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ESE 2020 : Mains Test Series

UPSC ENGINEERING SERVICES EXAMINATION

Electrical Engineering

Test-13: Full Syllabus Test

Paper-II

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Instructions for Candidates

1. Do furnish the appropriate details in the answer sheet (viz. Name & Roll No).
2. Answer must be written in English only.
3. Use only black/blue pen.
4. 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.
5. Any page or portion of the page left blank in the Question Cum Answer Booklet must be clearly struck off.
6. Last two pages of this booklet are provided for rough work. Strike off these two pages after completion of the examination.

FOR OFFICE USE

Question No.	Marks Obtained
Section-A	
Q.1	
Q.2	
Q.3	
Q.4	
Section-B	
Q.5	
Q.6	
Q.7	
Q.8	
Total Marks Obtained	

Signature of Evaluator .... Cross Checked by ....

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Section-A

Q.1 (a) A baseband signal $m(t) = \cos(1000t)\cos(3000t)$ is AM modulated using a carrier $\cos(10000t)$. (Take $K_a = 1\ v^{-1}$)

(i) Find the AM modulation index, μ.

(ii) Find the power efficiency, η.

(iii) Find the frequency components in the baseband signals and in the AM signal.

(iv) Sketch the spectrum.

[12 marks]

Ans. (a) $m(t) = \cos(1000t)\cos(3000t)$, carrier $= \cos(10000t)$

Given $k_a = 1\ v^{-1}$

∴ Standard AM wave $s(t) = A_c[1 + k_a A_m \cos(2\pi f_m t)] \cos 2\pi f_c t$ —① (with $k_a A_m \to \mu$)

here, $s'(t) = 1\cdot[1+\cos(1000t)\cos(3000t)]\cos(10000t)$

∴ $\cos A \cos B = \frac{1}{2}[\cos(A+B) + \cos(A-B)]$

So $s'(t) = 1\cdot[1 + 0.5\cos(4000t) + 0.5\cos(2000t)]\cos(10000t)$ —②

on comparing Eq ① & Eq ② $\mu_1 = 0.5$, $\mu_2 = 0.5$

So, Effective modulation index $\mu = \sqrt{\mu_1^2 + \mu_2^2} = \sqrt{0.5^2 + 0.5^2}$

∴ $\boxed{\mu = 0.707}$

Hence modulation index of AM wave is 0.707.

(ii) ∴ $P_t = P_c\left[1 + \frac{\mu^2}{2}\right]$ where P_t = total Power, P_c = carrier Power, μ = Modulation index.

⇒ $P_t = P_c + P_c\frac{\mu^2}{2}$ ⇒ Message signal Power / side band Power —③

Now, $P_c = \frac{1^2}{2} \Rightarrow 0.5$ watt.

So, $P_c \frac{\mu^2}{2} = 0.5 \times \frac{0.707^2}{2} = 0.125$ watt = Message power

So, Total Power, $P_t = 0.5 + 0.125 = 0.625$ watt.

Hence $\%\eta = \frac{\text{Message Signal Power}}{\text{Total Power}} \times 100 = \frac{0.125}{0.625} \times 100$

⇒ $\%\eta = 20\%$

Hence Percentage efficiency is 20%.

Ans (a) (i) (iii) Given $m(t) = 0.5\cos(4000t) + 0.5\cos(2000t)$ [from eq (2)]

Frequency of message signal is $4000\ \frac{rad}{s}$ & $2000\ \frac{rad}{sec}$

Also, from eq (2)

