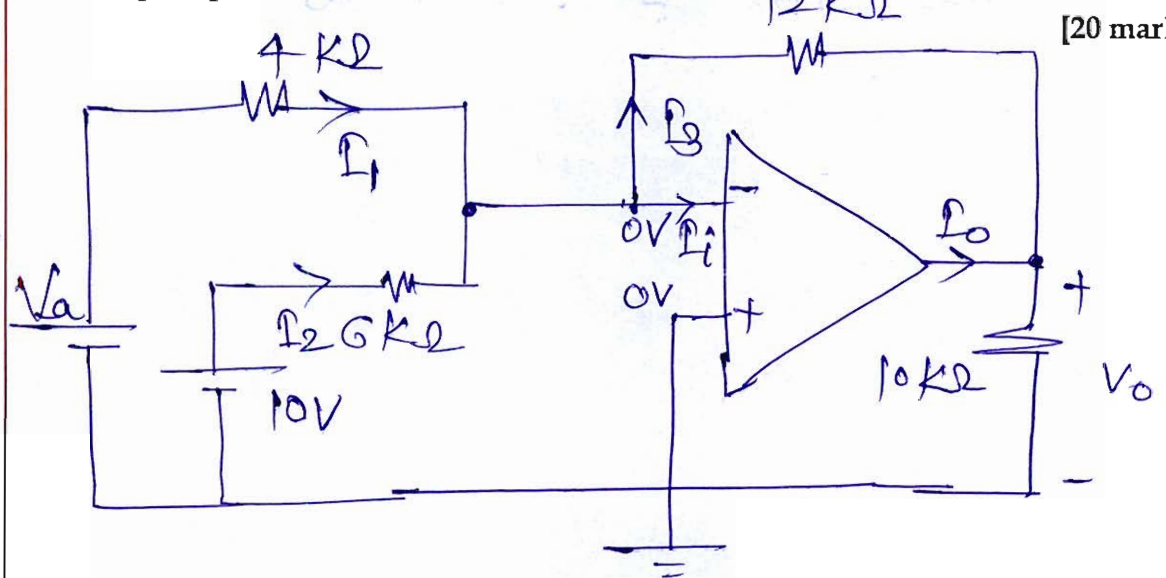
Q.4 (c) For the circuit shown below, the op-amp is considered to be ideal.



(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]



Using virtual ground Concept,

$$V_+ = V_- = 0V$$

As. $I_1 + I_2 = I_3 + I_i$

[Since due to high impedance of ideal opamp current $I_i = 0$]

$\Rightarrow \quad I_1 + I_2 = I_3$

$$\Rightarrow \quad \frac{V_a - 0}{4} + \frac{10 - 0}{6} = \frac{0 - V_o}{12}$$

For $V_a = 4V$

$$\frac{4-0}{4} + \frac{10-0}{6} = \frac{0-V_0}{12}$$

we get $\boxed{V_0 = -32 \text{ Volt}}$

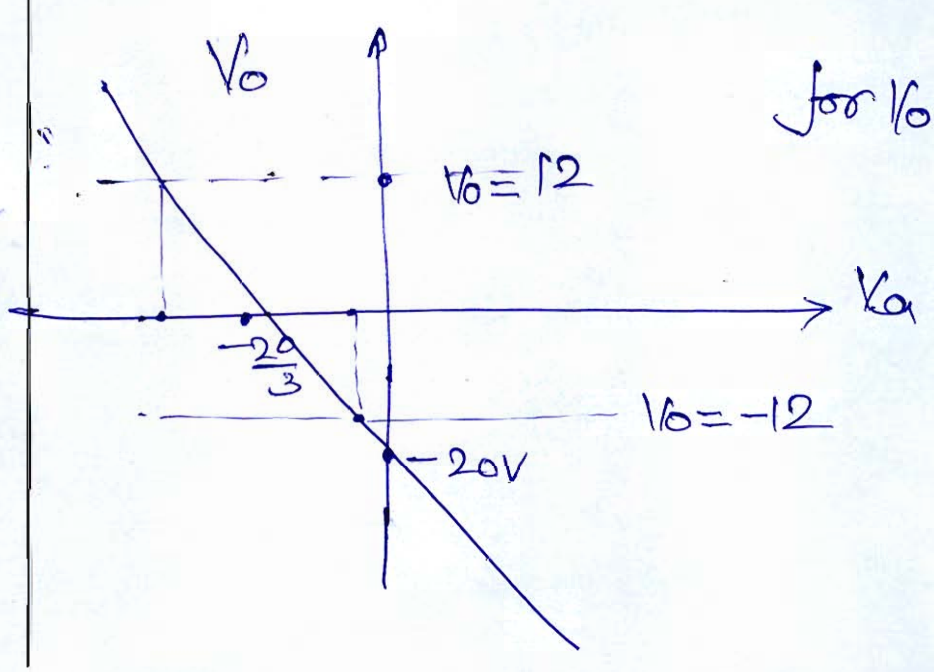
Since opamp has saturation voltage of ±12V so opamp in the given problem is saturated to −12 Volt.

Thus $V_0 = -12$ Volt.

(ii) As,

$$\frac{V_a - 0}{4} + \frac{10-0}{6} = \frac{0-V_0}{12}$$

we get $V_0 = -3V_a - 20$



for $V_0 = 12$ volt

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for $V_0 = 12$ volt

$$V_a = \frac{12+20}{-3} = \frac{-32}{3}$$

for $V_0 = -12$ volt

$$V_a = \frac{-12+20}{-3} = \frac{-8}{3}$$

Thus Range of V_a for linear operation

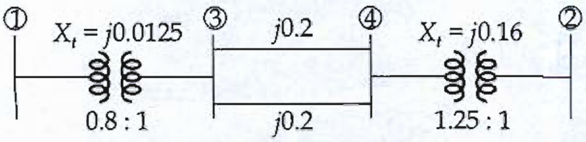
$$-\frac{32}{3} < V_a < -\frac{8}{3}$$

18

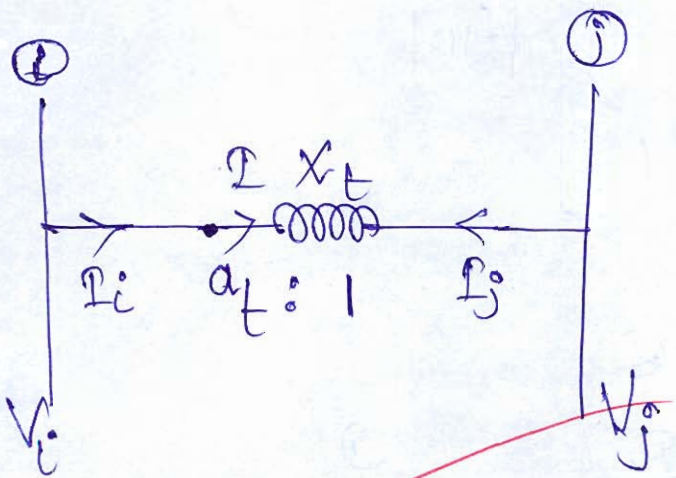
Good Approach

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]



$$I = \frac{V_i - V_j}{a X_t}$$

$$I_i = \frac{V_i - V_j}{X_t}$$

$$I_j = -\frac{I_i}{a_t} = \frac{V_j}{a_t X_t} - \frac{V_i}{a_t X_t}$$

$$\begin{bmatrix} I_i \\ I_j \end{bmatrix} = \begin{bmatrix} \frac{1}{X_t} & -\frac{1}{X_t} \\ \frac{-1}{a_t X_t} & \frac{1}{a_t X_t} \end{bmatrix} \begin{bmatrix} V_i \\ V_j \end{bmatrix}$$

