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ESE 2025 : Mains Test Series

UPSC ENGINEERING SERVICES EXAMINATION

Electrical Engineering

Test-6 : Power Systems + Power Electronics & Drives + Communication Systems

Name : ....

Roll No :

Test Centres			Student's Signature
Delhi ☑	Bhopal ☐	Jaipur ☐	
Pune ☐	Kolkata ☐	Hyderabad ☐	

Instructions for Candidates

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

FOR OFFICE USE

Question No.	Marks Obtained
Section-A	
Q.1	41
Q.2	
Q.3	
Q.4	35
Section-B	
Q.5	45
Q.6	
Q.7	41
Q.8	47
Total Marks Obtained	209

Signature of Evaluator: Saurabh 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

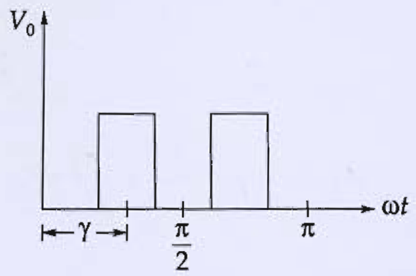
1. Read the Instructions on the cover page and strictly follow them.
2. Write your registration number and other particulars, in the space provided on the cover of QCAB.
3. Write legibly and neatly.
4. For rough notes or calculation, the last two blank pages of this booklet should be used. The rough 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.

Section-A : Power Systems + Power Electronics & Drives + Communication Systems

(a) Explain multiple pulse modulation with neat diagram.

(i) Derive the Fourier series expansion of output voltage V_0 in MPM PWM inverters.

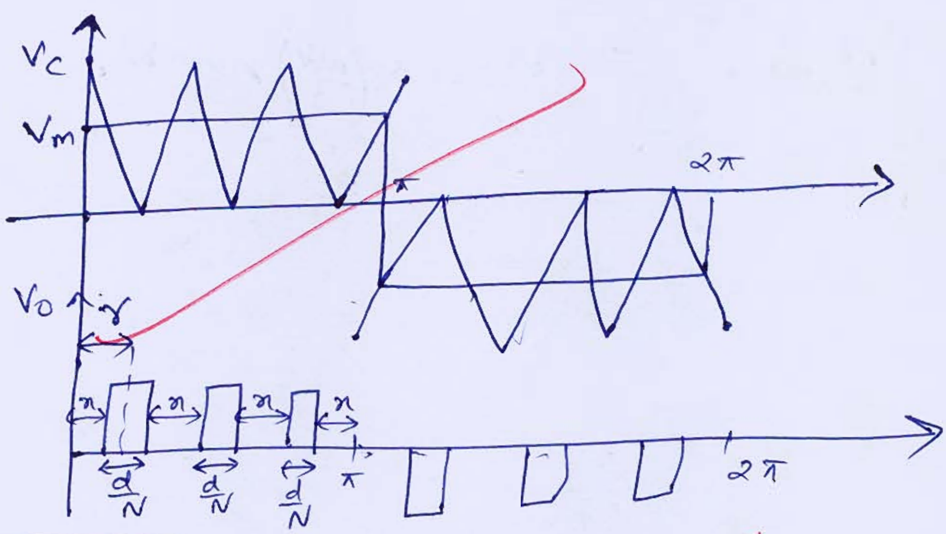
(ii)



From the above PWM waveform derive, the expression for γ in terms of N(Number of pulses per half cycle) and pulse width.

[12 marks]

In Multiple pulse modulation, in each half cycle of time period multiple pulse occurs when the peak values of reference wave and carrier wave are compared. Multiple pulse modulation helps in reduction of lower order harmonics easily.



No. of pulses ← $\boxed{N_p = \frac{f_c}{2f_m}}$

$$\boxed{2d = \frac{A_m}{A_c}\pi}$$

$2d \rightarrow$ pulse width

each pulse $= \frac{2d}{N}$

from the above waveform

$$\gamma = x + \frac{d}{2N}$$

Also, $4x = \pi - 2d$ (from figure).
(N_p+1) since there are three pulses $(N_p = 3)$

$$\gamma = \frac{\pi - 2d}{N+1} + \frac{d}{N}$$

$$\boxed{\gamma = \frac{\pi - 2d}{N+1} + \frac{d}{N}}$$ → expression for γ

Fourier series of the output voltage waveform is given by

$$\boxed{V_o(t) = \sum_{n=1,3,5\ldots}^{\infty} \frac{8V_s}{n\pi} \sin\left(\frac{nd}{2}\right) \sin(n\gamma) \sin n\omega t}$$

10

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1 (b) A 3-ϕ short transmission line is delivering power to a 3-ϕ load of 800 kW per phase at 0.8 p.f. leading. The transmission line is having series resistance of 0.015 Ω/km and series reactance of 0.02 Ω/km. The sending end voltage is maintained at 3300 V and the length of the line is 20 km. Calculate the receiving end voltage and line current.

[12 marks]

Given, Short line

800kW 0.8pf lead

$R = 0.3\,\Omega \quad X = 0.4\,\Omega$

$Z = 0.3 + j0.4 = 0.5\angle 53.13^\circ\,\Omega$

$V_S = 3300\,V = 1905.2$

$$\begin{pmatrix} V_S \\ I_S \end{pmatrix} = \begin{pmatrix} 1 & Z \\ 0 & 1 \end{pmatrix} \begin{pmatrix} V_R \\ I_R \end{pmatrix}$$

$V_S = V_R + Z I_R \rightarrow (1)$

$I_S = I_R \rightarrow (2)$

$$I_R = \frac{800 \times 3}{\sqrt{3} \times V_R \times 0.8} = \frac{800 \times 10^3}{V_R \times 0.8}$$

$$I_R = \frac{1000 \times 10^3}{V_R}\angle +36.86^\circ\ A$$

$V_R = |V_R|\angle 0^\circ$

$$Z I_R = \frac{500 \times 10^3}{V_R}\angle 90^\circ$$

$$V_S = \sqrt{V_R^2 + (Z I_R)^2}$$

$$(1905.2)^2 = V_R^2 + \frac{25 \times 10^{10}}{V_R^2}$$

$$(1905.2)^2 \times V_R^2 = V_R^4 + 25 \times 10^{10}$$

$$V_R^4 - (1905.2)^2 V_R^2 + 25 \times 10^{10} = 0$$

$$\boxed{V_R = 1886.8}\ V$$

Do not write in this marg

Recieving end voltage $= 1886.6\,V$ phase

$= 3267\,V$ line

<u>Line Current</u>

$$I = \frac{800 \times 10^3}{1886.6 \times 0.8} = 530.05\,A \angle 36.86^\circ$$

10

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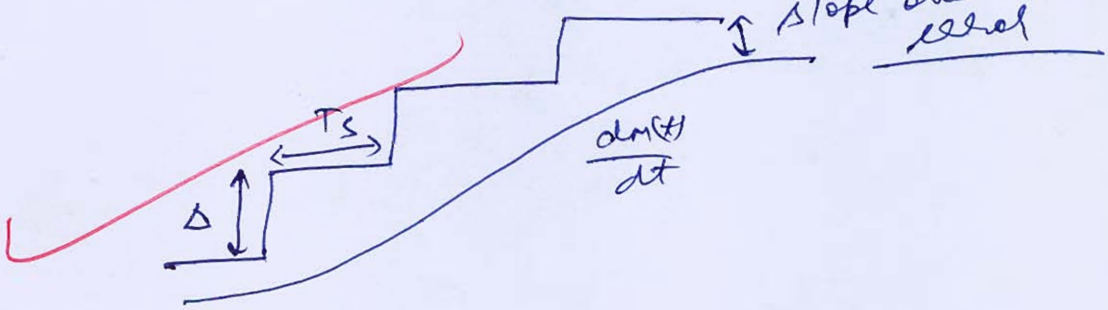
1 (c) What are the different types of error in Delta modulation? How can these errors be removed?

