Try to avoid calculation mistake

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ESE 2023 : Mains Test Series

UPSC ENGINEERING SERVICES EXAMINATION

Electrical Engineering

Test-4 : Electrical Machines + Power Systems-1 + Systems and Signal Processing-2 + Microprocessors-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	26
Q.2	31
Q.3	
Q.4	37
Section-B	
Q.5	34
Q.6	
Q.7	50
Q.8	
Total Marks Obtained	178

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.

Do not write in this margin

Section A : Electrical Machines

Q.1 (a) A ring of magnetic material has a rectangular cross-section. The inner diameter of ring is 20 cm and outer diameter is 25 cm, its thickness being 2 cm. An air-gap of 1 mm length is cut across the ring. The ring is wound with 500 turns and carrying a current of 3 A producing a flux density of 1.2 T in the air gap. Find :

(i) Magnetic field intensity in the magnetic material and in air-gap.

(ii) Relative permeability of the magnetic material.

(iii) Total reluctance of the magnetic circuit and component values. (Neglect the fringing effect).

[12 marks]

Q.1 (b) The core-loss (hysteresis + eddy-current loss) for a given specimen of magnetic material is found to be 2000 W at 50 Hz. Keeping the flux density constant, the frequency of supply is raised to 75 Hz resulting in a core loss of 3200 W. Compute separately hysteresis and eddy current losses at both the frequencies.

[12 marks]

Given $P_e + P_h = 2000\,W$ at 50 Hz

$P_e + P_h = 3200\,W$ at 75 Hz

we know if flux density is kept constant

$P_e = E f^2$, $P_h = Hf$

$\therefore$ $E(50)^2 + H(50) = 2000$ — ①

$E(75)^2 + H(75) = 3200$ — ①

$$\begin{bmatrix} 2500 & 50 \\ 5625 & 75 \end{bmatrix} \begin{bmatrix} E \\ H \end{bmatrix} = \begin{bmatrix} 2000 \\ 3200 \end{bmatrix}$$

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Write answer in detail

$\therefore$ $E = \frac{8}{75} = 0.1067$

$H = \frac{104}{3} = 34.6667$

$\therefore$ at 50 Hz

$P_e = E f^2 = 266.67\ W$

$P_h = Hf = 1733.33\ W$

at 75 Hz

$$P_e = Ef^2 = 600 \text{ W}$$

$$P_h = Hf = 2600 \text{ W}$$

Q.1 (c) A single phase load is fed through a 66 kV feeder whose impedance is $(120 + j400)\ \Omega$ and a 66/6.6 kV transformer of equivalent impedance (referred to LV) $(0.4 + j1.5)\ \Omega$. The load is 250 kW at 0.8 leading power factor at 6 kV. Compute :

(i) the voltage at sending end of the feeder.

(ii) the voltage at the primary terminals of the transformer.

(iii) complex power at the sending end of the feeder.

[12 marks]

load 250kW 0.8 pf lead 6 kV 1ϕ

$$\therefore I = \frac{250\times10^3}{6\times10^3\times0.8} = 52.08\ A$$

taking $V = 6k$ as reference

$$V = 6000\angle 0^\circ\ V$$

$$I = 52.08\angle 36.87^\circ\ A$$

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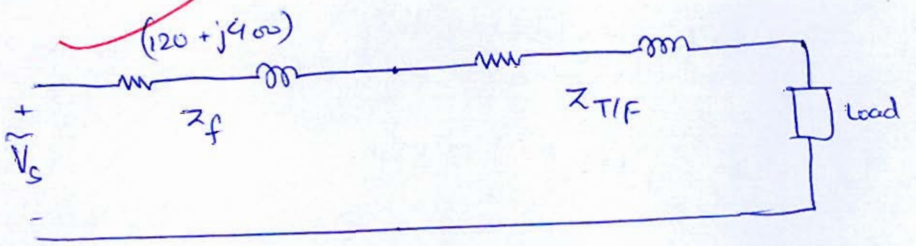
Good Approach



$V_{sy\ T/F} = 6kV$

$$\therefore V_{Py\ T/F} = 6000\angle 0 + 52.08\angle 36.87 \times (0.4 + j1.5)$$

$$= 5970.26\angle 0.72^\circ\ V \quad \text{referred to LV}$$

$$V_{Py\ T/F} = 5970.26\angle 0.72^\circ \times \frac{66}{6.6}$$

$$= 59702.65\angle 0.72\ V \quad \text{referred to HV}$$

$$I = 52.08\angle 36.87 \times \frac{6.6}{66} = 5.208\angle 36.87\ A$$

referred to HV

Do not write in this margin

$$\therefore \quad V_s = 59702.65 \angle 0.72^\circ + (120 + j400)(5.208 \angle 36.87^\circ)$$

$$= 59014.05 \angle 2.71^\circ \text{ V}$$

$\therefore$

(i) $V_s = 59014.05 \angle 2.71^\circ$ V

(ii) $V_{p_{4_{T/f}}} = 59702.65 \angle 0.72^\circ$ V

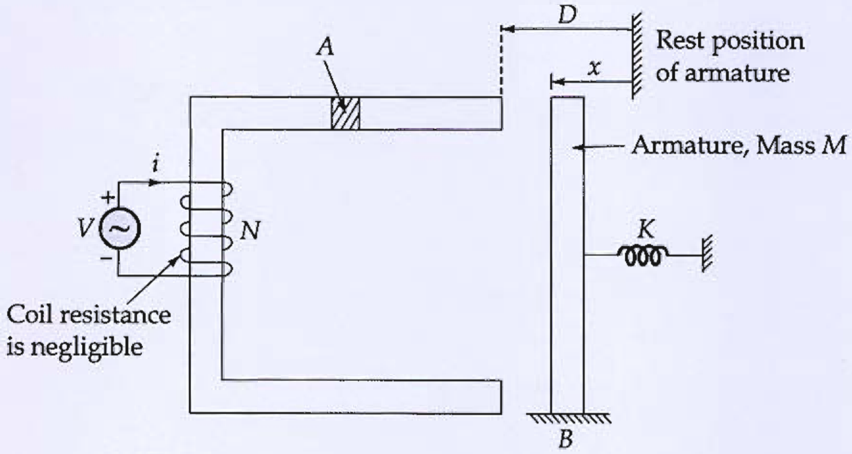
(iii) $S = V I^*$

$$= (59014.05 \angle 2.71^\circ)(5.208 \angle 36.87^\circ)^*$$

$$= (254319.76 - j172576.11) \text{ VA}$$

$$= (254.32 - j172.58) \text{ kVA}$$

Q.1 (d) For electromechanical system shown in figure, the air-gap flux density under steady operating condition is $B(t) = B_m \sin \omega t$.



Find :

(i) coil voltage

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

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

[12 marks]

(i) given $B(t) = B_m \sin\omega t$

$\phi = B \cdot A$

$\phi(t) = B_m A \sin\omega t$

as $V = -N \frac{d\phi}{dt}$

$= -N \frac{d(BA)}{dt}$

$= -NA \frac{d}{dt}(B_m \sin\omega t)$

$= -NAB_m \omega \cos\omega t$

$= -\omega NAB_m \cos\omega t$ V

2

(ii)

$$P = F \cdot v$$

$$\text{Power} = E/t$$

$$E = \frac{B^2}{2\mu}$$

$$= \frac{B_m \sin^2 \omega t}{2\mu}$$

$$F = P/v$$

Q.1 (e) The following data pertain to a 250 V DC series motor :

$$Z = 180, \frac{P}{A} = 1$$

$$\text{Flux/pole} = 3.75 \text{ mWb/field amp}$$

Total armature circuit resistance = 1 Ω

The motor is coupled to a centrifugal pump whose load torque is

$$T_L = 10^{-4}n^2 \text{ Nm where } n = \text{Speed in rpm}$$

Calculate the current drawn by the motor and the speed at which it will run for given load.