For we have

$$Y_1 = \begin{matrix} & ① & ③ \\ ① & \frac{1}{j0.0125} & \frac{-1}{j0.0125} \\ ③ & \frac{-1}{j0.0125 \times 0.8} & \frac{1}{j0.0125 \times 0.8} \end{matrix} = \begin{bmatrix} -j80 & j80 \\ j100 & -j100 \end{bmatrix}$$

Do not write in this margin

for j.2 and j.2

$j0.2 \parallel j0.2 = j0.1 \equiv -j10$ A

B/w ③ and ④

$$Y_2 = \begin{array}{c} \\ ③ \\ ④ \end{array}\begin{array}{c} \begin{array}{cc} ③ & ④ \end{array} \\ \begin{bmatrix} 1 & -1 \\ -1 & 1 \end{bmatrix} \end{array} [-j10]$$

5

B/w ④ and ②

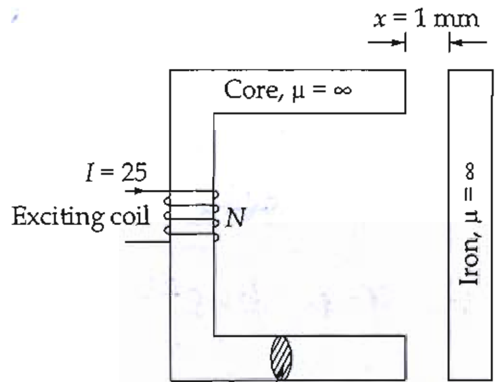
$$Y_3 = \begin{array}{c} \\ ④ \\ ② \end{array}\begin{array}{c} \begin{array}{cc} ④ & ② \end{array} \\ \begin{bmatrix} \frac{1}{j0.16} & \frac{-1}{j0.16} \\ \frac{-1}{j0.16 \times 1.25} & \frac{1}{j0.16 \times 1.25} \end{bmatrix} \end{array}$$

$$= \begin{array}{c} \\ ④ \\ ② \end{array}\begin{array}{c} \begin{array}{cc} ④ & ② \end{array} \\ \begin{bmatrix} -j6.25 & j6.25 \\ j5 & -j5 \end{bmatrix} \end{array}$$

$$Y_{Bus} = Y_1 + Y_2 + Y_3$$

$$= \begin{bmatrix} -j80 & 0 & j80 & 0 \\ 0 & -j5 & 0 & j5 \\ j80 & 0 & -j110 & j10 \\ 0 & j5 & j10 & -j16.25 \end{bmatrix}$$

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 mm² in area. Calculate the required number of turns in the exciting coil.



[12 marks]

For the electromagent,

Flux $\phi = \frac{NI}{R}$

where $R = \frac{2x}{\mu_0 A}$

$B = \frac{\phi}{A} = \frac{NI}{RA}$

$= \frac{NI}{\frac{2x}{\mu_0 A} \cdot A}$

$= \frac{\mu_0 N I}{2x}$

Energy Density in $\left(\frac{J}{m^3}\right)$ $= \frac{B^2}{2\mu_0}$

$= \frac{\left(\frac{\mu_0 N I}{2x}\right)^2}{2\mu_0} = \frac{\mu_0 N^2 I^2}{8x^2}$

Do not write in this margin

Energy stored = Energy density × volume

$$= \frac{\mu_0 N^2 I^2}{8x^2} \times (2Ax)$$

$$\text{Force} = \frac{\text{Energy stored}}{\text{Air gap length}}$$

$$= \frac{\frac{\mu_0 N^2 I^2}{8x^2} \times 2Ax}{x}$$

$$= \frac{\mu_0 N^2 I^2 A}{4x^2}$$

For 500 N

$$500 = \frac{~~8.85 \times 10^{-12}~~ 4\pi \times 10^{-7} \times N^2 \times 25^2 \times 600 \times 10^{-6}}{4 \times (10^{-3})^2}$$

(11)

we get,

$N = 65.147$

$N \approx 65$ turns

Good Approach

Do not write in this margin

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

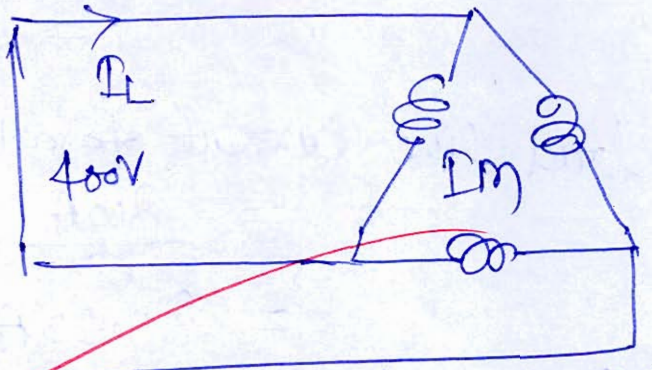
(i) it is directly connected to the supply mains?

(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)



Under full load condition

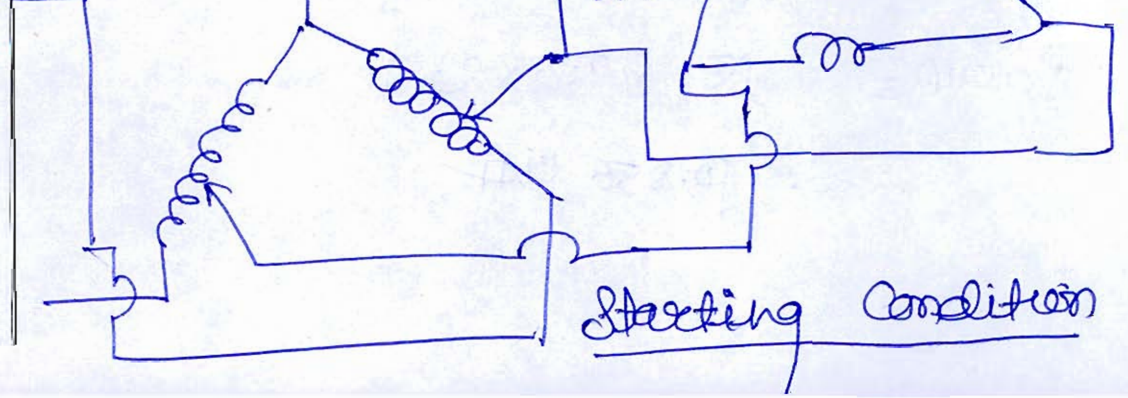
$$I_L = \frac{120A}{6} = 20\,A$$

Maximum permissible full KVA

$$= \sqrt{3} \times 400 \times 20$$

$$= 13.856 \quad KVA$$

(ii) 120A



Starting condition

For 60% tapping,

Line voltage to motor = 60% X 400V
= 240 V

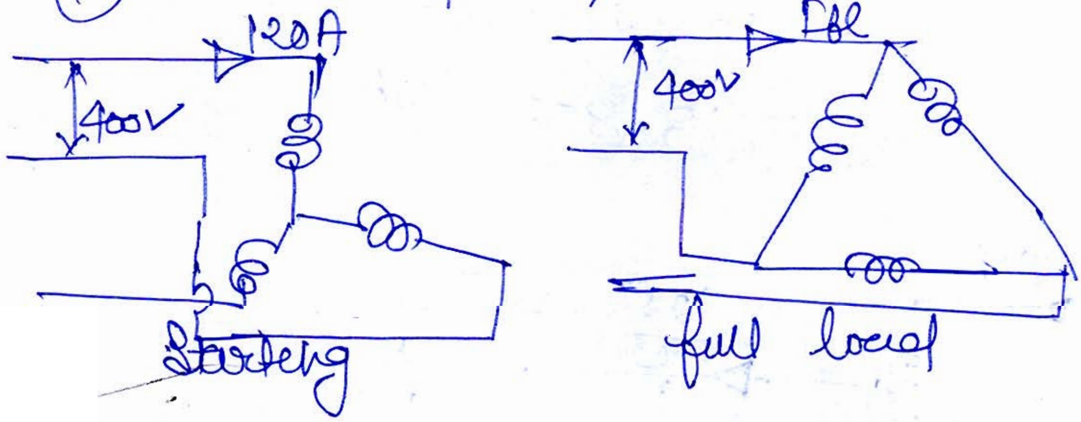
Starting Line Current to motor = $\frac{120A}{0.60}$
= 200 A

full load line current to motor
= $\frac{200A}{6}$ [See terms]
= 83.33A

full load KVA (maximum) = $\sqrt{3}$ X 240V X 33.33A
= 13.856 KVA

6

(iii) For Y–Δ Starter,



I_{fl} = 20 A
V_{fl} = 400V (L-L)