[12 marks]

There are two types of error in Delta Modulation

i) Slope overload error → It occurs when rate of change of signal is more than the step size in that time i.e.

$$\boxed{\frac{dm(t)}{dt} > \frac{\Delta}{T_s}}$$



(ii) Granular error → Another type of error in delta modulation

→ To remove slope overload error, the rate of change of message signal should be less than the step size i.e.

$$\boxed{\frac{\Delta}{T_s} > \frac{dm(t)}{dt}}$$

to avoid slope overload error

9

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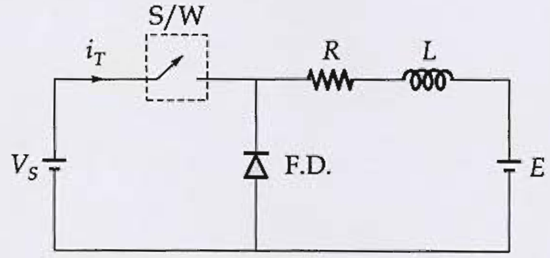
1 (d) With the help of suitable waveforms, for an ideal type-A chopper feeding RLE load as depicted in the figure below, show that the average input (or thyristor) current is given by

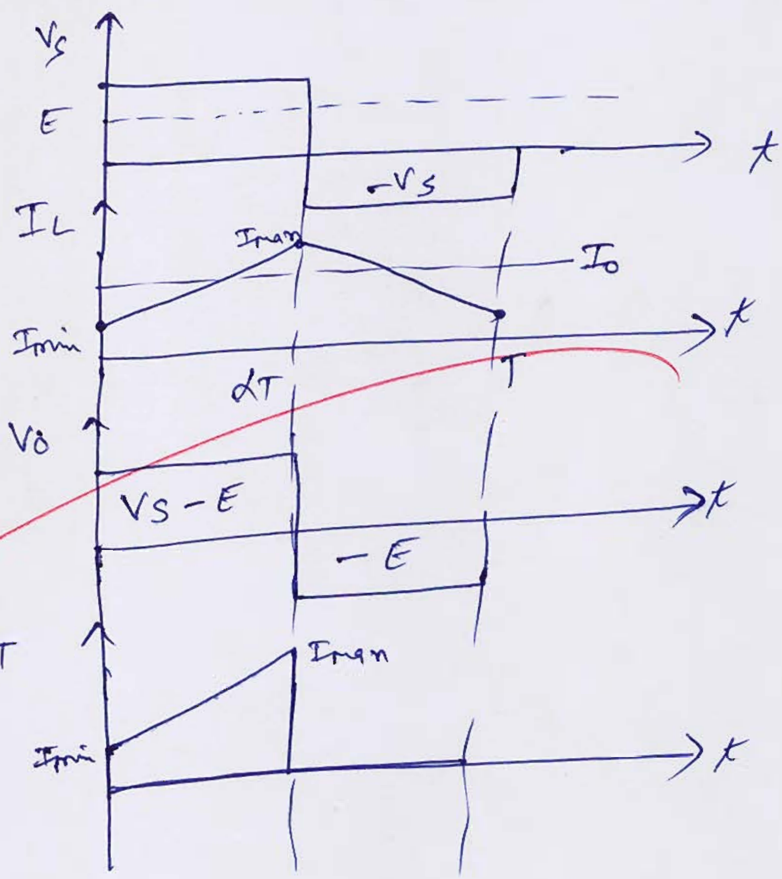
$$I_{T\text{avg}} = \frac{\alpha(V_S - E)}{R} - \frac{L}{RT}(I_{\max} - I_{\min})$$

(Where symbols have their usual meaning).



[12 marks]

for type A chopper



1

Incomplete Solution

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1 (e) The equation of FM wave is given by:

$V = 15 \sin [3 \times 10^8 t + 50 \sin(2500)t]$ volts

(i) What are the values of carrier and modulating frequencies?

(ii) Modulation index.

(iii) Maximum frequency deviation.

(iv) Power delivered to 75 Ω resistor by this wave.

[12 marks]

$V_{FM} = 15 \sin\left(3\times10^8 t + 50 \sin 2500 t\right)$

(i) $f_c = \frac{3\times10^8}{2\pi} = 47.77\ MHz$

$f_m = \frac{2500}{2\pi} = 398\ Hz$

(ii) On compairing above equation by

$S_{FM}(t) = A_c \sin\left(2\pi f_c t + \beta \sin 2\pi f_m t\right)$

$\boxed{\beta = 50} \rightarrow$ modulation index

(iii) $\beta = \frac{\Delta f}{f_m}$

$\Delta f = 50 \times 398 = 19.904\ KHz$

↳ max. freq. deviation

(iv) $Power = \frac{A_c^2}{2R}$ $\boxed{A_c = 15}$

$= \frac{(15)^2}{2\times 75}$

$= 1.5\ W$

11

Good Approach

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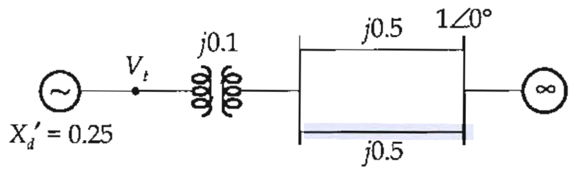
2 (a) The generator of figure given below is delivering 1.0 p.u. power to the infinite bus ($|V_t| = 1.0$ p.u.).



A fault occurs and line is shorted in the middle. The generator has an inertia constant of 4 MJ/MVA. What is the initial angular acceleration? If this acceleration can be assumed to remain constant for $\Delta t = 0.05s$, find the rotor angle at the end of this time interval and the new acceleration. (Take $f = 50$ Hz)

[20 marks]

Q.2 (b) A three phase 50 Hz, 400 km long transmission line is delivering power to a 3-ϕ load of 48 MVA at 0.75 p.f. leading and at 220 kV. The line parameters are:

$r = 0.125\ \Omega/\text{km}$, $L_1 = 1.273\ \text{mH/km}$ and $y = 2.8 \times 10^{-6}\ \mho/\text{km}$.

Determine:

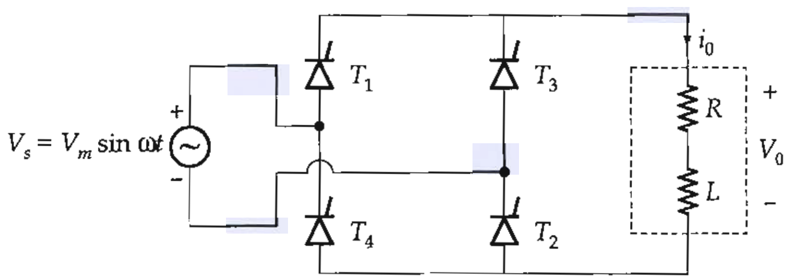
(i) The ABCD parameters of the line.

(ii) The sending end line voltage of the line.

(iii) Sending end power factor and power.

[20 marks]

2 (c) A single phase fully controlled converter is fed through a single phase, 120 V, 60 Hz ac mains to supply a load consisting of R = 10 Ω and L = 20 mH, as shown in the figure below.



For the firing angle of 60°,

Determine:

(i) The expression for the load current as a function of time.

(ii) The extinction angle (in degree) of the load current by using Newton-Raphson method and comment upon the continuity of the load current.

(iii) The average load current.

[6 + 10 + 4 marks]

Q.3 (a) A single phase 50 Hz alternator supplies an inductive load of $5000\sqrt{2}$ kVA at a power factor of $\frac{1}{\sqrt{2}}$ lagging by means of an overhead transmission line 20 km long. The line resistance and inductance of overhead line are 0.0195 Ω and 0.63 mH per km respectively. The voltage at the receiving end is required to be kept constant at 10 kV.

Find:

(i) The sending-end voltage and voltage regulation of the line.

(ii) The value of the capacitors to be placed in parallel with the load such that the regulation is reduced to 50% of that obtained in part (i).

(iii) Compare the transmission efficiency in part (i) and (ii).

[20 marks]

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.3 (b) The speed of 25 HP, 320 V, 960 rpm separately excited d.c. motor is controlled by a 3-ϕ full convertor. The field current is controlled by a three phase full converter and is set to a maximum possible value. The 3-ϕ a.c. input is star-connected 210 V, 50 Hz supply. The armature and field circuit resistances are 0.2 Ω and 130 Ω respectively. The motor torque constant is 1.2 V-sec/rad-A. Assuming the armature and field currents to be continuous and ripple free.

Determine:

(i) The firing angle of the armature converter if the field converter is operating at the maximum field current and the developed torque is 110 N-m at 960 rpm.

(ii) The speed of the motor if the field circuit converter is set for the maximum field current, the developed torque is 110 N-m and the firing angle of the armature converter is 0°.

(iii) The firing angle of the field converter if the speed has to increase to 1750 rpm, for the same load requirement in part (ii). Neglect the system losses.

[20 marks]

.3 (c) (i) Briefly explain the methods to improve string efficiency for an insulator.