[12 marks]

For a DC series motor

$E = k\phi\omega$, $T = k\phi I$

$K = \frac{ZP}{2\pi A}$ $\cancel{= \frac{180 \times 1}{2\pi} = 28.65}$

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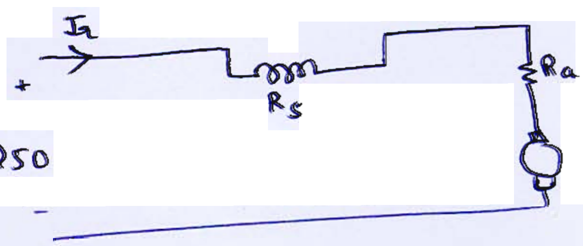
$\cancel{\phi = 28}$ $\phi = 3.75 \times 10^{-3}$ Wb $\times (I_f)$

$\cancel{= 3.75 \times 10^{-3} I_a}$ $(I_f = I_a)$



$R_a + R_s = 1$

$\therefore$ $E = (28.65)(3.75 \times 10^{-3}) I_a \cdot \omega$

$= 0.01125 \, I_a N$ $\left(\omega = \frac{2\pi}{60} N\right)$

$T = (28.65)(3.75 \times 10^{-3}) I_a \cdot I_a$

$= 0.107 \, I_a^2$

given $T_L = 10^{-4} N^2$

for steady state $T = T_L$

$$\therefore \quad 0.107\, I_a^2 = 10^{-4} N^2$$

$$N = 32.71\, I_a \quad \text{— (i)}$$

also from ckt

$$V = E + I_a (R_a + R_s)$$

$$250 = E + I_a (1)$$

$$250 = 0.01125\, I_a N + I_a \quad \text{— (ii)}$$

putting (i) in (ii)

$$250 = 0.368\, I_a^2 + I_a$$

$$\Rightarrow \quad I_a = 24.74 \text{ A}$$

$$\therefore \quad I_a = 24.74 \text{ A}$$

$$N = 809.25 \text{ rpm}$$

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Q.2 (a) A 3-ϕ, 12 kV, 15 MVA, 60 Hz, salient pole synchronous motor is run from a 12 kV, 60 Hz, balanced 3-ϕ supply. The machine reactances are $X_d = 1.2$ pu, $X_q = 0.6$ pu (with the machine rating as base). Neglect rotational losses and armature resistance losses. The machine excitation and load are varied to obtain the following conditions :

(i) Maximum power input is obtained with no field excitation. Determine the value of this power, armature current and the power factor of this condition.

(ii) Rated power output is obtained with minimum excitation. Determine this minimum value of excitation emf.

[20 marks]

3ϕ 12 KV 15 mVA 60 Hz

$X_d = 1.2$ pu

$X_q = 0.6$ pu

$$Z_{base} = \frac{KV_{base}^2}{mVA_{base}} = 9.6 \quad \text{(m/c rating)}$$

$$\therefore X_d = 1.2 \times 9.6 = 11.52\ \Omega$$

$$X_q = 0.6 \times 9.6 = 5.76\ \Omega$$

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(i)

$$P = \frac{EV}{X_d}\sin\delta + \frac{V^2}{2}\left(\frac{1}{X_q} - \frac{1}{X_d}\right)\sin 2\delta$$

at no field excitation $E = 0$

$$\therefore P = \frac{V^2}{2}\left(\frac{1}{X_q} - \frac{1}{X_d}\right)\sin 2\delta \quad \text{per phase}$$

$$P_{3\phi} = 3 \times \frac{\left(\frac{12}{\sqrt{3}}\right)^2}{2}\left(\frac{1}{5.76} - \frac{1}{11.52}\right)\sin 2\delta$$

$$= 6.25 \sin 2\delta \quad \text{MW}$$

for P_{max}, $\delta = 45^\circ$

$\therefore \quad P_{max} = 6.25 \text{ MW} \quad , \delta = 45^\circ$

also $\quad Q = 3\left[\frac{EV}{X_d}\cos\delta - \frac{V^2}{X_d} - V^2\left(\frac{1}{X_q} - \frac{1}{X_d}\right)\sin^2\delta\right]$

$\therefore \quad Q = 3\left[-\frac{(12/\sqrt{3})^2}{11.52} - (12/\sqrt{3})^2\left(\frac{1}{5.76} - \frac{1}{11.52}\right)\sin^2 45\right]$

$= -3\left[6.25\right]$

$= -18.75 \quad \text{MVAr}$

$\therefore \quad \tan\phi = \frac{-18.75}{6.25} = -3$

$\phi = -71.56^\circ$

$\cos\phi = 0.316 \quad \text{leading}$

as $\quad P = 3 V I \cos\phi$

$6.25 \times 10^6 = 3 \times \frac{12 \times 10^3}{\sqrt{3}} \times I \times 0.316$

$I = 951.59 \text{ A}$

$\therefore \quad P_{max} = 6.25 \text{ MW}$

$I = 951.59 \text{ A}$

$pf = 0.316 \text{ lead}$

(iii) rated power = 15 MVA

$$15 = 3\left[\frac{EV}{X_d} - \frac{V^2}{2}\sin 2\delta\left(\frac{1}{X_q} - \frac{1}{X_d}\right)\right]$$

$$5 = \frac{E \times 12/\sqrt{3}}{11.52} - \frac{(12/\sqrt{3})^2}{2}\sin 2\delta\left(\frac{1}{5.76} - \frac{1}{11.52}\right)$$

$$5 = 0.6E - 2.08\sin 2\delta$$

$$E = \frac{5 + 2.08\sin 2\delta}{0.6}$$

for E_{min} $\frac{dE}{d\delta} = 0$

$$\Rightarrow \cos 2\delta = 0$$

$$\delta = 45^\circ$$

$$\therefore E_{min} = \frac{5 + 2.08}{0.6}$$

$$= 11.8 \text{ kV} \quad \text{phase}$$

$$E_{min} = 20.44 \text{ kV} \quad \text{line}$$

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Q.2 (b) A 3-ϕ, 250 kW, 460 V, 60 Hz, 8-pole induction machine is driven by a wind turbine. The induction machine has the following parameters :

$$R_1 = 0.015\ \Omega,\ R_2' = 0.035\ \Omega$$
$$L_1 = 0.385\ \text{mH},\ L_2' = 0.358\ \text{mH},\ L_m = 17.24\ \text{mH}$$

The induction machine is connected to 460 V infinite bus through a feeder having a resistance of 0.01 Ω and inductance of 0.08 mH. The wind turbine drives the machine at a slip of –2.5%. Determine :

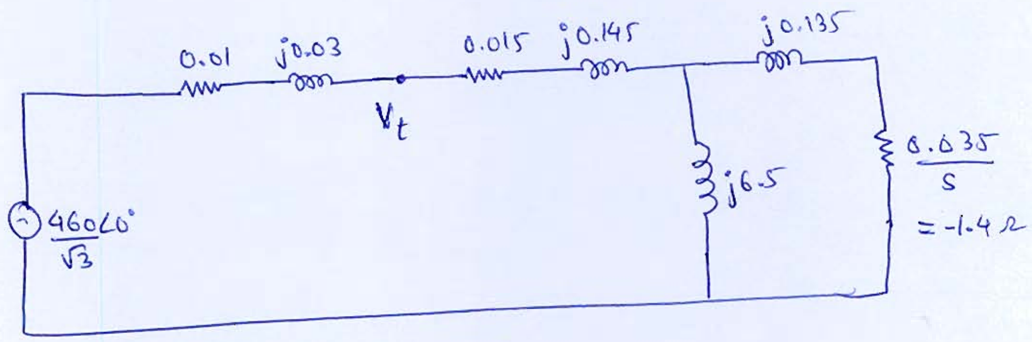
(i) the speed of turbine.

(ii) the voltage at the terminals of induction machine.

(iii) the power delivered to infinite bus and the power factor.

(iv) the efficiency of the system. Assume the rotational and core losses to be 3 kW.