So KVA = $\sqrt{3}$ X 400 X 20
= 13.856 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]

Assuming 1 hp = 735.5 watt

20 hp = 14.71 kwatt

$$\text{Electrical input} = \frac{14.71 \text{ kwatt}}{\text{efficiency}} = \frac{14.71}{0.9210} = 15.97 \text{ KW}$$

As torque depends on,

$$T = \frac{3}{\left(\frac{2\pi N_S}{60}\right)} \cdot \left[\frac{V_{ph}^2}{\left(\frac{R_2'}{S}\right)^2 + (X_2')^2}\right]\left[\frac{R_2'}{S}\right]$$

Ignoring As $N_S \propto f$, $X_2' \propto f$

$$T \propto \frac{V^2}{f^3} S$$

$$N_{S_1} = \frac{120f}{P} = \frac{120 \times 60}{6} = 1200 \text{ rpm}$$

$$\frac{V_1^2}{V_2^2} \cdot \frac{f_2^3}{f_1^3} \cdot \frac{S_2}{S_1} = 1 \quad \text{[for T constant)}$$

$$\frac{V_2}{V_1} = 0.90$$

$$\Rightarrow \frac{1}{(0.90)^2} \times (0.94)^3 \times \left(\frac{S_2}{S_1}\right) = 1$$

$$\frac{f_2}{f_1} = 0.94$$

$$\Rightarrow \frac{S_2}{S_1} = \frac{1}{48} \times \frac{0.90^2}{.94^3}$$

$$S_1 = \frac{1200 - 1175}{1200} = \frac{1}{48}$$

$$= 0.020$$

$$N_2 = (1 - S_2) N_{S_2} = \frac{(1 - S_2)\, 120 f_2}{P} = \frac{(1 - 0.020) \times 120 \times 60 \times .94}{6} = 1105 \text{ rpm}$$

(6)

Sum of row 1 = $-j6 + j2 + j2.5 = -j1.5$

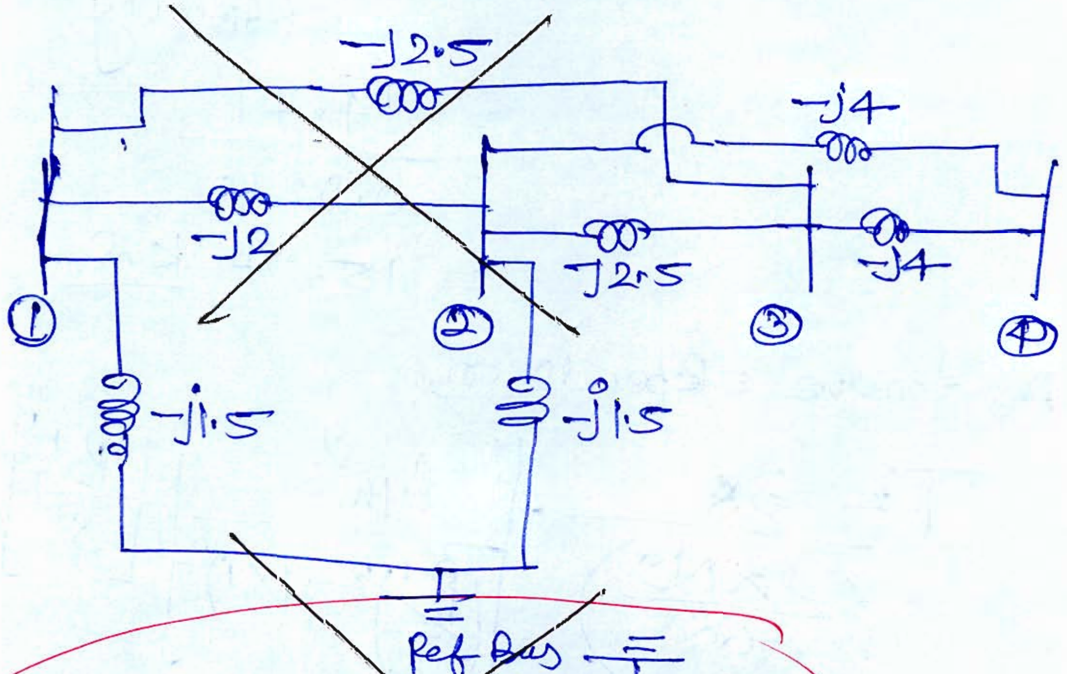
Sum of row 2 = $j2 - j10 + j2.5 + j4 = -j1.5$

Sum of row 3 = 0

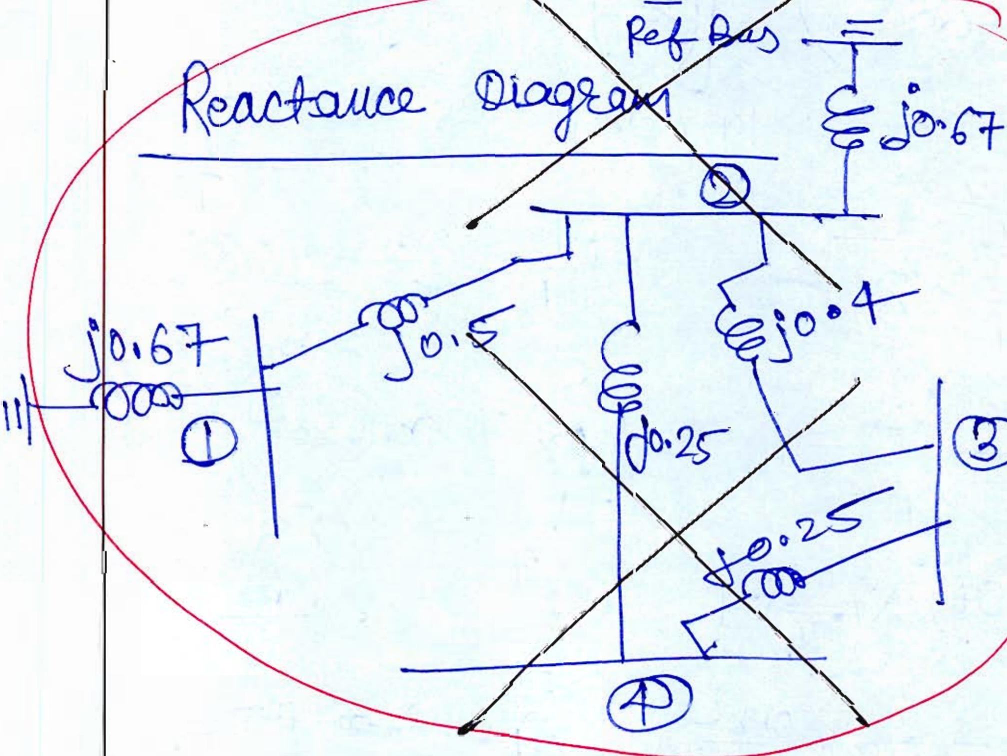
Sum of row 4 = 0

So

Admittance Diagram:



Reactance Diagram



Why you cut this

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]

From Ybus matrix,

(i) Y_{ij} denotes the negative of admittance b/w bus (i) and (j)

(ii) and Y_{ii} denotes the sum of all admittance to bus (i)

(iii) Further for any row if sum of elements is non-zero then that non-zero value of admittance is b/w that bus to reference bus.