(ii) A transmission line has a span of 270 m between level supports. The diameter of the conductor is 2.76 cm and height is 0.865 kg/m. Its ultimate strength is 9060 kg. If the conductor has ice coating of radial thickness 1.82 cm and subjected to a wind pressure of 3.8 gm/cm^2 of project area. Then determine the sag for a safely factor of 2. (Weight of 1 c.c. of ice is 0.91 gm)

[6 + 14 marks]

Q.4 (a) A single phase full bridge inverter fed from 230 V dc, is connected to an R-L load. The inverter is operating with output frequency of 50 Hz. The load parameters to be $R = 10\ \Omega$ and $L = 0.03$ H. Determine the power delivered to the load when the inverter is operating with

(i) square wave output,

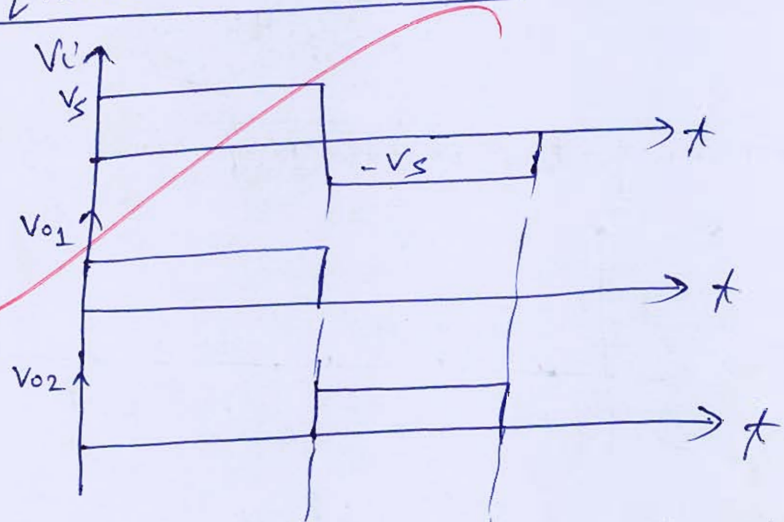
(ii) two symmetrically spaced pulses per half cycle with an ON-period of 0.5 of a cycle. (Consider significant harmonics upto 3rd harmonics).

[20 marks]

Given 1ϕ FBI $230 = V_s$, 50Hz

$R = 10\,\Omega \quad L = 0.03\,H$

(i) Square wave output



The fourier series of output voltage is given by

$$v_o(t) = \sum_{n=1,3,5...} \frac{4V_s}{n\pi} \sin n\omega t \rightarrow (1)$$

$n = 1$

$$(v_{o1})_{rms} = \frac{4V_s}{\pi\sqrt{2}} = \frac{4 \times 230}{\pi\sqrt{2}} = 207.04V$$

$n = 3$

$$(v_{o3})_{rms} = \frac{4V_s}{3\pi\sqrt{2}} = 69.01\,V$$

Impedance

$Z = R + jn\omega L$

$Z = 10 + jn \times 314.2 \times 0.03$

$Z = 10 + jn\,9.426$

$n = 1$

$Z_1 = 10 + j\,9.426 = 13.74\angle 43.3^\circ\,\Omega$

$n = 3$

$Z_3 = 10 + j\,28.27 = 29.98\angle 70.5^\circ\,\Omega$

$(I_{o1})_{rms} = \frac{(V_{o1})_{rms}}{Z_1} = 15.068A$

$(I_{o3})_{rms} = \frac{(V_{o3})_{rms}}{Z_3} = 2.301 A$

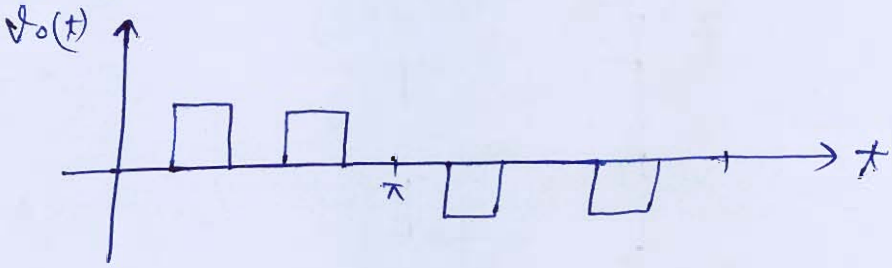
$I_{orms} = \sqrt{(I_{o1})^2 + (I_{o3})^2} = 15.24A$

Power delivered to load

$P = (I_{orms}^2) \times R = (15.24)^2 \times 10$

$P = 2323.43 \ W$

(ii) Two pulses with ON period of 0.5 of cycle



Total pulse width

$2d = 0.5 \times 180° = 90°$

$\boxed{d = 45°}$

Fourier series for quasi square wave is given by

$$\boxed{v_o(t) = \sum_{n=1,3,5\ldots}^{\infty} \frac{4V_s}{n\pi} \sin nd \sin n\omega t}$$

$(v_{o1})_{rms} = \frac{4 \times 230}{\sqrt{2} \times \pi} \sin 45° = 146.4V$

$(V_{o3})_r = \frac{4 \times 230}{3\pi\sqrt{2}} \sin 135° = 48.8V$

$(I_{o1})_r = \frac{146.4}{13.74} = 10.65A$

$(I_{o3})_r = \frac{48.8}{29.98} = 1.62A$

$$I_{orms} = \sqrt{(10.65)^2 + (1.62)^2} = 10.77A$$

$$P = I_{orms}^2 \times R = (10.77)^2 \times 10$$

$$P = 1161.53W$$

13

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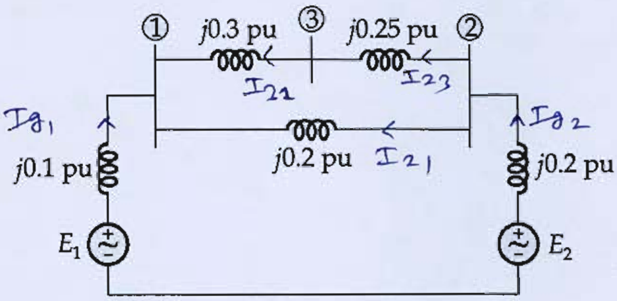
Q.4 (b) For the power system whose equivalent circuit is shown in figure below, compute the bus voltages and branch currents for a 3-ϕ fault on bus-1. Assuming the fault impedance $Z_f = j0.2$ pu.

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

(Assume a pre-fault constant voltage of 1.0∠0° pu.)



[20 marks]

Given fault (3ϕ) occured on bus-1

<u>fault Current</u>

$$I_f = \frac{1}{Z_{th} + Z_f} = \frac{1}{Z_{11} + Z_f}$$

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

$$\boxed{I_f = -j\,3.602 \text{ A}}$$

<u>Change in bus voltages</u>

$$V_1 = V_{prefault} - Z_{11} I_f$$

$$V_{prefault} = 1 \text{ pu}$$

$$V_1 = 1 - 0.0776 \times 3.602$$

Bus 1 ← $\boxed{V_1 = 0.72 \text{ pu}}$ = 0.72 pu

$$V_2 = 1 - Z_{12} I_f$$

$$V_2 = 1 - 0.0448 \times 3.602$$

Bus 2 ← $\boxed{V_2 = \text{ pu}}$ = 0.838 pu

Bus 3

$$V_3 = 1 - Z_{13} I_F$$

$$V_3 = 1 - 0.0597 \times \cancel{0.2776}\ 3.602$$

$$\boxed{V_3 = \cancel{0.983}\ 0.784\ pu}$$

Currents

from Gen. 1

$$I_{g1} = \frac{1 - V_1}{j0.1} = \cancel{j0.22pu}\ -j2.8pu$$

from Gen. 2

$$I_{g2} = \frac{1 - V_2}{j0.2} = \cancel{j0.065pu}\ -j0.81pu$$

Branches

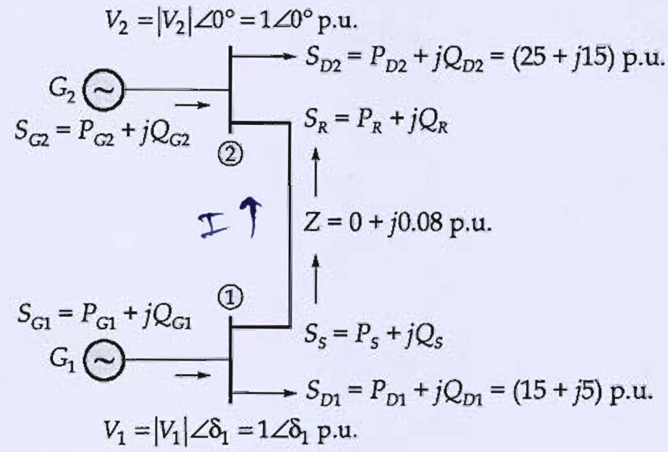
$$I_{23} = \frac{V_2 - V_3}{j0.25} = \cancel{j0.016pu}\ -j0.216pu$$

$$I_{21} = \frac{V_2 - V_1}{j0.2} = \cancel{j0.045pu}\ -j0.59pu$$

$$I_{31} = \frac{V_3 - V_1}{j0.3} = \cancel{j0.0167pu}\ -j0.213pu$$

12

Q.4 (c) An inter-connector cable links two generating stations as shown in the figure below. It is desired that the voltage profile is flat at the buses i.e., $|V_1| = |V_2| = 1.0$ p.u. The station loads are equalized by the flow of power in the cable. Estimate the torque angle and power factor of station-1 for the given cable of impedance $Z = 0 + j0.08$ p.u. It is known that the generator G_1 can generate a maximum of 30.0 p.u. real power.



