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ESE 2026 : Mains Test Series

UPSC ENGINEERING SERVICES EXAMINATION

Electrical Engineering

Test-4 : Electrical Machines + Power Systems-1 + Digital Electronics-2 + Microprocessor-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	45
Q.2	
Q.3	41
Q.4	42
Section-B	
Q.5	35
Q.6	42
Q.7	
Q.8	
Total Marks Obtained	205

Saurabh Kumar

Signature of Evaluator

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.

Section A : Electrical Machines

Q.1 (a) A 4-pole, 3-ϕ Slip Ring Induction Motor (SRIM) is used as a frequency changer. Its stator is excited from 3-phase, 50 Hz supply. A load requiring 3-phase, 20 Hz supply is connected to the star-connected rotor through three slip rings of SRIM.

(i) At what two speeds the prime mover should drive the rotor of this SRIM?

(ii) Find the ratio of two voltages available at the slip rings at the two speeds.

[12 marks]

Solution (i)

As $f = 50\,Hz$, $sf = 20\,Hz$

So $s = \frac{20}{50} = 0.4$

So $N_s = \frac{120f}{P} = \frac{120 \times 50}{4} = 1500$ rpm

$N_r = N_s(1-s) = 1500(1-0.4)$

$$\boxed{N_{r_1} = 900 \text{ rpm}}$$

for $s = -0.4$

$N_r = 1500(1+0.4) = 2100$ rpm

$$\boxed{N_{R_2} = 2100 \text{ rpm}}$$

and $N = \frac{120 \times 20}{4} = 600$ rpm

So $\boxed{\text{Speeds are } 600, 2100 \text{ rpm}}$

(ii) Ratio of voltages at Rotor terminal will be

$$\boxed{\frac{V_{2_1}'}{V_{2_2}'} = \frac{S_1}{S_2}}$$

So $S_1 = +0.4$

and $S_2 = -0.4$

So $\boxed{\dfrac{V_{21}'}{V_{22}'} = -1}$

11

Good Approach

Q.1 (b) The speed of a 4-pole induction motor is controlled by varying the supply frequency while maintaining the ratio of supply voltage to supply frequency (V/f) constant. At rated frequency of 50 Hz and rated voltage of 400 V its speed is 1440 rpm. Find the speed at 30 Hz, if the load torque is constant.

[12 marks]

Solution

$$\frac{V}{f} = \text{constant}$$

given $T_L = \text{constant}$

$N_1 = 1440$ rpm, $N_s = \frac{120 \times 50}{4} = 1500$ rpm

$$S_1 = \frac{1500 - 1440}{1500} = 0.04$$

$V_1 = 400$, $f_1 = 50$ Hz

Now $f_2 = 30$ Hz

As Torque is constant

$$\frac{SV^2}{f} = \text{const} \quad \text{and} \quad V/f = \text{const}$$

so $\frac{S_1}{\cancel{f_1}} = \frac{S_2}{\cancel{f_2}} \Rightarrow S_2 = \frac{S_1}{\cancel{f_1}} \times \cancel{f_2}$

$S_2 = \frac{0.04}{\cancel{50}} \cancel{\times 30}$

$S_2 = \cancel{0.024}\ 0.04$

So

$N_{s2} = \frac{120 \times 30}{4} = 900$ rpm

4

$N_2 = N_{s2}(1 - S_2)$

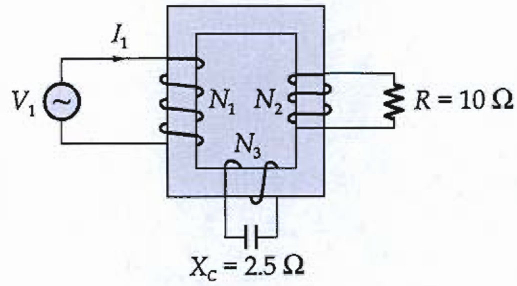
$N_2 = 9\cancel{00}(1 - \cancel{0.024})$ 0.04

$\boxed{\cancel{N_2 = 1464 \text{ rpm}}}$

$N_2 = 900(1 - 0.04)$

$\boxed{N_2 = 864 \text{ rpm}}$

Q.1 (c) The figure shows an ideal three winding transformer windings are wound on the same core as shown. The turns ratio $N_1 : N_2 : N_3$ is 4 : 2 : 1. A resistor of 10 Ω is connected across winding-2. A capacitor of reactance 2.5 Ω is connected across winding-3. Winding-1 is connected across a 400 V, as supply. If the supply voltage phasor $V_1 = 400\angle 0°$ V, find the supply current phasor I_1.



[12 marks]

Solution given $N_1 : N_2 : N_3 = 4 : 2 : 1$

$V_1 = 400\angle 0°$

so $\frac{V_2}{V_1} = \frac{N_2}{N_1} \Rightarrow V_2 = \frac{2}{4} \times V_1 = \frac{1}{2}\, 400\angle 0 = 200\angle 0°$

Similarly

$\frac{V_3}{V_1} = \frac{N_3}{N_1} = \frac{1}{4} \Rightarrow V_3 = 100\angle 0°$

Now

$I_2 = \frac{V_2}{R} = \frac{200}{10} = 20\angle 0°$

$I_3 = \frac{V_3}{-jX_c} = \frac{100\angle 0}{2.5\angle -90} = 40\angle 90°$

11

Good Approach

So

$\frac{I_2'}{I_2} = \frac{N_2}{N_1} = \frac{2}{4}$ (I_2' and I_3' are reffered to primary side)

$I_2' = 10\angle 0°$

and $\frac{I_3'}{I_3} = \frac{N_3}{N_1} \Rightarrow I_3' = \frac{40\angle 90°}{4} = 10\angle 90°$

So $I_1 = I_2' + I_3' = 10 + 10\angle 90$

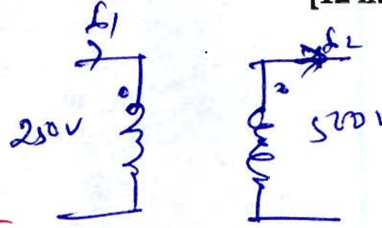
$\boxed{I_1 = 14.14\angle 45°}$ Amp.

Q.1 (d) A single-phase 50 kVA, 250 V/500 V two winding transformer has an efficiency of 95% at full load, unity power factor. If it is reconfigured as a 500 V/750 V autotransformer, find its efficiency at its new rated load at unity power factor.

[12 marks]

Solution

50 kVA , 250 V/500 V



$$I_1 = \frac{50\times10^3}{250} = 200\,A$$

$$I_2 = \frac{50\times10^3}{500} = 100\,A$$

Now given $\eta = 95\%$, at upf

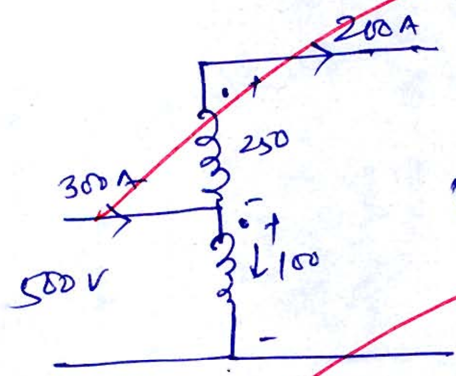
$$\text{loss} = \left(\frac{1}{\eta}-1\right)\times 50\times10^3\times 1$$

$$\text{Loss} = \left(\frac{1}{0.95}-1\right)\times 50\times10^3 = 2631.57 \text{ watt.}$$

Now Auto transformer

11

Good Approach



$V_2 = 750\,V$

Capacity of Auto transformer $= 750\times200$
$= 150$ kVA

$$\text{efficiency} = \frac{150\times10^3\times1}{150\times10^3\times1 + \text{Loss}}\times100\%$$

$$\boxed{\eta\% = \frac{150\times10^3}{150\times10^3+2631.57}\times100 = 98.27\%}$$

Do not write in this margin

Q.1 (e) A 5 kVA, 400 V, 50 Hz synchronous generator having synchronous reactance of 25 Ω is driven by a dc motor and is delivering 4 kW, to a 400 V mains at 0.8 power factor lagging. The field current of the dc motor is gradually increased till it begins to act as a generator delivering power to dc mains, while the synchronous machine acts as a motor drawing 4 kW from the ac mains. What is the total change in the power angle of the synchronous machine in this process? The field current of the synchronous machine is kept constant through out. Neglect all losses.

