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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 ☐	
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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	39
Q.2	
Q.3	46
Q.4	
Section-B	
Q.5	43
Q.6	27
Q.7	
Q.8	51
Total Marks Obtained	206

Signature of Evaluator: Sourabh kumar

Cross Checked by: ....

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→ Read instruction carefully

IMPORTANT INSTRUCTIONS

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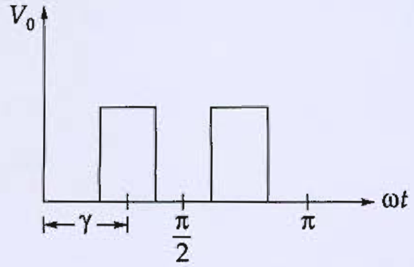
Section-A : Power Systems + Power Electronics & Drives + Communication Systems

.1 (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]

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Q.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]

By using Power Equations

$$P_R = \frac{V_s V_R}{B} \cdot \cos(\beta-\delta) - \frac{A V_R^2}{B} \cdot \cos(\beta-\alpha) \quad -(1)$$

and $$Q_R = \frac{V_s V_R}{B} \sin(\beta-\delta) - \frac{A V_R^2}{B} \cdot \sin(\beta-\alpha) \quad -(1)$$

given line is Short transmission line, for which

$A = 1\angle 0°$, $B = Z = (R + j\omega L)$

~~$B = 0.02 + j \times 2\pi \times 50$~~ ($\omega = 2\pi \times 50$) Assuming ($f = 50\,Hz$)

~~$B = 0.02 + j$~~

$B = (0.015 + j\,0.02) \times 20 = 0.3 + j0.4\,\Omega$

$B = 0.5 \angle 53.13°\,\Omega$

As load is given as $P_R = 800\,kW$

and $Q_R = P_R \tan\phi_R$

$= 800 \times \tan\cos^{-1}(0.8) = 600\,kVAR$ leading.

Now using (1) & (2)

$$800 \times 10^3 = \frac{3300 \times V_R}{0.5} \cdot \cos(\beta - 53.13) - \frac{V_R^2}{0.5} \cos(53.13)$$

$$4 \times 10^5 = 3300\,V_R \cos(\beta - 53.13) - 0.6\,V_R^2 \quad (3)$$

Similarly

$$-600 \times 10^3 = \frac{3300 \cdot V_R}{0.5} \sin(\beta - 53.13) - \frac{V_R^2}{0.5} \sin(53.13)$$

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$$-3\times10^5 = 3300\,V_R \sin(\beta-53.13) - 0.8\,V_R^2 \quad -④$$

$$\sin(\beta-53.13) = \frac{0.8\,V_R^2 - 3\times10^5}{3300\,V_R}$$

Using this in ③

$$4\times10^5 = 3300\,V_R \cos\left(\sin^{-1}\left(\frac{0.8V_R^2 - 3\times10^5}{3300V_R}\right)\right) - 0.6\,V_R^2$$

Solving this we get

$$\boxed{V_R = 3296.5\ V}$$

Receiving end voltage

$$P_R = \sqrt{3}\,V_R \times I_R \times \cos\phi_R$$

$$800\times10^3 = \sqrt{3}\times3296.5\times I_R\times0.8$$

Line Current $\boxed{I_R = 175.14\ A}$

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

[12 marks]

Delta modulation have a reference signal which keeps on changing as the modulating signal changes.

But when the changes are large or very small then reference signal is not able to change as desired which result in giving error.

The error in delta modulation are:

(i) Slope over load distortion

(ii) Granular distortion

Slope overload distortion

When the slope of modulating signal is much higher than the rate of change of step signal i.e, reference signal.

$$\frac{dm(t)}{dt} \geq \Delta . f_s$$

this will result is slope overload distortion.

Remedy

To remove this error we make the steps such that

$$\frac{\Delta_{opt}}{T_s} < \frac{dm(t)}{dt}$$

Granular distortion

When the rate of change of modulating signal is very small or the modulating signal is almost constant, the error resulted is the Granular distortion.

(Maximum Granual Noise is given by $\pm \Delta/2$)

as the reference signal keeps oscillating about the modulating signal.

Remedy

To remove this error, slope is made of smaller value to keep track of modulating signal.

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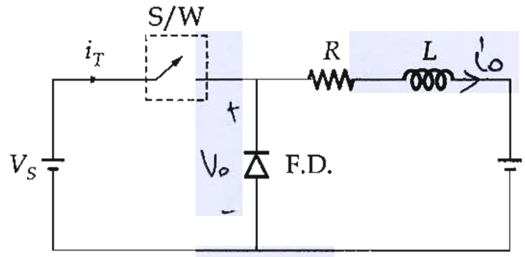
Q.1 (d) With the help of suitable waveforms, for an ideal type-A chopper feeding RLE load as depicted in the figure below, show that the average input (or thyristor) current is given by

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

(Where symbols have their usual meaning).



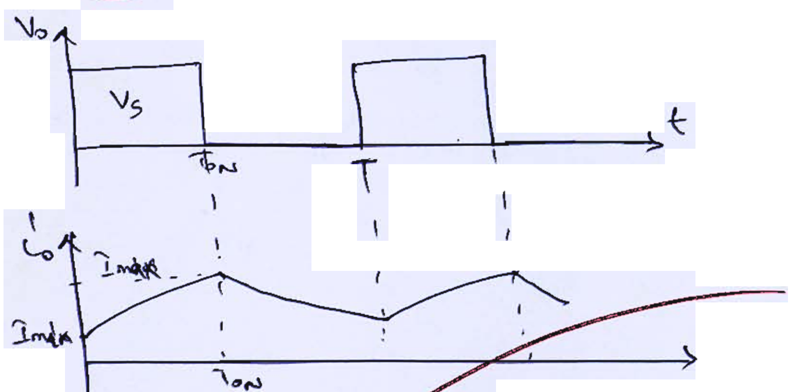
[12 marks]