[20 marks]

Given, $|V_1| = |V_2| = 1\,pu$

$Z = j0.08\,pu = X$

$(P_{G1})_{max} = 30\,pu$

From given network

$P_{G1} = P_{D1} + P_s$

$P_s = 30 - 15 = 15\,pu$

$\cancel{P_s = \frac{V_1 V_2}{X} \sin\delta_1}$

$\cancel{\sin\delta_1 = \frac{15 \times 0.08}{1} =}$

$I = \frac{V_1\angle\delta_1 - V_2\angle 0^\circ}{j0.08} = \frac{1\angle\delta_1 - 1}{j0.08} \rightarrow (1)$

$(P_s)_{max} = \frac{V_1 V_2}{X} = \frac{1 \times 1}{0.08} = 12.5\,pu$

$P_L = 30 - 15 - 12.5 = 2.5\,pu$

$$P_L = \frac{V_1 V_2}{X} \sin\delta_1$$

$$2.5 = \frac{1}{0.08} \sin\delta_1$$

torque angle $\leftarrow$ $\boxed{\delta_1 = 11.53^\circ}$

$$Q_L = \frac{V_1 V_2}{X} \cos\delta - \frac{V_2^2}{X}$$

$$Q_L = \frac{1}{0.08}\left(\cos 11.53^\circ - 1\right)$$

$$Q_L = -0.25\,pu$$

10

$$Q_S = -\frac{V_2^2}{X} = -12.5\,pu$$

$$Q_{G_1} = -12.5 - 0.25 + 5$$

$$Q_{G_1} = -7.75\,pU$$

for station 1

$$\tan\phi = \frac{Q_{G_1}}{P_{G_1}} = \frac{7.75}{30} = -14.48^\circ$$

$pf = \cos\phi = 0.968$ lag

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Section-B : Power Systems + Power Electronics & Drives + Communication Systems

Q.5 (a) A 600 V, 1500 rpm, 70 A separately excited dc motor is fed through a three-phase semiconverter from three-phase 400 V supply. If the motor armature resistance is 1 Ω and the armature current is assumed to be constant and ripple free then for the firing angle of 45° at 1200 rpm,

Determine:

(i) RMS value of source and thyristor currents.

(ii) Average value of thyristor current.

(iii) Input supply power factor.

[12 marks]

Given,

600V, 1500rpm, 70A dc motor

3ϕ Semiconv. 400V $R_a = 1\Omega$ $I_o = \text{const}$

$\alpha = 45°$ $N = 1200\,\text{rpm}$

for 3ϕ Semi conv.

$$V_o = \frac{3V_{ML}}{2\pi}(1+\cos\alpha) = \frac{3\times 400\sqrt{2}}{2\pi}\left(1+\frac{1}{\sqrt{2}}\right)$$

$$\boxed{V_o = 461\,V}$$

at 1500rpm

$$E = 600 - 70\times 1 = 530\,V$$

$$E \propto N \Rightarrow \frac{530}{E} = \frac{1500}{1200}$$

$$\boxed{E = 424\,V}$$

$$I_a = \frac{V-E}{R} = \frac{461-424}{1}$$

$$\boxed{I_a = 37A}$$

$$(I_T)_{rms} = \frac{I_0}{\sqrt{3}} = 21.36A$$

$$(I_s)_{rms} = I_0\sqrt{\frac{2}{3}} = 30.21A$$

$$(I_T)_{avg.} = \frac{I_0}{3} = 12.33A$$

Input power pF = distortion factor × Displacement factor

$$= \frac{3}{\pi} \cos\alpha$$

$$= \frac{3}{\pi} \cos 45^\circ$$

$$= 0.675 \text{ lag}$$

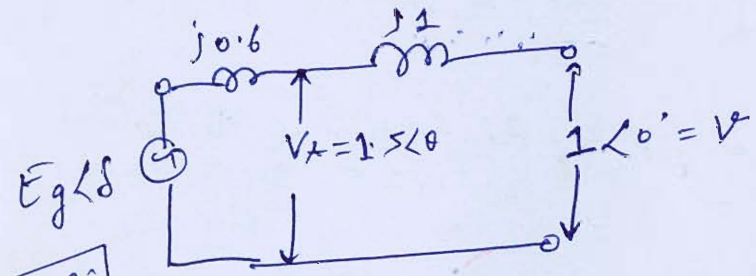
8

Q.5 (b) Find the steady state power limit of a power system consisting of a generator of equivalent reactance of 0.6 p.u. connected to an infinite bus through a series reactance of 1.0 p.u. The terminal voltage of the generator is held at 1.50 p.u. and the voltage of the infinite bus is 1.0 p.u.

[12 marks]

$X_g = 0.6\,pu \quad X_l = 1\,pu$

$V_t = 1.5\,pu \quad V = 1\,pu$



$\boxed{\delta = 90^\circ}$

$$P_{steady} = \frac{E_g V}{0.6+1} = \frac{E_g \times 1}{1.6} \rightarrow (1)$$

$$I = \frac{1.5\angle\theta - 1}{j1} = \frac{1.5(\cos\theta + j\sin\theta) - 1}{j1}$$

$$I = [(1.5\cos\theta - 1) + j\,1.5\sin\theta] \times -j$$

Now, $I = 1.5\sin\theta - j(1.5\cos\theta - 1) \rightarrow (2)$

$$E_g = 1.5\angle\theta + (0.6j)I$$

$$E_g = 1.5\angle\theta + 0.6j\left[1.5\sin\theta - j(1.5\cos\theta - 1)\right]$$

$$E_g = 1.5(\cos\theta + j\sin\theta) + 0.9j\sin\theta + 0.9\cos\theta - 0.6$$

$$E_g = (1.5\cos\theta + 0.9\cos\theta - 0.6) + j(1.5\sin\theta + 0.9\sin\theta)$$

Real part $= 0$ $(\delta = 90^\circ)$

$$\cos\theta = \frac{0.6}{2.4}$$

$$\boxed{\theta = 75.52^\circ}$$

$E_g = 2.4\sin\theta = 2.32\,pu$

from equation (1)

$$P_{steady} = \frac{2.32 \times 1}{1.6} = 1.45\,pu$$

11

Good Approach

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Q.5 (c) In a superheterodyne receiver having no RF amplifier the loaded Q of the antenna coupling circuit (at the input of mixer) is 90. If the intermediate frequency is 455 kHz calculate the following:

(i) The image frequency and image frequency rejection ratio at 950 kHz.

(ii) The image frequency and its rejection ratio at 10 MHz.