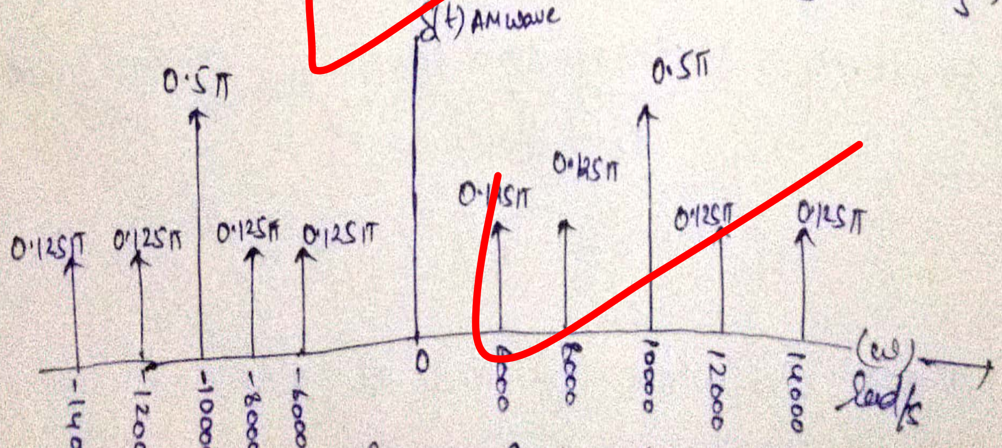
$s(t) = \cos(10000t) + 0.5\cos(4000t)\cos(10000t) + 0.5\cos(2000t)\cos(10000t)$

AM wave

$= \cos(10000t) + 0.25\cos(14000t) + 0.25\cos(6000t) + 0.25\cos(8000t)$
$+ 0.25\cos(12000t)$

Hence frequency components are :→ $6000\ \frac{rad}{s}$, $8000\ \frac{rad}{s}$, $10000\ \frac{rad}{s}$, $12000\ \frac{rad}{s}$, $14000\ \frac{rad}{s}$

(iv)



Frequency Spectrum of AM wave.

Q.1 (b) Gate-cathode characteristics of a thyristor have a spread given by relations:

$I_g = 2.1 \times 10^{-3} V_g^{\,2}$ and $I_g = 2.1 \times 10^{-3} V_g^{\,1.5}$

The gate source voltage is 16 V and load line has a slope of –128 V/A. Calculate the trigger voltage and trigger current for an average gate power dissipation of 0.5 W. Are the values of V_g, I_g obtained here justified?

[12 marks]

Ans 1 (b) Given $I_g = 2.1 \times 10^{-3} V_g^2$ and $I_g = 2.1 \times 10^{-3} V_g^{1.5}$

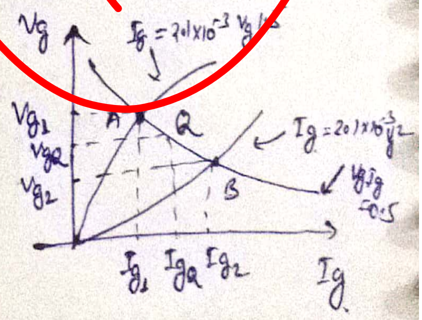
Also, slope of load line, $|m| = 128$ V/A. Hence gate source resistance $R = 128\ \Omega$

Average power dissipation, $V_g I_g = 0.5$ watt —— (1)

and $E = I_g R + V_g \Rightarrow 16 = I_g \times 128 + \frac{0.5}{I_g}$ [from Eq (1)]

$\Rightarrow 128 I_g^2 - 16 I_g + 0.5 = 0 \Rightarrow I_{gQ} = 0.0625\text{ A} = 62.5\text{ mA}$

So, $V_{gQ} = \frac{0.5}{I_g} = \frac{0.5}{0.0625} = 8\text{ V}$



Point A

$I_g = 2.1 \times 10^{-3} V_g^{1.5} = 2.1 \times 10^{-3} \left(\frac{0.5}{I_g}\right)^{1.5}$

$\Rightarrow I_{g1} = 56\text{ mA}, \Rightarrow V_{g1} = 8.927$ Volts

Point B

$I_{g2} = 2.1 \times 10^{-3} V_g^2 = 2.1 \times 10^{-3} \left(\frac{0.5}{I_g}\right)^2 \Rightarrow I_g = 80.67\text{ mA}$

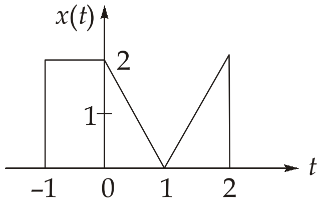
$V_{g2} = 6.198$ Volts

Clearly V_{gQ}, I_{gQ} operating points lie between point A and B

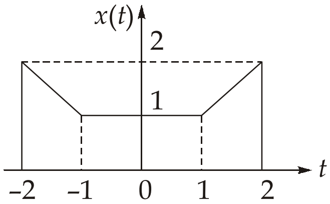
Hence operating point is justifiable.