[12 marks]

Solution Case-1 Generator

$$I_f = \frac{4000}{\sqrt{3} \times 400 \times 0.8} = \cancel{7.25 \angle -36.86'} \quad 7.21 \angle -36.86$$

and $\cancel{I_a} =$ 5

So $E_g = \frac{400}{\sqrt{3}} \angle 0 + \left(\frac{12.5}{\sqrt{3}} \angle -36.86\right)(25 \angle 90)$

$E_g = 287.413 \angle 23.04$, $\delta_1 = \cancel{30.8} \; 23.04°$

Now case-2 motor

$E_m = \frac{400}{\sqrt{3}} \angle 0 - \left(\frac{12.5}{\sqrt{3}} \angle -36.86\right)(25 \angle 90)$

$E_m = 189.48 \angle -49.534°$

$\delta_2 = \cancel{80.134} \; 49.534°$

Change in power Angle $= \cancel{80.134 + 30.8}$

$= \cancel{110.534}°$

$\Delta\delta = \delta_1 - \delta_2$

$\Delta\delta = 23.04 - (-49.53)$

$$\boxed{\Delta\delta = 72.57°}$$

8

Q.2 (a) (i) For the 150 kVA, 2400/240 V transformer whose circuit parameters are given:

$R_1 = 0.2\ \Omega$; $R_2 = 2 \times 10^{-3}\ \Omega$

$X_1 = 0.45\ \Omega$; $X_2 = 4.5 \times 10^{-3}\ \Omega$

$R_i = 10\ \text{k}\Omega$; $X_m = 1.6\ \text{k}\Omega$ (as seen from 2400 V side)

Draw the circuit model as seen from the HV side. Determine there from the voltage regulation and efficiency when the transformer is supplying full load at 0.8 lagging power factor on the secondary side at rated voltage. Under these conditions calculate also the HV side current and its power factor.

[15 marks]

Q.2 (a) **(ii)** The armature resistance of a permanent magnet dc motor is 0.8 Ω. At no load, the motor draws 1.5 A from a supply voltage of 25 V and runs at 1500 rpm. Find the efficiency of the motor while it is operating on load at 1500 rpm drawing a current of 3.5 A from the same source.

[5 marks]

Q.2 (b) (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

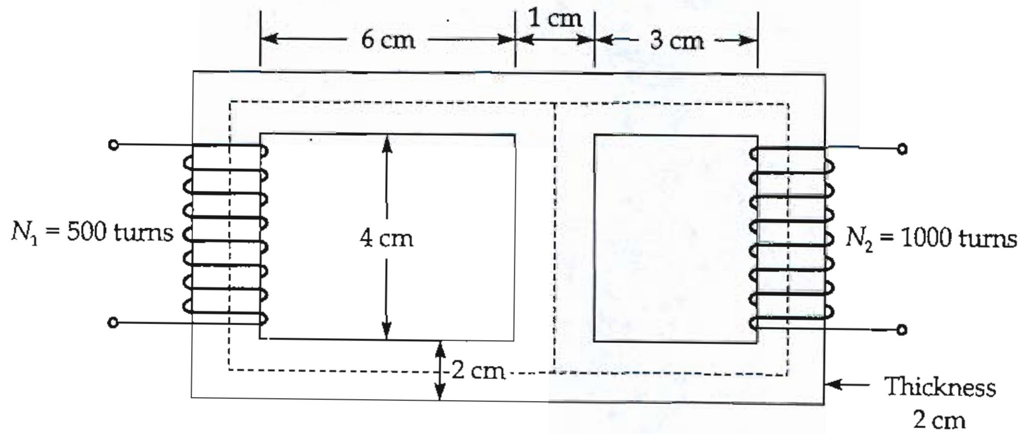
Compute the unsaturated value of synchronous reactance, its saturated value at rated voltage and short circuit ratio.

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]

Q.2 (c) For the magnetic circuit shown below, find the self inductances and mutual inductance between the two coils (core permeability = 1600).



[20 marks]

Q.3 (a) (i) 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.

[15 marks]

Solution

As Back emf is given by

$$E = \frac{\phi 2 N P}{60 A}$$

given $\phi = 3.75 \text{ mWb/field Amp} = 3.75\times10^{-3} I_a$ Wb.

so

$$E = \frac{3.75\times10^{-3}\times I_a\times180\times N}{60}$$

$$E = 11.25\times10^{-3} I_a N \quad \text{—— (1)}$$

As we know

$$E = V - I_a r_a = 250 - I_a \quad \text{—— (2)}$$

given $T = 10^{-4} N^2$ —— (3)

As we know

$$T = \frac{1}{2\pi}\phi Z I_a \cdot P/A$$

So

$$T = \frac{1}{2\pi}\times3.75\times10^{-3} I_a\times180\times I_a\times1 \quad \text{—— (4)}$$

from (3) & (4)

$$\frac{1}{2\pi}\times3.75\times10^{-3}\times180\times I_a^2 = 10^{-4}N^2$$

$$N = 31.50 I_a \quad \text{—— (5)}$$

from (1), (2) and (5)

$250 - I_a = 11.25\times10^{-3} I_a \times 31.50 I_a$

$0.3544 I_a^2 + I_a - 250 = 0$

By solving $\boxed{I_a = 25.186}$ Amp.

from (5)

$N = 31.50 \times 25.186$

$\boxed{N = 793.35 \text{ rpm}}$

$\boxed{I_a = 25.186 \text{ Amp.}}$

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Improve presentation

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Q.3 (a) (ii) A 4-pole, separately excited, wave wound DC machine with negligible armature resistance is rated for 230 V and 5 kW at a speed of 1200 rpm. If the same armature coils are reconnected to form a lap winding, what is the rated voltage (in volts) and power (in kW) respectively at 1200 rpm of the reconnected machine if the field circuit is left unchanged?

[5 marks]

Solution

$$I_a = \frac{5\times10^3}{230} = 21.74\ \text{Amp}$$

As wave wound so $A = 2$

in Lap wound $A = P = 4$

so Current in each parallel path $= I_a/A$

$$= \frac{21.74}{4} = 5.43\ \text{Amp}$$

As power will be same in wave wound and Lap wound winding, so

$$\boxed{P_{Lap} = P_{wave} = 5\ \text{kW}}$$

Now Armature current in wave wound

$$I_w = I_a/2 = \frac{21.74}{2} = 10.87\ \text{Amp}$$

So Voltage in wave wound winding

$$V_w \times I_w = 5000$$

$$V_w = \frac{5000}{10.87} = 460\ \text{Volt}$$

Now As $P_w = P_L$

$$V_L I_L = V_w I_w = 5000$$

$$\boxed{V_L = \frac{5000}{5.43} = 920\ \text{Volt}}$$

$$\boxed{V_L = \cancel{1103.75}\ \text{Volt}}$$

4

Q.3 (b) A 400 V, 4 pole, 1450 rpm, 50 Hz, Y-connected wound-rotor induction motor has the following circuit model parameters:

$R_1 = 0.3\,\Omega$; $R_2' = 0.25\,\Omega$; $X_1 = X_2' = 0.6\,\Omega$;
$X_m = 35\,\Omega$; Rotational loss = 1500 W

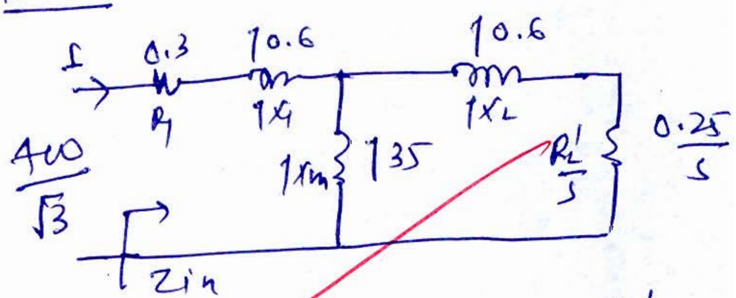
(i) Calculate the starting torque and current when the motor is started direct on full voltage.

(ii) Calculate the full-load current, power factor and torque.
Also find internal efficiency and overall efficiency internal efficiency is defined as $P_{out}\,(\text{gross})/P_{in}$; $P_{out}(\text{gross}) = (1-s)P_G$.