When SW → ON, FD → off

so, $V_o = V_s$

and when SW → off, FD → ON,

so $V_o = 0$



When SW → ON, Applying KVL

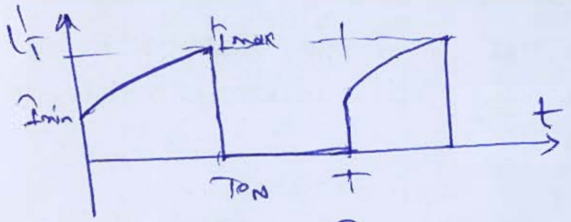
$$V_s = Ri_o + L\frac{di_o}{dt} + E$$

$$i_o = \left(\frac{V_s - E}{R}\right)\left(1 - e^{-t/\tau}\right) \qquad (\tau = L/R)$$

initially,

But in steady state

$$i_o = \left(\frac{V_s - E}{R}\right) + \left[I_{min} - \left(\frac{V_s - E}{R}\right)\right] \cdot e^{-t/\tau} \quad \text{—(1)}$$



from load current wave form

$$i_{T avg.} = \frac{1}{T}\int_0^{T_{ON}} i_o(\text{during } T_{ON})\cdot dt$$

$$= \frac{1}{T}\int_0^{T_{ON}} \left(\frac{V_s - E}{R}\right) + \left[I_{min} - \left(\frac{V_s-E}{R}\right)\right]\cdot e^{-t/\tau}\, dt$$

$$= \frac{1}{T}\left\{\left[\left(\frac{V_s-E}{R}\right)t\right]_0^{T_{ON}} + \left[\left[I_{min} - \left(\frac{V_s-E}{R}\right)\right]\cdot\frac{e^{-t/\tau}}{(-1)}\cdot\tau\right]\right\}$$

$$= \frac{T_{ON}}{T}\left(\frac{V_s-E}{R}\right) - \frac{L}{RT}\left[I_{min}\cdot e^{-t/\tau} - \left(\frac{V_s-E}{R}\right)\cdot e^{-t/\tau}\right]_0^{T_{ON}}\Big\}$$

As. $T_{ON}/T = \alpha$

$$= \alpha\left(\frac{V_s-E}{R}\right) - \frac{L}{RT}\left[I_{min}\, e^{-T_{ON}/\tau} - \left(\frac{V_s-E}{R}\right)\cdot e^{-T_{ON}/\tau} - I_{min} + \left(\frac{V_s-E}{R}\right)\right] \quad \text{— (2)}$$

Using (1) At $t = T_{ON}$

$$i_o = I_{max} = \frac{V_s - E}{R} + \left[I_{min} - \left(\frac{V_s-E}{R}\right)\right]\cdot e^{-T_{ON}/\tau} \quad \text{— (3)}$$

Using (3) in (2), we get

$$i_{T Avg.} = \frac{\alpha(V_s - E)}{R} - \frac{L}{RT}(I_{max} - I_{min})$$

Required result

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Good Approach

Q.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]

(i) FM signal is given by

$$S(t) = A_c \sin\left[\omega_c t + K_f \int m(t)\, dt\right]$$

Using this and given signal

Carrier frequency, $\omega_c = 3 \times 10^8$ rad/s

and $f_c = \omega_c / 2\pi = \frac{3 \times 10^8}{2\pi}$

$$f_c = 47.75 \text{ MHz}$$

modulating frequency ⇒ $\omega_m = 2500$ rad/s

$$f_m = \frac{\omega_m}{2\pi} = \frac{2500}{2\pi}$$

$$f_m = 397.89 \text{ Hz}$$

(ii) modulating index $= \left| K_f \int m(t) \cdot dt \right|_{max}$

On comparasion with given signal

$$\text{modulating index } (\beta) = 50$$

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(iii) instantaneous frequency $(f_i) = \frac{1}{2\pi}\frac{d\theta}{dt}$

$= \frac{1}{2\pi}\frac{d}{dt}\left(3\times10^8 t + 50\sin(2500)t\right)$

$= \frac{1}{2\pi}\times\left[3\times10^8 + 50\times2500\times\cos(2500t)\right]$

~~fma~~. $\Delta f = f_{max} - f_{min}$

$= \frac{1}{2\pi}\times[50\times2500 + 50\times2500]$

Try to avoid

$\Delta f = 50\times\frac{2500}{2\pi}$

$\boxed{\Delta f = 19.894\ \text{KHz}}$

(iv) $P_c = \frac{A_c^2}{2R}$ as, $A_c = 15\ V$

$P_c = \frac{15\times15}{2\times75}$

$\boxed{P_c = 1.5\ W}$ Power delivered

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Good Approach

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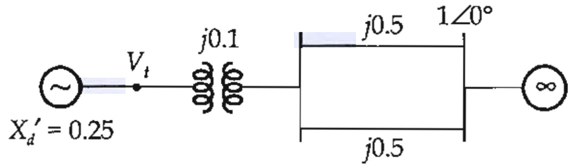
Q.2 (a) The generator of figure given below is delivering 1.0 p.u. power to the infinite bus ($|V_t| = 1.0$ p.u.).



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]

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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:

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

Determine:

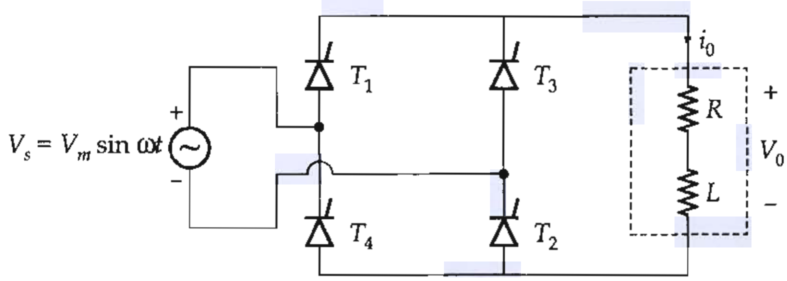
(i) The ABCD parameters of the line.

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

(iii) Sending end power factor and power.