[20 marks]



$X_{line} = 2\pi \times 60 \times 0.08 \times 10^{-3} = 0.03\ \Omega$

$X_1 = 2\pi \times 60 \times 0.385 \times 10^{-3} = 0.145\ \Omega$

$X_2' = 2\pi \times 60 \times 0.358 \times 10^{-3} = 0.135\ \Omega$

$X_m = 2\pi \times 60 \times 17.24 \times 10^{-3} = 6.5\ \Omega$

$S = -0.025$

$\therefore \frac{R_2}{S} = \frac{0.035}{-0.025} = -1.4$

(i) $N_s = \frac{120 f}{P} = \frac{120 \times 60}{8} = 900$ rpm

$N = (1-S)N_s = (1-(-0.025)) \times 900 = 922.5$ rpm

$(N > N_s \Rightarrow$ generator mode$)$

(ii) $Z_{rotor} = j0.135 - 1.4$

$Z_f = (j0.135 - 1.4) \,//\, j6.5$

$= -1.286 + j0.404$

$\therefore \quad Z_{machin} = Z_f + 0.015 + j0.145$

$= -1.271 + j0.549$

$\therefore \quad I = \dfrac{460/\sqrt{3}}{0.01 + j0.03 + (-1.271 + j0.549)}$

$= 191.376 \angle -155.355^\circ$ A

$\therefore \quad V_t = \dfrac{460}{\sqrt{3}} \angle 0 - I(0.01 + j0.03)$

$= 264.995 \angle 1.3^\circ$ V

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(iii) $\phi = -155.355^\circ$

$\cos\phi = -0.909$ lag

$\Rightarrow$ pf $= 0.909$ lead

$\therefore \quad P_{delivered} = 3 V I \cos\phi$

$= 138.6$ kW

(iv) $P_{air\ gap} = 3 \; I^2 \frac{R_2}{s}$

$= -153.82$ kW

$P_{rotor\ o/p} = (1-s) \; P_{air\ gap}$

$= -157.67$ kW

$P_{shaft\ o/p} = P_{rotor\ o/p} - P_{rot\ loss}$

$= -157.67$ kW $-$ 3kW

$= -160.67$ kW

$-$ve sign signifies Power i/p instead of output

$\therefore \; P_{i/p} = 160.67$ kW

$P_{o/p} = 138.6$ kW

$\eta = \frac{138.6}{160.67} \times 100$

$= 86.26\%$

Q.2 (c) A 10 kW, 100 V, 1000 rpm dc machine has armature resistance, $R_a = 0.1\ \Omega$ and is connected to 100 V dc supply.

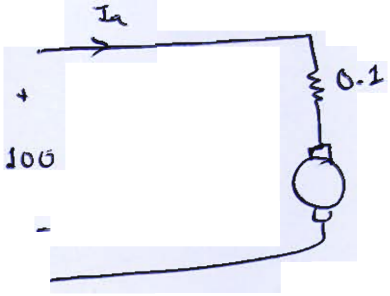
(i) Determine the starting current if no starting resistance is used in the circuit.

(ii) Determine the starting resistance if the starting current is limited to twice the rated current.

(iii) This dc machine is to be run as a motor, using a starter box. Determine the values of resistance required in (3-section) starter box such that the armature current I_a is constrained within 100 to 200% of its rated value (i.e., 1 to 2 pu) during start-up.

[2 + 2 + 16 marks]

(i) considering a separately excited DC ~~motor~~ machine



at starting $N = 0$

$\Rightarrow E \propto N$

$E = 0$

$\therefore I_{start} = \frac{V}{R_a} = \frac{100}{0.1} = 1000\ A$

(ii) $P = 10\,kW = V_t I_L$

$\therefore I_{L\,rated} = \frac{10 \times 10^3}{100} = 100\ A$

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$I_{start} = 2\ I_{rated} = 200\ A$

$I_{start} = \frac{V_t}{R_a + R_{ext}}$

$\therefore 200 = \frac{100}{0.1 + R_{ext}}$

$R_{ext} = 0.4\ \Omega$

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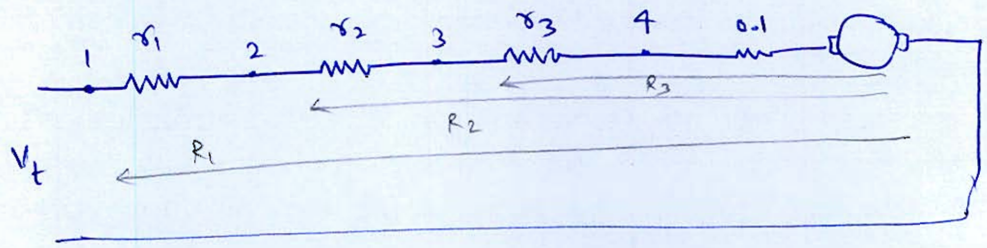
iii) with a 3 section starter



at start $I_1 = \dfrac{V_t}{R_1}$

as I_1 can be max 2 times rated

$\therefore$ $200 = \dfrac{100}{R_1}$

$R_1 = 0.5$

3

~~at stud 1)~~

$\cancel{I_2 = V}$

we know $\dfrac{I_1}{I_2} = k^{3}$ ~~n = no of studs~~

$\therefore$ $\dfrac{200}{\cancel{100}\, I_2} = k^{3}$

also $\dfrac{I_1}{I_2} = \dfrac{R_1}{R_2} = \dfrac{R_2}{R_3} = \dfrac{R_3}{R_a} = k$

$\therefore$ $\left(\dfrac{I_1}{I_2}\right)^3 = k^3 = \dfrac{R_1}{R_a}$

$$\therefore \quad K^3 = \frac{0.5}{0.1} = 5$$

$$K = 1.71$$

$$\therefore \quad \frac{I_1}{I_2} = 1.71$$

$$I_2 = \frac{200}{1.71} = 116.95 \quad > 100\text{ A (as per problem)}$$

$$\therefore$$

$$R_3 = K R_a = 0.171\ \Omega$$

$$R_2 = k^2 R_a = 0.292\ \Omega$$

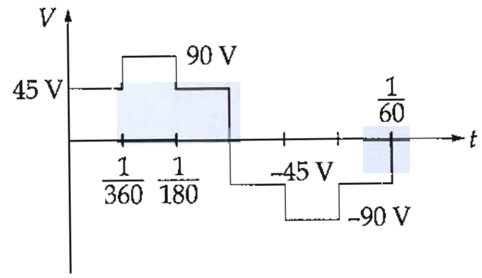
$$R_1 = K^3 R_a = 0.5\ \Omega$$

$$\therefore \quad r_1 = R_1 - R_2 = 0.208\ \Omega$$

$$r_2 = R_2 - R_3 = 0.121\ \Omega$$

$$r_3 = R_3 - R_a = 0.071\ \Omega$$

Q.3 (a) **(i)** A six-step voltage of frequency 60 Hz, as shown in figure, is applied on a coil wound on a magnetic core. The coil has 500 turns. Find the maximum value of flux and sketch the waveforms of voltage and flux as a function of time.



(ii) Find the number of series turns required for each phase of a 3-ϕ, 50 Hz, 10-pole alternator with 90 slots. Winding is to be connected to give a line voltage of 11 kV. The flux/pole is 0.16 Wb.

[15 + 5 marks]

Q.3 (b) Tests are performed on a 1-ϕ, 10 kVA, 2200/220 V, 50 Hz transformer and the following results are obtained :

	Open Circuit Test (HV side open)	Short Circuit Test (LV side shorted)
Voltmeter	220 V	150 V
Ammeter	2.5 A	4.55 A
Wattmeter	100 W	215 W

(i) Derive the parameters for approximate equivalent circuit referred to LV side and the HV side.

(ii) Determine the power factor for no-load and short-circuit tests.

(iii) Determine voltage regulation at 75% full load, 0.6 power factor lagging.

[10 + 2 + 8 marks]

Q.3 (c) A test on $\frac{1}{4}$ hp, 120 V, 60 Hz, 1725 rpm single phase induction motor reveals the following results :

Stator resistance : 2 Ω

Rotor resistance referred to stator : 4 Ω

Stator leakage reactance : 3 Ω

Stator leakage reactance referred to stator : 3 Ω

Resistance corresponding to the windage, friction and iron losses : 600 Ω

Magnetizing reactance : 60 Ω

Draw the equivalent circuit diagram of motor and determine the forward and backward branch rotor power, power output, efficiency and power factor of motor when it runs at 1725 rpm.