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

[20 marks]

Answer



(i) at starting $S=1 \Rightarrow R_2'/S = 0.25$

So $Z_{in} = (0.25 + j0.6) \| j35 + 0.3 + j0.6$

$Z_{in} = 1.3089 \angle 65.55°$

So $I_{st} = \dfrac{400/\sqrt{3}}{Z_{in}} = \dfrac{400/\sqrt{3}}{1.3089 \angle 65.55}$

$\boxed{I_{st} = 176.43 \angle -65.55°}$ Amp.

$T_{st} = \dfrac{3}{\omega_s} \cdot (I_{st})^2 \times R_2'/s = \dfrac{180}{2\pi N_s} (I_{st})^2 \times R_2'/s$

$T_{st} = \dfrac{180}{2\pi \times 1500} (176.43)^2 \times 0.25$

$\boxed{T_{st} = 148.69 \text{ N-m.}}$

(ii) Now $N_r = 1450$ rpm, $N_s = \cancel{1500}\ \dfrac{120 \times 50}{4} = 1500$

$S = \dfrac{N_s - N_r}{N_s} = \dfrac{1500 - 1450}{1500} = 0.033$

So $R_2'/s = \frac{0.25}{0.033} = 7.5\,\Omega$

So

$Z_{in} = 0.3 + j0.6 + (7.5 + j0.6) \,||\, j35$

$Z_{in} = 0.3 + j0.6 + 6.94 + j2.05$
$(R_f + jX_f)$.

$Z_{in} = 7.71 \angle 20.11$

So $I_{in} = \frac{400/\sqrt{3}}{7.71\angle 20.11} = 29.95 \angle -20.11$

So $\boxed{I_{fl} = 29.95 \text{ Amp.}}$ $\boxed{\cos\phi = \cos 20.11 = 0.939 \text{ lag}}$

$T_{fl} = \frac{180}{2\pi N_s}(I_{fl})^2 \times \frac{R_2'}{s} = \frac{180}{2\pi \times 1500} \times (29.95)^2 \times 7.5$

$\boxed{T_{fl} = 128.55 \text{ N-m.}}$

Now $P_g = 3 I_2'^2 \times \frac{R_2'}{s} = 3 \times (29.95)^2 \times 7.5$

$\boxed{P_g = 20.18 \text{ kW}}$

$P_{gross} = P_g(1-s) = 20.18(1-0.033)$

$\boxed{P_{gross} = 19.516 \text{ kW}}$

Internal efficiency $= \frac{19.516}{20.18} \times 100 = 96.70\%$

$P_{out} = P_{gross} - $ Rotational loss
$= 19.516 - 1.5 = 18.016$ kW

Overall efficiency $= \frac{18.016}{P_{in}} \times 100$

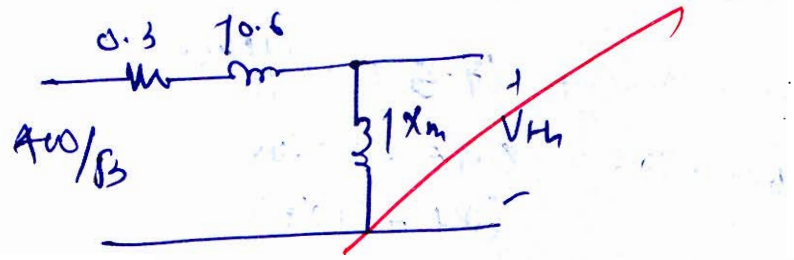
$P_{in} = \sqrt{3} \times V_L I_L \cos\phi = \sqrt{3} \times 400 \times 29.95 \times 0.939$

$P_{in} = P_g + $ Stator cu loss $= 20.98$ kW

$\%\eta = \frac{18.016}{20.98} \times 100 = 86\%$.

4

(iii) for maximum torque, using thevenin theorem

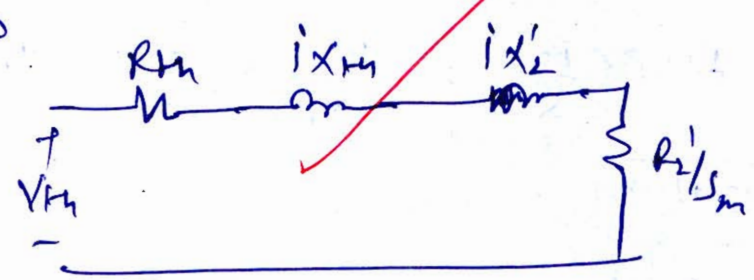


$$V_{Th} = \frac{j35}{0.3+j35.6} \times 400/\sqrt{3} = 227.039\angle 0.48° \text{ Volt}$$

$$Z_{th} = (0.3+j0.6)\,||\,jX_m = (0.3+j0.6)\,||\,35j$$

$$Z_{th} = 0.2899 + j0.5923 = R_{th} + jX_{th}$$

So



So

$$\frac{R_2'}{S_m} = \sqrt{(R_{th})^2 + (X_{th}+X_2')^2}$$

$$S_m = \frac{0.25}{\sqrt{(0.2899)^2 + (0.5923+0.6)^2}} \quad 0.2037$$

$$\boxed{S_m = 0.2037}$$

15

$$I_m = \frac{V_{th}}{Z_{th}+Z_2} = \frac{227.039}{0.2899+j0.5923+j0.6+\frac{0.25}{0.2037}}$$

$$I_m = 117.65\angle -38°$$

So

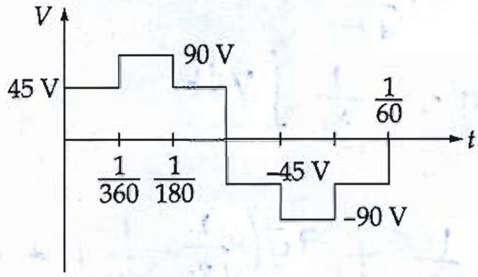
$$T_m = \frac{180}{2\pi N_s} \times I_m^2 \times \frac{R_2'}{S_m}$$

$$T_m = \frac{180}{2\pi \times 1500} \times (117.65)^2 \times \frac{0.25}{0.2037}$$

$$\boxed{T_m = 324.60 \text{ N-m}}$$

Go through the made easy solution

Q.3 (c) **(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]

Solution

(ii) slots = 90 , $\phi = 0.16$ wb , $f = 50$ Hz

$$\gamma = \frac{180}{S/P} = \frac{180}{90/10} = 20$$

$$m = S/\text{pole} \times 3 = \frac{180}{10 \times 3} = 6$$

$$K_d = \frac{\sin\frac{m\gamma}{2}}{m \sin\gamma/2} = \frac{\sin\frac{6\times 20}{2}}{6 \sin 20/2} = 0.8312$$