[20 marks]

Q.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 $R = 10\ \Omega$ 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]

$V_{RL} = 10 \text{ kV}$

$Z = R + j\omega L = (0.0195 + j \times 2\pi \times 50 \times 0.63 \times 10^{-3}) \times 20$

$= 0.39 + j\,3.9584\ \Omega$

$= 3.9776 \angle 84.37^\circ\ \Omega$

Given line is short line,

for which $A = 1\angle 0^\circ$, and $B = Z = 3.9776 \angle 84.37^\circ$

also, $S_R = 5000\sqrt{2}$ KVA at $1/\sqrt{2}$ lagging P.f

$S_R = \sqrt{3}\, V_{RL} \times I_R$

$5\sqrt{2} = \sqrt{3} \times 10 \times I_R \Rightarrow I_R = 0.40825$ KA

as, $V_s = A V_R + B I_R$

$= 1\angle 0 \times \frac{10}{\sqrt{3}} + 3.9776 \angle 84.37 \times 0.40825 \angle -\cos^{-1}(0.7071)$

$\Rightarrow V_s = 7.104 \angle 8.33$ KV

$V_{SL} = 7.104\sqrt{3} = 12.304$ KV

↳ sending end line-line voltage

$$V.R = \frac{V_s/A - V_R}{V_R} \times 100 = \frac{12.304 - 10}{10} \times 100$$

$$\boxed{V.R = 23.05\ \%}$$ ⇒ Voltage Regulation

Now

$$V.R = 0.5 \times 23.05 = 11.525\ \%$$

i.e,

$$\Rightarrow 0.11525 = \frac{V_s - 10}{10}$$

$$V_s = 11.1525\ KV$$

As, load is same hence, using Power equation

$$P_R = \frac{V_s V_R}{B} \cdot \cos(\beta - \delta) - \frac{A V_R^2}{B} \cdot \cos(\beta - \alpha)$$

$$5\sqrt{2} \times \frac{1}{\sqrt{2}} = \frac{11.1525 \times 10}{3.9776} \cdot \cos(84.37 - \delta) - \frac{10^2}{3.9776} \times \cos(84.37)$$

$$\underline{\delta = 9.814^\circ}$$

so,
$$Q_R = \frac{11.1525 \times 10}{3.4776} \sin(84.37 - 9.814) - \frac{10^2}{3.4776} \times \sin(84.37)$$

$$Q_R = 2\ \text{MVAR}$$

$$Q_{Load} = S_R \times \sin\phi_R = 5\sqrt{2} \times \frac{1}{\sqrt{2}} = 5\,\text{MVAR}$$

$$Q_R = Q_L - Q_c$$

$$2 = 5 - Q_c \Rightarrow \underline{Q_c = 3\ \text{M.VAR}}$$

$Q_c = 3 \times V_{ph}^2 \times \omega C$ $(V_{ph} = 10/\sqrt{3}\ kV)$

$3 = 3 \times \frac{10 \times 10}{3} \times 2\pi \times 50 \times C_{ph.}$

$C_{ph.} = 95.5\ \mu F$

(iii) $\eta_I = \frac{P_R}{\sqrt{3}\, V_{SL} \times I_R \times \cos(V_s - I_R)} \times 100$

$= \frac{5}{\sqrt{3} \times 12.304 \times 0.40825 \times \cos(8.33+45)} \times 100$

$\eta_I = 96.23\ \%$

$\eta_{II} = \frac{5}{P_{in}} \times 100$

$P_{in} = \frac{D V_s^2}{B} \cos(\beta - \alpha) - \frac{V_s V_R}{B} \cdot \cos(\beta + \delta)$

$= \frac{11.1525^2}{3.9776} \cos(84.37) - \frac{10 \times 11.1525}{3.9776} \times \cos(84.37 + 9.814)$

$= 5.1133\ MW$

$\eta_{II} = \frac{5}{5.1133} \times 100$

$\eta_{II} = 97.78\ \%$

hence by using Capacitors in Parallel with load, efficiency is improved.

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Good Approach

Q.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]

(i) $T = 110$ Nm, $N = 960$ rpm, $K = 1.2$ V-sec/rad-A

$\Rightarrow \omega = \frac{2\pi N}{60} = 32\pi$ rad/s

$T = K I_a$ (since field current is constant)

$110 = 1.2 \times I_a \Rightarrow I_a = 91.667$ A

$E_b \propto \omega\phi$

$E_b = K\omega \Rightarrow E_b = 1.2 \times 32\pi$

$E_b = 120.637$ V

As, $V_o = E_b + I_a . R_a$

$= 120.637 + 91.667 \times 0.2$

$V_o = 138.97$ V

For 3ϕ full Converter

$V_o = \frac{3V_{mL}}{\pi} . \cos\alpha$

~~138.97 = 3 × 320~~

$$138.97 = \frac{3 \times 210\sqrt{2}}{\pi} \times \cos\alpha$$

$$\boxed{\alpha = 60.6^\circ}$$

(ii) $V_o = \frac{3V_{ml}}{\pi} \cdot \cos\alpha = \frac{3 \times 210\sqrt{2}}{\pi} \cdot \cos 0^\circ$

$V_o = 283.6\ V$

$V_o = E_b + I_a \cdot R_a$

for $T = 110\ Nm$, $I_a = 91.667\ A$

(Since field is Constant)

So,

$283.6 = E_b + 91.667 \times 0.2$

$E_b = 265.266\ V$

$E_b = K \times \omega$

$265.266 = 1.2 \times \omega \Rightarrow \omega = 221.05\ rad/s$

$N = \frac{60}{2\pi} \times 221.05$

$$\boxed{N = 2110.9\ rpm}$$

(iii) Now, $N = 1750$ rpm and same load

So, $T = 110\ Nm$

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~~$E_b \cdot I_a = T \times \omega$~~

~~$\Rightarrow E_b \times 91.667 = 110 \times 2\pi \times 1750/60$~~

~~$E_b = 219.91$~~

$E_b \propto K \omega \phi$

So, $\frac{E_{b2}}{E_{b1}} = \frac{N_2}{N_1} \times \frac{\phi_2}{\phi_1} = \frac{N_2}{N_1} \times \frac{I_{f2}}{I_{f1}}$ — (1) $(\phi \propto I_f)$

When $E_{b1} = 265.266$, $N_1 = 2110.9$ rpm

for $I_{f1} = \frac{V_0 \text{ (field circuit)}}{R_f}$

$= \frac{3 V_{mL}}{\pi} \times \frac{1}{R_f}$ (for maximum field current)

$= \frac{3 \times 210\sqrt{2}}{\pi \times 130} = 2.18$ A

~~So, using (1)~~

~~$\frac{219.91}{265.266} = \frac{1750}{2110.9} \times \frac{I_{f2}}{2.18}$~~

For the same condition as in (ii)

