Try to avoid calculation mistake

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ESE 2024 : Mains Test Series

UPSC ENGINEERING SERVICES EXAMINATION

Electrical Engineering

Test-4 : Electrical Machines [All topics]

+ Power System-1 + Systems and Signal Processing-2 (Part Syllabus)

+ Microprocessor-2 (Part Syllabus)

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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	54
Q.2	~~36~~ 48
Q.3	
Q.4	39
Section-B	
Q.5	28
Q.6	23
Q.7	
Q.8	
Total Marks Obtained	192

Signature of Evaluator: Sourabh Kumar

Cross Checked by

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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 : Electrical Machines

Q.1 (a) A 10 kVA single-phase transformer, rated for 2000/400 V has resistances and leakage reactance as follows.

Primary winding: $R_1 = 5.5\ \Omega$, $X_1 = 12\ \Omega$

Secondary winding: $R_2 = 0.2\ \Omega$, $X_2 = 0.45\ \Omega$.

Determine the approximate value of the secondary voltage at full-load 0.8 power-factor lagging when the primary voltage is 2000 V and also calculate the voltage regulation at this load.

[12 marks]

referred on primary side

$R_1 = 5.5\ \Omega$ $X_1 = 12\ \Omega$

secondary winding impedance $= 0.2 + j(0.45)$

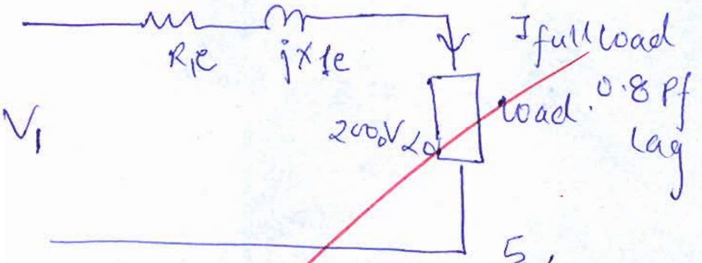
secondary winding impedance referred on primary side $= \left(\frac{N_1}{N_2}\right)^2 (Z_{secondary})$

$= \left(\frac{2000}{400}\right)^2 [0.2 + j0.45]$

$= (5 + 11.25i)\ \Omega$

$R_{1e} = 5.5 + 5 = 11.5\ \Omega$

$X_{1e} = 12 + 11.25 = 23.25\ \Omega$



$I_{full\ load} = \left(\frac{10000}{2000}\right) = 5A$

$V_1 = 2000 + (R_{1e} + jX_{1e}) \times 5\angle -36.86°$

$= 2000 + (11.5 + j23.25) \times 5\angle -36.86°$

$V_1 = 2116.549\angle 1.589°$

approximate value of secondary voltage

$= 2116.549 \left(\frac{400}{2000}\right)$

$V_2 = 423.31\text{ V}$

R_{1e} = overall resistance = primary + secondary refferred to primary.

$R_{1e} = 11.5\Omega$

base 10kVA, 2000V.

$Z_{base} = \frac{2000 \times 2000}{10 \times 1000} = 400\Omega$

$R_{1e\,pu} = \left(\frac{11.5}{400}\right)$, $X_{1e\,pu} = \left(\frac{23.25}{400}\right)$

$= 0.02875$ $X_{1e\,pu} = 0.05812$

pf = 0.8 lag full load.

$VR = (R_{pu}\cos\phi + X_{pu}\sin\phi) \times 100\%$

$= (0.02875 \times 0.8 + 0.05812 \times .6) \times 100\%$

$VR = (2.3 + 3.5232)\%$

$VR = 5.82\%$

11

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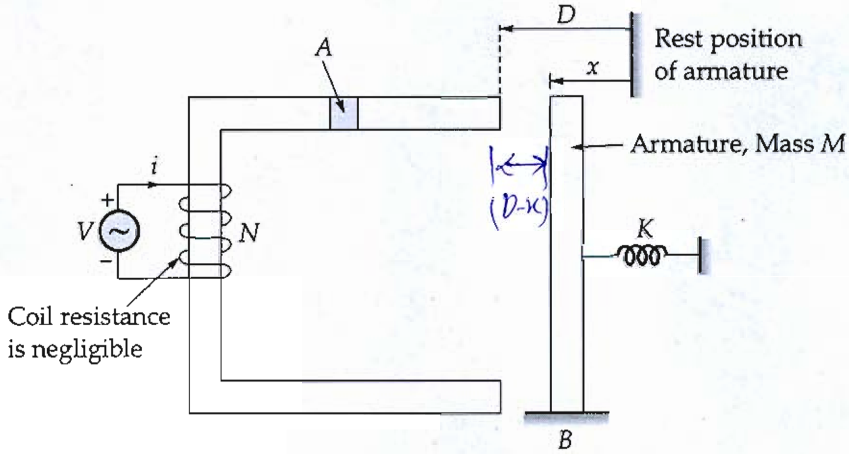
Q.1 (b) For electromechanical system shown in figure, the air-gap flux density under steady operating condition is $B(t) = B_m \sin \omega t$.



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]

reluctance of core + airgap = $R_{core} + R_{airgap}$

Let permeability of core is ∞

hence reluctance of core = 0

Now total reluctance = airgap reluctance

$$R_{airgap} = \left(\frac{2(D-x)}{\mu_0 A}\right)$$

A = area of cross section

flux = $(B \cdot A)$

flux linkage $\lambda = N(B \cdot A)$

(N = Number of turns)

Coil voltage $= -\left(\frac{d\lambda}{dt}\right)$

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

$$e = -NB_m A\omega \cos\omega t$$

$$\text{Reluctance} = \left(\frac{2(D-x)}{\mu_0 A}\right)$$

$$\text{Self inductance} = \left(\frac{N^2}{R}\right)$$

$$= \left(\frac{N^2 \mu_0 A}{2(D-x)}\right)$$

$$W = \text{energy} = \frac{1}{2}Li^2 = \frac{1}{2}\frac{N^2\mu_0 A i^2}{2(D-x)}$$

$$\text{force} = \left(\frac{dW}{dx}\right) = \frac{N^2 i^2 \mu_0 A}{4}\left(+\frac{1}{(D-x)^2}\right) \quad \text{—(1)}$$

$$\text{Force} = \frac{\mu_0 A (Ni)^2}{4(D-x)^2}$$

$$\boxed{Ni = \phi R} = \text{mmf}$$

$$Ni = B\cdot A \frac{2(D-x)}{\mu_0 A} \quad (\phi = B\cdot A)$$

$$\boxed{Ni = \frac{2B}{\mu_0}(D-x)}$$

Put value of Ni in equation (1)

$$F = \frac{B^2 2^2}{\mu_0^2}(D-x)^2 \times \frac{\mu_0 A}{4}\left(\frac{1}{D-x}\right)^2$$

(10)

$$F = \left(\frac{B^2 A}{\mu_0}\right) \qquad B = B_m \sin\omega t$$

$$\boxed{F = \frac{B_m^2 A}{\mu_0}\sin^2\omega t} = ma$$

$$a = \frac{dv}{dt} = \left(\frac{B_m^2 A}{\mu_0 m}\right)\left(\frac{1-\cos 2\omega t}{2}\right)$$

$$v = \frac{B_m^2 A}{2\mu_0 m}\int\left(\frac{1}{2} - \cos 2\omega t\right)dt \qquad \boxed{v = \frac{B_m^2 A}{2\mu_0 m}\left[t - \frac{\sin 2\omega t}{\omega}\right]}$$

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Q.1 (c) The power input to a 500 V, 50 Hz, 6-pole, 3-phase induction motor running at 975 rpm is 40 kW. The stator losses are 1 kW and friction and windage losses total 2 kW.