As

$$E = 4.44 \times f \times \phi \times N \times K_d$$

$$\frac{11000}{\sqrt{3}} = 4.44 \times 50 \times 0.16 \times N \times 0.8312$$

$$N = 215.10$$

So Number of turns per phase =

$$\boxed{N = 216}$$

Solution (i) given $N = 500$, $f = 60Hz$

As $V = N\frac{d\phi}{dt}$

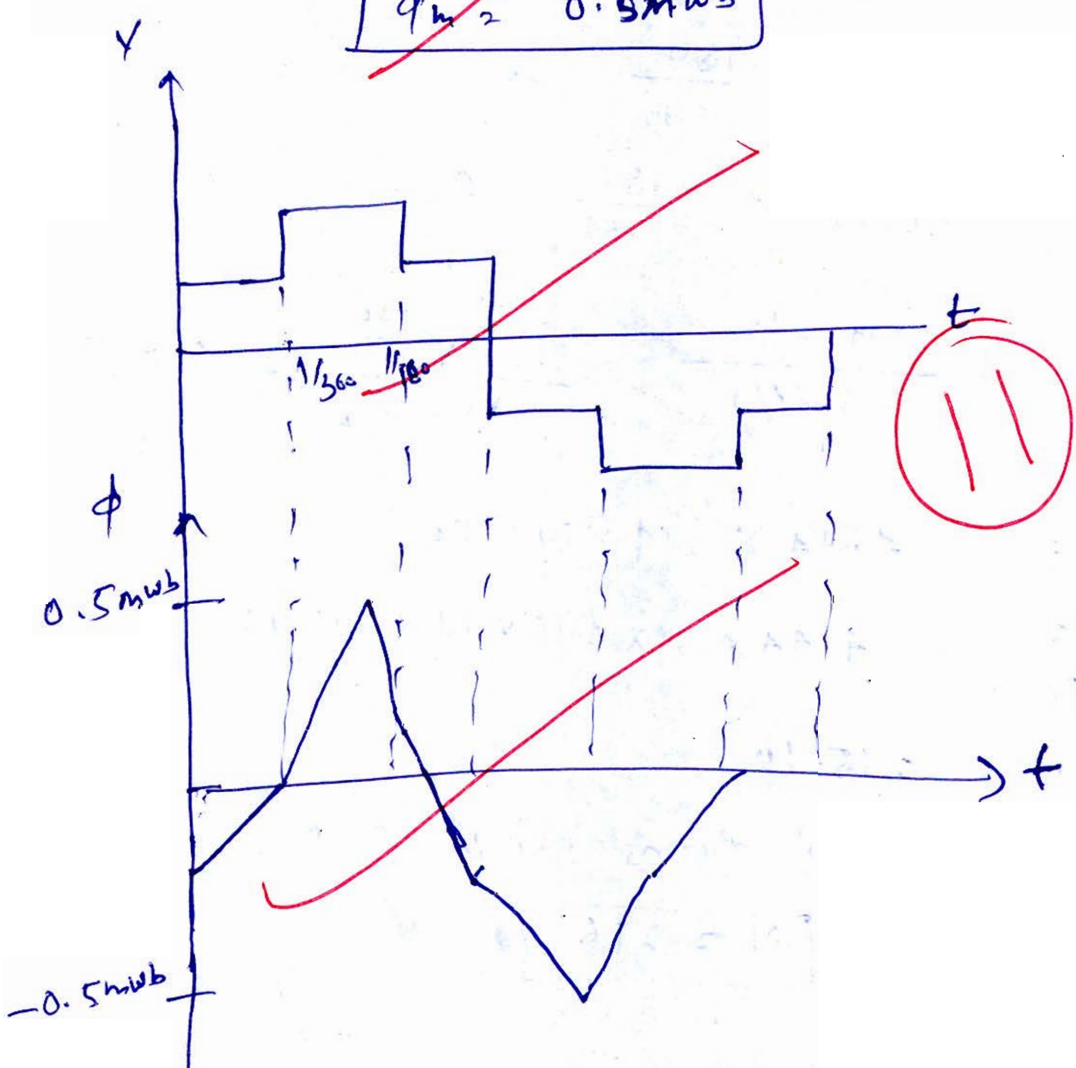
So $\phi = \frac{1}{N}\int V dt$

$$\phi = \frac{1}{500}\left[\left(45\times\frac{1}{360} + 90\left(\frac{1}{180}-\frac{1}{360}\right) + 45\times\frac{1}{360}\right)\right.$$

$\phi = 0.001\ wb = 1mwb.$

So peek value of flux $= \frac{\phi}{2}$

$$\boxed{\phi_m = 0.5mwb}$$



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Note! (flux is lagging by 90° w.r.t voltage)

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Q.4 (a) (i) A 220 V, 7.5 kW series motor is mechanically coupled to a fan. When running at 400 rpm the motor draws 30 A from the mains (220 V). The torque required by the fan is proportional to the square of speed. $R_a = 0.6\ \Omega$, $R_{se} = 0.4\ \Omega$. Neglect armature reaction and rotational loss. Also assume the magnetization characteristic of the motor to be linear.

1. Determine the power delivered to the fan and torque developed by the motor.
2. Calculate the external resistance to be added in series to the armature circuit to reduce the fan speed to 200 rpm. Calculate also the power delivered to the fan at this speed.

[12 marks]

Solution (i) $T \propto N^2$, $I_a = 30A$, $V = 220V$

$R_a = 0.6$, $R_{se} = 0.4$

$N_1 = 400$ rpm

(1.)

$E_{b1} = V - I_a(R_a + R_{se})$

$E_{b1} = 220 - 30\times 1 = 190$ volts

As in series motor $T \propto I_a^2$

So power delivered to the fan, $(P) = E_b I_a$

$P = 190 \times 30$

$\boxed{P = 5700 \text{ watt}}$

Torque $T = \frac{P}{\omega} = \frac{5700}{2\pi N} \times 60 = \frac{5700\times 60}{2\pi \times 400}$

$\boxed{T = 136.146 \text{ N-m}}$

(2) given $N_2 = 200$ rpm

So

$\frac{N_2^2}{N_1^2} = \frac{I_{a2}^2}{I_{a1}^2} \Rightarrow I_{a2} = \frac{N_2}{N_1} \times I_{a1} = \frac{200}{400} \times 30$

$\boxed{I_{a2} = 15 \text{ Amp}}$

So $E_{b2} = V - I_{a2}(R_a + R_{se} + R_{ext.})$ —— (1)

As we know

$\frac{N_2}{N_1} = \frac{E_{b2}}{E_{b1}} \times \frac{I_{a1}}{I_{a2}}$

$$\frac{200}{400} = \frac{E_{b_2}}{190} \times \frac{30}{15}$$

$E_{b_2} = 47.5$ volt

So

$E_{b_2} = 220 - 15(1 + R_{ext})$

$\boxed{R_{ext} = 10.5\ \Omega}$

11

Good Approach

Do not write in this margin

Q.4 (a) **(ii)** A separately excited DC motor has an armature resistance $R_a = 0.05\ \Omega$. The field excitation is kept constant. At an armature voltage of 100 V, the motor produces a torque of 500 Nm at zero speed. Neglecting all mechanical losses, the no-load speed of the motor (in radian/s) for an armature voltage of 150 V.

[8 marks]

Solution $R_a = 0.05\Omega$

At $N = 0$, $T = 500$ N-m

given $V_a = 100V$

As torque $T = P/\omega = \frac{V_a I_a}{\omega}$

$T = K_m I_a$

as $V_a = I_a r_a \Rightarrow I_a = \frac{100}{0.05} = 2000$ Amp

$K_m = T/I_a = \frac{500}{2000} = \frac{1}{4}$ Nm/Amp

Now

$E_{b_2} = V_{a_2} - I_a r_a = 150$ Volt.

As $E_{b_2} = K_m \omega$

$150 = \frac{1}{4}\omega$

$$\boxed{\omega = 600 \text{ rad/sec}}$$

7

Good Approach

Do not write in this margin

Q.4 (b) (i) A 100 kVA, 415 V (line-line), star-connected synchronous machine generates rated open circuit voltage of 415 V at a field current of 15 A. The short circuit armature current at a field current of 10 A is equal to the rated armature current. Find the per unit saturated synchronous reactance.

[8 marks]

Solution

$$I_a = \frac{100\times10^3}{\sqrt{3}\times 415} = 139.12 \text{ Amp.}$$

given $V_{oc} = \frac{415}{\sqrt{3}}$ Volt at $I_f = 15A$

also $I_{sc} = 139.12$ Amp at $I_f = 10A$

So As we know $I_{sc} \propto I_f$

then, I_{sc} at $I_f = 15A$

$$\frac{I_{sc_2}}{I_{sc_1}} = \frac{15}{10} \Rightarrow I_{sc_2} = 1.5\times139.12$$

$$I_{sc_2} = 208.68 \text{ Amp}$$

So

$$X_s = \frac{V_{oc} \text{ at } I_f = 15}{I_{sc} \text{ at } I_f = 15}$$

$$X_s = \frac{415/\sqrt{3}}{208.68}$$

$$\boxed{X_s = 1.148\ \Omega}$$

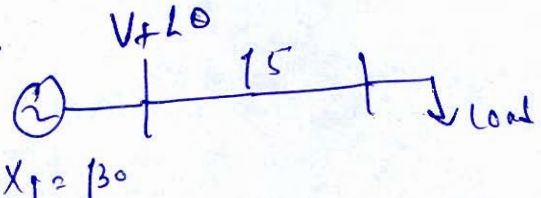
7

Good Approach

Q.4 (b) **(ii)** A 3-phase, 11 kV, 10 MVA synchronous generator is connected to an inductive load of power factor $(\sqrt{3}/2)$ via a lossless line with a per-phase inductive reactance of $5\ \Omega$. The per-phase synchronous reactance of the generator is $30\ \Omega$ with negligible armature resistance. If the generator is producing the rated current at the rated voltage, find the power factor at the terminal of the generator.