[12 marks]

Given, $Q = 90$

$If = 455\,kHz$

(i) $f_s = 950\,kHz$

Image freq.

$$f_{si} = f_s + 2I_f = 950 + 910$$

$$\boxed{f_{si} = 1860\,kHz}$$

$$\rho = \frac{f_{si}}{f_s} - \frac{f_s}{f_{si}} = \frac{1860}{950} - \frac{950}{1860}$$

$$\boxed{\rho = 1.447}$$

Image freq. rejection ratio

$$\alpha = \sqrt{1 + \rho^2 Q^2}$$

$$\alpha = \sqrt{1 + (1.447)^2 \times 90^2}$$

$$\boxed{\alpha \simeq 130.24}$$

(ii) $f_s = 10\,MHz$

Image freq. $f_{si} = f_s + 2I_f = 10 + 0.91$

$= 10.91\,MHz$

Do not write in this margin

$$P = \frac{10.91}{10} - \frac{10}{10.91} = 0.174$$

$$\alpha = \sqrt{1 + (0.174)^2 (90)^2}$$

$$\boxed{\alpha = 15.72}$$

→ Image freq. rejection ratio

11

Good Approach

Q.5 (d) Design a PCM multiplexing system using a 256 level quantizer for the transmission of 3 signals $m_1(t)$, $m_2(t)$ and $m_3(t)$ band limited to 5 kHz, 10 kHz and 5 kHz respectively. Assume that each signal is sampled at Nyquist rate. Compute :

(i) Maximum bit duration.

(ii) Channel bandwidth required to pass the PCM signal.

(iii) Commutator speed in RPM.

(iv) Increment in the channel bandwidth if 512 quantization levels are used.

[12 marks]

Given,

$$l = 256 = 2^n$$

$$\boxed{n = 8} \text{ bits}$$

$N = 3$

$$f_{s_1} = 5 KHz$$
$$f_{s_2} = 10 KHz$$
$$f_{s_3} = 5 KHz$$

(i) Since, $(f_s)_{max} = 10 KHz$

$$\text{max. bit duration} = \frac{1}{10 KHz} = 0.1 \text{ msec.}$$

(ii) Channel bandwidth

$$BW = \frac{R_b}{2} = \frac{N n f_s}{2} = \frac{3 \times 8 \times 10}{2}$$

$$\boxed{BW = 120 KHz}$$

(iii) Commutator speed (f_c)

$$f_c = N n f_s = 3 \times 8 \times 10 = 240 KHz$$

In rpm

1 rev —— 2π rad.

$$\frac{240 \times 10^3}{60} \times 2\pi = 25120$$

(iv) if $l = 512 = 2^n$

$$\boxed{n = 9}$$

$$\text{Bandwidth} = \frac{R_b}{2} = \frac{Nnf_s}{2} = \frac{3 \times 9 \times 10}{2}$$

$$\underline{BW = 135\,kHz}$$

Increase in bandwidth $= 135 - 120$
$= 45\,kHz$

8

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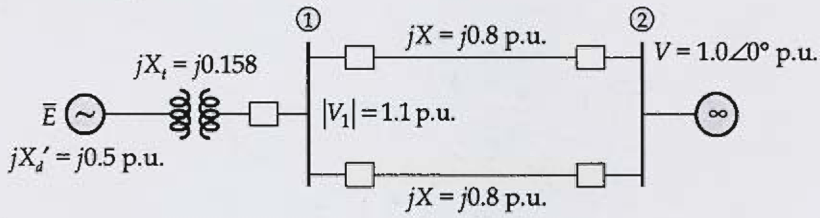
Q.5 (e) A 60 Hz alternator has a transient reactance of 0.5 p.u. and an inertia constant of 5.66 MJ/MVA. The generator is connected to an infinite bus through a transformer and a double circuit line, as shown in the figure below. Resistances are neglected and reactances are expressed on a common MVA base. The generator is delivering a real power of 0.95 per unit to the bus bar-1. The voltage magnitude at bus-1 is 1.1 and the infinite bus voltage $V = 1.0\angle 0°$ p.u.



Determine:

(i) The generator excitation voltage and the power angle.

(ii) Obtain the swing equation for the given system.

[12 marks]

$f = 60\,Hz \quad X_g = 0.5\,pu \quad H = 5.66\,MJ/MVA$

$P = 0.95\,pu \quad V_1 = 1.1 \quad V = 1\,pu$

$$P = 0.95 = \frac{E \times 1.1}{0.5 + 0.158} \sin\delta_1$$

$$\boxed{E\sin\delta_1 = 0.568} \rightarrow (1)$$

Let, $V_1 = 1.1\angle\theta$

$$I = \frac{1.1\angle\theta - 1}{j0.4}$$

$$I = \frac{1.1(\cos\theta + j\sin\theta) - 1}{j0.4}$$

$$I = (1.1\cos\theta + j\,1.1\sin\theta - 1) \times -2.5j$$

$$I = -2.75j\cos\theta + 2.75\sin\theta + j2.5$$

$E = 1.1\angle\theta + j\,0.658\left((-2.75\cos\theta + 2.5)j + 2.75\sin\theta\right)$

$E = 1.1(\cos\theta + j\sin\theta) - 1.645 + 1.8\cos\theta + j\,1.8\sin\theta$

$\therefore$ Real$(E) = 0$

$1.1\cos\theta + 1.8\cos\theta = 1.645$

$\boxed{\theta = 55.44^\circ}$

$E = 1.8\sin\theta + 1.1\sin\theta$

$E = 2.9\sin\theta$

$\boxed{E = 2.38\,pu}$

$I = 2.45\angle 22.54^\circ$

from (1) $\sin\delta_1 = \frac{0.562}{2.38} = 0.238$

$\boxed{\delta_1 = 13.8^\circ}$

So power angle

$\delta = 55.44 + 13.8 = 69.24^\circ$

For Swing equation

$\boxed{P_a = P_m - P_e = \frac{d^2\delta}{dt^2}}$

$M = \frac{GH}{\pi f} = \frac{5.66}{\pi \times 60} = 0.03$

$\boxed{P_a = M\alpha}$

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$$P_m - P_e = M\alpha$$

$$P_m - P_e = \frac{H}{\pi F}\alpha$$

$$\boxed{P_m - P_e = 0.03\frac{d^2\delta}{dt^2}}$$

7

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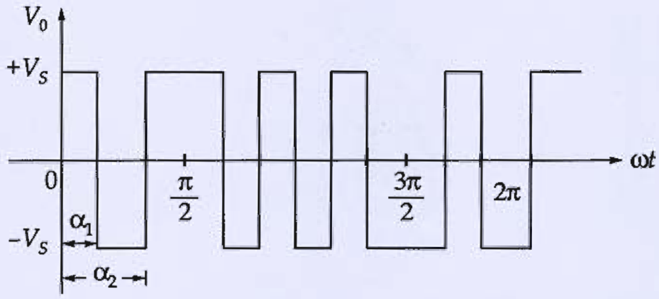
Q.6 (a) (i) A two notch PWM inverter output voltage waveform as shown in the figure below. Show that the Fourier series representation of the output voltage is given by:

$$V_0(t) = \sum_{n=1,3,5}^{\infty} C_n \sin n\omega t \;; \qquad \text{where, } C_n = \frac{4V_s}{n\pi}[1 - 2\cos n\alpha_1 + 2\cos n\alpha_2]$$



(ii) Determine the values of α_1 and α_2 to eliminate 3rd and 5th harmonic from the output.

[20 marks]

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Q.6 (b) (i) Using the Gauss-Seidel method, determine the values of the voltage at bus 2 and 3 [Two iterations]. For the power system shown in figure below.

(ii) Find the slack bus real and reactive power after second iteration.

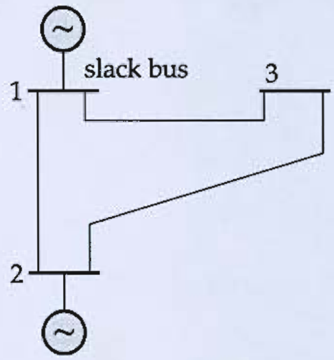

Table-1 : Scheduled generation are as loads and assumed bus voltage for sample power system [Base MVA = 100].

		Generation		Load	
Bus code (1)	**Assumed bus voltage**	**MW**	**MVAR**	**MW**	**MVAR**
1 (SB)	1.05 + *j*0.0	-	-	0	0
2	1 + *j*0.0	50	30	305.6	140.2
3	1.0 + *j*0.0	0.0	0.0	138.6	45.2

Table-2 : Line impedances

Bus code ($i - k$)	**Impedance Z_{ik}(pu)**
1 - 2	0.02 + *j*0.04
1 - 3	0.01 + *j*0.03
2 - 3	0.0125 + *j*0.025

[20 marks]

Q.6 (c) A 50 Hz, 4 pole, turbogenerator rated 200 MVA, 11 kV has moment of inertia of 81000 kg-m^2. The generator was initially delivering 40 MW to an electrical load. When the input to the generator is suddenly raised to 60 MW.

(i) Find the inertia constant (in MJ/MVA) and the stored Kinetic energy.