[20 marks]

Q.4 (a) **(i)** A 230 V, 250 rpm, 100 A separately excited dc motor has armature resistance of 0.5 Ω. The motor is connected to 230 V dc supply and rated dc voltage applied to field winding. It is driving a load whose torque speed characteristics is given by $T_L = 500 - 10\omega$, where ω is the rotational speed in rad/sec and load torque in N-m. Find the steady state speed at which motor will drive the load and armature current drawn by it from source. Neglect the rotational losses of the machine.

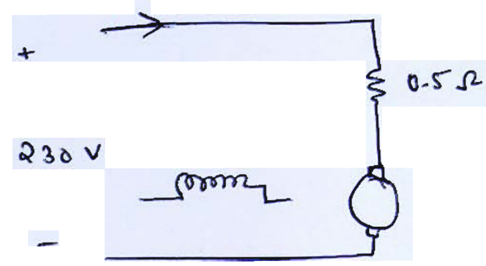
(ii) A 200 V dc shunt motor takes 22 A at rated voltage and runs at 1000 rpm. Its field resistance is 100 Ω and armature circuit resistance (including brushes) is 0.1 Ω. Compute the value of additional resistance required in armature circuit to reduce its speed to 800 rpm, when

(a) load torque is independent of speed.

(b) load torque is proportional to speed.

[10 + 5 + 5 marks]

(i) $T_L = 500 - 10\omega$



At rated condition

$V = 230$ $\quad \omega = \frac{2\pi}{60} \times 250$ $\quad I_a = 100$

$\therefore \quad E = V - I_a R_a$ $\quad E = k\phi\omega$

$= 180 \text{ V}$ $\quad \therefore \; k\phi = 6.875 \;\; \text{Vs/rad}$

Now

as $E = k\phi\omega$

$\Rightarrow E \propto \omega$

& $T = k\phi I$

given $T_L = 500 - 10\omega$

at steady state $T = T_L$

$\therefore \quad K\phi\, I = 500 - 10\omega$

$6.875\, I_a = 500 - 10\omega \quad$ — (i)

also $\quad E = V - I_a R_a$

$K\phi\,\omega = 230 - I_a(0.5)$

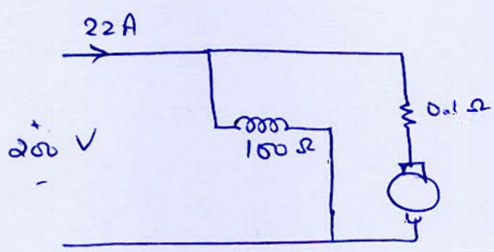
$6.875\,\omega = 230 - 0.5\, I_a \quad$ —(ii)

solving (i) & (ii)

$I_a = 26.91$ A $\qquad \omega = 31.497$ rad/s

$= 300.77$ rpm

(ii)



$I_f = \frac{200}{100} = 2$ A

$\therefore \quad I_a = 22 - 2 = 20$ A

$\therefore \quad E = V - I_a R_a$

$= 200 - 20 \times 0.1$

$= 198$ V

$N = 1000$ rpm

Now $\quad$ case (a) $\qquad T_L = $ constant $\qquad (N = 800$ rpm$)$

$\therefore \quad T = T_L = K\phi\, I = $ constant

$\therefore \quad I_a = 20$ A

$\therefore \quad I_L = 22$ A

$\frac{E_1}{E_2} = \frac{N_1}{N_2} \quad \Rightarrow \quad E_2 = \frac{198 \times 800}{1000}$

$= 158.4$ V

$E = V - I_2 (R_a + R_{ext})$

$158.4 = 200 - 20(0.1 + R_{ext})$

$\therefore$ ~~$R_{ext} = 3.48\ \Omega$~~ $R_{ext} = 1.98\ \Omega$

case (b) $T_L \propto \omega$

$\therefore \dfrac{T_2}{T_1} = \dfrac{\omega_2}{\omega_1} = \dfrac{800}{1000}$

as $T = K\phi I$

$\therefore \dfrac{I_2}{I_1} = \dfrac{800}{1000} \Rightarrow I_{2a} = 16\ A$

$\dfrac{E_1}{E_2} = \dfrac{N_1}{N_2} \Rightarrow E_2 = 158.4\ V$

$\therefore E_2 = V - I_{a_2}(R_a + R_{ext})$

$158.4 = 200 - 16(0.1 + R_{ext})$

$R_{ext} = 2.5\ \Omega$

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Good Approach

Do not write in this margin

Q.4 (b) A 3-ϕ, 25 kW, 400 V, 50 Hz, 8-pole induction motor has rotor resistance of 0.08 Ω and standstill reactance of 0.4 Ω. The effective stator/rotor turns ratio is 2.5/1. The motor is to drive a constant-torque load of 25 Nm. Neglect stator impedance.

(i) Calculate the minimum resistance to be added in rotor circuit for motor to start-up on load.

(ii) At what speed would the motor run, if the added resistance is (a) left in the circuit, and (b) subsequently short circuited?

[20 marks]

$R_2 = 0.08\ \Omega$ $\quad$ $X_2 = 0.4\ \Omega$

1

$K = 2.5$ $\quad \Rightarrow R_2' = K^2 R_2 = 0.5\ \Omega$

$X_2' = K^2 X_2 = 2.5\ \Omega$

$T_L = 25$ Nm

Incomplete Solution

(i)

Do not write in this margin

Q.4 (c) (i) The following data are taken from the open circuit and short circuit characteristics of a 45 kVA, 3-ϕ, Y-connected, 220 V(L-L), 6 pole, synchronous machine. From the open circuit characteristics :

Line-to-line voltage (V_L) = 220 V

Field current (I_f) = 2.84 A

From the short circuit characteristics :

Armature current (A)	118	152
Field current (A)	2.20	2.84

From the air gap line :

Field current (I_f) = 2.20 A; Line to line voltage (V_L) = 202 V

Compute the unsaturated value of synchronous reactance, its saturated value at rated voltage and short circuit ratio.

Express the synchronous reactance in ohm per phase and in per unit on machine rating as base.

(ii) A 325 MVA, 26 kV, 60 Hz, 3-ϕ, salient synchronous generator is observed to be operating at power output of 250 MW and a lagging power factor of 0.89 at a terminal voltage of 26 kV. The generator synchronous reactances are X_d = 1.95 and X_q = 1.18, both in per unit. Calculate generated emf and load angle between the generator terminal voltage and generated emf.

[12 + 8 marks]

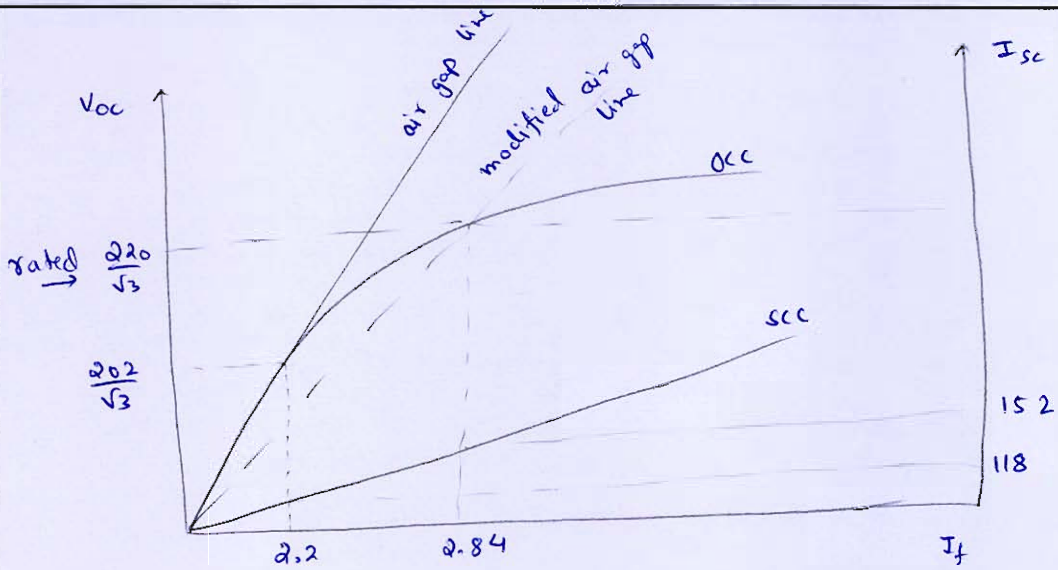
(i) 45 kVA 3ϕ Y 220V 6P

OCC : $I_f = 2.84A$ $V_{oc} = \frac{220}{\sqrt{3}}$

SCC : $I_f = 2.2$ $I_{sc} = 118$

$I_f = 2.84$ $I_{sc} = 152$

air gap $I_f = 2.2$ $V_{oc} = \frac{202}{\sqrt{3}}$



in unsaturated region

$$Z_s \simeq X_s = \frac{V_{oc} \text{ from air gap line corresponding to } I_f}{I_{sc} \text{ from scc at same } I_f}$$