[12 marks]

Solution



$$I_a = \frac{10\times10^3}{\sqrt{3}\times 11} = 524.86\ \text{Amp.}$$

$$I_a = 524.86\angle -30^\circ$$

So

$$E_g = \frac{11000}{\sqrt{3}}\angle 0 + (524.86\angle -30)(j5 + j30)$$

$$E_g = \cancel{22.22}\ 22.236\angle 45.67^\circ\ \text{kV}$$

Now

$$V_t\angle 0 = E_g - I_a \times j30$$

$$V_t\angle 0 = 22.236\angle 45.87 - 524.86\angle -30^\circ \times j30$$

$$V_t\angle 0 = 7.992\angle 16.51$$

So $\boxed{\cos 16.51 = 0.958\ \text{Lead}}$

So at terminal of generator, power factor will be $= 0.958$ lead.

5

Do not write in this margin

Q.4 (c) A double cage, three-phase, 6-pole, Y-connected induction motor has an inner cage impedance of $(0.1 + j0.6)\ \Omega/\text{phase}$ and an outer cage impedance of $(0.4 + j0.1)\ \Omega/\text{phase}$. Determine the ratio of the torque developed by the two cages at standstill and 5% slip. What is the slip at which the torque developed by the two cages is the same?

[20 marks]

Solution

$Z_{in} = 0.1 + j0.6$, $S = 0.05$

$Z_{out} = 0.4 + j0.1$

As torque is given by , $R_{2in} = 0.1$, $X_i = 0.6$

$R_o = 0.4$, $X_o = 0.1$

$$T = \frac{180}{2\pi N} \cdot I^2 \times R_2/s$$

and $$I = \frac{V_{ph}}{\sqrt{(R_2/s)^2 + X_2^2}}$$

So

$$\frac{T_{out}}{T_{in}} = \frac{\left(\frac{R_{2in}}{s}\right)^2 + X_{in}^2}{\left(\frac{R_{out}}{s}\right)^2 + X_o^2} \times \frac{R_o}{R_i}$$

$$\frac{T_{out}}{T_i} = \frac{\left(\frac{0.1}{0.05}\right)^2 + (0.6)^2}{\left(\frac{0.4}{0.05}\right)^2 + (0.1)^2} \times \frac{0.4}{0.1}$$

$$\frac{T_{out}}{T_i} = 0.2724$$

or $$\boxed{\frac{T_i}{T_{out}} = 3.67}$$

Now $T_i = T_{ou}$.

$$\frac{1}{\omega_s} \times \frac{3V_{ph}^2}{\left(\frac{R_i}{s}\right)^2 + X_i^2} \times \frac{R_i}{s} = \frac{1}{\omega_s} \times \frac{3V_{ph}^2}{\left(\frac{R_o}{s}\right)^2 + X_o^2} \times \frac{R_o}{s}$$

$$\frac{1}{\left(\frac{0.1}{s}\right)^2 + 0.6^2} \times \frac{0.1}{s} = \frac{1}{\left(\frac{0.4}{s}\right)^2 + 0.1^2} \times \frac{0.4}{s}$$

$$\left(\frac{0.4}{s}\right)^2 + 0.36 = 4\left(\frac{0.1^2}{s^2} + 0.36\right)$$

$$0.16 + 0.36s^2 = 0.04 + 0.36 \times 4 s^2$$

$$1.08s^2 = 0.12$$

$$\boxed{s = 0.333}$$

at which $T_{inner} = T_{outer}$

12

Improve Hand writing

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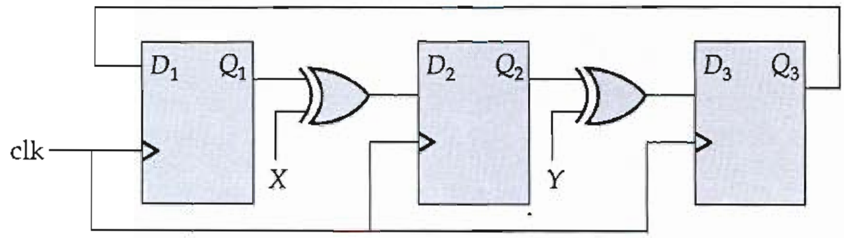
Section B : Power Systems-1 + Digital Electronics-2 + Microprocessors -2

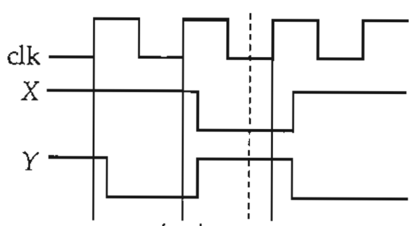
Q.5 (a) Consider the sequential circuit shown below:



(i) Fill in the table for the next state values of the three flip-flops for the given current state of the flip-flops and the inputs X and Y. Assume setup and hold times are synchronized with flip-flop inputs.

Q_1	Q_2	Q_3	X	Y	Q_1^+	Q_2^+	Q_3^+
0	0	0	0	1			
1	1	0	1	1			
0	0	1	1	0			

(ii) For the timing diagram shown below, what is the value of Q_1, Q_2 and Q_3 at the time indicated by the dashed line in the figure if the value at $t = t_1$ for $Q_1Q_2Q_3 = 001$? (Assume the flip-flops are negative edge triggered)



$t = t_1$

[12 marks]

Solution (i)

As $D_1 = Q_1 \Rightarrow Q_1 = Q_3$

$D_2 = X \oplus Q_1$, $D_3 = Y \oplus Q_2$, $D_1 = Q_3$

$Q_1^+ = D_1 = Q_3$

Q_1	Q_2	Q_3	X	Y	Q_1^+	Q_2^+	Q_3^+
0	0	0	0	1	0	0	1
1	1	0	1	1	1	0	1
0	0	1	1	0	1	0	0

(ii) given $Q_1 Q_2 Q_3 = 001$ at $t = t_1$

so $X = 0$, $Y = 1$ at dashed line

So $D_1 = Q_3 = 1$

So $Q_1^+ = D_1 = 1$

Now $D_2 = Q_1^+ \oplus X = 1 \oplus 0 = 1$

So $Q_2^+ = 1$

Now $D_3 = Q_2^+ \oplus Y = 1 \oplus 1 = 0$

So $Q_3^+ = 0$

So for $Q_1 Q_2 Q_3 = 001$

then at dashed line for $X = 0, Y = 1$

$$\boxed{Q_1 Q_2 Q_3 = 110}$$

3

Do not write in this margin

Q.5 (b) A 230 V (Phase), 50 Hz, three-phase, 4-wire, system has a sequence *ABC*. A unity power-factor load of 4 kW is connected between phase *A* and neutral *N*. It is desired to achieve zero neutral current through the use of a pure inductor and pure capacitor in the other two phases. Find the value of inductor and capacitor.

[12 marks]

Solution

Now $I_A = \dfrac{4000}{230} = 17.39\angle 0°$

Now ~~$I_B = 17.39\angle -120$~~

~~$I_C = 17.39\angle -240$~~

$V_{AN} = 230\angle 0°$, $V_{BN} = 230\angle -120$, $V_{CN} = 230\angle -240$

given $I_N = 0 = I_A + I_B + I_C$

So $17.39\angle 0 + \dfrac{230\angle -120}{jX_L} + \dfrac{230\angle 120}{-jX_C} = 0$

$17.39 + \dfrac{230}{X_L}\angle -210 + \dfrac{230}{X_C}\angle 210 = 0$

$17.39 + \left(-\dfrac{199.185}{X_L} - \dfrac{199.185}{X_C}\right) + j\left(\dfrac{+115}{X_L} - \dfrac{115}{X_C}\right) = 0$

By comparing both side

$X_L = X_C$ — (1)

and $199.185\left(\dfrac{1}{X_C} + \dfrac{1}{X_C}\right) = 17.39$

So $\dfrac{2}{X_L} = \dfrac{17.39}{199.185}$ (As $X_L = X_C$)

$\boxed{X_L = 22.91 = X_C}$

So $X_L = \omega L = 2\pi \times 50 \times L = 22.91$

Do not write in this margin

$$\boxed{L = 0.0729\ H}$$

and $X_c = 22.91$

$$\frac{1}{\omega C} = 22.91$$

$$\boxed{C = 139.0\ \mu f}$$

$$\boxed{L = 72.9\ mH}$$

10

Good Approach

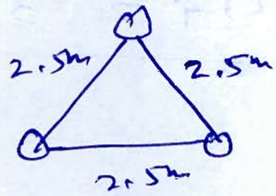
Q.5 (c) Estimate the corona loss for a three-phase 110 kV, 50 Hz, 150 km long transmission line consisting of three conductors each of 10 mm diameter and spaced 2.5 m apart in an equilateral triangle formation. The temperature of air is 30°C and the atmospheric pressure is 750 mm of mercury. Take the irregularity factor as 0.85. Ionization of air may be assumed to take place at a maximum voltage gradient of 30 kV/cm.