(ii) For the said sudden change in input to the generator find the rotor acceleration in rpm/sec.

(iii) If the rotor acceleration is maintained for 15 cycles, determine the change in rotor angle and rotor speed in rpm at the end of this period.

[20 marks]

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.7 (a) (i) A boost converter supplies an output voltage of 10 V from 5 V supply. It has a non ideal inductor with r_L as the series resistance. Determine the expression for efficiency in terms of duty ratio D, load resistance R and r_L. Assume inductor current to be continuous.

(ii) For $R = 10\ \Omega$ and $r_L = 48\ \text{m}\Omega$, calculate the efficiency.

[20 marks]

$$\boxed{\frac{V_o}{V_s} = \frac{1-\alpha}{\frac{r}{R} + (1-\alpha)^2}}$$

for $R = 10\ \Omega$

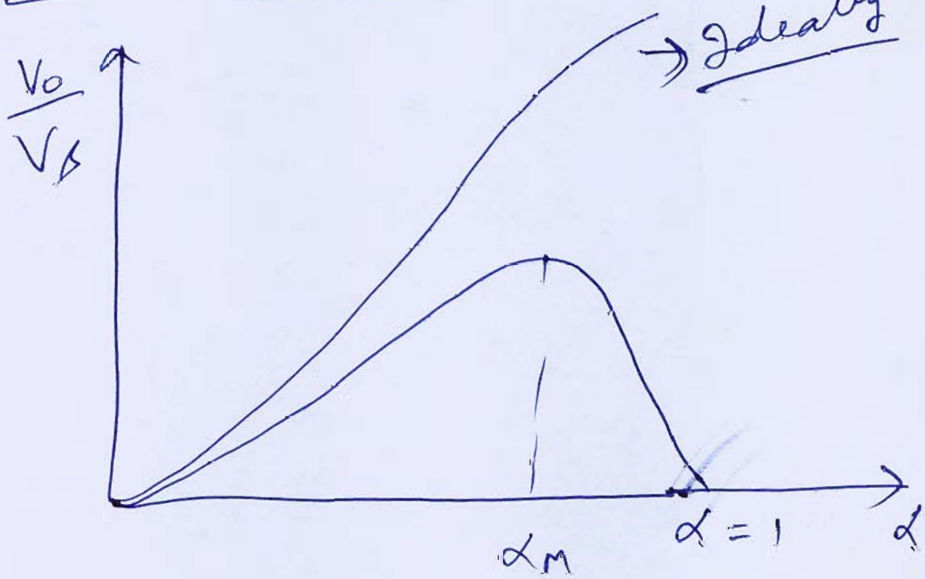
$r_L = 48\ \text{m}\Omega$

$$1-\alpha = \frac{5}{10}$$

$$\boxed{\alpha = 0.5}$$

$$\frac{V_o}{V_s} = \frac{0.5}{\frac{48\times10^{-3}}{10} + (0.5)^2}$$

$$\boxed{\frac{V_o}{V_s} = 1.962}$$

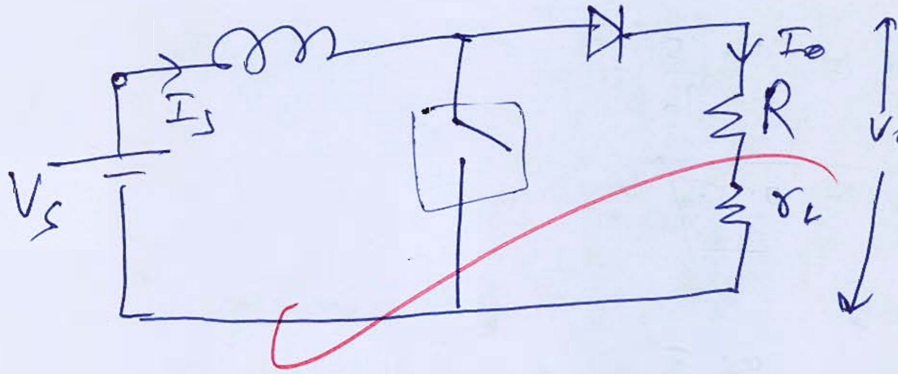


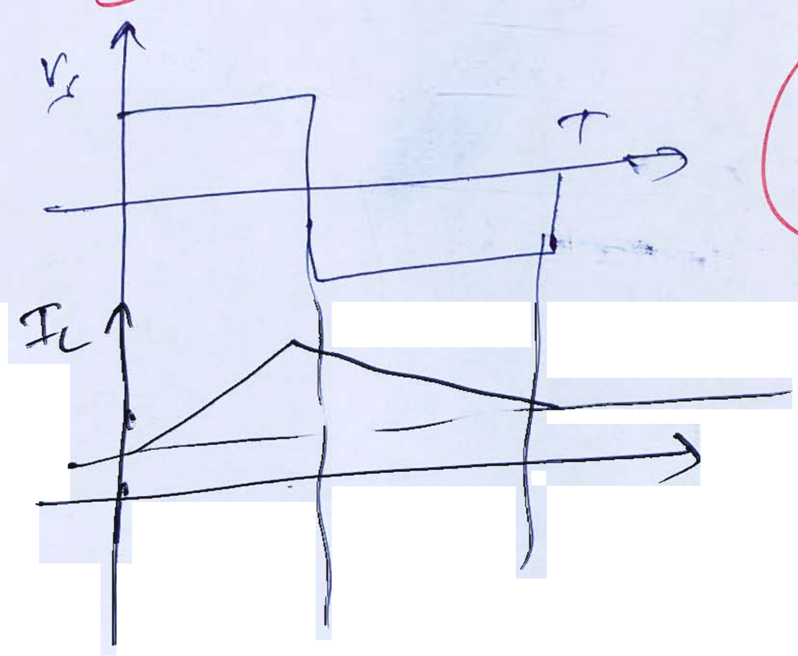
efficiency

$$\eta = \frac{V_0 I_0}{V_s I_s} = 1.962 \times \frac{1}{2}$$

$$= 0.981$$

$$I_s = \frac{I_0}{1-\alpha} = \frac{I_0}{0.5} = 2 I_0$$





17

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Q.7 (b) What is the universal relay torque equation? Using this equation, derive the impedance relay, reactance relay and mho relay characteristics. Also, draw the operating characteristic and indicate clearly the zones of operation and no operation.

[20 marks]

Universal relay torque equation

$$\boxed{T = K_1 V^2 - K_2 I^2 - K_3 VI \sin\theta + K_4}$$

(i) For Impedance relay

$$K_3 = K_4 = 0$$

$$Z = \frac{V}{I} = \sqrt{\frac{K_2}{K_1}} = \text{const.}$$

Reactance relay

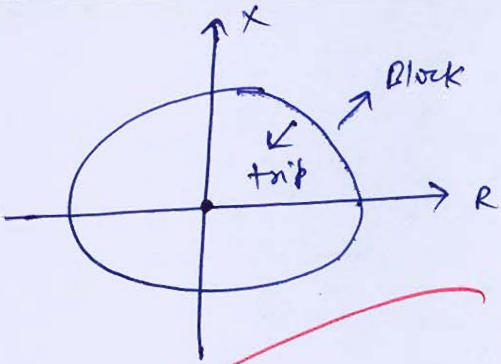
$$K_1 = K_4 = 0$$

$$X = \frac{V\sin\theta}{I} = \frac{K_2'}{K_3} = \text{const.}$$

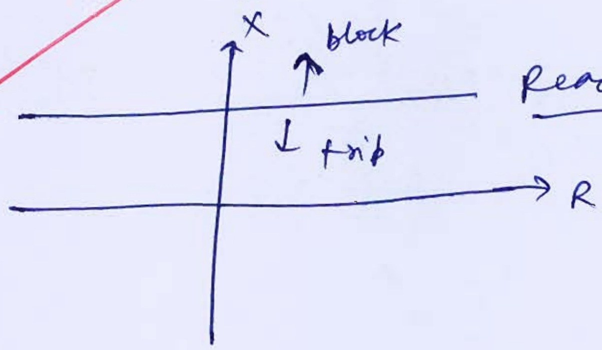
Mho relay

$$K_3 = K_4 = 0$$

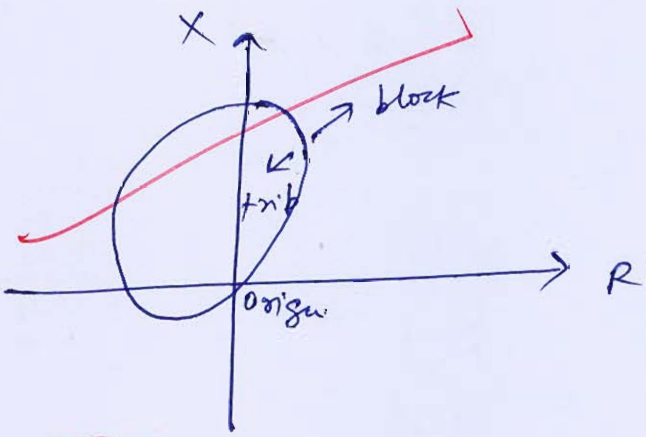
$$\frac{I}{V} = \sqrt{\frac{K_1}{K_2}} = \text{Const.}$$



Impedance relay



Reactance Relay



Mho relay

17

7 (c) A 220 kV circuit breaker is used to protect a line. During short circuit, the power factor of the fault was 0.5 lag, the armature reaction demagnetizing effect brought down the voltage to 90% of rated voltage and the natural frequency of oscillation was found to be 20 kHz.