Calculate:

(i) the slip,

(ii) the rotor copper loss,

(iii) the output horsepower and

(iv) the efficiency.

[12 marks]

500 V, 50 Hz, 6 pole, 3φ N = 975 rpm

$N_s = \frac{120 \times 50}{6} = 1000$ rpm

$slip = \left(\frac{N_s - N}{N_s}\right) = \left(\frac{25}{1000}\right) = \left(\frac{1}{40}\right) \rightarrow$ 0.025 = slip

Power input = 40 kW

stator losses = 1 kW

→ airgap power = $P_{input} - P_{stator\ loss}$

$= (40 - 1) = 39$ kW

→ rotor cu loss $= \left(\frac{P_{airgap}}{(1/slip)}\right) = (39 \times slip)$

$= (0.025 \times 39)$ kW

$= 0.975$ kW

rotor cu loss = 975 W

→ rotor output power = P_{airgap} - rotor cu loss

$= 38.025$ kW

P_{shaft} = output - friction & windage loss

$= 38.025 - 2$

$P_{shaft} = 36.025$ kW

$$\text{efficiency} = \left(\frac{P_{shaft}}{P_{input}}\right) \times 100\%$$

$$= \left(\frac{36.025}{40}\right) \times 100\%$$

$$\boxed{\eta = 90.0625\%}$$

11

Good Approach

Q.1 (d) A 240 V dc shunt motor runs on no-load at 800 rpm with no extra resistance in the field or armature circuit, the armature current being 2 A. Calculate the resistance required in series with the shunt winding so that the motor may run at 950 rpm when taking a line current of 30 A. Shunt winding resistance is 160 Ω, armature resistance is 0.4 Ω, Assume that flux is proportional to field current.

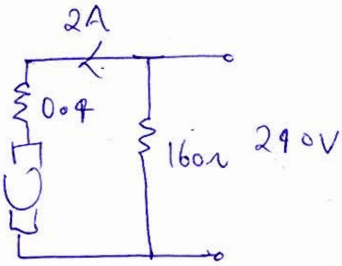
[12 marks]

240V DC shunt motor

on no load at 800rpm

armature no load current = 2A

$r_a = 0.4$, $r_{sh} = 160\Omega$



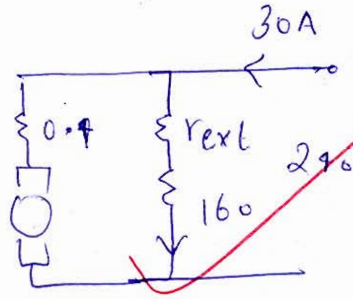
$emf_{NL} = 240 - 2\times0.4$

$= 240 - 0.8$

$= 239.2$

$I_f = I_{sh} = \frac{240}{160} = 1.5$ A

Now



Now motor speed = 950 rpm.

$I_f = I_{sh} = \left(\frac{240}{160+r_{ex}}\right)$

armature current $= 30 - \left(\frac{240}{160+r_{ext}}\right)$

$emf = K\phi\omega$

at Noload $emf_{NL} = K\phi_{NL}\omega_{NL}$

at load $emf = K\phi\omega_L$

$(\phi \propto I_f)$

$$\left(\frac{emf_{NL}}{emf}\right) = \left(\frac{\phi_{NL}\omega_{NL}}{\phi\,\omega_L}\right)$$

$$\left(\frac{239.2}{emf}\right) = \left(\frac{1.5\times800}{\left(\frac{240}{160+r_{ext}}\right)\times950}\right)$$

$$emf = \frac{239.2 \times \left(\frac{240}{160+r_{ex}}\right)(950)}{1.5 \times 800}$$

$$emf = (189.366) \times \frac{240}{160+r_{ext}} \quad \text{—— (I)}$$

Now $$emf = 240 - \left(30 - \frac{240}{160+r_{ext}}\right) \times 0.4 \quad \text{—— (II)}$$

(I) = (II)

$$\frac{189.366 \times 240}{160+r_{ext}} = 240 - 12 + \left(\frac{240}{160+r_{ext}}\right) \times 0.4$$

$$45448 = 228 \times 160 + 228 \times r_{ext} + 96$$

$$8968 - 96 = 228 r_{ext}$$

$$228 r_{ext} = 8872$$

$$\boxed{r_{ext} = 38.912}$$

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Q.1 (e) Two transformers *A* and *B* each rated for 40 kVA have core-losses of 500 and 250 W respectively and full-load copper-losses of 500 and 750 W respectively. Compare the all-day efficiencies of the two transformers if they are to be used to supply a lighting load 'with outputs varying as follows:

Output-four hours at full-load, eight hours at half-load and the remaining 12 hours at no-load.

[12 marks]

Two T/F
A 40kVA
core loss = 500W
full load culoss = 500 W

T/F
B 40kVA
core loss = 250W
full load culoss = 750W

1. T/F A.

o/p 4 hr at full load
8 hr at half load
& 12 hr no load.

power factor is not given
let assume unity power factor

$$o/p_A\ \text{kW-hr} = 4\times40 + 8\times\left(\frac{40}{2}\right) = 160+160 = 320\ \text{kW-hr}$$

$$T/F_A\ \text{core loss-hr} = \frac{24\times(500)}{1000}\text{kW-h} = 12\ \text{kW-hr}$$

$$T/F_A\ \text{cu loss} = \frac{(1)^2\times500\times4}{1000} + \frac{\left(\frac{1}{2}\right)^2\times500\times8}{1000} = 3\ \text{kW-hr}$$

$$\text{all day efficiency of } T/F_A = \left(\frac{o/p\ \text{kW-hr}}{o/p\ \text{kW-hr} + \text{loss}}\right)\times100\%$$

$$= \left(\frac{320}{320+12+3}\right)\times100\%$$

$$\boxed{\eta_A = 95.52\%}$$

T/F B:

Core loss = 250 W

full load cu loss = 750 W

O/P 4 hrs at full load
8 hrs at half load
12 hrs at no load

(assume unity p.f.)

$$O/P_B \text{ kW-hr} = \left(4\times 40 + 8\times\left(\frac{40}{2}\right)\right)$$

$$= (160 + 160) = 320 \text{ kW-hr}$$

$$\text{T/F total core loss (kW-hr)} = 24\times\left(\frac{250}{1000}\right) = 6 \text{ kW-hr}$$

$$\text{T/F total full load cu loss (kW-hr)} = 4\times(1)^2\times\left(\frac{750}{1000}\right) + 8\left(\frac{1}{2}\right)^2\times\left(\frac{750}{1000}\right)$$

$$= 3 + 2\times\frac{1}{4}\times 3$$

$$= 3+\frac{3}{2} = 4.5 \text{ kW-hr}$$

11

Good Approach

$$\text{all day efficiency of T/F B} = \left(\frac{\text{O/P kW-hr}}{\text{O/P kW-hr} + \text{loss}}\right)\times 100\%$$

$$= \left(\frac{320}{320+6+4.5}\right)\times 100\%$$

$$= 96.82\%$$

all day η of T/F B is more than all day η of T/F A because T/F B has less core loss.