[12 marks]

Solution $d = 2.5\,m$

$r = 5\,mm = 5\times10^{-3}\,m$

$r = 0.5\,cm$



$T = 30°C$

disruptive voltage $V_d = m g_r \delta \ln(d/r)$

$$\delta = \frac{3.92 b}{273+T} = \frac{3.92\times750\times10^{-3}}{273+30} = 0.970\ cm$$

So

$$V_d = 0.85\times\frac{30}{\sqrt{2}}\times10^3\times0.5\times0.97\ \ln\left(\frac{2.5}{5\times10^{-3}}\right)$$

$V_d = 54.347$ kV/phase

given $V_{ph} = \frac{110}{\sqrt{3}} = 63.50$ kV.

So Corona loss

$$P_L = 241\times10^{-5}\left(\frac{f+25}{\delta}\right)\sqrt{\frac{r}{d}}\,(V_{ph}-V_d)^2\ \text{kW/km/ph}$$

$$P_L = 241\times10^{-5}\left(\frac{50+25}{0.97}\right)\sqrt{\frac{5\times10^{-3}}{2.5}}\,(63.50-54.35)^2$$

9

$P_{L_{ph}} = 0.6976$ kW/km/phase

$P_{L_{3\phi}} = 3\times0.6976$

$$\boxed{P_L = 2.093\ \text{kW/km}}$$

for 150 km

$P_{L3\phi} = 150 \times 2.093$

$\boxed{P_{L3\phi} = 313.96 \text{ kW}}$

10

Good Approach

Q.5 (d) Explain the mathematical function that is performed by the following instructions of 8085 microprocessor :

MVI A, 07H
RLC
MOV B, A
RLC
RLC
ADD B

[12 marks]

Solution

MVI A, 07 : Move 07H Data into Accumulator

[A] = [07]H

RLC : Rotate accumulator content left without carry

CY ← | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 |

| 0 | 0 | 0 | 0 | 1 | 1 | 1 | 0 |

[A] = [0E]H , CY = 0

MOV B, A : Move content of A into B

[B] = [0E]H

RLC : Rotate content of A Left without carry

CY ← | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 0 |

[A] = [1C]H , CY = 0

RLC : Rotate content of A Left without carry By 1-bit

10

CY ← | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 |

After Rotate Left [A] = [38]H, CY = 0

Improve presentation

ADD B : [A] + [B] → [A]

So [A] = 38H + 0E H

$\boxed{[A] = 46\ H}$

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

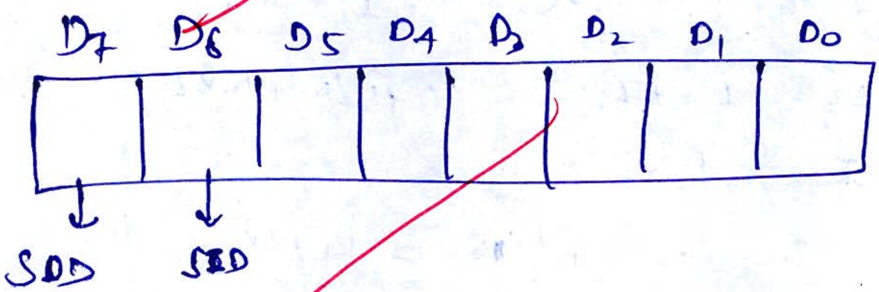
[12 marks]

Solution

RIM Instruction

— It is used to read the status of Interrupt mask.

— It is a 8-bit Length of Instruction



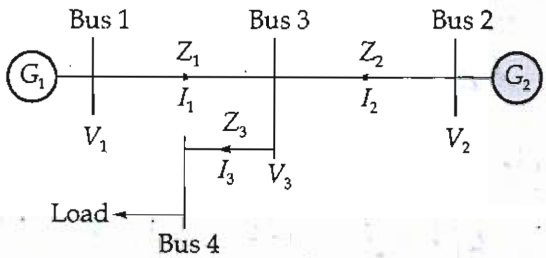
— D7 bit will provide the bit for reading the status of masked interrupt

2

Incomplete Solution

Q.6 (a) (i) Calculate the power loss in the transmission system given in the following figure. The numerical values of transmission system are :

$I_1 = 0.75\angle 0°$ pu, $I_2 = 0.8\angle 0°$ pu,
$V_3 = 1.2\angle 0°$ pu, $Z_1 = (0.07 + j0.15)$ pu,
$Z_2 = (0.06 + j0.20)$ pu, $Z_3 = (0.05 + j0.06)$ pu



[10 marks]

Answer

given $I_1 = 0.75\angle 0°$, $I_2 = 0.8\angle 0°$

$I_3 = I_1 + I_2 = 0.75\angle 0 + 0.8\angle 0°$

$I_3 = 1.55\angle 0$

given $Z_1 = 0.07 + j0.15 = R_1 + jX_1$

$R_1 = 0.07$

Loss Due to $R_1 = I_1^2 \times R_1 = (0.75)^2 \times 0.07 = 0.039375$ pu

$Z_2 = 0.06 + j0.20$, $R_2 = 0.06$

Loss due to $R_2 = I_2^2 \times R_2 = (0.8)^2 \times 0.06 = 0.0384$ pu

$Z_3 = 0.05 + j0.06 \Rightarrow R_3 = 0.05$

Loss due to $R_3 = I_3^2 \times R_3 = (1.55)^2 \times 0.05$
$= 0.120125$

total loss $= P_1 + P_2 + P_3$

$= 0.039375 + 0.0384 + 0.120125$

$\boxed{P_L = 0.1979 \text{ pu}}$

9

Good Approach

Q.6 (a) (ii) Calculate the real and reactive power at sending end of a transmission line while delivering 10 MVA load at 0.85 lagging power factor at receiving end of line. The line parameters are $A = 1$, $B = 12.12\angle 64.64°\ \Omega$, $D = 1$ and receiving end voltage of line is 33 kV. (Assume the single phase line)

[10 marks]

Solution

$V_R = 33\text{ kV}$

$I_R = \dfrac{10\times10^6}{\cancel{\sqrt{3}}\times 33\times10^3} = \sqrt{3}\times174.95\angle -31.78\text{ Amp.} = 303.02\angle -31.78$

As we know

$V_S = AV_{Rph} + BI_R$

$V_{Sph} = 1\times\dfrac{33000}{1\cancel{\sqrt{3}}} + (12.12\angle 64.64)(303.02\ \cancel{174.95}\angle -31.78)$

$\cancel{V_{Sph} = 20865.43\angle 3.16}$

$V_{S\,phase} = 36.139\angle 3.16\text{ kV}$

Now

$I_S = CV_{Rph} + DI_R$

$I_S = I_R = 303.02\angle -31.78$

So Input MVA capacity

$S_{in} = V_S I_S^* = (36.139\angle 3.16)(303.02\angle -31.78)^*\text{ kVA}$

$S_{in} = 10.95\angle 34.94\text{ MVA}$

So $\boxed{S_{in} = 8.976 + j6.27}$ MVA

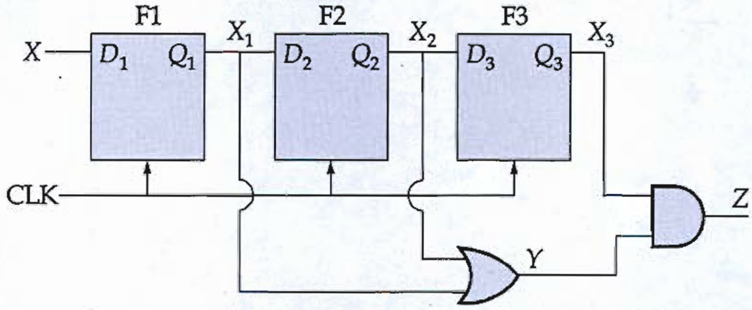
9

Real power $P = 8.976\text{ MW}$

Reactive power $Q = 6.27\text{ MVAr}$

Improve presentation

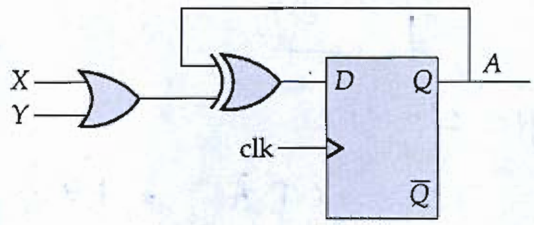
Q.6 (b) (i) A digital design is implemented by the circuit given below:



The design has *D*-type flip flops, F1, F2 and F3 driven by the clock 'CLK'. It has one input 'X' and one output 'Z'.