$V_0 = 283.6$ $E_b + I_a R_a = 283.6$

~~$(E_b - I_a R_a) \alpha = 28$~~

as, $E_b \cdot I_a = T \times \omega$

$\Rightarrow (283.6 - 0.2 I_a) \cdot I_a = 110 \times 2\pi \times 1750/60$

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$0.2 I_a^2 - 283.6 I_a + 20158.55 \Rightarrow$

$I_a = 75.05\text{ A}, \; 1342.94\text{ A}$ ↓ neglecting since unstable

So, $I_a = 75.05\text{ A}$

$E_b = 283.6 - 75.05 \times 0.2 = 268.59$

Now

$$\frac{E_{b2}}{E_{b1}} = \frac{N_2}{N_1} \times \frac{I_{f2}}{I_{f1}}$$

$$\Rightarrow \frac{268.59}{265.266} = \frac{1750}{~~2100~~ \; 2110.9} \times \frac{I_{f2}}{2.18}$$

~~$I_{f2} = 2$~~

$I_{f2} = 2.66$

15

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Q.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]

(i) For improving the string efficiency of insulator

→ Guard wire is used such that the voltage across each conductor becomes equal.

→ Cross arm length is increased such that link to earth capacitance in reduced

→ Different material of insulator is used to make the voltage across each insulator same.

(ii) $l = 270\,m$ $\qquad W_c = 0.865\,Kg/m$

$$T = \frac{\text{Ultimate strength}}{\text{Safety factor}}$$

$$= \frac{9060}{2} = 4530\,Kg.$$

Weight of ice = W_i = Density $\times \left[\frac{\pi(d+2t)^2 - \pi d^2}{4}\right]$

$$= 0.910 \times 10^3 \times \pi/4 \left[\left[(2.76 + 2\times 1.82)\times 10^{-2}\right]^2 - \left(2.76\times 10^{-2}\right)^2\right]$$

$W_c = 2.383\,Kg/m$

Weight due to wind (w_w)

$= 3.8 \times 10^{-3} \times 10^4 \times$ Area

$= 3.8 \times 10 \times (d + 2t)$

$= 3.8 \times 10 \times (2.76 + 2 \times 1.82) \times 10^{-2}$

$w_w = 2.432$ Kg/m

$w = \sqrt{(w_i + w_c)^2 + (w_w)^2}$

$= \sqrt{(0.865 + 2.383)^2 + (2.432)^2} = 4.057$ Kg/m

Sag is given by

$S = \frac{w l^2}{8T} = \frac{4.057 \times 270^2}{8 \times 4530}$

$S = 8.16$ m

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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]

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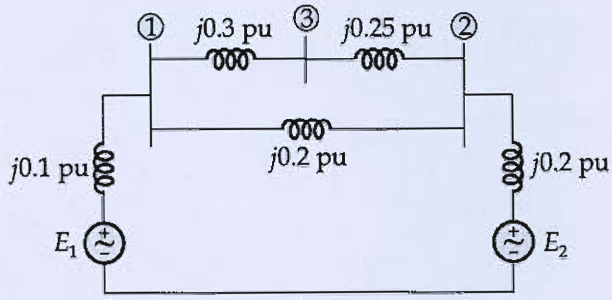
Q.4 (b) For the power system whose equivalent circuit is shown in figure below, compute the bus voltages and branch currents for a 3-ϕ fault on bus-1. Assuming the fault impedance $Z_f = j0.2$ pu.

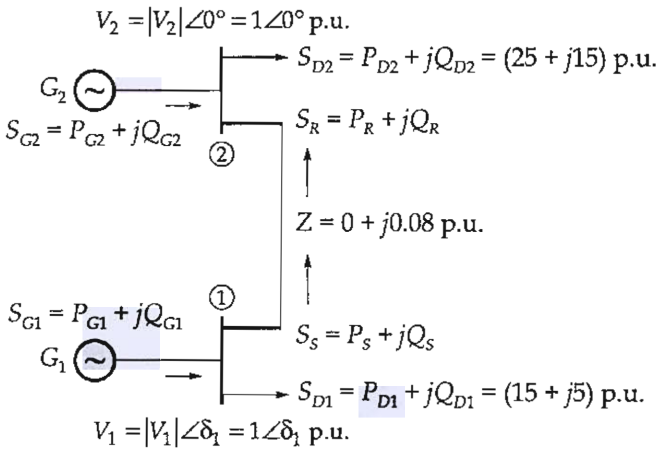
$$[Z_{bus}] = j\begin{bmatrix} 0.0776 & 0.0448 & 0.0597 \\ 0.0448 & 0.1104 & 0.0806 \\ 0.0597 & 0.0806 & 0.2075 \end{bmatrix}$$

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



[20 marks]

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]

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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]

$V_o = \frac{3V_{mL}}{2\pi}(1+\cos\alpha)$ (for 3ϕ semiconverter)

$= \frac{3 \times 400\sqrt{2}}{2\pi}(1+\cos 45°) = 461.1\ V$

Now given that

$V = 600V$, $N = 1500$ rpm, $I_a = 70$ A

At this condition

$E_b = V - I_a R_a = 600 - 70 \times 1 = 530\ V$

as, $E_b \propto \omega\phi$ (since ϕ = constant)

$E_b \propto \omega$

$\propto N$

So, $\frac{E_{b2}}{E_{b1}} = \frac{N_2}{N_1} \Rightarrow \frac{E_{b2}}{530} = \frac{1200}{1500}$

$E_{b2} = 424\ V$

Now

$V_o = E_{b2} + I_a R_a$

$\Rightarrow 461.1 = 424 + I_a \cdot 1$

$I_a = 37.1\ A$

(i) ~~$I_{sr} = I_a \times \sqrt{2\pi/3}$~~

$$I_{sr} = I_a\sqrt{\frac{\pi-\alpha}{\pi}} = 37.1\sqrt{\frac{\pi-\pi/4}{\pi}}$$

Rms source Current = 32.13 A

$$I_{T\,Rms} = I_a\sqrt{\left(\frac{2\pi/3-\alpha}{2\pi}\right)}$$

$$= 37.1\sqrt{\frac{120-45}{360}} \Rightarrow \boxed{I_{T\,Rms} = 16.93\ A}$$

(ii) $$I_{T\,Avg.} = I_a\left(\frac{2\pi/3-\alpha}{2\pi}\right)$$

$$= 37.1\times\left(\frac{120-45}{360}\right) \quad \boxed{I_{Avg.} = 7.73\ A}$$

(iii) $$P.F = \frac{V_o I_o}{\sqrt{3}V_s I_{sr}} = \frac{461.1\times 37.1}{\sqrt{3}\times 400\times 32.13}$$