So we have

$y_{12} = -j2 = y_{21}$ $\quad$ $y_{34} = y_{43} = -j4$

$y_{13} = -j2.5 = y_{31}$

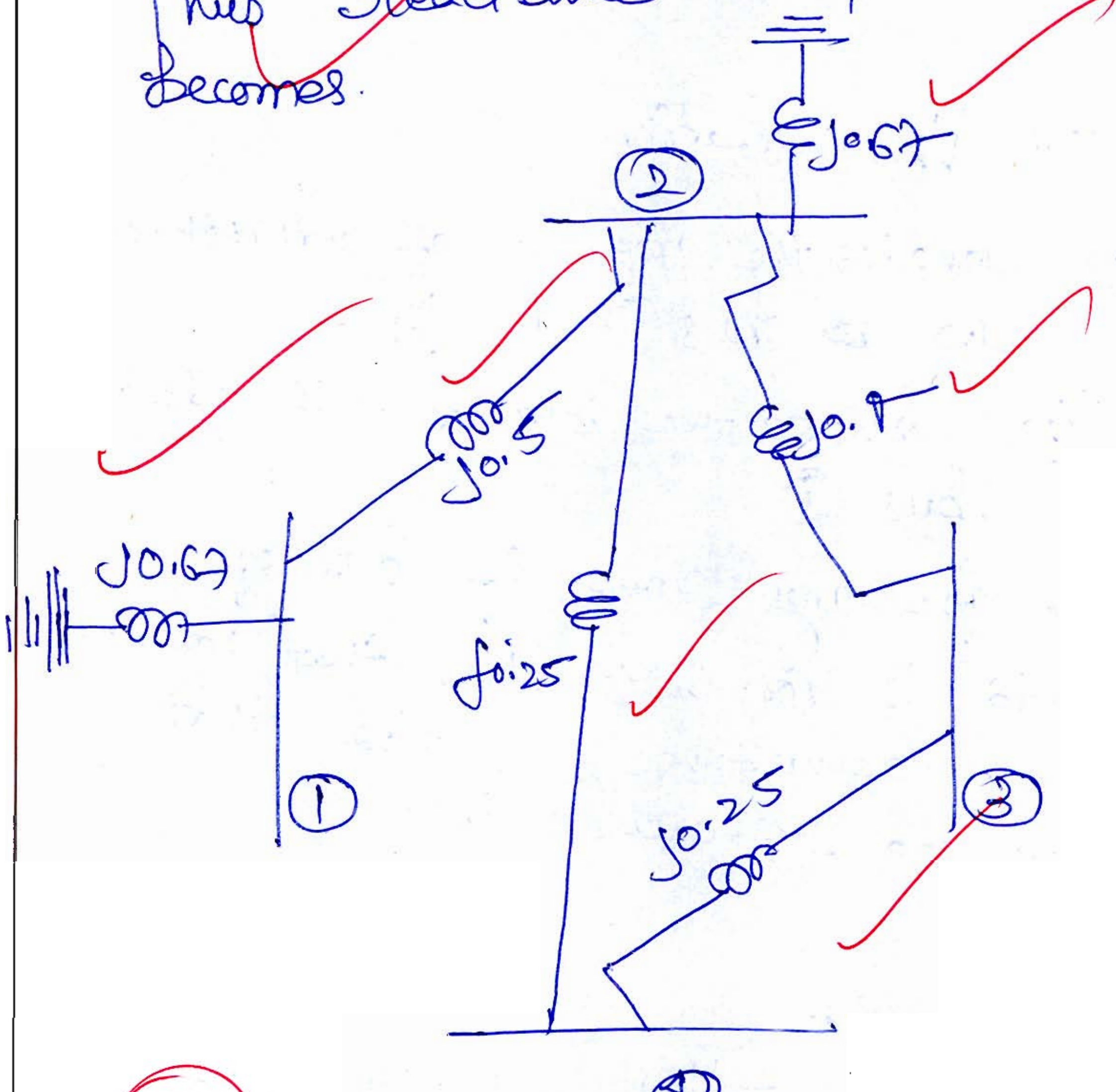
$y_{14} = 0 = y_{41}$

$y_{23} = -j2.5 = y_{32}$

$y_{24} = -j4 = y_{42}$

Sum of row1 and row2 = -j1.5
Sum of row3 and row4 = 0

Thus Reactance Diagram becomes.



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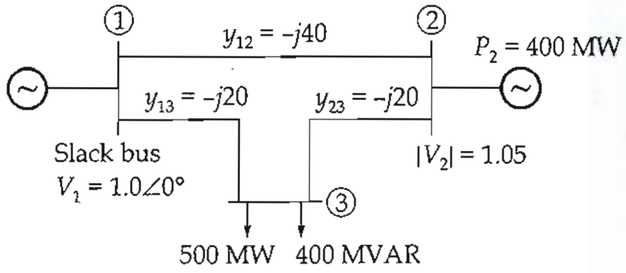
Q.6 (a) The figure shows the single line diagram of a simple three-bus power system with generation at bus-(1) and bus-(2). The voltage at bus-(1) is $V = 1.0\angle 0°$ pu. The voltage magnitude at bus-(2) is fixed at 1.05 pu with real power generation of 400 MW. A load consisting of 500 MW and 400 MVAR 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]

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]

Q.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]

~~= 110 + f12~~

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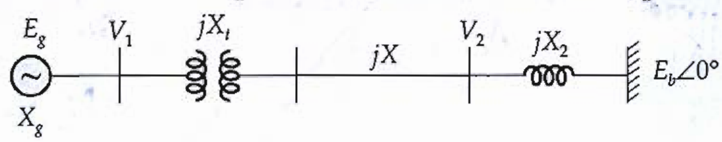
Q.7 (a) A single machine is connected to a load centre through a transmission line as shown in figure. The load centre is represented by a reactance connected to an infinite bus. The generator is initially operating with $P_e = 1.0$ pu and the magnitudes of voltages V_1 and V_2 are 1.0 pu. Assume $X_g = 0.3$ pu, $X_t = 0.1$ pu, $X = 0.4$ pu and $X_2 = 0.1$ pu.

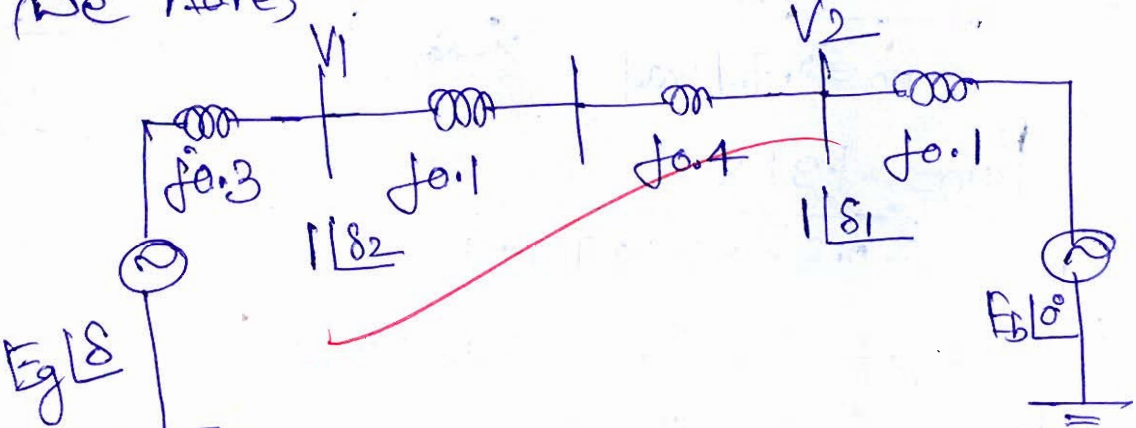
(i) Find the maximum step increase in mechanical power that will not cause transient instability.