Q.1 (c) Express $x(t)$ in terms of rectangular pulse and triangular pulse, and compute the Fourier transforms of the signals using standard Fourier transform relations.

(i)

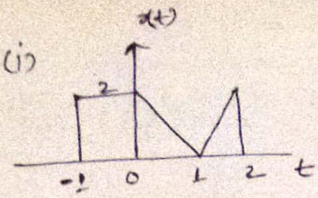


(ii)



[12 marks]

Ans 1 (c) (i)



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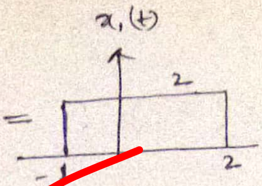

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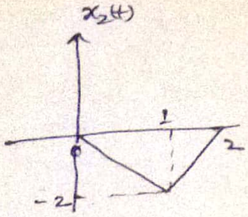
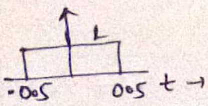


$x_1(t) = 2\,\text{rec}\left(\frac{t-0.5}{3}\right)$ and $x_2(t) = -2\,\text{tri}\left(\frac{t-1}{1}\right)$

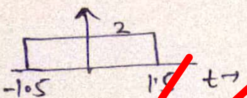
Hence $\boxed{x(t) = 2\,\text{rec}\left(\frac{t-0.5}{3}\right) + (-2)\,\text{tri}\left(\frac{t-1}{1}\right)}$

$\therefore$ $\text{rec}\left(\frac{t}{1}\right)$ =



$\xrightarrow{F.T.}$ $1\,Sa(0.5\omega)$

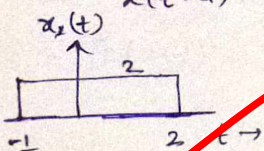
So $2\,\text{rec}\,\frac{t}{3}$ =



$\xrightarrow{F.T.}$ $6\,Sa\left(\frac{3}{2}\omega\right)$

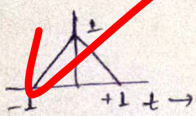
By using shifting property $x(t) \xrightarrow{F.T.} X(\omega)$
$x(t-a) \xrightarrow{F.T.} e^{-j\omega a} X(\omega)$ —— ①

So $2\,\text{rec}\left(\frac{t-0.5}{3}\right) = x_1(t)$ =



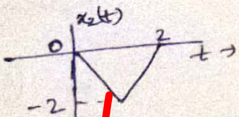
$\xrightarrow{F.T.}$ $6\,Sa\left(\frac{3}{2}\omega\right) e^{-\frac{j\omega}{2}}$ —— ②

Similarly $\text{tri}\left(\frac{t}{1}\right)$ =



$\xrightarrow{F.T.}$ $Sa^2\left(\frac{\omega}{2}\right)$

So $-2\,\text{tri}\left(\frac{t-1}{1}\right)$ =

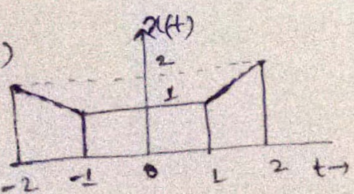


$\xrightarrow{F.T.}$ $-2\,Sa^2\left(\frac{\omega}{2}\right) e^{-j\omega}$ —— ③

[from Eq ①]

Hence Fourier transform of $\boxed{x(t) = X(\omega) = 6\,Sa\left(\frac{3}{2}\omega\right) e^{-\frac{j\omega}{2}} - 2\,Sa^2\left(\frac{\omega}{2}\right) e^{-j\omega}}$

(ii)



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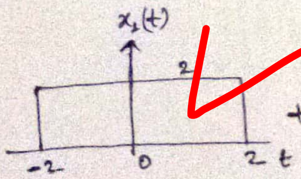