P.F = 0.7685 lag

6

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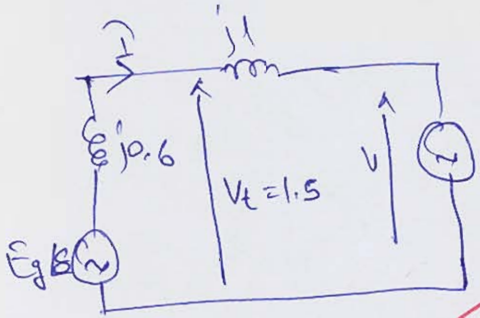
Q.5 (b) Find the steady state power limit of a power system consisting of a generator of equivalent reactance of 0.6 p.u. connected to an infinite bus through a series reactance of 1.0 p.u. The terminal voltage of the generator is held at 1.50 p.u. and the voltage of the infinite bus is 1.0 p.u.

[12 marks]



$V = 1\angle 0^\circ$

For steady state power limit ⇒ $\delta = 90^\circ$

So, ~~$I = E_g\angle 90^\circ - 1.5\angle\theta$~~

$$I = \frac{E_g\angle\delta - V_t\angle\theta}{j0.6} = \frac{V_t\angle\theta - V}{j1}$$

$$\Rightarrow E_g\angle 90^\circ - 1.5\angle\theta = 0.6 \times [1.5\angle\theta - 1\angle 0^\circ]$$

$$\Rightarrow jE_g = 2.4\cos\theta + j2.4\sin\theta - 1$$

Equating real and imaginary parts,

$2.4\cos\theta = 1 \Rightarrow \theta = 65.37^\circ$

and $E_g = 2.4\sin\theta$

$= 2.4\sin 65.37 = 2.1817$

$$P_{SSL} = \frac{E_g \times V}{X_{total}} = \frac{2.1817 \times 1}{0.6 + 1.0}$$

5

The steady state power limit is

$$P_{s3L} = 1.3636\ P_4$$

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]

$Q = 90, \quad I.F = 455\,KF$

(i) $f_I = f_c + 2IF$ (image frequency)

$= 950 + 2 \times 455$

$f_I = 1860\,KHz$

$\rho = \frac{f_I}{f_c} - \frac{f_c}{f_I} = \frac{1860}{950} - \frac{950}{1860}$

$= 1.447$

$\alpha = \sqrt{1 + \rho^2 Q^2}$ (image rejection ratio)

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

$\alpha = 130.24$

(ii) At $f_c = 10\,MHz$

$f_I = 10 \times 10^3 + 2 \times 455$

$f_I = 10.91\,MHz$

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$\beta = \frac{10.91}{10} - \frac{10}{10.91} = 0.1744$

$\alpha = \sqrt{1 + (0.1744)^2 \times 90^2}$

$\alpha = 15.73$

10

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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]

$f_{s1} = 2 \times 5 = 10\,KHz$ $\quad (f_{Ny} = 2 \times f_m)$

$f_{s2} = 2 \times 10 = 20\,KHz$

$f_{s3} = 2 \times 5 = 10\,KHz$

$R_b = nNf_s = n \times [f_{s1} + f_{s2} + f_{s3}]$

$n = \log_2(\#\text{ levels}) = \log_2(256) = 8\text{ bit}$

$R_b = 8 \times [10 + 20 + 10] = 320\text{ K bits/sec}$

$\text{bit duration} = \frac{1}{R_b} = \frac{1}{320 \times 10^3}$

$T_b = 3.125\ \mu sec$

(ii) $B.W = \frac{R_b}{2} = \frac{320}{2} \Rightarrow B.W = 160\,KHz$

(iii) $f_s = 40\,KHz$

$\Rightarrow 1\,sec \Rightarrow 40\text{ K samples.}$

$\Rightarrow 1\,rev \Rightarrow 3\text{ samples}$

$\Rightarrow 1\text{ sample} \Rightarrow \frac{1}{40 \times 10^3}\text{ sec.}$

$\Rightarrow 3\text{ sample} = \frac{3}{40 \times 10^3}\text{ sec} \Rightarrow 1\text{ rev.}$

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1 sec ⇒ $\frac{40 \times 10^3}{3}$ = 13333.33 revolution

1 minute ⇒ 13333.33 × 60

~~N = 8 × 10^4 RPM~~

Speed of Commutator in RPM = 8×10^5 RPM

(iv) When # levels = 512

$R_b = 9 \times 40 = 360$ K bits/sec

B.W = $\frac{360}{2}$ = 180 KHz

Increment = 180 − 160

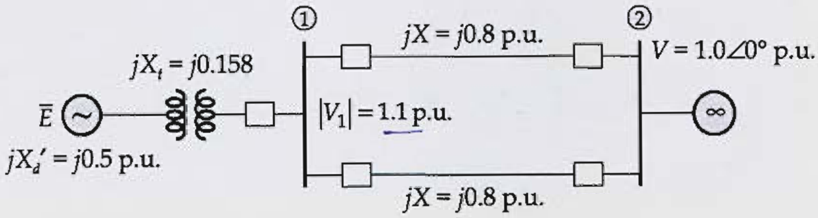
= 20 KHz

↑ increment in Bandwidth

11

Good Approach

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.