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Q.2 (a) A 50 kVA 13800/208 V, Δ-Y distribution transformers has a resistance of 1 percent and a reactance of 7 percent per unit.

(i) What is the transformer's phase impedance referred to high voltage side?

(ii) Calculate this transformer's voltage regulation at full load and 0.8 p.f. lagging using the calculated high voltage side impedance.

(iii) Calculate this transformer's voltage regulation under the same condition, using the per unit system.

[20 marks]

50kVA 13800/208V, Δ-Y distribution T/F

resistance = 1%, reactance = 7%

Z_{base} on high voltage side $= \left(\frac{V_{phase}^2}{S_{phase}}\right)$ (Δ side)

$$= \left(\frac{13800^2}{\left(\frac{50\times10^3}{3}\right)}\right)$$

$$= \left(\frac{3\times13800\times13800}{50\times10^3}\right)$$

$$Z_{base\ \Delta\ side} = (11426.4)\ \Omega$$

resistance on primary side $= (R_{pu})\times Z_{base}$

$$= \left(\frac{1}{100}\right)\times(11426.4)$$

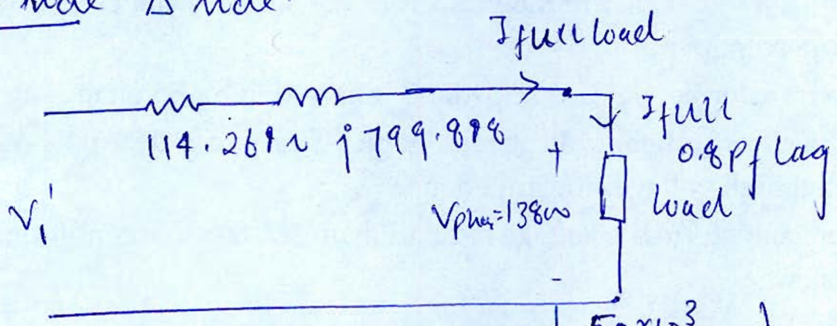
$$R_{on\ hv\ side} = 114.264\ \Omega$$

reactance on primary side $= X_{pu} Z_{base}$

$$= \frac{7}{100}\times(11426.4)$$

$$X_{on\ hv\ side} = 799.848\ \Omega$$

→ hv side: Δ side.



$$I_{full} = \left(\frac{50\times10^3}{13800\times\sqrt{3}}\right)$$

$$I_{line} = 2.0918 \angle -36.86\ A$$

$$I_{phase} = 1.2077 \angle -36.86$$

$$V_1' = 13800 + 1.2077\angle -36.86\,(114.264 + j799.898)$$

$$\boxed{V_1' = 14506.288}$$

$$V.R = \left(\frac{V_1' - V_1}{V_1}\right)\times 100\%$$

$$= \left(\frac{14506.288 - 13800}{13800}\right)\times 100\%$$

$$VR = 0.05118 \times 100\%$$

$$\boxed{V.R = 5.118\%}$$

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→ Calculate voltage regulation by using per unit system.

$R_{pu} = 1\% = \left(\frac{1}{100}\right)$

$X_{pu} = 7\% = \left(7/100\right)$

Pf = 0.8 lag.

formula

$$V.R = \left(R_{pu}\cos\phi + X_{pu}\sin\phi\right) \times 100\%$$

$$V.R = \left(\frac{1}{100} \times 0.8 + \frac{7}{100} \times 0.6\right) \times 100\%$$

$$= (0.8 + 4.2)\%$$

$$VR = 5\%$$ → by using per unit system.

(18)

Good Approach

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Q.2 (b) (i) A 70 MVA, 13.8 kV, 60 Hz, Y-connected, three-phase, salient-pole, synchronous generator has $X_d = 1.83\ \Omega$ and $X_q = 1.21\ \Omega$. It delivers the rated load at 0.8 pf lagging. The armature resistance is negligible. Determine :

1. the voltage regulation and
2. the power developed by the generator.

[10 marks]

70 MVA, 13.8 kV, 60 Hz

$X_d = 1.83\ \Omega$, $X_q = 1.21\ \Omega$. Power factor = 0.8 lagging

$P_\cdot = 1$ pu

$P = 70 \times 0.8 = 56$ MW

$$I_a = \left(\frac{56 \times 10^6}{\sqrt{3} \times 13.8 \times 10^3 \times 0.8}\right)$$

$$\boxed{I_a = 2.928 \text{ kA}}$$

$$\tan\psi = \left(\frac{V_t \sin\phi + I_a X_q}{V_t \cos\phi}\right)$$

$$\tan\psi = \left(\frac{\frac{13.8}{\sqrt{3}} \times 0.6 + 2.928 \times 1.21}{\frac{13.8}{\sqrt{3}} \times 0.8}\right)$$

$$\boxed{\psi = 52.555}$$

$\phi - \delta = \psi$

δ = load angle = $\psi - \phi$

$$\boxed{\delta = 15.695}$$

$I_d = I_a \sin\psi$

$= 2.928 \times \sin 52.55$

$$\boxed{I_d = 2.3246 \text{ kA}}$$

$emf = V_t \cos\delta + I_d X_d$

$= \frac{13.8}{\sqrt{3}}(\cos 15.695) + (2.3296)\times(1.83)$

$emf = 11.924$ kV/phase.

$VR = \left(\frac{emf - V_t}{V_t}\right) \times 100\%$.

$= \left(\frac{20.653 - 13.8}{13.8}\right) \times 100\%$.

$VR = 49.66\%$.

(ii) δ = load angle = $15.695°$

power developed by the generator $= S\cos\phi$

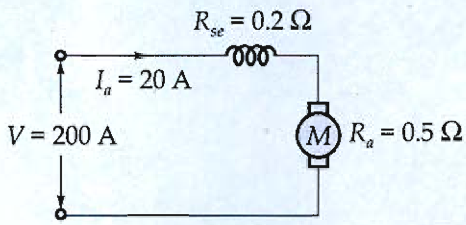
$= 70\times10^6\times0.8$

$P_{dev} = 56 MW$

9

Good Approach

Q.2 (b) **(ii)** A dc series motor runs at 1000 rpm when taking 20 A at 200 V. The resistance of the armature circuit is 0.5 Ω and that of the field winding is 0.2 Ω. Find the speed for a total current of 20 A, 200 V, when a 0.2 Ω resistor is joined in parallel with the field winding. The flux for a field current of 10 A is 70% of that for 20 A.



[10 marks]

dc series motor

N = 1000 rpm

taking 20 A at 200 V

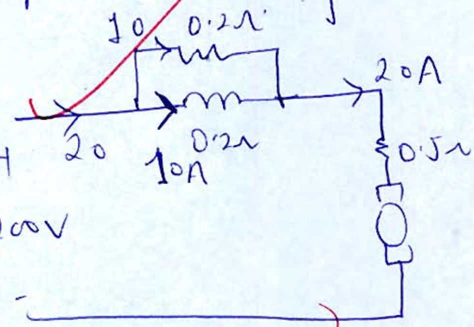
ϕ_1 = flux of 20 A in ϕ.