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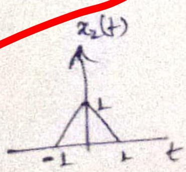

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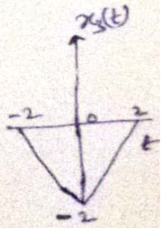

$x(t) = x_1(t) + x_2(t) + x_3(t)$ —— ①

Now $x_1(t) = 2\,rec(t/4)$; $x_2(t) = 1 \cdot tri\left(\frac{t}{1}\right)$; $x_3(t) = -2\,tri(t/2)$

So $x(t) = 2\,rec\left(\frac{t}{4}\right) + tri\left(\frac{t}{1}\right) - 2\,tri\left(t/2\right)$

Similarly $X(\omega) = X_1(\omega) + X_2(\omega) + X_3(\omega)$ —— ②

$x_1(t) \xrightarrow{F.T.} X_1(\omega) = 8\,Sa(2\omega)$; $X_2(\omega) = Sa^2(\omega/2)$

and $X_3(\omega) = -4\,Sa^2(\omega)$

Hence $X(\omega) = 8\,Sa(2\omega) + Sa^2\left(\frac{\omega}{2}\right) - 4\,Sa^2(\omega)$

fourier transform of $x(t)$

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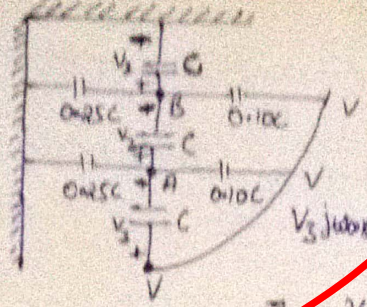
Q.1 (d) Calculate the string efficiency of a 3-unit suspension insulator, if the capacitance of the link pins to earth and the line are respectively 25% and 10% of self capacitance of each unit. What should be the values of link pins to the line capacitance for 100% string efficiency?

[12 marks]

Ans 1(d)



$V_1 + V_2 + V_3 = V$ ——— (1)

Applying KCL at Node A

$V_3 j\omega (0.1)C + V_3 j\omega C = (V_1+V_2) j\omega 0.25C + V_2 j\omega C$

$\Rightarrow V_3[1+0.1] = 0.25[V_1+V_2] + V_2$

$\Rightarrow 1.1 V_3 = 1.25 V_2 + 0.25 V_1 \Rightarrow 1.1 = 1.25\frac{V_2}{V_3} + 0.25\frac{V_1}{V_3}$ ——— (2)

Applying KCL at Node B

$(V_2+V_3) j\omega 0.1C + V_2(j\omega C) = V_1 j\omega 0.25C + V_1 j\omega C$

$\Rightarrow 0.1V_2 + 0.1V_3 + V_2 = 0.25V_1 + V_1$

$\Rightarrow 1.1V_2 + 0.1V_3 = (0.25+1)V_1 = 1.25V_1$

$\Rightarrow 0.1 = -1.1\frac{V_2}{V_3} + 1.25\frac{V_1}{V_3}$ ——— (3)

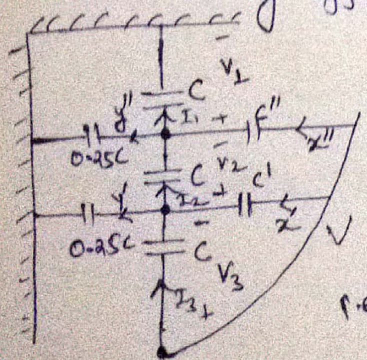
from Eq (2) & (3) we get $\frac{V_2}{V_3} = \frac{36}{49}$, $\frac{V_1}{V_3} = \frac{178}{245}$

Now $\therefore$ String efficiency, $\%\eta = \frac{V_1+V_2+V_3}{3V_3}\times 100 = \frac{1}{3}\left[\frac{V_1}{V_3}+\frac{V_2}{V_3}+1\right]\times 100$