1. Find output logic expression for 'Z'.
2. Identify the functionality of the given circuit.

(ii) Analyze the logic circuit shown below and also draw the state diagram for the given circuit.



[10 + 10 marks]

Solution (i)

① from above logic circuit

$$Y = X_1 + X_2$$

and

$$Z = Y \cdot X_3 = (X_1 + X_2) X_3$$

$$\boxed{Z = X_1 X_3 + X_2 X_3}$$

② As per characteristic equation of D-flipflop

$$\boxed{Q_{n+1} = D}$$

3

So $X_1 = X$, $X_2 = X_1 = X$, $X_3 = X_2 = X_1 = X$

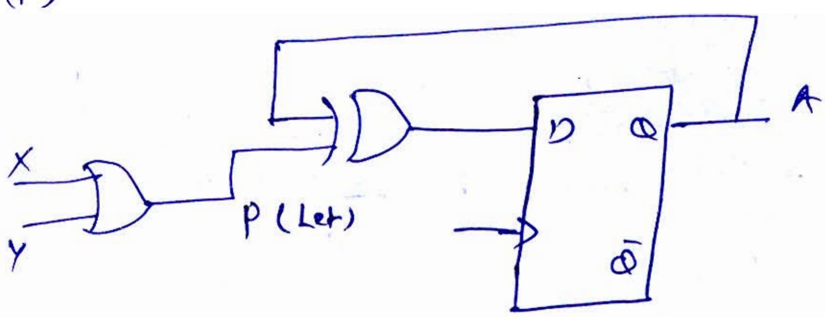
So

$$Z = X \cdot X + X \cdot X$$

$$Z = X + X$$

$$\boxed{Z = X}$$

(ii)



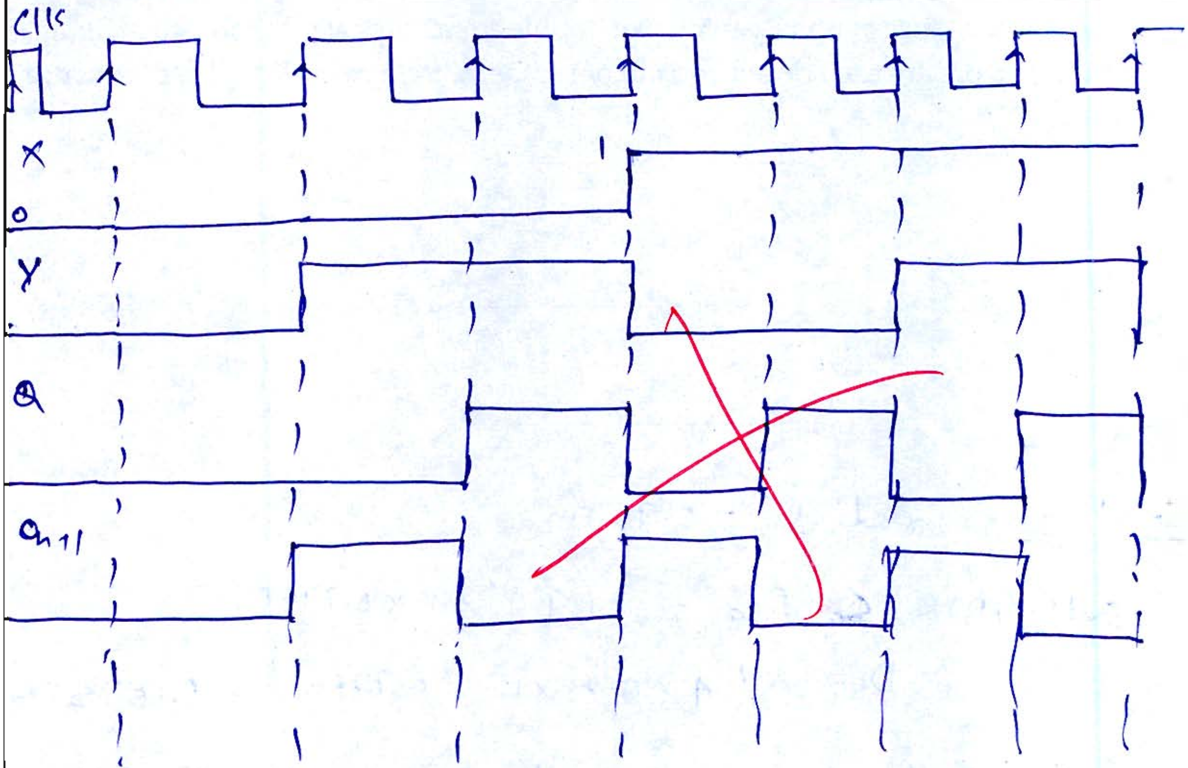
from above logic circuit

$P = X+Y$, $D = P \oplus A = P \oplus Q$

$$\boxed{D = (X+Y) \oplus Q = \overline{(X+Y)}\,Q + (X+Y)\,\overline{Q}}$$

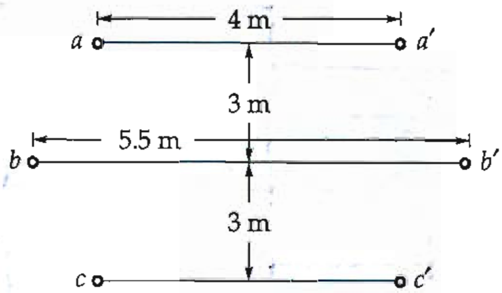
Truth table

X	Y	$Q = A$	$X+Y$	D	Output $Q_{n+1} = A$
0	0	0	0	0	0
0	0	0	0	0	0
0	1	0	1	1	1
0	1	1	1	0	0
1	0	0	1	1	1
1	0	1	1	0	0
1	1	0	1	1	1
1	1	1	1	0	0



3

Q.6 (c) (i) Find the inductance per phase per km of double circuit 3-phase line shown in figure. The conductors are transposed and are of radius 0.75 cm each. The phase sequence is *ABC*.



[12 marks]

<u>Solution</u> radius = 0.75 cm

Self GMR ~~Sa~~ $D_{sa} = (aa' \times r \times 0.7788)^{1/2}$

$D_{sa} = (4 \times 0.75 \times 10^{-2} \times 0.7788)^{1/2} = 0.15285\,m$

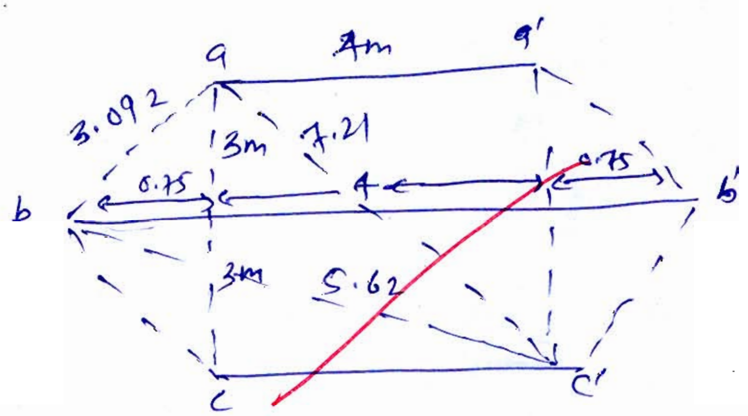
$D_{sb} = (bb' \times r \times 0.7788)^{1/2} = (5.5 \times 0.75 \times 10^{-2} \times 0.7788)^{1/2}$
$= 0.1792\,m$