(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]

We here,



Assume $E_b = 1\angle 0°$.

So for $P_e = 1$ pu

$$\Rightarrow \frac{V_2 E_b}{X_2}\sin\delta_1 = 1$$

$$\Rightarrow \frac{1 \times 1}{0.1}\sin\delta_1 = 1$$

$$\delta_1 = 5.74°$$

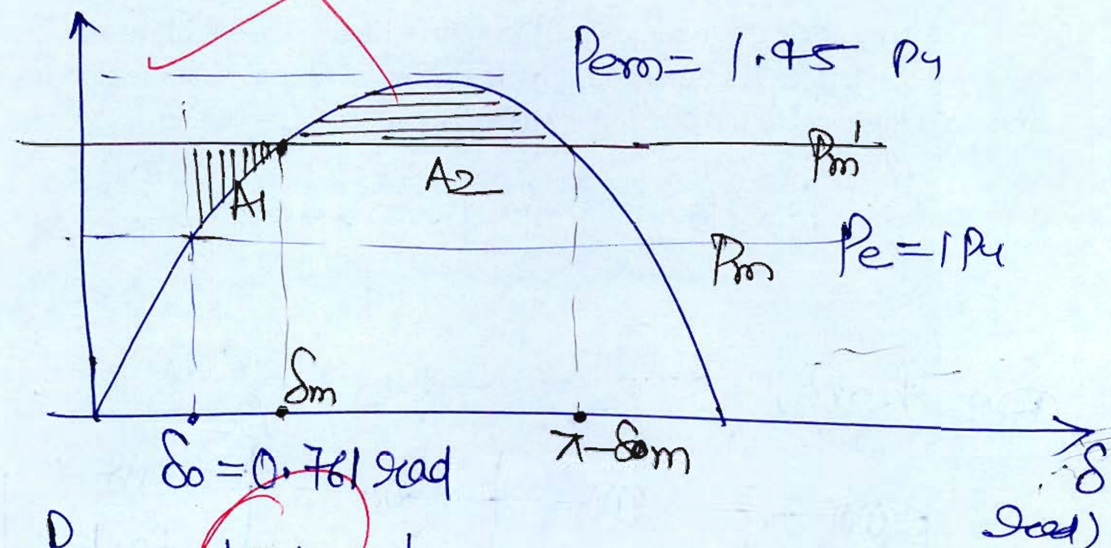
$$I = \frac{1\angle 5.74° - 1\angle 0°}{j0.1} = 1\angle 2.87°$$

$$E_g = E_b\angle 0° + I(jX_g + jX_t + jX + jX_2)$$

$= 1 + \dfrac{1\angle 2.87}{(j0.3 + j0.1 + j0.4 + j0.1)}$

$= 1.31 \angle 43.3^\circ$ pu

(i)



$P_{em} = \dfrac{1.31 \times 1}{0.3 + 0.1 + 0.4 + 0.1}$

Assuming P_m increased to P_m'

For stability

$A_1 = A_2$

$\Rightarrow \int_{\delta_0}^{\delta_m} (P_m' - 1.45 \sin\delta)\, d\delta = \int_{\delta_m}^{\pi - \delta_m} 1.45 \sin\delta - P_m'$

$\Rightarrow P_m'(\delta_m - \delta_0) - 1.45[\cos\delta_0 - \cos\delta_m]$

$= 1.45[\cos\delta_m - \cos(\pi - \delta_m)] - P_m'(\pi - \delta_m - \delta_m)$

~~$\Rightarrow P_m'(\pi - 2\delta_0) = 1.45[$~~

~~$P_m'(\pi - \delta_0 - \delta_m) = 1.45[2\cos\delta_m]$~~

$\delta_o = 0.761$

~~$P_m' (2.38 - \delta_m) = 2.1$~~

~~$\Rightarrow 1.45 \sin \delta_m (2.38 - \delta_m) = 2.1$~~

~~$\Rightarrow \delta_m =$~~

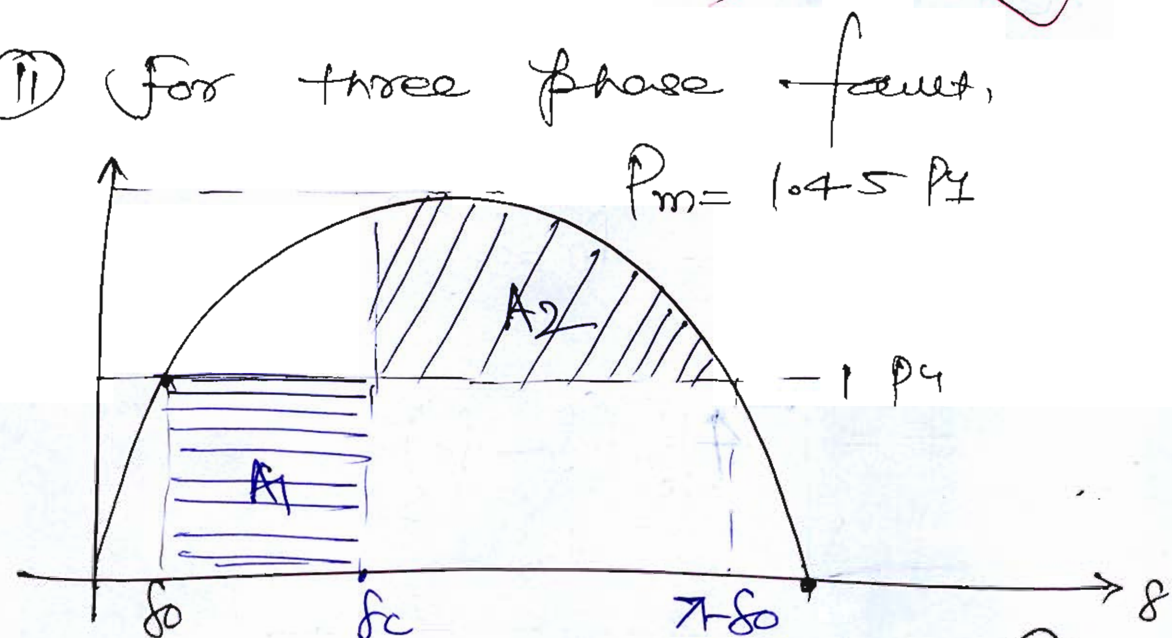
$1.45 \sin \delta_m (2.38 - \delta_m) = 1.45 [\cos \delta_m + \cos \delta_o]$

$\sin \delta_m (2.38 - \delta_m) = \cos \delta_m + 0.7241$

We get $\delta_m = 1.17$ rad $= 67^\circ$

~~Step increase $= P_m' - P_m = 1.45 \sin 67^\circ - 1$~~
~~$= 0.3347$ pu~~

(ii) For three phase fault,



$A_1 = A_2$

$$\Rightarrow \int_{\delta_o}^{\delta_c} 1 \, d\delta = \int_{\delta_c}^{\pi - \delta_o} 1.45 \sin \delta - 1$$

$$\Rightarrow \delta_c - \delta_o = 1.45 (\cos \delta_c + \cos \delta_o) - (\pi - \delta_o - \delta_c)$$

$$\pi - 2\delta_0 = 1.45\left[\cos\delta_c + \cos\delta_0\right]$$

we get

$$\delta_c = \cos^{-1}\left[\frac{(\pi - 2\delta_0)}{1.45} - \cos\delta_0\right]$$