$\%\eta = \frac{1}{3}\left[\frac{178}{245}+\frac{36}{49}+1\right]\times 100$

$= 82.04\%$

for 100% String efficiency $V_1 = V_2 = V_3 = V/3$



$I_1 = I_2 = I_3 = I$

and current supplied by link to line is equal to current absorbed by line to Earth capacitance.

i.e. $x = y$

$j\omega C' V_3 = j\omega 0.25C(V_1+V_2)$

$j\omega C' V_3 = j\omega 0.25C(2V_3) \Rightarrow \boxed{C' = 0.5C}$

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Similarly $x'' = y''$ [Currents are equal]

So $(V-V_1)\, j\omega C'' = V_1\, j\omega\, 0.25\, C \Rightarrow C'' = 0.125\, C$

Hence link capacitors for 100% efficiency are $0.125\,C$ and $0.5\,C$ farad.

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Q.1 (e) A unity feedback system with loop transfer function,

$$G(s) = \frac{(s+2\alpha)}{s^3 + (1+\alpha)s^2 + (\alpha-1)s + (1-2\alpha)}$$

The magnitude of the steady-state error of the unity-feedback closed-loop system to a step-input should be less than or equal to 10%. Determine the range of α that will achieve desired steady-state error.

[12 marks]

Ans 1(e) Given $G(s) = \frac{(s+2\alpha)}{s^3+(1+\alpha)s^2+(\alpha-1)s+(1-2\alpha)}$

$\Rightarrow e_{ss} \leq 0.1$ or 10%.

$\therefore e_{ss} = \lim_{s\to 0} \frac{s \times R(s)}{1+G(s)H(s)}$ where $R(s)$ = input signal

$e_{ss} = \lim_{s\to 0} \frac{s \times 1/s}{1+\frac{(s+2\alpha)}{s^3+(1+\alpha)s^2+(\alpha-1)s+(1-2\alpha)} \times 1} \leq \pm 0.1$

$e_{ss} = \lim_{s\to 0} \frac{1}{1+\frac{2\alpha}{(1-2\alpha)}} \leq \pm 0.1$

$e_{ss} = \frac{(1-2\alpha)}{1-2\alpha+2\alpha} \Rightarrow -0.1 \leq \frac{1-2\alpha}{1} \leq 0.1$

So, $-0.1 \leq 1-2\alpha$ or $1-2\alpha \leq 0.1$

$\Rightarrow +2\alpha \leq 1.1$ or $1-0.1 \leq 2\alpha$

$\boxed{\alpha \leq 0.55}$ or $\boxed{0.45 \leq \alpha}$ —(1)

But we should also check stability condition too,

Characteristic Equation $s^3 + (1+\alpha)s^2 + (\alpha-1)s + (1-2\alpha)$

Using R-H criteria

s^3 1 $(\alpha-1)$

s^2 $(1+\alpha)$ $(1-2\alpha)$

s^1 $\frac{\alpha+\alpha^2-1}{\alpha+1}$ 0

s^0 1

1st element, $1>0$

2nd element, $1+\alpha > 0 \Rightarrow \alpha > -1$ ⟵ (2)

3rd element, $\frac{\alpha^2+\alpha-1}{\alpha+1} > 0$

$\Rightarrow \left(\alpha+\frac{1}{2}\right)^2 > \left(\frac{\sqrt{5}}{2}\right)^2$

So $\alpha > \frac{\sqrt{5}-1}{2}$ and $\alpha < \frac{-\sqrt{5}-1}{2}$ —— (3)

From eq (1), (2) and (3)

$\boxed{\alpha > 0.618}$

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Q.2 (a) Consider the loop transfer function of a closed-loop system is

$$L(s) = \frac{Ke^{-s}}{s(s+1)(s+2)}, K = 1$$

Draw the approximate Nyquist plot on the graph. From the plot obtain the phase margin and gain margin. (Students are adviced to use graph paper)

[20 marks]

Q.2 (b) **(i)** Explain with a diagram the working of a DC shunt motor three point starter.

(ii) A 10 kW, 250 V, dc shunt motor with an armature resistance of 0.8 Ω and a field resistance of 275 Ω takes 3.91 A, where running light at rated voltage and rated speed.