$$= \frac{202/\sqrt{3}}{118}$$

$$= 0.988\ \Omega \qquad \text{(unsaturated)}$$

in saturated region

$$Z_s \simeq X_s = \frac{V_{oc} \text{ from modified air gap line corresponding to } I_f}{I_{sc} \text{ from scc at same } I_f}$$

$$= \frac{220/\sqrt{3}}{152}$$

$$= 0.836\ \Omega \qquad \text{(saturated)}$$

Now $Z_{base} = \dfrac{KV_{base}^2}{MVA_{base}} = \dfrac{220^2}{45\times10^3} = 1.0756\ \Omega$

Do not write in this margin

$\therefore X_s$ unsaturated $= 0.988\ \Omega = \frac{0.988}{1.0756}$ pu

$= 0.919$ pu

X_s saturated $= 0.836\ \Omega = \frac{0.836}{1.0756}$ pu

$= 0.777$ pu

SCC (short circuit ratio) $= \frac{1}{X_{s_{sat}}}$ pu

$= \frac{1}{\cancel{0.07}} = \frac{1}{0.777}$

$= 1.2866$

(ii) $P = 250$ MW

0.89 lag pf $\Rightarrow \phi = 27.127°$

$V_t = 26$ kV line

$X_d = 1.95$ pu

$X_q = 1.18$ pu

$Z_b = \frac{26^2}{325} = 2.08$

$\therefore X_d = 1.95 \times 2.08 = 4.056\ \Omega$

$X_q = 1.18 \times 2.08 = 2.454\ \Omega$

we know

$$E = V\cos\delta + I_q R_a + I_d X_d$$

$$\psi = \delta + \phi$$

$$\tan\psi = \frac{V\sin\phi + I_a X_q}{V\cos\phi + I_a R_a}$$

as $R_a = 0$

$\therefore$ ~~$\tan\psi = 2$~~

given $P = 250$ mw

$$\therefore 250 \times 10^6 = \sqrt{3} \times 26 \times 10^3 \times I_a \times 0.89$$

$$I_a = 6237.579 \text{ A}$$

$$\therefore \tan\psi = \frac{(26000/\sqrt{3})\sin(27.127) + (6237.579)(2.454)}{(26000/\sqrt{3})\cos(27.127) + 0}$$

$$= 1.658$$

18

$$\therefore \psi = 58.905^\circ \Rightarrow \delta = 31.778^\circ$$

Good APPROACH

$$I_d = I_a \sin\psi = 5341.315 \text{ A}$$

$$\therefore E = \frac{26000}{\sqrt{3}}\cos 31.778 + 0 + 5341.315 \times 4.056$$

$$= 34425.24 \text{ V}$$

$$\therefore E_{ph} = 34.4 \text{ KV}$$

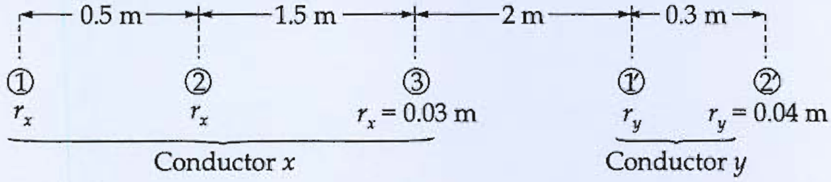
$$E_{line} = 59.6 \text{ kV}$$

$$\delta = 31.778^\circ$$

Do not write in this margin

Section B : Power Systems-1 + Systems and Signal Processing-2 + Microprocessors-2

Q.5 (a) Evaluate the inductance of phase '*X*' and '*Y*' for the single phase two conductor line shown in figure and therefore calculate the total inductance of given line.



[12 marks]

$$L = \frac{\mu_0 \mu_r}{2\pi} \ln\left(\frac{GMD}{GMR}\right)$$

for GMD (same for both phase)

$$= \left(r_{11'} \; r_{12'} \; r_{21'} \; r_{22'} \; r_{31'} \; r_{32'}\right)^{\frac{1}{6}}$$

$$= (4 \times 4.3 \times 3.5 \times 3.8 \times 2 \times 2.3)^{1/6}$$

$$= 3.189 \text{ m}$$

Now GMR (phase x)

$$= \begin{pmatrix} 0.7788 \times 0.03 \times 0.5 \times 2 \times 0.7788 \times 0.03 \times 0.5 \times 1.5 \\ \times 0.7788 \times 0.03 \times 2 \times 1.5 \end{pmatrix}^{\frac{1}{9}}$$

$$= 0.3128 \text{ m}$$

Now GMR (phase Y)

$$= (0.7788 \times 0.04 \times 0.3 \times 0.7788 \times 0.04 \times 0.3)^{\frac{1}{4}}$$

$$= 0.0967 \text{ m}$$

$\therefore L_{x} = 2 \times 10^{-7} \ln\left(\frac{3.189}{0.3128}\right)$

$= 4.64 \times 10^{-7}$ F/m

$L_y = 2 \times 10^{-7} \ln \frac{3.189}{0.0967}$

$= 6.99 \times 10^{-7}$ F/m

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$L_x = 0.464$ mF/km

$L_y = 0.699$ mF/km

Total inductance $= L_x + L_y$

$= 1.163$ mF/km

Write answer in detail

Q.5 (b) A 3-ϕ, 400 kV, 50 Hz transmission line has a series inductive reactance of 0.30 Ω/km and shunt susceptance of 3.75 × 10^{-6} S/km. If the line is 400 km long, then determine its

(i) Surge impedance

(ii) Propagation constant

(iii) ABCD constant

(iv) Wavelength

(v) SIL

[12 marks]

$$\cancel{Z_1 = j\omega L_1 = j(2\pi \times 50 \times 0.3) = j94.247 \ \Omega/km}$$

$$\cancel{Y_1 = j\omega C =}$$

$$Z_1 = j0.3 \ \Omega/km$$

$$Y_1 = j3.75 \times 10^{-6} \ \mho/km$$

$$l = 400 \ km$$

$$V = 400 \ kV$$

(i) $$Z_s = \sqrt{\frac{Z_1}{Y_1}} = \sqrt{\frac{j0.3}{j3.75 \times 10^{-6}}} = 282.84 \ \Omega$$

(ii) $$y = \alpha + j\beta = \sqrt{Z_1 Y_1} = \sqrt{j0.3 \times j3.75 \times 10^{-6}}$$

$$= j1.06 \times 10^{-3}$$

$$\therefore \alpha = 0$$

$$\beta = 1.06 \times 10^{-3} \ rad/sec$$

iii) $A = D = \cosh(ly) = \cosh(400 \times 1.06 \times 10^{-3} j)$

$= \cosh(0.424 j)$

$= \cos(0.424)$

$= 0.9114 \angle 0^\circ$

$\sinh(ly) = \sinh(0.424j) = j \sin(0.424)$

$= 0.4114 \angle 90^\circ$

$\therefore B = Z_c \sinh(ly) = 116.36 \angle 90^\circ$

$C = \dfrac{\sinh(ly)}{Z_C} = 1.45 \times 10^{-3} \angle 90^\circ$

iv) $\beta = \dfrac{2\pi}{\lambda} \quad \therefore \lambda = \dfrac{2\pi}{\beta} = 5927.53 \text{ m}$

10

v) $SIL = \dfrac{V^2}{Z_s} = \dfrac{400^2}{282.84} = 565.69 \text{ MW}$

Do not write in this margin

Q.5 (c) Show the RIM instruction format and discuss the same.