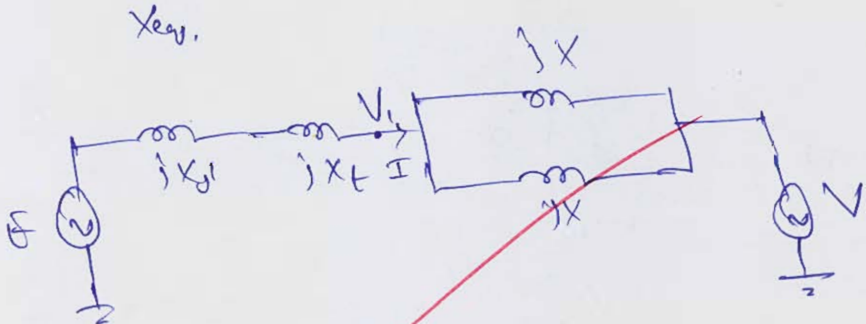
Determine:

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

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

[12 marks]

$$P = \frac{E \times V}{X_{eq}} \sin\delta$$



also, $P = \frac{V_1 \times V}{X/2} \cdot \sin\theta$

$$0.95 = \frac{1.1 \times 1.0}{0.8/2} \sin\theta \Rightarrow \theta = 20.21°$$

$$I = \frac{V_1\angle\theta - V\angle 0°}{jX/2} = \frac{1.1\angle 20.21 - 1\angle 0°}{j0.4}$$

$$I = 0.9534\angle -4.85$$

$E = I(jX_d' + jX_t) + V_1\angle\theta$

$= 1.1\angle 20.21 + 0.9534\angle -4.85 \times (j0.158 + j0.5)$

$E = 1.4793\angle 42.8$ pu

excitation voltage.

Power angle ⇒ $\delta = 42.8°$

(ii) Swing equation is given by

$$\frac{2HS}{\omega_s}\frac{d^2\delta}{dt^2} = (P_m - P_e)$$

At pu

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

$P_m = 0.95$

and $P_e = \frac{E_g \times V}{X_{eq}}\sin\delta$

$= \frac{1.4793 \times 1}{0.158 + 0.570.8/2}\sin\delta = 1.3982\sin\delta$

⇒ So,

$$\frac{2 \times 5.66}{2\pi \times 60}\cdot\frac{d^2\delta}{dt^2} = 0.95 - 1.3982\sin\delta$$

$$0.03\frac{d^2\delta}{dt^2} = 0.95 - 1.3982\sin\delta$$

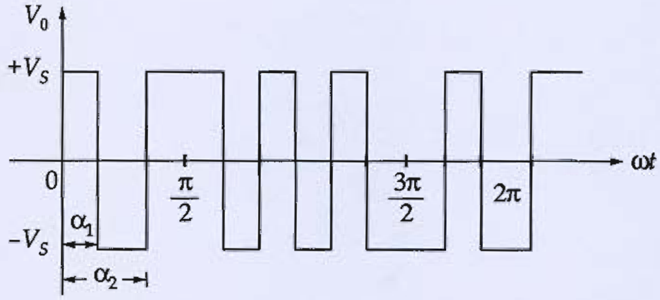
Required swing equation.

6

11

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 3[rd] and 5[th] harmonic from the output.

[20 marks]

(1) given Signal (v_0) is having odd Symmetry ~~and also~~, quarter wave Symmetry.

Hence, $a_n = 0$, $V_{dc} = 0$, so only odd Harmonics will be there,

$$V_0(t) = V_{dc} + \sum_{n=1}^{\infty} (a_n \cos n\omega t + b_n \sin n\omega t)$$

So, $V_0(t) = \sum_{n=1}^{\infty} b_n \sin n\omega t$

given $b_n = C_n$

$$b_n = \frac{2}{\omega T} \int_{\omega t} V_0(t) \cdot \sin n\omega t \cdot d\omega t$$

$$= \frac{2 \times 2 \times 2}{2\pi} \int_0^{\pi/2} V_0(t) \cdot \sin(n\omega t)\, d\omega t$$

(due to quarter wave symmetry)

$$= \frac{4V_s}{\pi} \left\{ \int_0^{\alpha_1} \sin n\omega t\, d\omega t - \int_{\alpha_1}^{\alpha_2} \sin n\omega t \cdot d\omega t + \int_{\alpha_2}^{\pi/2} \sin n\omega t \cdot d\omega t \right\}$$

$= \frac{4V_s}{4\pi} \times \left\{ \left[-\cos n\omega t\right]_0^{\alpha_1} + \left[\cos n\omega t\right]_{\alpha_1}^{\alpha_2} + \left[-\cos n\omega t\right]_{\alpha_2}^{\pi/2} \right\}$

$= \frac{4V_s}{n\pi} \left\{ \cos n\alpha_1 - 1 - \cos n\alpha_2 + \cos n\alpha_1 + 0 - \cos n\alpha_2 \right\}$

$b_n = \frac{4V_s}{n\pi}$

$b_n = \frac{4V_s}{n\pi} \left[1 - \cos n\alpha_1 + \cos n\alpha_2 - \cos n\alpha_1 + \cos n\alpha_2 - 0 \right]$

$b_n = C_n = \frac{4V_s}{n\pi} \left[1 - 2\cos n\alpha_1 + 2\cos n\alpha_2 \right]$

Hence,

Hence,

$V_o(t) = \sum_{n=1,3,5}^{\infty} \frac{4V_s}{n\pi} \left(1 - 2\cos n\alpha_1 + 2\cos n\alpha_2 \right) \cdot \sin n\omega t$

(ii) Now for eliminating 3rd Harmonic,

$C_3 = 0 \Rightarrow$ i.e, $1 - 2\cos 3\alpha_1 + 2\cos 3\alpha_2 = 0$

and for 5th Harmonic,

$1 - 2\cos 5\alpha_1 + 2\cos 5\alpha_2 = 0$

13

Incomplete solution

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.

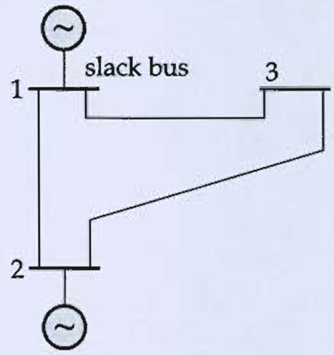


Table-1 : Scheduled generation are as loads and assumed bus voltage for sample power system [Base MVA = 100].