1. Calculate the machine efficiency as a generator when delivering and output of 10 kW at rated voltage and speed and as a motor drawing an input of 10 kW.
2. Determine the maximum efficiencies of the machine when generating and when motoring.

[8 + 12 marks]

Q.2 (c) **(i)** Design a combinational circuit with 3 inputs that will produce logic 1 when the output binary number is less than 3 or greater than 6.

(ii) A 10-bit A/D converter of the successive approximation type has a resolution of 10 mV. Determine the digital output for an analog input of 4.365 V.

[12 + 8 marks]

Q.3 (a) A single-phase full-bridge inverter has RLC load of $R = 4\ \Omega$, $L = 35$ mH, $C = 155\ \mu$F. The dc input voltage is 230 V and the output frequency is 50 Hz.

(i) Find an expression for load current upto fifth harmonic.

(ii) Calculate the fundamental power and power absorbed by load.

(iii) The rms and peak current of each thyristor.

[20 marks]

Ans (a) Given, $R = 4\Omega$, $L = 35$ mH, $C = 155\ \mu F$, $V_{in} = 230$ V and 50Hz o/p

$\therefore\ \omega = 2\pi f = 2\pi \times 50 = 100\pi$ rad/sec.

As output voltage, $V_o = \sum_{n=1,3,5} \frac{4V_s}{n\pi} \sin n\omega t \Rightarrow \frac{4V_s}{\pi}\sin\omega t + \frac{4V_s}{3\pi}\sin 3\omega t + \frac{4V_s}{5\pi}\sin 5\omega t$

$\Rightarrow V_o(t) = \frac{4\times 230}{\pi}\sin 314t + \frac{4\times 230}{3\pi}\sin(3\times 314t) + \frac{4\times 230}{5\pi}\sin(5\times 314t)$

$V_o(t) = 292.85\sin(314t) + 97.62\sin(942t) + 58.57\sin(1570t)$

Now load impedance at n^{th} frequency

$Z_n = 4 + j\left[2\pi\times 50\times 35\times 10^{-3} n - \frac{1}{2\pi\times 50 n\times 155\times 10^{-6}}\right]$

$Z_n = 4 + j\left[11n - \frac{20.54}{n}\right]\Omega$

So Z_1 = put $n=1$, $|Z_1| = \sqrt{4^2 + (11-20.54)^2} = 10.345\Omega$

put $n=3$, $|Z_3| = \sqrt{4^2 + \left(33 - \frac{20.54}{3}\right)^2} = 26.46\Omega$

and $n=5$, $|Z_5| = \sqrt{4^2 + \left(55 - \frac{20.54}{5}\right)^2} = 51.05\Omega$

and $\phi_1 = \tan^{-1}\left(\frac{11-20.54}{4}\right) = -67.25°$

$\phi_3 = \tan^{-1}\left(\frac{33-\frac{20.54}{3}}{4}\right) = 81.30°$

$\phi_5 = \tan^{-1}\left(\frac{55-\frac{20.54}{5}}{4}\right) = 85.50°$

So, load current $i_o(t) = \frac{V_{o1}}{Z_1} + \frac{V_{o3}}{Z_3} + \frac{V_{o5}}{Z_5}$

$i_o(t) = \frac{292.85}{10.345}\sin(314t + 67.25°) + \frac{97.62}{26.46}\sin(914t - 81.30) + \frac{58.57}{51.05}\sin(1570t - 85.5°)$

$\Rightarrow i_o(t) = 28.31\sin(314t + 67.25°) + 3.69\sin(914t - 81.30) + 1.147\sin(1570t - 85.5°)$

(ii) fundamental load Power, $P_{o1} = I_{o1}^2 \times R$

$= \frac{28.31^2}{2}\times 4 = 1602.9$ watt.

RMS load current, $I_{or} = \sqrt{\frac{28.31^2 + 3.69^2 + 1.147^2}{2}} = 20.204\,A$

load Power $= (I_{or})^2 \times R = 20.204^2 \times 4 = 1632.81$ Watt.