$r_a = 0.5$, $r_{se} = 0.2$

$emf_1 = 200 - 20 \times (.7)$

$= 200 - 14 = 186$ Volt.

when we connect 0.2 Ω resistance parallel to series (field) winding



Now

$emf_2 = 200 - 10(0.2) - 20 \times 0.5$

$= 188$ V.

$\phi_2 = 0.7\,\phi_1$ (given)

$emf_1 = K\phi_1\omega_1$ —— (I)

$emf_2 = K\phi_2\omega_2$ —— (II)

equation (I) ÷ (II)

$$\left(\frac{emf_1}{emf_2}\right) = \left(\frac{\phi_1}{\phi_2}\right)\left(\frac{\omega_1}{\omega_2}\right)$$

$$\left(\frac{186}{188}\right) = \left(\frac{\phi_1}{0.7\phi_1}\right)\left(\frac{1000}{N_2}\right)$$

$$N_2 = \left(\frac{1000 \times 188}{0.7 \times 186}\right)$$

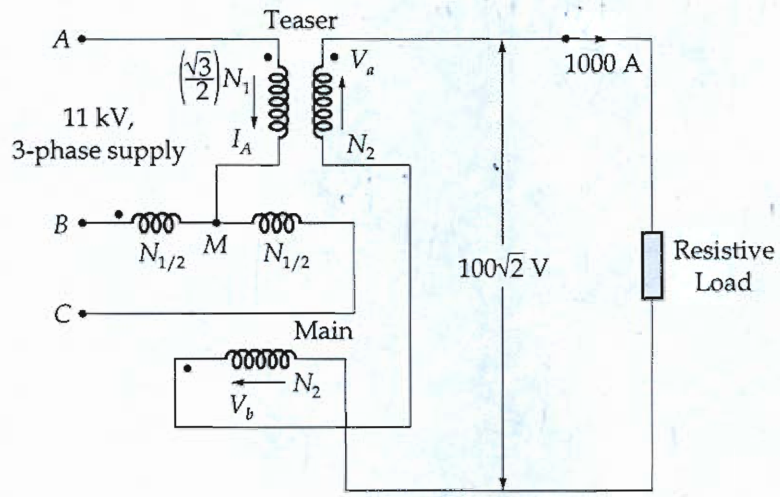
$$\boxed{N_2 = 1443.93 \text{ rpm}}$$

9

Good Approach

Q.2 (c) (i) Figure shows a Scott-connected transformer, supplied from 11 kV, 3-ϕ, 50 Hz mains. Secondaries are series-connected as shown, supply 1000 A at a voltage of $100\sqrt{2}$ V to a resistive load. The phase sequence of the 3-ϕ is *ABC*.

1. Calculate the turns ratio of the teaser transformer.
2. Calculate the line current I_B and its phase angle with respect to the voltage of phase *A* to neutral on the 3-ϕ side.



(ii) A 50 Hz, single-phase transformer draws a short circuit current of 30 A at 0.2 pf lag when connected to 16 V, 50 Hz source. What will be the short circuit current and its p.f. when the same transformer is energized from 16 V, 25 Hz source?

[12 + 8 marks]

Scott connection

It is used to convert 3φ to 2φ.

11 kV, 3φ, 50 HZ.

secondary are series connected and supply

$I_a = 1000$ A.

$V_{result} = 100\sqrt{2}$

means $V_a = 100$ V,

$V_b = 100\angle 90°$ V.

turn ratio of teaser transformer

$= \frac{\sqrt{3}}{2}\left(\frac{N_1}{N_2}\right) : 1$

$= 0.866\left(\frac{N_1}{N_2}\right) : 1$

Do not write in this margin

$= 0.866\left(\frac{11\times1000}{100}\right) : 1$

turn ratio $= 95.26 : 1$

9

$I_A = (1000\angle 0)\times\left(\frac{1}{95.26}\right)$

$I_A = 10.497\angle 0$ A

$I_{BC} = 9.09\angle 0°$

line current $I_B = -\vec{I_{BC}} - \left(\frac{I_A}{2}\right)$

$=$

(ii) at 50 Hz.

T/F draws short ckt current = 30 A at 0.2 pf. when connected to (16 V, 50 Hz)

$$\phi = \left(\frac{16}{50}\right) = \left(\frac{8}{25}\right)$$

Now at 16 V, 25 Hz

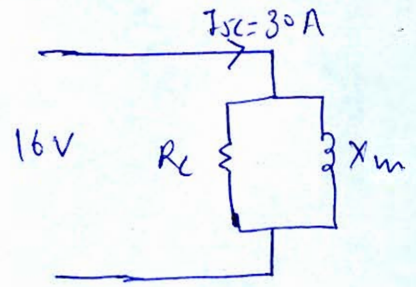
$$\phi = \left(\frac{16}{25}\right)$$

ϕ is increased 2 times

3

at 50 Hz.

$I_{sc} = 30$ at 0.2 pf



$R_c = 30 \times 0.2$

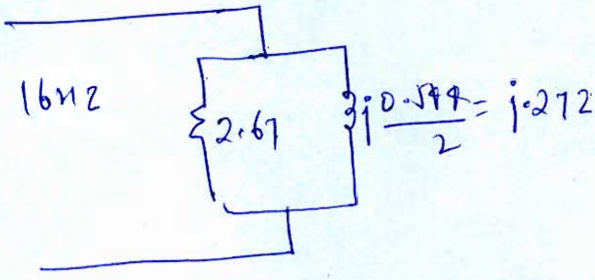
$I_c = 6\,A$

$R_c = \left(\frac{16}{6}\right) = 2.67\,\Omega$

$I_m = 29.393$

$X_m = 0.544$ (at 50 Hz).

Now at 25 Hz.



$$I_{short\,ckt} = 16\left(\frac{1}{2.67} + \frac{1}{j.272}\right)$$

Now at 16V, 25Hz.

short ckt current = 59.128 A

Powerfactor = cos(84.176)

= 0.1014 lag.

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Q.3 (a) A 1200 KVA, 3300 V, 50 Hz, three-phase, star-connected alternator has armature resistance of 0.25 Ω per phase. A field current of 40 A produces a short circuit current of 200 A and an open-circuit emf of 1100 V line-to-line. Calculate the regulation on **(i)** full-load 0.8 power factor lagging; **(ii)** full-load 0.8 leading power-factor

[20 marks]

Q.3 (b) A 11/0.4 kV, Y-Δ transformer is connected to 3-phase balanced load of 300 kVA at unity p.f. and also to a single phase load of 60 kVA at unity p.f. Determine the values of the current in each phase on the primary side. Neglect the no load current and the internal leakage impedance drop.

[20 marks]

Q.3 (c) A 600 V, 6-pole, 3-phase, 50 Hz, star-connected synchronous motor has a resistance and synchronous reactance of 0.4 Ω and 7 Ω respectively. It takes a current of 15 A at UPF when operating with a certain field current. With the field current remaining constant, the load torque is increased until the motor draws a current of 50 A. Find the torque (gross) developed and the new power factor.