[12 marks]

RIM — Read interrupt mask

It is used to read what all interrupts are generated in 8085.

the instruction format is

D7	D6	D5	D4	D3	D2	D1	D0
SID	X		Control for interrupts		RST5.5	RST6.5	RST 7.5

1

Incomplete Solution

Q.5 (d) Consider the causal system with input $x(n)$ and output $y(n)$ characterized by the difference equation

$$2y(n) + y(n-1) = x(n)$$

If $x(n) = \left(\frac{1}{4}\right)^n u(n)$ and $y(-1) = 2$, find $y(n)$.

[12 marks]

$$2\,y(n) + y(n-1) = x(n)$$

applying unilateral z T

$$\cancel{2\,Y(z) + Y(z)\ z^{-1}\left[y\right.}$$

$$2\,Y(z) + z^{-1}\,Y(z) + y(-1) = X(z)$$

$$2\,Y(z) + z^{-1}\,Y(z) + 2 = \frac{1}{1-\frac{1}{4}z^{-1}}$$

$$Y(z)\left(2+z^{-1}\right) = \frac{1}{1-\frac{1}{4}z^{-1}} - 2$$

$$= \frac{1-2+\frac{1}{2}z^{-1}}{1-\frac{1}{4}z^{-1}}$$

$$Y(z) = \frac{-1+\frac{1}{2}z^{-1}}{\left(2+z^{-1}\right)\left(1-\frac{1}{4}z^{-1}\right)}$$

$$= \frac{-\frac{1}{2}+\frac{1}{4}z^{-1}}{\left(1+\frac{1}{2}z^{-1}\right)\left(1-\frac{1}{4}z^{-1}\right)}$$

Do not write in this margin

$$= \frac{-2/3}{\left(1+\frac{1}{2}z^{-1}\right)} + \frac{1/6}{\left(1-\frac{1}{4}z^{-1}\right)}$$

$$= -\frac{2}{3}\,\frac{1}{1-\left(-\frac{1}{2}\right)z^{-1}} + \frac{1}{6}\,\frac{1}{1-\frac{1}{4}z^{-1}}$$

$$= \left[-\frac{2}{3}\left(-\frac{1}{2}\right)^n + \frac{1}{6}\left(\frac{1}{4}\right)^n\right] u(n)$$

10

Write answer in detail

Q.5 (e) The transfer function of RLC circuit is

$$H(s) = \frac{Y(s)}{X(s)} = \frac{2s}{s^2+2s+1}$$

(i) Obtain the ordinary differential equation with input $x(t)$ and output $y(t)$. Approximating the derivatives by differences (let $T = 1$), obtain the difference equation that approximates the differential equations.

(ii) Let the input be a constant source, so that $x(n) = u(n)$ and let the initial conditions for difference equation be zero. Solve the difference equation using the z-transform.

[12 marks]

(i)

$$H(s) = \frac{Y(s)}{X(s)} = \frac{2s}{s^2+2s+1}$$

$$s^2 Y(s) + 2s\,Y(s) + Y(s) = 2s\,X(s)$$

applying inverse Laplace Transform

$$\frac{d^2y(t)}{dt^2} + 2\frac{dy(t)}{dt} + y(t) = 2\frac{dx(t)}{dt}$$

2

$$H(s) = \frac{2s}{(s+1)^2}$$

$$= \frac{A}{s+1} + \frac{B}{(s+1)^2}$$

$$\therefore 2s = As + A + B$$

$$A = 2, \quad B = -2$$

$$\therefore H(s) = \frac{2}{s+1} - \frac{2}{(s+1)^2}$$

$$\therefore h(t) = (2e^{-t} - 2te^{-t})\, u(t)$$

$$t = nT_s \qquad (T_s = 1)$$

$$\therefore h(n) = (2e^{-n} - 2ne^{-n})\, u(n)$$

$$\frac{y(n)}{x(n)} = 2e^{-n} - 2ne^{-n}$$

$$y(n) = 2e^{-n}x(n) - 2ne^{-n}x(n)$$

(ii) $x(n) = u(n)$

$$\therefore X(z) = \frac{1}{1-z^{-1}}$$

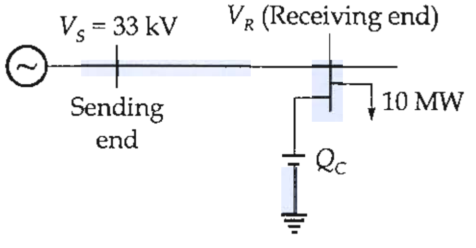
$$\therefore H(z) = \frac{2}{1-\frac{1}{e}z^{-1}} - \frac{2}{(1-\frac{1}{e}z^{-1})^2}$$

Incomplete Solution

Q.6 (a) The figure shows a 3-ϕ, 33 kV line feeding a per-phase load of 10 MW. The line impedance is $z = j20\ \Omega$.

(i) Determine the load angle and the reactive power to be supplied by the capacitive source connected at the load end to maintain a line voltage of 33 kV at the load.

(ii) If the capacitive source is removed, what is the maximum real power which can be supplied to load and what will be the power angle and the voltage to supply to load?



[6 + 14 marks]

Q.6 (b) **(i)** Using the properties of z-transform and z-transform pair,

$$u(n) \xleftrightarrow{Z.T.} \frac{z}{z-1}, \; |z| > 1$$

Find the z-transform $X(z)$ and ROC of the sequence

$$x(n) = \sum_{k=-\infty}^{n} [u(k+5) - u(k)]$$

(ii) Prove that :

(a) $x(n) * h(n) = h(n) * x(n)$

(b) $(x_1(n) * h_1(n)) * h_2(n) = x_1(n) * (h_1(n) * h_2(n))$

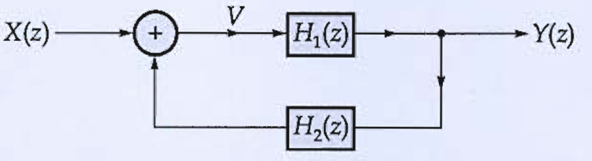
[10 + 3 + 7 marks]

Q.6 (c) **(i)** Determine the parallel realisation of the IIR digital filter transfer function

$$H(z) = \frac{3\left[2z^2 + 5z + 4\right]}{(2z+1)(z+2)}$$

(ii) Consider a feedback system shown in figure. The input $X(z)$ and output is $Y(z)$. The system is formed by the interconnection of two causal LTI system labelled with their transfer functions $H_1(z)$ and $H_2(z)$, where

$$H_1(z) = \frac{10\beta z}{(z-1)} \text{ and } H_2(z) = 1$$



where β is a real constant. Find the overall transfer function and determine the value of β for which system is BIBO stable.

[12 + 8 marks]

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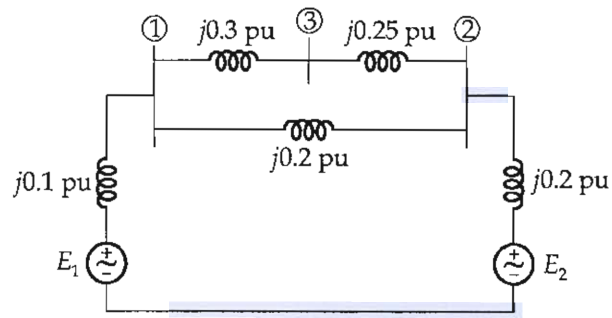
Q.7 (a) For the power system whose equivalent circuit is shown in figure, compute the bus voltages and branch currents for a 3-ϕ fault on bus (1). Assuming the fault impedance $Z_f = j0.2$ pu.