$\delta_0 = 0.761$ rad

$$= \cos^{-1}\left[\frac{(\pi - 2\times .761)}{1.45} - \cos .761\right]$$

$$\delta_c = 66.87^0 = 1.167 \text{ rad}$$

Applying Swing Equation.

$$\frac{2H}{\omega_s}\frac{d^2\delta}{dt^2} = P_m - P_e^{\,0}$$

we get

$$t = \sqrt{\frac{\frac{4H}{\omega_s}(\delta_c - \delta_0)}{P_m}}$$

$$= \sqrt{\frac{\frac{4\times 4}{100\pi}(1.167 - 0.761)}{1}}$$

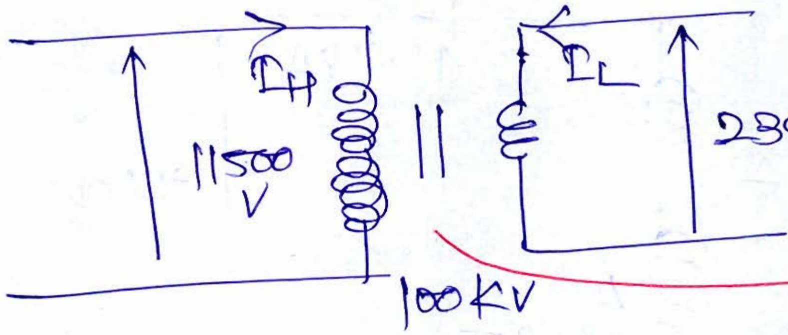
$= 0.1438$ ~~δc~~

8

Q.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]

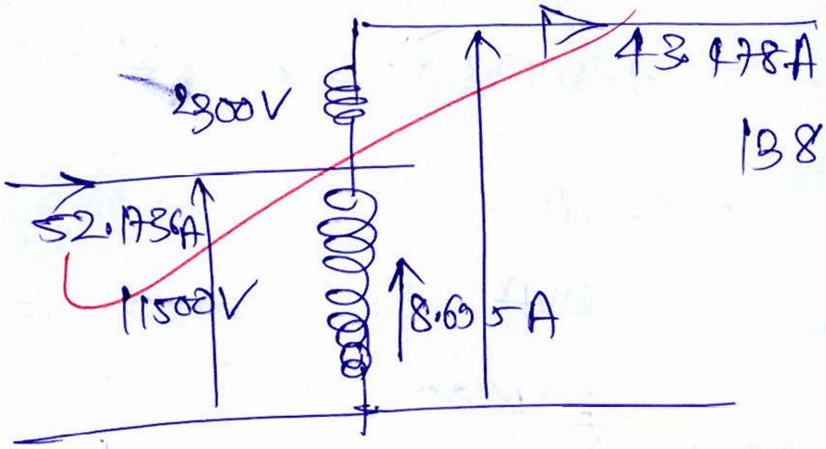


Draw diagram properly

$I_H = \frac{100 \times 10^3}{11500} = 8.695$ A

$I_L = \frac{100 \times 10^3}{2300} = 43.478$ A

(i) HV Common Additive Connection



Voltage Ratio $= \frac{11500}{13800} = \frac{5}{6} = K$

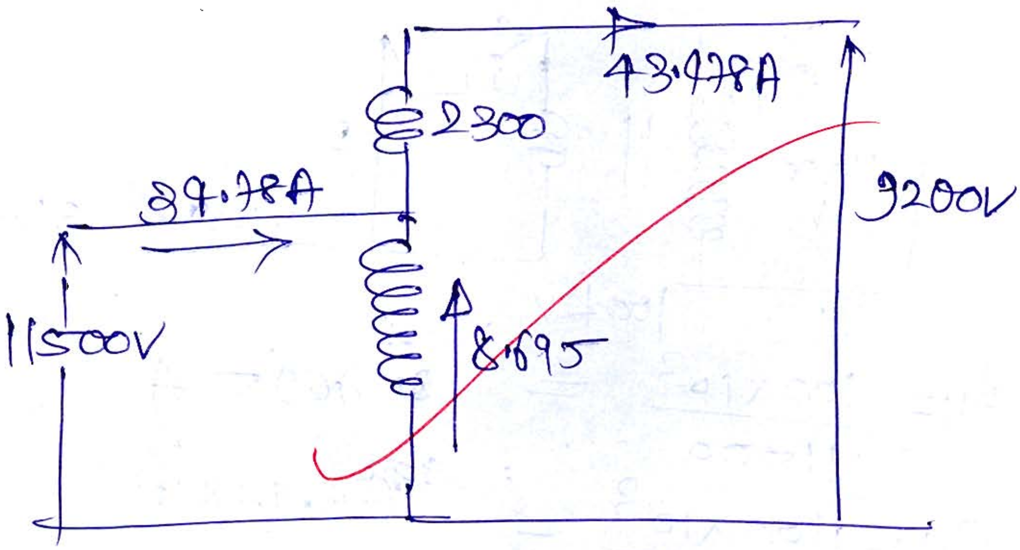
KVA Output $= 13800 \times 43.478$
≈ 600 KVA

Power through Conduction,
$S_{cond} = 600$ KVA $- 100$ KVA
$= 500$ KVA

$S_{ind} = 100$ KVA [always]

% Saving = $1-K = \frac{1}{6} = 16.67\%$

(II) HV Common Subtractive:-



Voltage Ratio = $\frac{9200}{11500} = \frac{4}{5}$

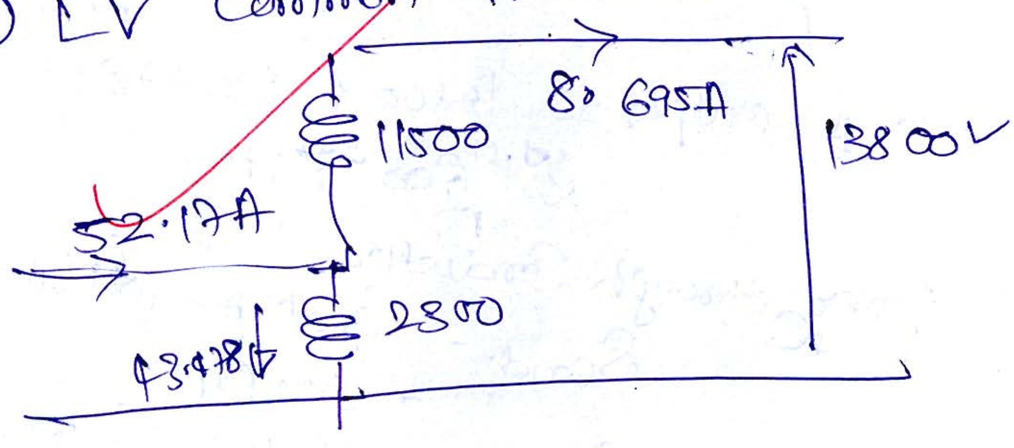
KVA output = $43.478 \times 9200 = 400$ KVA