[20 marks]

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Q.4 (a) (i) The maximum efficiency of a 500 kVA, 3300/500 V, 50 Hz, single phase transformer is 97% and occurs at 75% of full-load, unity power factor. If the impedance is 10%, calculate the regulation at full-load power factor 0.8 lagging.

[10 marks]

max efficiency = 97%.
occurs at load 75% of full load, u.p.f.

500 kVA

$$\%\eta = \left(\frac{O/P\ kVA \times Pf}{O/P\ kVA \times Pf + P_{core} + P_{cu}}\right) \times 100\%$$

$$0.97 = \frac{1 \times 0.75}{0.75 \times 1 + 2P_i}$$

$P_i = 0.01160$

for max efficiency.

$x^2 P_{cu} = P_i$

$P_{cu} = \left(P_i / x^2\right) = 0.0206$.

$R_{pu} = 0.0206 = 2.06\%$.

impedance = 10%.

$X = \left(\sqrt{100 - 2.06^2}\right)\%$

$= 9.785\%$.

V.R at full load $= \left(R_{pu}\cos\phi + X_{pu}\sin\phi\right) \times 100\%$.

$= \left(\frac{2.06}{100} \times 0.8 + \frac{9.785}{100} \times 0.6\right) \times 100\%$.

V.R = 7.52%.

8

Q.4 (a) (ii) The resistance of the armature circuit of a 250 V dc shunt motor is 0.3 Ω and its full-load speed is 1000 rpm. Calculate the resistance required in series with the armature to reduce the speed with the full-load torque to 800 rpm, the full-load armature current being 50 A. If the load torque is then halved, at what speed will the motor run? The armature reaction effect is to be neglected.

[10 marks]

dc shunt motor 250V

$r_a = 0.3$, full load speed = 1000 rpm.

by adding resistance in series with armature reduce speed = 800 rpm at full load.

$I_{full\ load} = 50A$ (armature current)

$emf_1 = 250 - (0.3 \times 50) = 235$

$$\frac{emf}{T} = \frac{K\phi\omega}{K\phi I_a}$$

$$\frac{235}{T_{full}} = \frac{1000 \times (2\pi)}{60 \times 50}$$

$T_{full} = 112.204$ N-m

after adding resistance speed is = 800 rpm.

$I_a = 50A$

$$\frac{emf}{T_{full}} = \frac{800 \times 2\pi}{60\ I_a}$$

$$emf = \frac{800 \times 2\pi}{60 I_a}(112.204) = \left(\frac{9399.98}{I_a}\right)$$

$emf = 189$ V

$250 - 50(0.3 + r_{ext}) = 188$

$r_{ext} = 0.94\ \Omega$

if load torque is half.

$T_{load} \propto K\phi I_a$

$\phi = \text{const.}$

$T_{load} \propto I_a$

load torque half means current is half

$I_a = 25A.$

$emf = 250 - 25(0.99 + 0.3)$

$= 219 \text{ volt.}$

$\frac{235}{219} = \frac{1000}{N_2 \text{ at half torque load}}$

$N_2 = 932 \text{ rpm}$

9

Good Approach

Do not write in this margin

Q.4 (b) A 6 pole, 3 phase, 50 Hz alternator has 12 slots per pole and 4 conductors per slot. The winding is five-sixth pitch and the flux per pole is 1.5 wb. The armature coils are all connected in series with star connection. Calculate the induced emf per phase.

[20 marks]

6 pole, 3∅ 50Hz alternator has 12 slot/pole.

4 conductor per slot

Slot = 12×6 = 72

Conductor = 4 × 72

= 288 conductor

No. of turns = 144

$m = \left(\frac{\text{slot}}{\text{pole} \times \text{phase}}\right)$

$m = \left(\frac{12}{3}\right) = 4$

$\beta = \left(\frac{180}{12}\right) = 15°$

(8)

Kd = distribution factor

$K_d = \left(\frac{\sin m\beta/2}{m \sin \beta/2}\right) = \frac{\sin\left(\frac{4\times15}{2}\right)}{4\sin\left[15/2\right]}$

$K_d = 0.9576$

K_p = short pitched factor = $\cos(\epsilon/2)$

$k_p = \cos(15/2)$

$k_p = 0.991$

flux per pole $= (1.5\, wb)$

induced emf /phase $= 4.44 f (N_{ph}) \phi\, k_p k_d$

$= 4.44 \times 50 \left(\frac{144}{3}\right) \times (1.5) \times 0.991 \times 0.9576$

induced emf $= 15168.52$ V/phase

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Q.4 (c) A 7.5 hp, four pole, 208 V, 60 Hz, Y connected induction motor has rated current of 28 A. The following test data was recorded :

DC Test : V_{DC} = 13.6 V, I_{DC} = 28 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, I_C = 8.18 A

Blocked rotor test :

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

I_A = 28.1 V, I_B = 28 A, I_C = 27.6 A

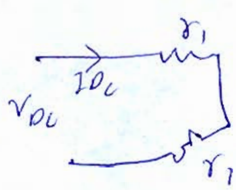
Assume reactance value obtained by blocked rotor is equally divided between rotor and stator and neglect skin effect.

(i) Obtain induction motor per phase parameters and neatly draw per phase equivalent circuit of motor.

(ii) Calculate the slip at pull out torque and value of pull out torque also.

[20 marks]

DC test $R_{dc} = \left(\frac{V_{DC}}{I_{DC}}\right) = \left(\frac{13.6}{28}\right)$



$R = 0.4857\ \Omega$

$R_1 = \left(\frac{0.4857}{2}\right) = 0.243\ \Omega$

$R_{1dc} = R_{1ac}$ (because we neglect skin effect

No load test;

f = 60 Hz.

$\cos\phi_0 = \frac{420}{\sqrt{3}\times 208 \times (8.167)}$

$\cos\phi_0 = 0.1427$ $I_0 = 8.167$ A

$\phi_0 = 81.79°$

$I_c = I_0\cos\phi_0 = 1.165$ A

$I_m = I_0\sin\phi_0 = 8.0829$ A

$R_{NL} \left(\frac{V}{I_L}\right) = 103.097\ \Omega$

$X_{NL} = 14.847$ at 60 Hz.

Blocked rotor test. $I_{BR} = 27.9A$.

$$Z_{BR} = \left|\frac{25/\sqrt{3}}{27.9}\right| = 0.5173\,\Omega$$

$$R_{BR} = \left(\frac{920}{3 \times 27.9^2}\right) = 0.394\,\Omega$$

~~$X_{BR} = 0.3352$ (at 15 Hz)~~

~~$X_1 = X_2 = 0.1676$ (at 15 Hz)~~

at 60 Hz. $X_1 = X_2 = 0.6705\,\Omega$ (at 60 Hz).