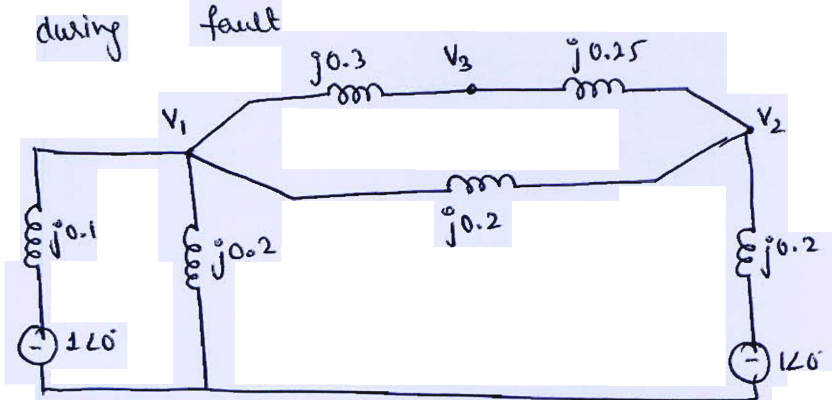
$$[Z_{bus}] = j\begin{bmatrix} 0.0776 & 0.0448 & 0.0597 \\ 0.0448 & 0.1104 & 0.0806 \\ 0.0597 & 0.0806 & 0.2075 \end{bmatrix}$$

Assume a pre-fault constant voltage of $1.0\angle 0°$ pu.



[20 marks]

circuit during fault



pre fault voltages are $1\angle 0°$

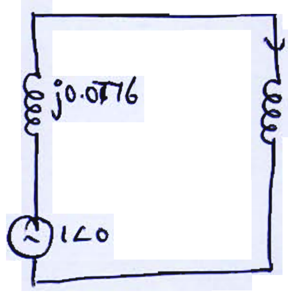
$\therefore V_{1_{pf}} = 1\angle 0°$

To find Z_{th} b/w fault point & ground before fault, we'll use Z_{bus}

we know Z_{th} at a bus wrt ground is given by diagonal element

$\therefore \; Z_{th_{①}} = Z_{11} = j\,0.0776$

$\therefore$



$I_f = \dfrac{1}{j0.2 + j0.0776}$

$= 3.602 \angle -90^\circ$

$\therefore \; V_{1_f} = I_f Z_f = 3.602 \angle -90 \times j0.2$

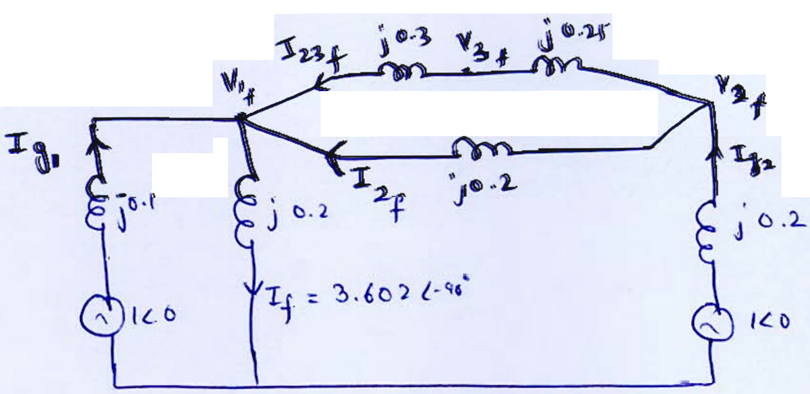
$= 0.7204$ pu

$Z_{th_{12}} = Z_{11} + Z_{22} - 2Z_{12} = j\,0.0984$

$Z_{th_{13}} = Z_{11} + Z_{33} - 2Z_{13} = j\,0.1657$

$\therefore$ ~~for bus 2~~

~~$V_{2f} = V$~~



$Z_{b/w}$ ① & ② $= j\left[(0.3 + 0.25) \,//\, 0.2\right] = j\,0.1467$

$I_{g_1} = \dfrac{1\angle 0 - V_{1f}}{j0.1} = 2.796 \angle -90$

$\therefore \quad I_{12} = I_{g_1} - I_f = 0.806 \angle 90°$

$\frac{V_{1f} - V_{2f}}{j0.1467} = 0.806 \angle 90$

$\therefore \quad V_{2f} = 0.839$

$\therefore \quad I_{g_2} = \frac{1 - 0.839}{j0.2} = 0.805 \angle -90°$

$I_{2f} = \frac{V_{2f} - V_{1f}}{j0.2} = 0.593 \angle -90°$

$I_{23f} = \frac{V_{2f} - V_{1f}}{j0.55} = 0.2156 \angle -90°$

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$\therefore \quad V_{3f} = V_{2f} - j0.25 (I_{23f})$

$= 0.7851$

$\therefore \quad V_{1f} = 0.7204$ pu

$V_{2f} = 0.839$ pu

$V_{3f} = 0.7851$ pu

$I_{g_1} = 2.796 \angle -90$ pu

$I_{g_2} = 0.805 \angle -90$ pu

$I_f = 3.602 \angle -90$ pu

$I_{21} = I_{2f} = 0.593 \angle -90°$ pu

$I_{23} = I_{23f} = 0.2156 \angle -90°$ pu

Q.7 (b) (i) A star connected 3-ϕ, 12 MVA, 11 kV alternator has a reactance of 10%. It is protected by Merz-price circulating current scheme which is set to operate for fault current not less than 200 A. Calculate the value of earthing resistance to be provided in order to ensure that only 15% of alternator winding remain unprotected.

(ii) For a 132 kV, 50 Hz system reactance and capacitance upto the location of circuit breaker is 3 Ω and 0.015 μF respectively. Calculate, frequency of transient oscillation, maximum value of restriking voltage across the contacts of circuit breaker and maximum value of RRRV.

[10 + 10 marks]

(i)

$X = 0.1$

$Z_{base} = \frac{11^2}{12} = 10.083$ $\quad \therefore X = 1.008\ \Omega$

$I_f = 200$

% winding unprotected = 15%

$\therefore x = 0.15$

Now $x \cdot V_{ph} = I_f\ (R_n + j\, x\, X_{ph})$

$$0.15 \times \frac{11000}{\sqrt{3}} = 200\ (R_n + j\ 0.15 \times 1.008)$$

$$4.76 = R_n + j\ 0.1512$$

$$R_n^2 + 0.1512^2 = 4.76^2$$

$$R_n = 4.757\ \Omega$$

8

(ii) $X_L = 3\Omega$

$C = 0.015\ \mu f$

$X_L = 2\pi f L$

$\Rightarrow L = \frac{3}{2\pi \times 50} = 9.55\ mH$

$$\omega_n = \frac{1}{\sqrt{LC}} = \frac{1}{\sqrt{9.55\times10^{-3} \times 0.015\times10^{-6}}}$$

$= 83551.198$ rad/s

$f_n = 13.29$ kHz

8

we know $V_{CB} = V_m(1 - \cos\omega_n t)$

$V_{CB\,max} = 2V_m$

now $V_m = \frac{V_L}{\sqrt{3}} \times \sqrt{2}$

$= 107.78$ kV

$\therefore V_{RV\,max} = 2V_m = 215.55$ kV

Do not write in this margin

as $RRRV = V_m \omega_n \sin\omega_n t$

$\therefore RRRV_{max} = \omega_n V_m$

$= 1432.39 \times 10^6$ V/s

$= 1.432$ kV/μs

$\therefore f_n = 13.29$ kHz

$V_{RV_{max}} = 215.55$ kV

$RRRV_{max} = 1.432$ kV/μs

Q.7 (c) Write a program for 8085 microprocessor to provide signal for ON/OFF time to three traffic lights (Green, Red, Yellow) and two pedestrian signs (walk and don't walk). The traffic lights and signs are turned ON/OFF by the data bits of output port as given below :

S.No.	Signal	Data Bits	On Time
1.	Green	D_0	15 sec
2.	Yellow	D_2	5 sec
3.	Red	D_4	20 sec
4.	Walk	D_6	15 sec
5.	Don't Walk	D_7	25 sec

Use one second delay subroutine program for interval. Assume traffic and pedestrian flow are in same direction, the pedestrian should cross the road when green light is ON. Also draw neat flow chart for execution of program by traffic signal controller.