S_{ind} = 100 KVA

$S_{cond.}$ = 300 KVA

% Saving = $\left(1-\frac{4}{5}\right)\times 100 = 20\%$

(III) LV Common Additive



$VR = \frac{2300}{13800} = \frac{1}{6}$

KVA output $= 13800\,V \times 8.695\,A$

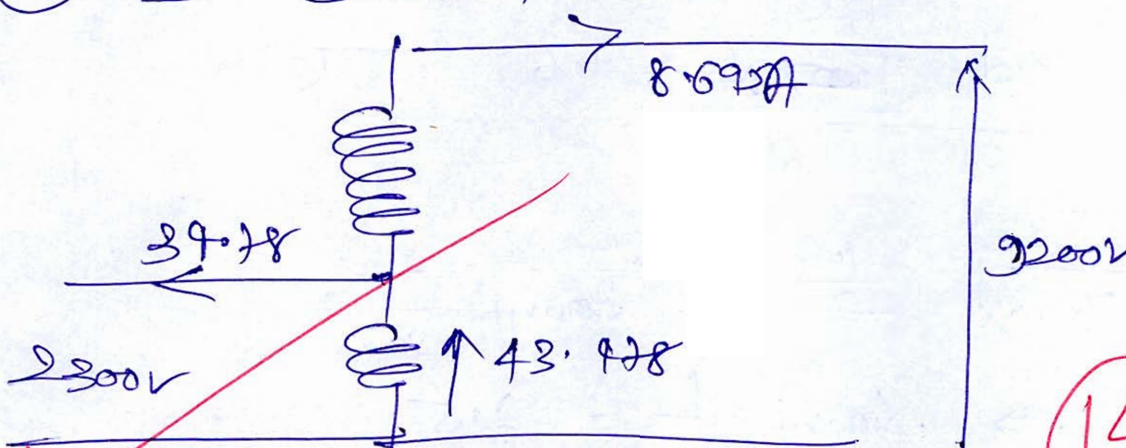
$\simeq 120\ KVA$

$S_{ind} = 100\ KVA$

$S_{cond} = 20\ KVA$

% Saving $= \left(1 - \frac{1}{6}\right) \times 100 = 83.33\%$

(IV) LV Common Subtractive



14

$VR = \frac{2300}{9200} = \frac{1}{4}$

$S = 9200 \times 8.695 = 80\ KVA$

$S_{ind} = 100\ KVA$

$S_{cond} = 80 - 100 = -20\ KVA$

% Saving $= \left(1 - \frac{1}{4}\right) \times 100 = 75\%$

(ii) Applications of Auto Transformer

(i) used in laboratory for variable supply.

(ii) It is used to start Induction motor.

(iii) Used as a transformer for voltage ratio close to 1.

(iv)

3

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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]

We have,

$$\frac{T_{max}}{T_{fl}} = 2 \quad \text{---(1)}$$

and $$\frac{T_{st}}{T_{fl}} = 1.6 \quad \text{---(2)}$$

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

$$\Rightarrow S_{max} + \frac{1}{S_{max}} = 2.5$$

$$S_{max} = 0.5$$

4

from (1) $$\frac{T_{fl}}{T_{max}} = \frac{1}{2} = \frac{2}{\frac{S_{max}}{S_{fl}} + \frac{S_{fl}}{S_{max}}}$$

$$\Rightarrow \frac{1}{2} = \frac{2}{\frac{0.5}{S_{fl}} + \frac{S_{fl}}{0.5}}$$

$$\Rightarrow \frac{0.5}{S_{fl}} + 2S_{fl} = 4$$

$$2S_{fl}^2 - 4S_{fl} + 0.5 = 0$$

we get $S_{fl} = 0.134$

As $S_{max} = 0.5 = \frac{R_2'}{X_2'}$

$R_2' = 0.5 X_2'$

for $S_{fl} = 0.05$

And as maximum torque does not change by changing R_2'.

So we have,

$$\frac{T_{fl}}{T_{max}} = \frac{1}{2} = \frac{2}{\frac{S_m'}{0.05} + \frac{0.05}{S_m'}}$$

$$\Rightarrow 20 S_m' + \frac{0.05}{S_m'} = 4$$

Solving, $S_m' = 0.0134$

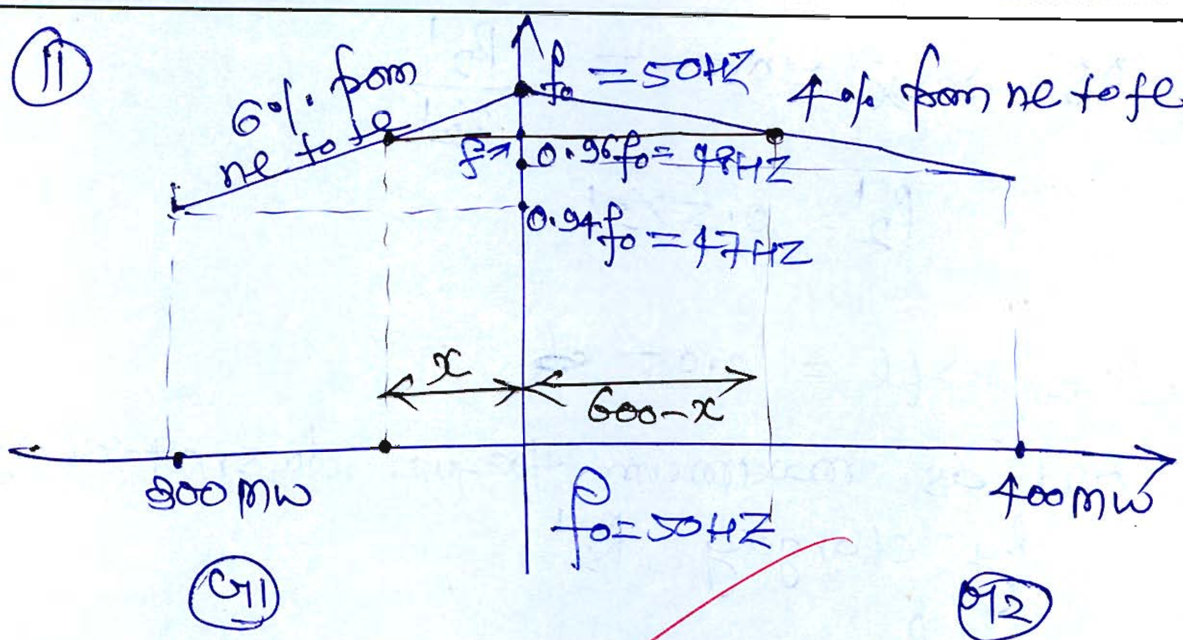
$$\Rightarrow \frac{R_2'_{new}}{X_2'} = 0.0134$$

$R_2'_{new} = 0.0134 X_2'$

~~percent Reduction = $\left(\frac{0.5X_2' - 0.0134X_2'}{0.5X_2'}\right) \times 100$~~

~~$= \underline{97.32\%}$~~

(11)



~~For G1~~

~~$\frac{0.06 f_o}{800} = f_o -$~~

For G1

$$\text{Slope} = \frac{3\ HZ}{300\ mw} = \frac{50-f}{x} \quad \text{— (1)}$$

for G2

$$\text{Slope} = \frac{2\ HZ}{400\ mw} = \frac{50-f}{600-x} \quad \text{— (2)}$$

(1) ÷ (2)

$$2 = \frac{600-x}{x}$$

$x = 200$ mw

from (1) $\frac{3}{300} = \frac{50-f}{x=200}$

$f = 48$ HZ

Thus Load by $G_1 = x = 200$ mw

Load by $G_2 = 600-x = 400$ mw

operating frequency $= f = 48HZ$

9

Q.8 (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 : $\alpha = 15°$, $X = 15\ \Omega$

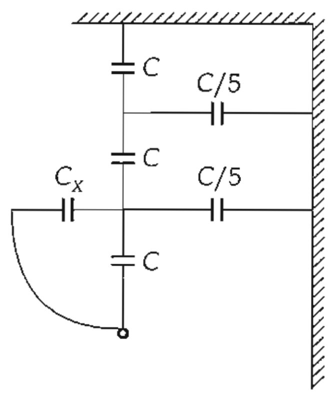
Inverter : $\delta_o = 10°$, $\gamma = 15°$, $X = 15\ \Omega$. Allow 5° margin on δ_o for δ.