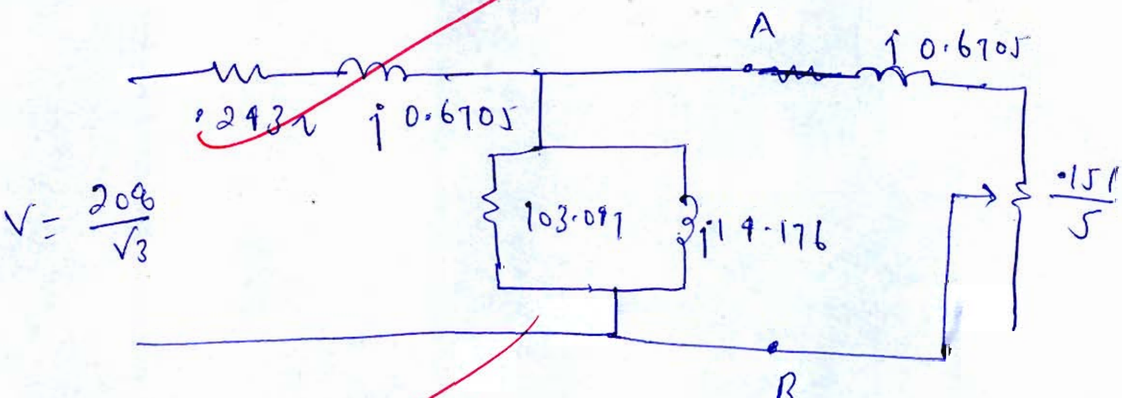
$X_m = X_{NL} - X_1 = 14.176\,\Omega$; ~~$R_1 = R_2 = 0.494$~~

$R_{BR} = R_1 + R_2 = 0.394$

$R_2 = 0.151\,\Omega$

$R_1 = 0.243\,\Omega$

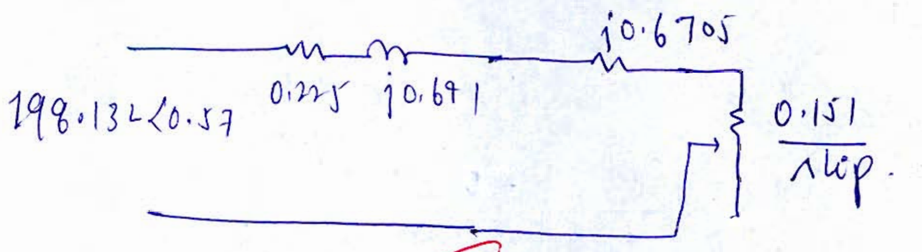
Perphase equivalent diagram.



Thevenin equivalent across AB.

$$Z_{th,AB} = \frac{1}{\left(\frac{1}{103.097} + \frac{1}{j14.176} + \frac{1}{.243 + j0.6705}\right)}$$

$$\boxed{Z_{AB} = 0.0225 + j\,0.641}$$



$$slip = \frac{0.151}{\sqrt{.225^2 + (.691 + 0.6705)^2}}$$

$$\boxed{slip_{max} = 0.1134}$$

$$\omega_s = \frac{120 \times 60}{4} \times \frac{2\pi}{60} = 60\pi$$

Now.

$$T_{max} = \frac{3V^2}{2\omega_s \left(R_1 + \sqrt{R_1^2 + (X_1 + X_2)^2}\right)}$$

$$= \frac{312.39}{\left(.225 + \sqrt{.225^2 + (.691 + .6705)^2}\right)}$$

$$\boxed{T_{max} = 200.81 \text{ N-m}}$$

14

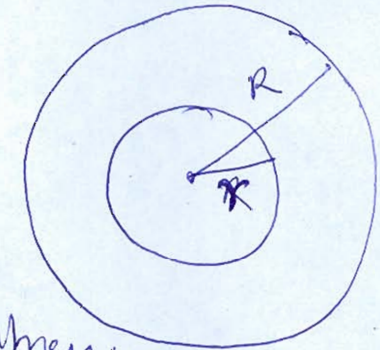
Section B : Power Systems-1 +Systems and Signal Processing-2 + Microprocessor-2

Q.5 (a) A 60 kV (rms) single-core metal sheathed cable is to be graded by means of a metallic intersheath. The safe electric stress of the insulating material is 4 kV/mm (rms).

(i) Calculate the diameter of the intersheath and the voltage at which it must be maintained in order to obtain minimum overall diameter. Calculate also the corresponding conductor diameter.

(ii) Compare the conductor diameter obtained in (i) with that of an ungraded cable working under the same conditions.

[12 marks]



Electric field stress.

$$E = \frac{V}{r \ln(R/r)}$$

E_{max}

$r \ln(R/r)$ min

at $(R/r) = e$

1

$R = re$

for minimum

$r = R/e$ for ungraded cable.

Incomplete solution

Q.5 (b) A three-phase transmission line has a resistance 10 Ω per phase and a reactance of 30 Ω per phase.

(i) Determine the maximum power which may be transmitted if 132 kV were maintained at each end.

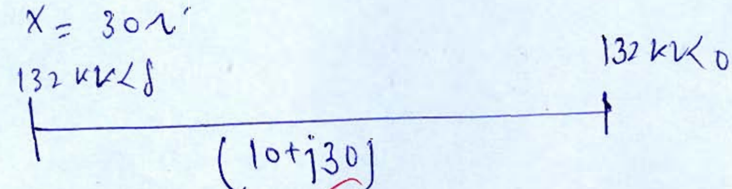
(ii) What is the phase difference between the receiving-end and sending-end voltages for maximum power transmitted?

(iii) Also, determine the rating of a synchronous phase modifier required to supply 100 MW at 0.9 power factor lagging at the receiving end.

[12 marks]

3ϕ transmission line

$R = 10\Omega \quad X = 30\Omega$



$$P_{transmitted} = \frac{132^2}{Z_s}\cos(\theta - \delta) - \frac{132^2}{Z_s}\cos(\theta)$$

for max power transmitted

$$\boxed{\theta = \delta}$$

$$Z = 10 + j30 = 31.622\angle 71.56^\circ$$

$$P_{max} = \frac{132^2}{31.622}\left[1 - \cos 71.56\right]$$

$$\boxed{P_{max} = 376.71\,MW}$$

Phase difference b/w receiving end & sending is $= \delta$

$$\boxed{\theta = 71.56^\circ}$$

rating of synchronous phase modifier required to supply ⇒ 100 MW at 0.9 pf lagging at receiving end.

↓ load = (100 + j48.432) MVA.

$P_{R_{max}} = 316.71$

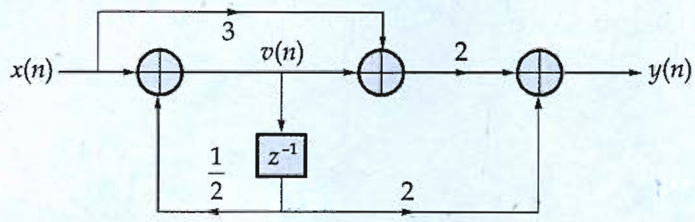
$Q_R = \frac{132^2}{31.622}\left[\sin(\theta-\delta) - \sin\theta\right] = -522.705$ MVAR.

Phase synchronous modifier

$P =$

8

Q.5 (c) Determine the system function and the impulse response of the system shown in the figure below.