[20 marks]

walk → $D_6 = 1$, $D_0 = 1$ (walk on green light)

∴ 0100 0001 ⇒ 41 H (15 sec)

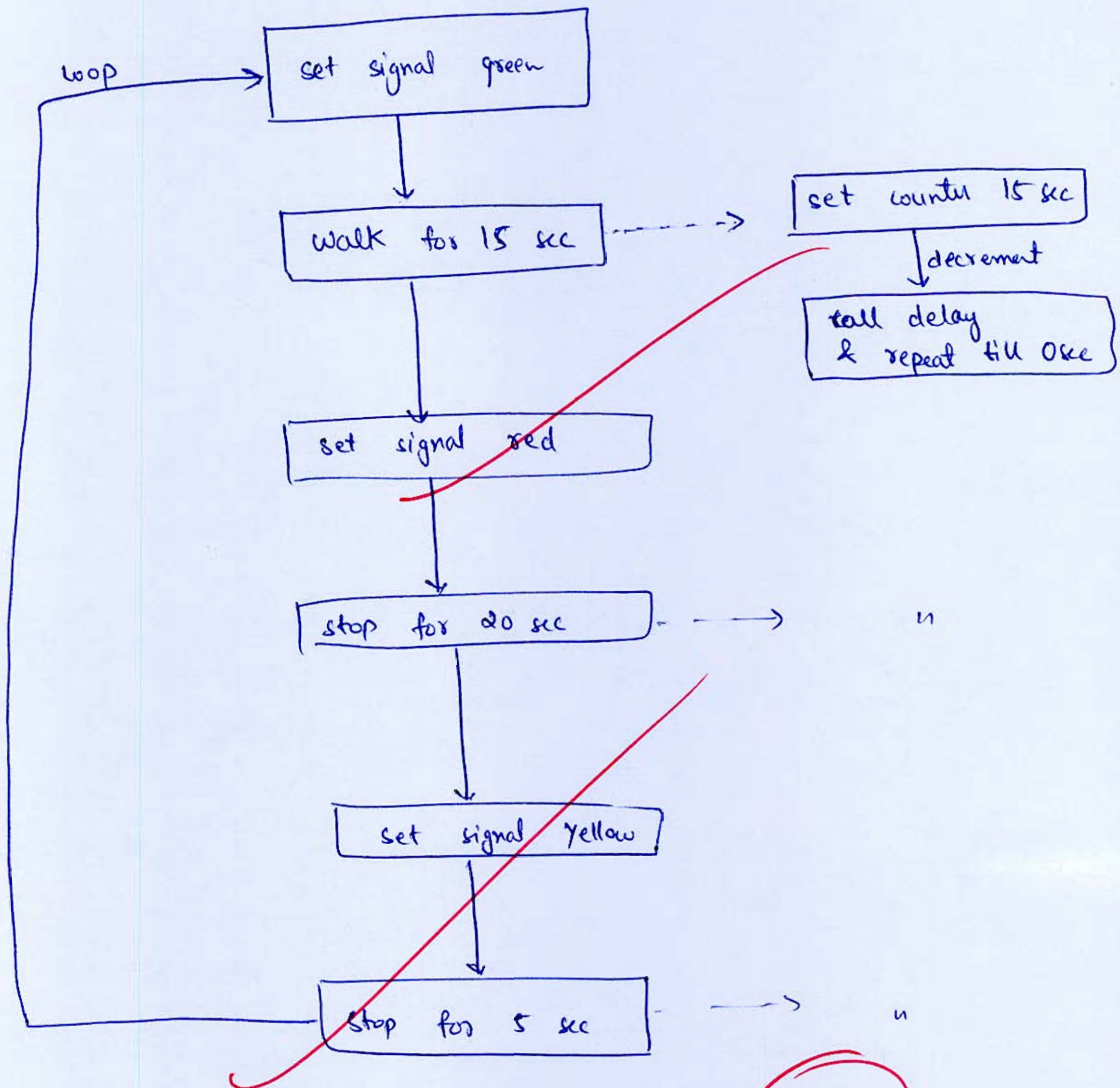
dont walk → $D_7 = 1$ $D_6 = 0$ either $D_4 = 1$ or $D_2 = 1$

yellow 1000 0100 ⇒ 84 H (5 sec)

red 1001 0000 ⇒ 90 H (20 sec)

let delay be the address of subroutine program for 1 second delay.

```
      MVI  C, 05 H          (yellow light counter)
      MVI  D, 14 H          (red light counter)
      MVI  E, 0F H          (green light counter)
      ~~MVI  A, 4~~

again MVI  A, 41 H          (green , walk)
      OUT  #Port No
      MVI  C, 0F H
loop1: CALL Delay
      DCR  C
      JNZ  loop 1

      MVI  A, 84 H          (yellow , stop)
      OUT  # Port No
      MVI  C, 05 H
loop2: CALL Delay
      DCR  C
      JNZ  loop 2

      MVI  A, 90 H          (red , stop)
      OUT  # Port No
      MVI  C, 14 H
loop 3: CALL Delay
      DCR  C
      JNZ  loop 3

      JMP  again

      HLT
```


loop
set signal green
walk for 15 sec
set counter 15 sec
decrement
tall delay
& repeat till 0sec
set signal red
stop for 20 sec
"
set signal yellow
stop for 5 sec
"

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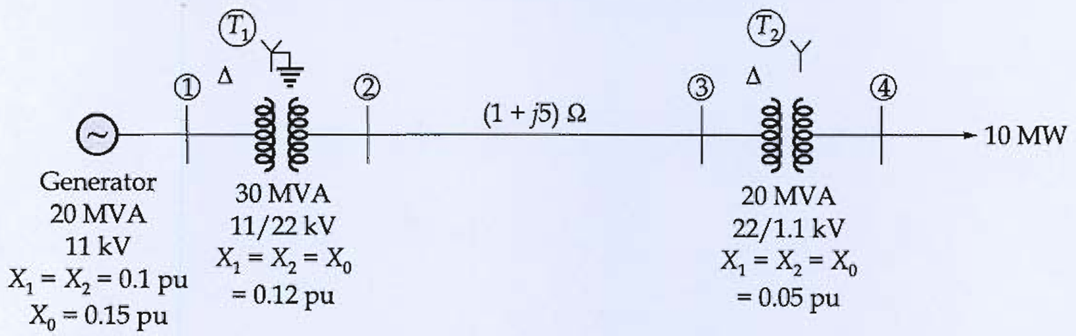
Q.8 (a) The power system shown in figure is supplying 10 MW UPF load at 1.10 kV. An SLG fault occurs at bus-3. Determine the fault current. Assuming that fault resistance is 6.6 Ω. The equipment parameters are shown in figure :



[20 marks]

Q.8 (b) A second-order transfer function is given as

$$H(z) = \frac{(1 - 0.25z^{-2})}{1 + 0.9z^{-1} + 0.18z^{-2}}$$

Perform the filter realizations to obtain

(i) Direct form I and direct form II.

(ii) Cascade form via first order section.

(iii) Parallel form via first order section.

[20 marks]

Q.8 (c) Use four point DFT and IDFT to determine the circular convolution of following sequences :

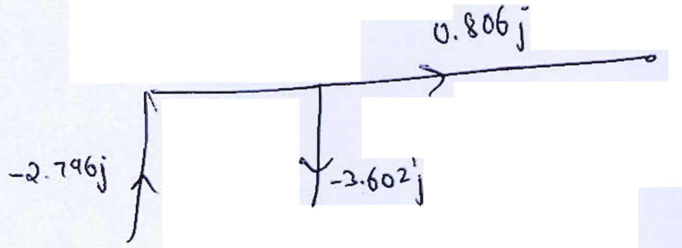
$$x_1(n) = \{\underset{\uparrow}{1},2,3,1\} \text{ and } x_2(n) = \{\underset{\uparrow}{4},3,2,2\}$$

[20 marks]

OOOO

Space for Rough Work

Space for Rough Work



$V_2 = 0.8386$

$$\frac{V_1 - V_2}{11j/75} = 0.806j$$