$D_{sc} = D_{sa} = 0.15285\,m$

So Self GMD ⇒ GMR $= D_s = (D_{sa} \times D_{sb} \times D_{sc})^{1/3}$

$D_s = (0.15285^2 \times 0.1792)^{1/3} = 0.1612\,m$

Now



GMD of a ⇒ $D_{ma} = (ab \times ac \times ab' \times ac')^{1/4} = D_{mc}$

$D_{ma} = D_{mc} = (3.092 \times 6 \times 5.62 \times 7.21)^{1/4} = 5.236\,m$

$D_{mb} = (ba \times ba' \times bc \times bc')^{1/4}$

$= (3.092 \times 5.62 \times 3.092 \times 5.62)^{1/4}$

$= 4.1685\,m$

Overall GMD $D_m = (D_{ma} \times D_{mb} \times D_{mc})^{1/3}$

$D_m = (5.236^2 \times 4.1685)^{1/3}$

$D_m = 4.8528$ m

So Inductance

$L = 0.2 \ln\left(\frac{D_m}{D_s}\right)$ mH/km/ph

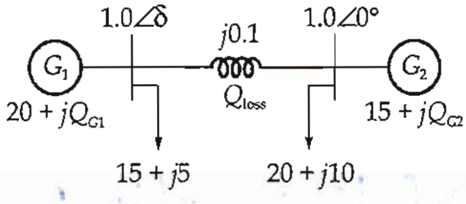
$L = 0.2 \ln\left(\frac{4.8528}{0.1612}\right)$

$\boxed{L = 0.6809 \text{ mH/km/phase}}$

11

Good Approach

Q.6 (c) **(ii)** Consider the two bus power system network with given loads as shown in the figure below. All the values shown in the figure are in per km unit. The reactive power supplied by generator G_1 and G_2 are Q_{G1} and Q_{G2} respectively. Find the per unit values of Q_{G1}, Q_{G2}, and line reactive power loss (Q_{loss}).



[8 marks]

Solution

$P_{G_1} = 20 \text{ pu}, \quad P_{D_1} = 15 \text{ pu}$

So $P_S = P_R = P_{G_1} - P_{D_1} = 20 - 15 = 5 \text{ pu}$

So

$$P_s = \frac{1 \times 1}{0.1} \sin\delta = 5$$

$$\boxed{\delta = 30°}$$

So

$$Q_R = \frac{1 \times 1}{0.1}(\cos\delta - 1) = 10(\cos 30 - 1)$$

$$Q_R = -1.34 \text{ pu}$$

So $Q_S = 1.34 \text{ pu}$

As $Q_{G_1} = Q_{D_1} + Q_S = 5 + 1.34$

$$\boxed{Q_{G_1} = 6.34 \text{ pu}}$$

Similarly

$Q_{G_2} = Q_{D_2} + Q_R = 10 + 1.34$

$$\boxed{Q_{G_2} = 11.34 \text{ pu.}}$$

$Q_L = Q_S - Q_R = 1.34 - (-1.34)$

$$\boxed{Q_L = 2.68 \text{ pu}}$$

7

Good Approach

Q.7 (a) (i) Draw a schematic arrangement of Hydroelectric plant and explain its working in brief.

[10 marks]

Q.7 (a) (ii) An overhead transmission line having a surge impedance of 500 Ω branches into two lines having a surge impedance of 40 Ω and 60 Ω respectively. If a travelling wave of vertical front and magnitude 100 kV travels along the overhead line, calculate the magnitude of voltage and current in the overhead line and in the two branches immediately after the travelling wave has reached the fork.

[10 marks]

Q.7 (b) Design a digital sequence detector circuit to detect the sequence 0110 in a serial input signal, using D flip-flops. The sequence detector should produce an output 1 whenever it detects the sequence 0110 in the serial input signal, e.g.,

Serial Input X : 00110101101

Output Y : 00001000010

[20 marks]

Q.7 (c) Calculate 3-zone setting for

(i) Reactance relay,

(ii) Mho relay of 60°, for the following data :

CT : 400/1 A

PT : 132 kV/110 V

Impedance for first section is $(2.5 + j5)\Omega$ and that of second section is $(3.5 + j7)\Omega$. Assume first zone cover 80% of first section. Second zone covers first section plus 30% of the second section. The third zone covers the entire first zone plus 120% of the second section.

[20 marks]

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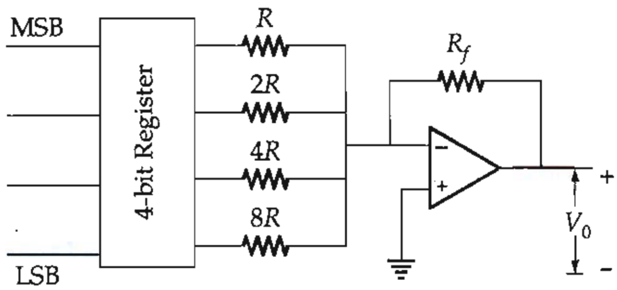
Q.8 (a) **(i)** Calculate the output voltage for an input code word 0110 if a logic 1 is 10 V and logic 0 is 0 V. Assume $R = R_f = 1\ \text{k}\Omega$.



[10 marks]

Q.8 (a) (ii) Describe memory segmentation in 8086 microprocessor with the help of block diagram.

[10 marks]

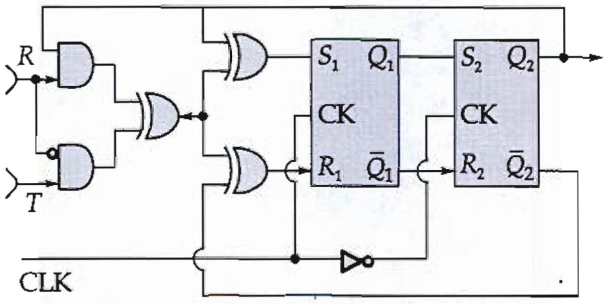
Q.8 (b) **(i)** In case of a circuit breaker, define the terms 'restriking voltage' and 'RRRV', and express their maximum values in terms of system voltage.

(ii) Which circuit breaker is preferred for voltages 132 kV and above?

(iii) In a 132 kV system, the reactance per phase up to the location of circuit breaker is 5 Ω and capacitance to earth is 0.03 μF. Calculate the maximum value of restriking voltage, the maximum value of RRRV and frequency of transient oscillation.

[20 marks]

Q.8 (c) (i) For the sequential logic circuit shown in figure express S_1 and R_1 as function of Q_2, R and T.



[10 marks]

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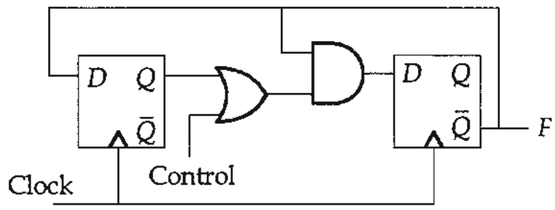
Q.8 (c) (ii) The clock frequency of the digital circuit shown in the figure is 12 MHz. Find the frequencies of the output (F) corresponding to Control = 0 and Control = 1.



[10 marks]

Space for Rough Work

$I_N = I_a + I_b + I_c = 0$

$17.39 + \frac{230\angle -120}{X_1} + \frac{230\angle 120}{-X_2} = 0$

$17.39 + \frac{230}{X_1}(\angle -120) + \frac{230}{X_C}\angle 120 = 0$

$\frac{SV_1^2}{f} = \frac{S_2V_2^2}{f}$

$S_1V_1 = S_2V_2$

$T = \frac{180}{2\pi N} \times \frac{V^2}{\left(\frac{R_2}{S}\right)^2} \times \frac{R'}{S}$

$T = \frac{SV^2}{2\pi N}$ $S_1V_1 = S_2V_2$

$S_2 = \frac{120 \times 50}{P}$. $\frac{S_1V^2}{N_1} = \frac{S_2V_1^2}{N_2}$

$\underline{0\,0\,0}\ \underline{1\,1\,1\,0\,0}$

$1C$

$\underline{0\,0\,1\,1}\ \underline{1\,0\,0\,0}$

$(38)_H$

Space for Rough Work

$2100 = 1500(1-S_1)$

$1-S_1 = 1.4 \qquad \cancel{-0.4}$

0.4

$600 = 1500(1-S)$

$$T = \frac{E_a I_a}{2\pi N} \times 60$$

$$T = \frac{\phi Z N P}{60 A} \times \frac{I_a \times 60}{2\pi N}$$

$$T = \frac{1}{2\pi}\phi Z I_a \frac{P}{A}$$