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

[14 + 6 marks]

Q.8 (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

σ

$\sigma = \frac{ne^2 t}{m}$

$\frac{1}{m^3} \times \frac{c^2 \times sec}{Kg}$

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ESE 2023 : Mains Test Series

UPSC ENGINEERING SERVICES EXAMINATION

Mechanical Engineering

Test-5 : Section A : Production Engineering & Material Science [All Topics]

Section B : Theory of Machines-1 [Part Syllabus]

Fluid Mechanics & Turbo Machinery-2 [Part Syllabus]

Name : Jitendra Kumar Patel

Roll No : | M | E | 2 | 3 | M | D | D | L | A | 1 | 3 | 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. 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	51
Q.3	—
Q.4	40-3=37
Section-B	
Q.5	26
Q.6	36
Q.7	—
Q.8	—
Total Marks Obtained	197

Signature of Evaluator: [signature] 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.

COMMENTS:

1. Improve representation. Try to write in such a manner which should be visible clearly.
2. The attempt is very good. work on calculation mistakes.
3. Improve theoretical portion to make a complete package for mains exam.

Do not write in this margin

Section : A

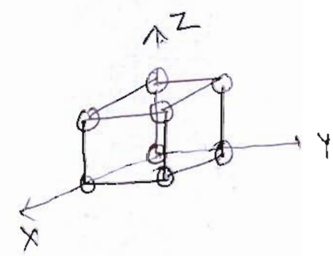
Q.1 (a) What do you understand by linear and planar densities?
Zinc has an atomic radius of 0.135 nm with an HCP crystal structure, and atomic weight of 65.39 g/mol. Considering $\frac{c}{a}$ ratio to be 1.856 for zinc, calculate the density for the same in g/cc.

[12 marks]

Linear Density: No of atoms centre are intersected per unit length in a particular direction is called linear density.

eg. BCC [1 0 0]

$\rho_l = \frac{\frac{1}{2}\times 2}{a} = \frac{1}{a}$



Planar Density: The no of centre of atom occupies per unit area is called planar density.

eg for BCC (100) plane

$\rho_p = \frac{\frac{1}{4}\times 4}{a^2} = \frac{1}{a^2}$

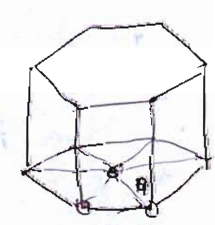
Zn - HCP.

$r = 0.135$ nm $= 0.135\times10^{-7}$ cm

$A = 65.39$ g/mol

$\frac{c}{a} = 1.856$

$\rho_v = \frac{N_{av}\times \text{Molecular weight}}{\text{Base area}\times\text{Height}}$



Base area $= 6\times\frac{\sqrt{3}}{4}\times a^2$

$\because a = 2r$

Base area $= \frac{3\sqrt{3}}{2}\times 4r^2$

$= 6\sqrt{3}\,r^2$

for HCP $N_{av} = 6$

$\rho = \frac{6\times\frac{4}{3}\pi r^3}{}$

$$\rho_v = \frac{6 \times 65.39}{6.0623 \times 10^{23} \times 6\sqrt{3}\, r^2 \times 1.856 \times 2r}$$

$$\rho_v = \frac{6 \times 65.39}{6.0623 \times 10^{23} \times 6\sqrt{3} \times 1.856 \times 2 \times r^3}$$

$$\rho_v = \frac{6 \times 65.39}{6.0623 \times 10^{23} \times 6\sqrt{3} \times 2 \times 1.856 \times (0.135 \times 10^{-7})^{3}}$$

$$\rho_v = 6.8632 \ g/cc$$

12

Q.1 (b) During an electric discharge drilling of a 12 mm square hole in a low carbon steel plate of 6 mm thickness, brass tool and kerosene are used. The resistance and the capacitance in the relaxation circuit are 60 Ω and 12 μF respectively. The supply voltage is 220 Volts and the gap is maintained at such a value that the discharge (sparking) takes place at 150 Volts. In case of machining steels, the removal rate can be approximately expressed as $Q \simeq 27.4 \ W^{1.54}$, where Q is the removal rate of steel in mm³/min and W is the power input in kW. Estimate the time required to accomplish the drilling operation.

[12 marks]

given $V_o = 220$ V $\quad R = 60\,\Omega$

$V_d = 150$ V $\quad C = 12 \times 10^{-6}$

$$V_d = V_o\left(1 - e^{-t_1/RC}\right)$$

$$150 = 220\left(1 - e^{\frac{-t_1}{60 \times 12 \times 10^{-6}}}\right)$$

$$t_1 = 8.244 \times 10^{-4} \ s$$

$$\text{Energy}(E) = \frac{1}{2} \times C \times V_d^2$$

$$\text{Power} = \frac{E}{t_1} = \frac{C V_d^2}{2 t_1}$$

$$= \frac{12 \times 10^{-6} \times (150)^2}{2 \times 8.244 \times 10^{-4}}$$

$$\text{Power} = 163.736 \ W$$

Power = 0.16373 kW

$MRR = 27.4 \times (0.16373)^{1.54}$

$= 1.688 \ mm^3/min.$

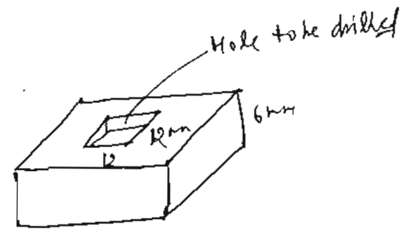
$MRR = \frac{Volume}{Time}$

$1.688 = \frac{Area \times thickness}{Time}$

$time = \frac{12 \times 12 \times 6}{1.688}$

$= 511.657 \ s$

$= 8.52 \ Min$



(12)

Q.1 (c) A hole 150 mm diameter is to be punched in a steel plate of 8 mm thickness. The material is cold rolled C40 steel for which the maximum shear strength can be taken as 560 MPa. With normal clearance on the tools, cutting is complete at 40% penetration of the punch. Estimate suitable diameters for the punch and die, and shear angle on the punch (assuming balanced shear) in order to bring the work within the capacity of a 250 kN press available.

[12 marks]

given $t = 8\,mm$

$D = 150$

$\tau_u = 560\,MPa$

$pt = 0.4 \times t$

$P = 250\,kN$

Punch force $= \tau_u \times$ perimeter $\times$ thickness

~~$250 \times 10^3 = 560 \times 10^6 \times$ penetration.~~

Assume Trapezoidal load - displacement diagram $F_{max} \times pt = F_s \times s$

$WD = F_s \times s$

$F_{max} \times pt = F_s \times s$

↓

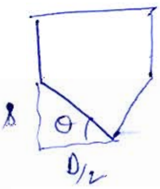
$\tau_u \times \pi D t \times pt = F_s \times s$ → shear on punch.

$560 \times 10^6 \times \pi \times 0.150 \times 8 \times 10^{-3} \times 0.4 \times 8 \times 10^{-3} = 250 \times 10^3 \times s$

$s = 0.027\,m$

$s = 27\,mm$

Assume shear on Both side.



Shear angle $\tan\theta = \frac{s}{D/2}$

$\tan\theta = \frac{27}{150/2}$

$\theta = 19.79°$

$\boxed{\theta = 19.79°}$

Clearance $= 0.0032 \times t \sqrt{\tau_u}$

$= 0.0032 \times 8 \times \sqrt{560}$

$= 0.605\,mm = 6.05\,mm$

In this operation Punch should be exact so.