		Generation		Load	
Bus code (1)	**Assumed bus voltage**	**MW**	**MVAR**	**MW**	**MVAR**
1 (SB)	1.05 + j0.0	–	–	0	0
2	1 + j0.0	50	30	305.6	140.2
3	1.0 + j0.0	0.0	0.0	138.6	45.2

Table-2 : Line impedances

Bus code (i - k)	**Impedance Z_{ik}(pu)**
1 - 2	0.02 + j0.04
1 - 3	0.01 + j0.03
2 - 3	0.0125 + j0.025

[20 marks]

$[Y]_{Bus} = \begin{bmatrix} 20-j50 & 10-j20 & 10-j30 \\ 10-j20 & & \\ 10-j30 & & \end{bmatrix}$

Incomplete Solution

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Q.6 (c) A 50 Hz, 4 pole, turbogenerator rated 200 MVA, 11 kV has moment of inertia of 81000 kg-m². 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]

$J = 81000 \text{ Kg-m}^2$

$P_e = 40 \text{ MW}$ $\quad P_m = 60 \text{ MW}$

(i) Stored Kinetic energy $= \frac{1}{2} J \omega_s^2$

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

$$\omega_s = \frac{2\pi N_s}{60} = \frac{2\pi \times 1500}{60} = 50\pi$$

$$E = \frac{1}{2} \times 81 \times 10^3 \times (50\pi)^2$$

$$\boxed{E = 999.3 \text{ MJ}}$$

$$H = \frac{\text{Kinetic energy stored}}{\text{MVA}}$$

$$= \frac{999.3}{200} \quad 4.996 \text{ MJ/MVA}$$

$$\boxed{H \simeq 5 \text{ MJ/MVA}}$$

(ii) by Swing equation

$$\frac{2HS}{\omega_s} \cdot \frac{d^2\delta}{dt^2} = P_m - P_e$$

$$\frac{2 \times 5 \times 200}{360^\circ \times f} \frac{d^2\delta}{dt^2} = 60 - 40$$

$$\frac{d^2\delta}{dt^2} = 180 \text{ elec deg/sec}^2$$

$$= 180 \times \frac{2}{4} = 90 \text{ mech deg/s}^2$$

$$= \frac{90}{360} \times 60 \text{ /sec} = 15 \text{ rpm/sec}$$

rotor acceleration = 15 rpm/sec

(iii) for 15 cycles

$$\frac{d^2\delta}{dt^2} = 180$$

$$\frac{d\delta}{dt} = 180t + C$$

At $t = 0$, $\frac{d\delta}{dt} = 0$ ⇒ $C = 0$

$$\delta = \frac{180^\circ \times t^2}{2} + C$$

At $t = 0$, $C = \delta_0$

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Change in $\delta \Rightarrow \delta - \delta_0 = \Delta\delta = \frac{180^\circ \times t^2}{2}$

$t = 15 \times \frac{1}{50} = 0.3$ sec.

$\Delta\delta = 180 \times \frac{0.3 \times 0.3}{2}$

$\boxed{\Delta\delta = 8.1}$

14

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]

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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]

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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:

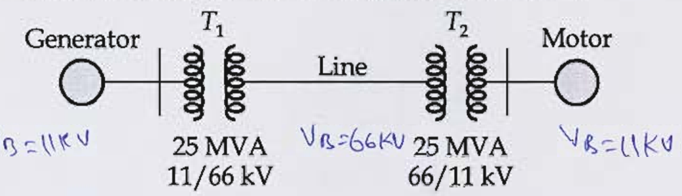
(i) The maximum value of RRRV for grounded fault and ungrounded fault.

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

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

[20 marks]

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]

Taking $S_B = 25 MVA$ and respective voltage bases is shown

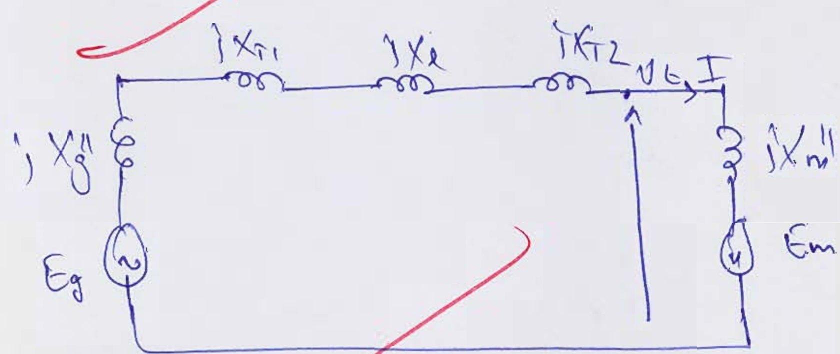
$X_g'' = X_m'' = 0.15$ pu

For transform

$X_{T_1} = X_{T2} = 0.1$ pu

For line

$X_l = 0.1$



$V_t = \frac{10.6}{11} = 0.9636$ pu

$\phi = \cos^{-1} 0.8 = 36.87°$

$P = \sqrt{3} V_t \times I \times \cos\phi$

$\Rightarrow$ ~~$15 = \sqrt{3} \times 10.6 \times I$~~

$P = \frac{15}{S_{Base}} = \frac{15}{25} = 0.6$

$P = V_t I \times \cos\phi \Rightarrow 0.6 = 0.9636 \times I \times 0.8$

$I = 0.7783 \angle 36.87^\circ$ pu

$E_g = 0.9636\angle 0^\circ + 0.7783 \angle 36.87 \times j(0.15 + 0.1 + 0.1 + 0.1)$

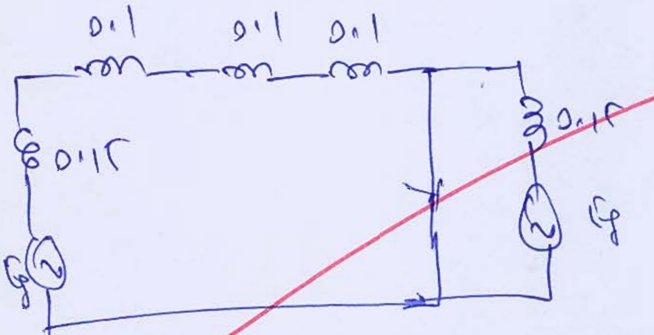
$E_g = 0.8039 \angle 20.4^\circ$

and $E_m = 0.9636 \angle 0^\circ - 0.7783 \angle 36.87 \times j0.15$

$E_m = 1.0378 \angle -5.16$

Now when 3φ fault occurs at motor terminal,

$V_{th} = V_t = 0.9636$



$X_{th} = (0.15 + 0.3) \,||\, [0.15]$

$= 0.1125$

$I_F = \frac{V_{th}}{X_{th}} = \frac{0.9636}{0.1125} = 8.56$ pu

Fault current

~~$I_{Fg} = 1.0378$~~

Subtransient current in generator

$I''_{Fg} = \frac{E_g}{j0.15 + j0.3} = \frac{0.8039 \angle 20.4}{j0.15 + j0.3}$

$|I''_{Fg}| = 1.7864$ pu

$$I_{fg} = 1.7864 \times \frac{S_{Base}}{\sqrt{3} \times V_{Base}} = 1.7864 \times \frac{25}{\sqrt{3} \times 11}$$