(iii) RMS value of thyristor current $= I_{or}\sqrt{\frac{180°}{360°}} \Rightarrow \frac{I_{or}}{\sqrt{2}}$

$I_{rms\,T} = \frac{20.204}{\sqrt{2}} = 14.286\,A$

Peak thyristor current, $I_m = \sqrt{2} \times I_{or} = \sqrt{2} \times 20.204 = 28.572$ Amps

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Q.3 (b) **(i)** A 100 MVA, 50 Hz turbo alternator operates at no load at 3000 rpm. A load of 25 MW is suddenly applied to the machine and the steam valves to the turbine commence to open after 0.6 sec due to the time lag in the governor system. Assuming inertia constant of 4.5 kW-sec per kVA of generator capacity. Calculate the frequency to which the generated voltage drops before the steam flow commences to increase to meet the new load. Also determine the frequency if the further added delay of 0.2 sec takes place in opening valves due to time lag in the governor system.

(ii) A surge of 100 kV travelling in a line of natural impedance 600 ohms arrives at a junction with two lines of impedances 800 ohms and 200 ohms respectively. Find the surge voltages and currents transmitted into each branch line.

[10 + 10 marks]

Ans 3(b) Given 100 MVA, 50 Hz at no load at 3000 rpm

Valve open after = 0.6 sec. , $H = 4.5 \frac{kW-sec}{kVA} \Rightarrow 4.5 \frac{MW-sec}{MVA}$

So Energy stored in rotor/turbine = $\frac{4.5 \text{ MJoule}}{MVA}$

For 100 MVA, Energy stored = 4.5×100 = 450 MJoule

load applied = 25 MW

So Energy drawn during 0.6 sec = 25×0.6 = 15 MJoule.

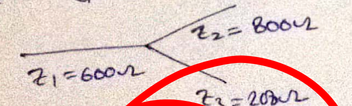
Hence $f_{new} = f_{old}\sqrt{\frac{\text{Kinetic Energy Stored} - \text{Energy drawn before Valve open}}{\text{Kinetic energy Stored}}}$

$f_{new} = 50\sqrt{\frac{450-15}{450}}$ = 49.159 ≈ 49.16 Hz.

For further delay of 0.2 sec, total energy drawn = 25×0.8 = 20 MJ

So $f_{new} = 50\sqrt{\frac{450-20}{450}}$ = 48.876 Hz.

(ii) Given $Z_1 = 600\Omega$, $Z_2 = 800\Omega$, $Z_3 = 200\Omega$



Given Surge magnitude, V = 100 kV

Here 2 lines are in parallel so voltage of transmitted wave would be same for both lines.

$V_T = \frac{2E}{1+\frac{Z_1}{Z_2}+\frac{Z_1}{Z_3}} \Rightarrow \frac{2\times 100}{1+\frac{600}{800}+\frac{600}{200}} = \frac{200}{4.75}$ = 42.105 kV

So, transmitted current in line 2, $= \frac{V_T}{Z_2} = \frac{42.105\times 10^3}{800}$ = 52.63 A

and transmitted current in line 3, $= \frac{V_T}{Z_3} = \frac{42.105\times 10^3}{200}$ = 210.525 Amps

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Q.3 (c) Derive the Fourier transform of the following signals.

(i) $\dfrac{1}{1+t^2}$ (ii) $\dfrac{1}{1-t^2}$

[10 + 10 marks]

Ans 3(c) fourier transform of $x(t)$ can be written as

$$X(j\omega) = \int_{-\infty}^{\infty} x(t)e^{-j\omega t}\,dt$$

(i) Given $x(t) = \frac{1}{1+t^2} = \frac{1}{(1+jt)(1-jt)} = \frac{1}{2}\left[\frac{1}{1+jt} + \frac{1}{1-jt}\right]$