[12 marks]

$$\frac{y(n)}{x(n)} = h(n)$$

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

$$H(z) = \left(\frac{8 + 2z^{-1} - 3z^{-1}}{1 - \frac{1}{2}z^{-1}} \right)$$

$$H(z) = \left(\frac{8 - z^{-1}}{1 - \frac{1}{2}z^{-1}} \right)$$

$$H(z) = \frac{8}{\left(1 - \frac{1}{2}z^{-1}\right)} - \frac{z^{-1}}{\left(1 - \frac{1}{2}z^{-1}\right)}$$

(11)

Good Approach

taking, inverse Z transform

$$h(n) = 8\left(\tfrac{1}{2}\right)^n u(n) - \left(\tfrac{1}{2}\right)^{n-1} u(n-1)$$

impulse response.

Do not write in this margin

Q.5 (d) Find $y(n)$, $n \geq 0$ for the following difference equation :

(i) $$y(n) = \frac{1}{2}y(n-1) + x(n)$$

where $$x(n) = \left(\frac{1}{3}\right)^n u(n),\ y(-1) = 1$$

(ii) $$y(n) + \frac{1}{2}y(n-1) + \frac{1}{4}y(n-2) = 0$$

where, $$y(-1) = y(-2) = 1$$

[6 + 6 marks]

(1) $$y(n) = \frac{1}{2}y(n-1) + x(n) \qquad X(z) = \left(\frac{1}{1-\frac{1}{3}z^{-1}}\right)$$

$$y(-1) = 1$$

$$y(n) - \frac{1}{2}y(n-1) = x(n)$$

take z transform.

$$Y(z) - \frac{1}{2}z^{-1}Y(z) - \frac{1}{2}Y(-1) = X(z)$$

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

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

$$Y(z) = \frac{-\frac{1}{2}}{\left(1-\frac{1}{3}z^{-1}\right)} + \frac{\frac{7}{2}}{\left(1-\frac{z^{-1}}{2}\right)}$$

take inverse

$$y(n) = -\frac{1}{2}\left(\frac{1}{3}\right)^n u(n) + \frac{7}{2}\left(\frac{1}{2}\right)^n u(n)$$

$y(n) + \frac{1}{2} y(n-1) + \frac{1}{4} y(n-2) = 0$

take z transform

$Y(z) + \frac{1}{2}\left[z^{-1}Y(z) + y(-1)\right] + \frac{1}{4}\left[z^{-2}Y(z) + z^{-1}y(-1) + y(-2)\right] = 0$

$Y(z)\left[1 + \frac{z^{-1}}{2} + \frac{z^{-2}}{4}\right] + \frac{1}{2} + \frac{1}{4}z^{-1} + \frac{1}{4} = 0$

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

(2)

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

Incomplete solution

Do not write in this margin

Q.5 (e) Compare memory mapping and input-output mapping of input output devices in 8085 based system?

[12 marks]

memory mapping	i/p o/p mapping
(i) It is 16 bit address	① It is 8 bit address bus
(ii) It has 2^16 address	② It has less address
(iii) It require more hard ware device	③ It is required less hard ware because of 8 bit
(iv) It is required to decrypt 16 bit	④ It is required for decript 8 bits

6

Q.6 (a) (i) A 20 MVA transformer which is used to operate at 30% overload feeding an 11 kV bus bar through a circuit breaker. The transformer circuit breaker is equipped with a 1000/5 current transformer and the feeder circuit breaker with 400/5 current transformer and both the current transformers feed IDMT relays having the following characteristics

Plug setting multiplier	2	3	5	10	15	20
Time (seconds)	10	6	4.1	3	2.5	2.2

The relay on the feeder circuit breaker has 125% plug setting and a 0.3 time multiplier setting. If a fault current of 5000 A flows from the transformer to the feeder, determine:

1. operating time of feeder relay.
2. suggest suitable plug setting and TMS of the transformer relay to ensure adequate discrimination of 0.5*s* between the transformer relay and feeder relay.
   [Given time for PSM of 3.33 = 5.6 *s*]

[10 marks]

Fault current = 5000 A.

plug setting multiplier = 125%

$I_{PK} = 125\% \times (5)$

$= \frac{125}{100} \times 5 = \left(\frac{25}{4}\right) A.$

$PSM = \left(\frac{I_{fault\ current}}{I_{pk} \times CT\ ratio}\right)$

$= \frac{5000}{\frac{25}{4} \times \left(\frac{400}{5}\right)}$

$PSM = \frac{5000}{500} = 10$

PSM = 10

Plug setting multiplier = 10

$T_{op} = \underline{3 sec.}$

$T_{operating}$ of feeder relay = 3 × 0.3
= 0.9 sec.

T/F have overloading 30%.

$I_{T/F} = \left(\frac{20 \times 10^3 \times 10^3}{11 \times 10^3}\right)$

$I_{overload} = \left(\frac{1.3 \times 20 \times 1000}{11}\right) = 2.3636\,kA$.

$I_{PK} = (x\%) \times 5$

$PSM = \left(\frac{I_{overload}}{I_{PK} \times 1000/5}\right)$

$T_{o/p}$ of T/F = 0.9 + 0.5 = 1.4 sec.

1.4 = $T_{o/p}$ × time multiplier

$T_{o/p}$ of T/F = 4.66

PSM = 4.8

$4.8 = \left(\frac{2363.6}{\frac{x}{100} \times 5 \times \frac{1000}{5}}\right)$

$x = 49.24\%$

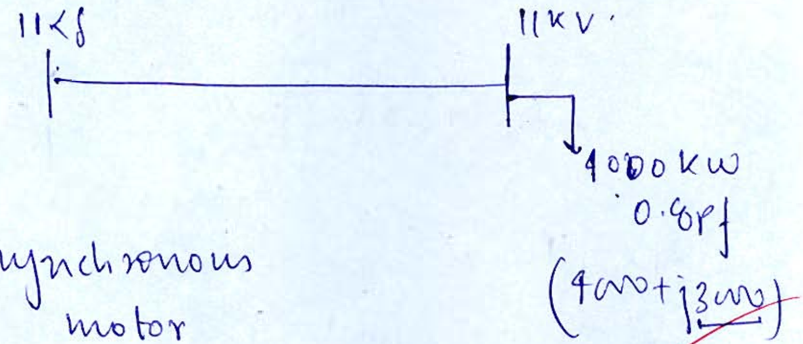
suitable plug setting = 49.24%.

6

Q.6 (a) **(ii)** An industrial load of 4000 kW is supplied at 11 kV, the p.f. being 0.8 lagging. A synchronous motor is required to meet an additional load of 1103.25 kW and at the same time to raise the resultant power factor to 0.95 lagging. Determine the kVA capacity of the synchronous motor and the power factor at which it must operate. Take the efficiency of the synchronous motor as 80%.

[10 marks]

4000 kW is supplied at 11 kV pf 0.8 lagging



Now synchronous motor

$P_{in} = \left(\frac{1103.25}{0.8}\right) = \underline{1379.0625\,kW}$.

Now resultant power factor = 0.95 lagging

Now = total p load = 5379.0625

pf = 0.95 lag.

Overall Q = 5379.0625 tan(cos⁻¹(0.95))

= 1768.0123.