$$I_{fg}'' = 2.344 \text{ KA}$$

subtransient current in fault

$$I_{FM}'' = \frac{1.0378}{0.15} = 6.9187 \text{ Pu}$$

$$I_{FM}'' = 6.918 \times \frac{25}{11\sqrt{3}}$$

$$I_{FM}'' = 9.07 \text{ KA}$$

$$\text{fault Current} = 8.56 \times \frac{25}{\sqrt{3} \times 11}$$

$$I_F = 11.23 \text{ KA}$$

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Good Approach

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Q.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) For AM wave

$$\eta = \frac{\mu^2}{2+\mu^2} \times 100 = \frac{0.3^2}{2+0.3^2} \times 100$$

$$\boxed{\eta = 4.306\ \%} \text{ efficiency}$$

$$\% P_{SB} = \frac{P_c \times \mu^2/2}{P_c(1+\mu^2/2)} \times 100$$

$$= \frac{0.3^2/2}{(1+0.3^2/2)}$$

$$\boxed{\% P_{SB} = 4.306\ \%}$$

When transmitted as DSB-SC

$$\% \text{ saving} = \frac{P_c}{(1+\mu^2/2) \cdot P_c} \times 100$$

$$= \frac{1}{(1+0.3^2/2)} \times 100$$

$$\boxed{\% \text{ saving} = 95.694\ \%}$$

% saving for SSB-SC

$$\% \text{ saving} = \frac{P_c(1+\mu^2/4)}{P_c(1+\mu^2/2)} \times 100$$

$$\boxed{\% \text{ saving} = 97.0847\%}$$

(iii) $\phi_{PM}(t) = A_c \cos[\omega_c t + K_p m(t)]$

$A_c = 10\,V,\ \omega_c = 10^6,\ K_p = 1$

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

$\phi_{FM}(t) = A_c \cos[\omega_c t + K_f \int m(t)\,dt]$

15

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

$= \frac{2}{100}\sin 100t + \frac{18}{2000\pi}\sin 2000\pi t$

$\phi_{FM}(t) = 10\cos\left(10^6 t + 1000\pi \times \frac{2}{100}\sin 100t + 1000\pi \times \frac{18}{2000\pi}\sin 2000\pi t\right)$

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

2. ~~$\phi_{FM} = \alpha \times (\beta+1) \cdot f_m$~~

$\phi_{PM} = \alpha \times (\beta+1) \cdot f_m$

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.

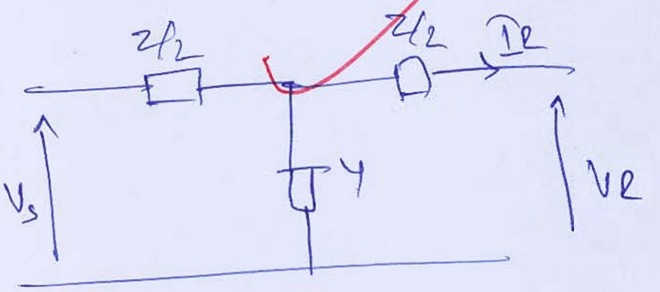
[20 marks]

$P_R = 40\,MW$ at $\cos\phi_R = 0.9$ lag $V_{RL} = 220\,kV$

$Z = (R + jX_L) = (0.2 + j0.4) \times 150 \times 2$

$= 60 + j120\,\Omega = 134.164 \angle 63.435^\circ\,\Omega$

$Y = j2.5 \times 10^{-6} \times 150 = j3.75 \times 10^{-4}\,S$



⇐ Nominal T

For nominal-T, A, B, C, D parameters are

$A = D = 1 + \frac{YZ}{2}$

$= 1 + \frac{j3.75 \times 10^{-4} \times 134.164 \angle 63.435}{2}$

$A = D = 0.9775 \angle 0.6594^\circ$

$B = Z\left(1 + \frac{YZ}{4}\right) \Rightarrow B = 132.66 \angle 63.76^\circ$

$C = Y = 3.75 \times 10^{-4} \angle 90^\circ$

Do not write in this margin

~~As, $V_s = V$~~ $P_R = \sqrt{3} V_{RL} \times I_R \times \cos\phi_R$

$40 = \sqrt{3} \times 220 \times I_R \times 0.9$

$I_R = 0.1166 \angle -\cos^{-1} 0.9$ KA

$= 0.1166 \angle -25.84°$ KA

As, $V_s = A V_R + B I_R$

$= 0.9775 \angle 0.6594 * \frac{220}{\sqrt{3}} + 132.66 \angle 63.76 \times 0.1166 \angle -25.84$

$V_{sph} = 136.79 \angle 4.58°$ KV

$V_{sL-L} = 136.79 \sqrt{3} = 236.93$ KV

sending end voltage

and,

$I_s = C V_R + D I_R$

$= 3.75 \times 10^{-4} \angle 90° \times \frac{220}{\sqrt{3}} + 0.9775 \angle 0.6594 \times 0.1166 \angle -25.84$

$I_s = 0.10315 \angle -0.48°$ KA

Sending end Current

$I_s = 103.15 \angle -0.48$ A

(iii) $P_{in} = \sqrt{3} V_{sL} \times I_s \times \cos\phi_s$

$= \sqrt{3} \times 236.93 \times 0.10315 \times \cos(4.58 + 0.48)$

$P_{in} = 42.16$ MW

efficiency (η) $\Rightarrow \frac{P_{out}}{P_{in}} \times 100$

$= \frac{P_e}{P_s} \times 100$

$= \frac{40}{42.16} \times 100$

$\eta = 94.865\%$

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Good Approach

Space for Rough Work

Space for Rough Work