Determine:

(i) The maximum value of RRRV for grounded fault and ungrounded fault.

(ii) The average RRRV for grounded fault and ungrounded fault.

(iii) The time at which maximum transient recovery voltage occurs.

[20 marks]

Given, 220 kV CB

$\cos\phi = pf = 0.5$ lag

$\sin\phi = 0.866 = K_1$

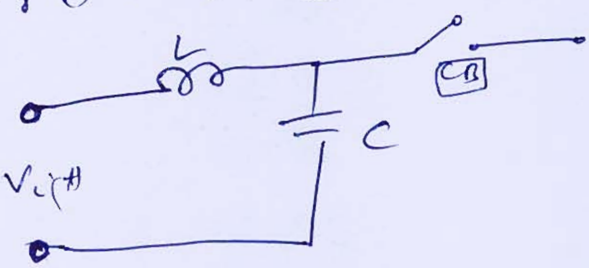
$K_2 = 0.9 \rightarrow$ arm^r reaction effect

$f = 20\,kHz$

$K_3 = 1 \rightarrow$ grounded fault

$= 1.5 \rightarrow$ ungrounded fault

(i) $v_r(t) = V_m(1 - \cos\omega t)$



$$\frac{dv}{dt} = V_m\,\omega \sin\omega t$$

$$(RRRV)_{max} = V_m\,\omega$$

for grounded fault

$$(RRRV)_{max} = 2\pi f \times \left(\frac{220\times\sqrt{2}}{\sqrt{3}}\right) \times \underset{K_1}{0.866} \times \underset{K_2}{0.9} \times \underset{K_3}{1}$$

$(RRRV)_{max} = 17595.58\ kV \rightarrow$ for grounded fault

$(RRRV)_{max} = 26393.37\ kV \rightarrow$ for ungrounded fault ($K_3 = 1.5$)

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(ii) Average RRRV $= \frac{V_r \omega}{2}$ (K3)

$= \frac{2\pi F}{2} \times \frac{220\sqrt{2}}{\sqrt{3}} \times 0.866 \times 0.9 \times 1$

$= \cancel{405513.48}$ 8797.8 kV → for grounded

$= \cancel{158260.22}$ 13196.6 kV → for ungrounded

(iii) Maxim. transient recovery voltage occurs at

$$t = \frac{\pi\sqrt{LC}}{2}$$

$$t = \frac{\pi}{2\omega} = \frac{\pi}{2\pi f \times 2}$$

$$t = \frac{1}{2f \times 2}$$

$$t = \frac{1}{2 \times 60 \times 10^3 \times 2}$$

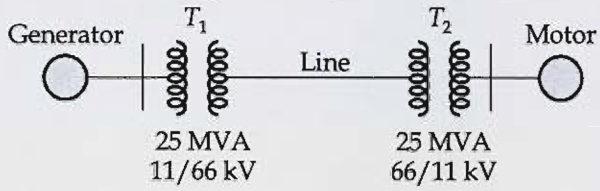
$$t = \frac{8.33\ \mu sec}{2}$$

$$\boxed{t = 4.16\ \mu sec}$$

7

Recovery Voltage $\Rightarrow \boxed{V_r = K_1 K_2 K_3 \frac{V_m \sqrt{2}}{\sqrt{3}}}$

Q.8 (a) A synchronous generator and a synchronous motor each rated 25 MVA, 11 kV having 15% subtransient reactance are connected through transformers and a line as shown in the figure below. The transformers are rated 25 MVA, 11/66 kV and 25 MVA, 66/11 kV with leakage reactance of 10% each. The line has a leakage reactance of 10% on a base of 25 MVA, 66 kV. The motor is drawing 15 MW at 0.8 power factor leading and a terminal voltage of 10.6 kV when a symmetrical 3-phase fault occurs at the motor terminals. Find the subtransient current in the generator, motor and fault.



[20 marks]

Gen. & Motor → 25 MVA, 11 kV $X = 15\%$

$X_T = 10\%$ $X_L = 10\%$

Base MVA = 25 MVA

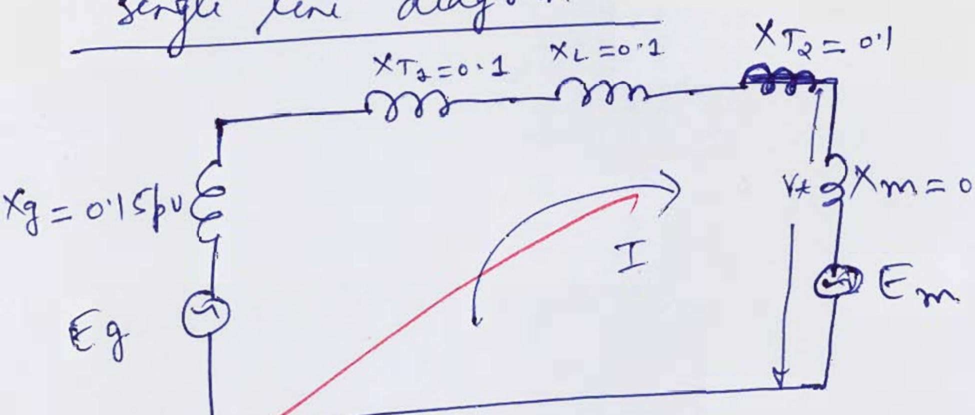
Base kV = 11 kV

Load ⇒ 15 MW, 0.8 pf lead, $V_t = 10.6$ kV

$$V_t = \frac{10.6}{11} = 0.963 \text{ pu}$$

3φ fault at motor terminal

Single line diagram



(fig 1)

when a 3φ fault occurs at the motor terminal

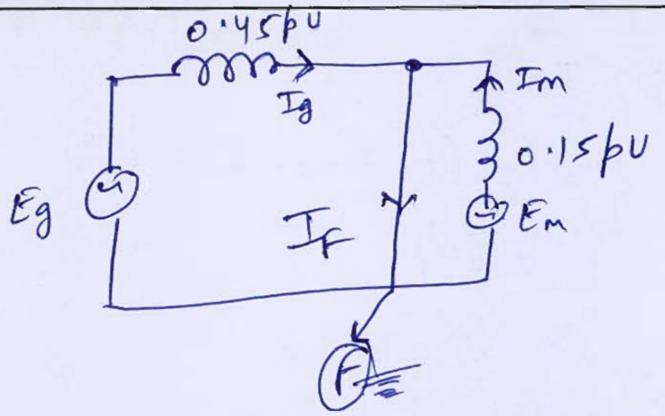


fig (2)

$V_t = 0.963\,pu$

Subtransient Current

Generator

$$I_g = \frac{1 - 0.963}{j0.45} =$$

Motor

$$I_m = \frac{1 - 0.963}{j0.15} =$$

Fault

$$I_F = I_g + I_m =$$

Given $\quad P_L = \frac{15\,MW}{25\,MVA} = 0.6\,pu$

$$P = VI\cos\phi \Rightarrow I = \frac{0.6}{0.963 \times 0.8}$$

$$\boxed{I = 0.7788\angle{+36.86^\circ}\,pu}$$

$$E_g = V_t\angle 0^\circ + j(0.15 + 0.1 + 0.1 + 0.1) \times I$$

$$E_g = 0.963\angle 0^\circ + j0.45 \times 0.7788\angle 36.86^\circ$$

$$\boxed{E_g = 0.803\angle 20.43^\circ\,pu}$$

$E_m = V_g - j0.15 I$

$E_m = 0.963\angle 0^\circ - j0.15 \times (0.7788\angle 36.86^\circ)$

$\boxed{E_m = 1.037\angle -5.17^\circ \text{ pu}}$

Subtransient Currents

Generator

$$I_g = \frac{E_g - V_t}{j0.45} = \frac{0.803\angle 20.43 - 0.963}{j0.45}$$

$I_g = 0.7789\angle 36.9 \text{ pu}$

Motor

$$I_m = \frac{E_m - V_t}{j0.15} = \frac{1.037\angle -5.17 - 0.963}{j0.15}$$

$I_m = 0.7775\angle -143.24^\circ \text{ pu}$

Fault

$I_f = I_g + I_m$

$I_f = 0.00246\angle 92.18 \text{ pu}$

$$I_{base} = \frac{25000}{\sqrt{3}\times 11} = 1312.15 A$$

$|I_g| = 1022.04 A$

$|I_m| = 1020.19 A$

14

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8 (b) (i) Determine efficiency and percentage of total power carried by the sidebands of the AM wave for the modulation index = 0.3. Also find the percentage power saving, when transmitted as DSB-SC and SSB signal.