Qmotor + 3000 = 1768.0123

Qmotor = 1231.987.

motor

Psupplied = 1379.0625

Qsupplied = −1231.987.

rating of synchronous motor

$$= \sqrt{(1379.0625)^2 + (1231.987)^2}$$

$$= 1849.217 \text{ KVA}.$$

P.f of synchronous motor $= \cos\left(\tan^{-1}\left(\frac{1231.987}{1379.0625}\right)\right)$

P.f $=$ 0.745 lead.

9

Good Approach

Do not write this n

Q.6 (b) Consider a discrete time system with the input-output relationship,

$$y(n) = \begin{cases} x(n); & n \geq 1 \\ 0; & n = 0 \\ x(n+1); & n \leq -1 \end{cases}$$

where $x(n)$ is the input and $y(n)$ is the output of the given system. Check whether the system is (i) linear (ii) causal (iii) time-invariant (iv) stable.

[20 marks]

$$y(n) = \begin{cases} x(n) & n \geq 1 \\ 0 & n = 0 \\ x(n+1) & n \leq -1 \end{cases}$$

(I) system is linear or not.

sys is non linier

$$y(n) = \begin{cases} x(n) & n \geq 1 \\ 0 & n = 0 \\ x(n+1) & n \leq -1 \end{cases}$$

(II) system is causal system.

because y(n) is only depend on present & future value.

at $y(-1) = x(0)$

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

$y(2) = x(2)$

Causal system.

$$y(n) = \begin{cases} x(n) & n \geq 1 \\ 0 & n = 0 \\ x(n+1 & n \leq -1 \end{cases}$$

if (x(n) is bounded then
y(n) is must be bounded
hence
y(n) is stable.

For example

$x(n) = u(n)$

$$y(n) = \begin{cases} u(n) & n \geq 1 \\ 0 & n = 0 \\ u(n+1) & n \leq -1 \end{cases}$$

y(n) is also bounded.

5

5 (c) Determine the inverse z-transform of the following signals:

(i) $X(z) = \log(1 + az^{-1})$, $|z| > |a|$.

(ii) $X(z) = \dfrac{z^3 - 10z^2 - 4z + 4}{2z^2 - 2z - 4}$ with ROC $|z| > 2$.

[20 marks]

(i) $X(z) = \log(1 + az^{-1})$

differentiate both side.

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

$$x(n) \rightleftharpoons X(z)$$

$$n\,x(n) \rightleftharpoons -z\frac{dX(z)}{dz}$$

$$-\frac{z\,dX(z)}{dz} = \left(\frac{az^{-1}}{1+az^{-1}}\right) \longrightarrow \text{by apply z transform.}$$

$$n\,x(n) = z^{-1}\left(\frac{az^{-1}}{1+az^{-1}}\right)$$

$$n\,x(n) = a(-a)^{n-1}u(n-1)$$

$$x(n) = \frac{a}{n}(-a)^n \times \left(\frac{1}{-a}\right)u(n-1)$$

$$x(n) = -\frac{1}{n}(-a)^n u(n-1)$$

(11)

$$X(z) = \frac{z^3 - 10z^2 - 4z + 4}{2z^2 - 2z - 4}$$

$$\frac{X(z)}{z} = \frac{(z^3 - 10z^2 - 4z + 4)}{(z+2)(z+1)}$$

$$X(z) = \frac{z^2(z-10)}{(z+2)(z+1)} - \frac{4(z-1)}{(z+2)(z+1)}$$

$$X(z) = \frac{z-10}{(1+z^{-1})(1+2z^{-1})} - \frac{4(z^{-1}-1)z^{-1}}{(1+2z^{-1})(1+z^{-1})}$$

$$X(z) = \frac{+11}{(1+z^{-1})} + \frac{-21/2}{1+2z^{-1}} - 4z^{-1}\left(\frac{2}{1+z^{-1}}\right) - \frac{4z^{-1} \times -3}{(1+2z^{-1})}$$

3

$$x(n) = 11(-1)^n u(n) - 21\left(-\tfrac{1}{2}\right)^n u(n) - 8\left(-\tfrac{1}{2}\right)^{n-1} u(n-1) + 12\left(-\tfrac{1}{2}\right)^{n-1} u(n-1)$$

$$x(n) = 11(-1)^n u(n) - 8(-1)^{n-1} u(n-1) - 21\left(-\tfrac{1}{2}\right)^n u(n) + 12\left(-\tfrac{1}{2}\right)^{n-1} u(n-1)$$

Do writ— this

Q.7 (a) A three-phase, 50 Hz, transmission line, 40 km long delivers 36 MW at 0.8 power factor lagging at 60 kV (phase). The line constants per conductor are, $R = 2.5\ \Omega$, $L = 0.1$ H, $C = 0.25\ \mu F$. Shunt leakage may be neglected. Determine the voltage, current, power factor, active power and reactive volt-amperes at the sending end. Also, determine the efficiency and regulation of the line. Use (a) nominal T method, (b) nominal Π method.

[20 marks]

Do not write in this

Q.7 (b) Using a rectangular window, design a low-pass filter with passband gain of unity, cut-off frequency of 1 kHz and working at a sampling frequency of 5 kHz. The length of the impulse response should be 7.

[20 marks]

7 (c) (i) In programming of 8085, what are main logic instructions related to command group 'ROTATE'? Describe briefly each instruction and their significance on register values with example, assuming accumulator content AAH and carry flag, CY = 0, before execution of instruction.

[10 marks]

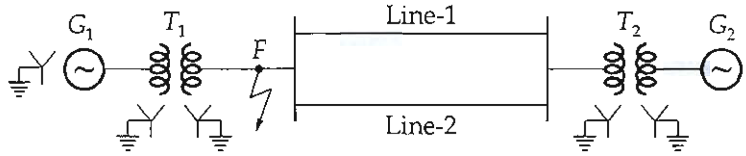
7 (c) **(ii)** Write a program for transferring sixteen bytes of data stored in memory location at XX50H to XX5FH. Transfer the entire data set to new memory location starting at XX70H.

[10 marks]

Q.8 (a) Draw the sequence networks for the system shown in figure. Determine the fault current when **(i)** LLG and **(ii)** LL fault occurs at point F. The per unit reactances all referred to the same base are as follows:

	X_0	X_1	X_2
Generator G_1	0.05	0.3	0.2
Generator G_2	0.03	0.25	0.15
Line 1	0.70	0.3	0.3
Line 2	0.70	0.3	0.3
Transformer T_1	0.12	0.12	0.12
Transformer T_2	0.10	0.1	0.1

Both the generators are generating 1 p.u. voltage.



[20 marks]

Q8 (b) Find the voltage distribution and string efficiency of a three unit suspension insulator string if the capacitances of the link pins to earth and to the line are respectively 20 per cent and 10 per cent of the self capacitance of each unit. If a guard ring increases the capacitance to the line of lower link pin to 35 per cent of the self capacitance of each unit, find the redistribution of voltage and string efficiency.

[20 marks]

Q.8 (c) (i) Write short notes on the following:

1. PROM
2. EPROM
3. EE-PROM
4. MASKED ROM
5. CONTROL BUS

[10 marks]

Q.8 (c) (ii) What are the steps needed for data flow from memory to the MPU in 8085 microprocessor? Draw clear schematic timing diagram representing transfer of byte from memory to MPU.

[10 marks]

OOOO

Space for Rough Work

Space for Rough Work

Space for Rough Work