(ii) For a modulating signal:

$$m(t) = 2\cos 100t + 18\cos 2000\pi t$$

1. Write expression for $\phi_{PM}(t)$ and $\phi_{FM}(t)$ when amplitude of carrier wave $A = 10$ Volt. $\omega_c = 10^6$, $k_f = 1000\pi$ and $k_p = 1$.
2. Estimate the bandwidth of $\phi_{FM}(t)$ and $\phi_{PM}(t)$.

[10 + 10 marks]

(i) In Amplitude Modulation, expression is given by

$$\boxed{S_{AM}(t) = A_c(1+\mu\cos 2\pi f_m t)\cos 2\pi f_c t} \rightarrow (1)$$

$\mu = K_a A_m \rightarrow$ modulation index

Total transmitted power is given by

$$\boxed{P_t = P_c\left(1+\frac{\mu^2}{2}\right)}$$

$P_c \rightarrow$ Carrier power

$$\boxed{P_{SB} = \frac{P_c\mu^2}{2}} \rightarrow \boxed{\text{side band power}}$$

Efficiency

$$\eta = \frac{P_{SB}}{P_t} = \frac{P_c\frac{\mu^2}{2}}{P_c\left(1+\frac{\mu^2}{2}\right)}$$

$$\boxed{\eta = \frac{\mu^2}{\mu^2+2}}$$

from equation (1)

$$S(t) = A_c\cos 2\pi f_c t + \underbrace{\frac{A_c\mu}{2}\cos 2\pi(f_c+f_m)t + \frac{A_c\mu}{2}\cos 2\pi(f_c-f_m)t}_{\text{Sidebands}}$$

$$P_{SB} = \frac{\left(\frac{A_c\mu}{2}\right)^2}{2R}\times 2 = \frac{A_c^2\mu^2}{8R}\times 2 = \frac{A_c^2\mu^2}{4R}$$

In AM

$$P_t = P_c\left(1 + \frac{\mu^2}{2}\right)$$

In DSB-SC

$$P_t = P_c \frac{\mu^2}{2}$$

$$\%\ \text{saving in power} = \frac{P_c}{P_t} = \frac{1}{1+\frac{\mu^2}{2}} = \frac{2}{\mu^2+2} \times 100$$

In SSB

$$\%\ \text{Saving in power} = \frac{P_c + \frac{P_c\mu^2}{4}}{P_t} = \frac{P_c\left(1+\frac{\mu^2}{4}\right)}{P_c\left(1+\frac{\mu^2}{2}\right)}$$

$$= \frac{(\mu^2+4)}{2(\mu^2+2)} \times 100$$

(ii) Given

$$\boxed{m(t) = 2\cos 100\,t + 18\cos 2000\pi t}$$

1) $A_c = 10\,V$ $\quad \omega_c = 10^6$ $\quad K_f = 1000\pi$ $\quad K_p = 1$

Expression of FM

$$S_{FM}(t) = A_c \cos\left(2\pi f_c t + K_F \int m(t)\right)$$

$$S_{FM}(t) = 10\cos\left(10^6 t + 10^3\pi\left(\frac{2\sin 100t}{100} + \frac{18\sin 2000\pi t}{2000\pi}\right)\right)$$

$$\boxed{S_{FM}(t) = 10\cos(10^6 t + 20\pi\sin 100t + 9\sin 2000\pi t)}$$

Expression of PM

$$S_{PM}(t) = A_c \cos\left(2\pi f_c t + K_p m(t)\right)$$

$$\boxed{S_{PM}(t) = 10\cos(10^6 t + 2\cos 100t + 18\cos 2000\pi t)}$$

2) Bandwidths

For FM signal

$$\beta_{eqvt.} = \frac{\beta_1 f_{m_1} + \beta_2 f_{m_2}}{(f_m)_{max}}$$

$$= \frac{20\pi \times 100 + 9 \times 2000\pi}{2000\pi} = 10$$

$$(\text{Bandwidth})_{FM} = 2(\beta+1) f_{max} = 2 \times 11 \times 2000\pi$$

$$= 44000\pi \text{ rad/sec.}$$

$$= 22 \text{ kHz}$$

For PM signal

$$\beta_{eqvt} = \frac{100 \times 2 + 18 \times 2000\pi}{2000\pi} = 18$$

$$(BW)_{PM} = 2(\beta+1) f_{max} = 2 \times 19 \times 2000\pi$$

$$= 38 \text{ kHz}$$

15

Q.8 (c) A 3-ϕ, 60 Hz transmission line of length 150 km is delivering 40 MW at 0.9 p.f. lagging at 220 kV. The resistance and reactance of the line per phase per half kilometer are 0.2 and 0.4 Ω respectively, while capacitive admittance is 2.5×10^{-6} S/km/phase.

Determine:

(i) The current and voltage at sending end.

(ii) Efficiency of transmission.

Using nominal *T*-method.

[20 marks]

Given, 3ϕ 60 Hz $l = 150$ km

40 MW, 0.9 pf lag at 220 kV

$R = 0.2 \times 300 = 60\,\Omega/\text{ph}$ $\quad Z = R + jX$

$X = 0.4 \times 300 = 120\,\Omega/\text{ph}.$ $\quad Z = 134.16\angle 63.43\,\Omega$

$Y = 2.5\times10^{-6} \times 150 = 3.75\times10^{-4}$ S/ph.

for Nominal T-method

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} 1 + \frac{YZ}{2} & Z\left(1+\frac{YZ}{4}\right) \\ Y & 1+\frac{YZ}{2} \end{bmatrix}$$

$$A = 1 + \frac{YZ}{2} = 1 + \frac{(3.75\times10^{-4}\angle 90^\circ)(134.16\angle 63.43)}{2}$$

$$A = 0.977\angle 0.66 = D$$

$$B = Z\left(1 + \frac{YZ}{4}\right) = 132.65\angle 63.75$$

$$C = j\,3.75\times10^{-4}$$

$$I_R = \frac{40\times10^3}{\sqrt{3}\times 220\times 0.9} = 116.63\angle -25.84\ \text{A}$$

$$V_S = AV_R + BI_R \qquad V_R = \frac{220}{\sqrt{3}} = 127.01\ \text{kV}$$

$$I_S = CV_R + DI_R$$

$$V_S = 0.977\angle 0.66 \times 127.01 \times 10^3 + 132.65\angle 62.75 \times 116.63\angle -25.84°$$

$$\boxed{V_S = 138.768 \angle +4.58° \text{ kV}}$$

$$I_S = (j3.75\times10^{-4}) \times 127.01\times10^3 + (0.977\angle 0.66)\times 116.63\angle -25.84$$

$$\boxed{I_S = 103.12\angle -0.47° \text{ A}}$$

$|V_S| = 138.768 \text{ kV}$ $\quad |I_S| = 103.12$ A

$$P_S = 3V_S I_S \cos\phi = 3\times 138.768\times 103.12 \times \cos(5.05°)$$

$$\boxed{P_S = \cancel{361.912}\ 42.14 \text{ MW}}$$

Efficiency

$$\%\eta = \frac{P_R}{P_S} = \frac{40 \text{ MW}}{42.14 \text{ MW}} \times 100$$

$$\boxed{\%\eta \simeq 94.9\%}$$

18

Good Approach