So $X(j\omega) = \int_{-\infty}^{\infty} \frac{1}{1+t^2} e^{-j\omega t}\,dt$

using fourier transform properties, $e^{-t}u(t) \xrightarrow{F.T.} \frac{1}{1+j\omega}$

using duality property $\frac{1}{1+jt} \xrightarrow{F.T} 2\pi e^{\omega} u(-\omega)$ — (1)

and $\frac{1}{1-jt} \xrightarrow{F.T} 2\pi e^{-\omega} u(\omega)$ ← (2)

So $x(t) \xrightarrow{F.T.} X(\omega) = \dfrac{2\pi e^{\omega} u(-\omega) + 2\pi e^{-\omega} u(\omega)}{2}$ [from Eq (1) & (2)]

So $X(\omega) = \pi\left[e^{\omega}u(-\omega) + e^{-\omega}u(\omega)\right]$

So $X(\omega) = \begin{cases} \pi e^{-\omega}, & \omega > 0 \\ \pi, & \omega = 0 \\ \pi e^{\omega}, & \omega < 0 \end{cases}$

10

(ii) $x(t) = \frac{1}{1-t^2} = \frac{1}{(1-t)} \cdot \frac{1}{(1+t)} \Rightarrow \frac{1}{2}\left[\frac{1}{(1+t)} + \frac{1}{(1-t)}\right]$ — (1)

Now, As we know that $sgn(t) \xrightarrow{F.T} \frac{2}{j\omega}$

So by duality principle $\frac{2}{jt} \xrightarrow{F.T} 2\pi\, sgn(-\omega)$

By eq $\frac{1}{t} \xrightarrow{F.T} j\pi\, sgn(-\omega) = -j\pi\, sgn(\omega)$

By shifting property, $\frac{1}{1+t} \xrightarrow{F.T.} -j\pi\, sgn(\omega)\, e^{j\omega}$ ← (2)

and $\frac{1}{1-t} \xrightarrow{F.T} j\pi\, sgn(\omega)\, e^{-j\omega}$ — (3)

So, By using Eq (1), (2) & (3)

$x(t) \xrightarrow{F.T} X(\omega) = \frac{1}{2} j\pi\, sgn\left[e^{-j\omega} - e^{j\omega}\right]$

So, $\frac{1}{1-t^2} \xrightarrow{F.T.} \pi \, sgn(\omega) \sin(\omega) = X(\omega)$

or $X(\omega) = \begin{cases} -\pi \sin \omega , & \omega < 0 \\ 0 , & \omega = 0 \\ \pi \sin(\omega) , & \omega > 0 \end{cases}$

10

Q.4 (a) **(i)** A 3-phase 50 Hz, 12 pole, 200 kW slip-ring induction motor drives a fan whose torque is proportional to the square of speed. At full load, the motor slip is 0.045. The rotor resistance measured between any two slip-rings is 61 mΩ. What resistance should be added in the rotor circuit to reduce the fan speed to 450 rpm?

(ii) Elucidate the phenomenon of cogging and crawling with respect to induction machine.

[12 + 8 marks]

Ans 4 (i) Given, 3φ, 50Hz, 12 Pole, 200kW slip-ring induction motor

$T \propto N^2$, $S_{fl} = 0.045$, $2r_2 = 61 m\Omega \Rightarrow \boxed{r_2 = 30.5 m\Omega}$

where r_2 is rotor resistance.

Synchronous Speed, $N_s = \frac{f \times 120}{P} = \frac{50 \times 120}{12} = 500$ rpm.

So Rotor Speed, $N_1 = N_s(1-S_1) = 500(1-0.045) = 477.5$ rpm

$\omega_s = \frac{2\pi N_s}{60} = \frac{2 \times \pi \times 500}{60} = 52.36$ rad/sec.

Now, ∴ Torque, $T = \frac{3}{\omega_s} \times \frac{V^2 \times (R_2/s)}{\left(\frac{R_2}{s}\right)^2 + (X_2)^2}$

So $T \propto \left(\frac{R_2}{s}\right)^{-1} \propto \frac{s}{R_2}$ [∵ during running condition $\frac{R_2}{s} >> X_2$]

So $T_1 = \frac{k S_1}{R_2}$ where k is proportionality constant.

Let x be the (mΩ) resistance to be added to the rotor circuit.

So $\frac{T_1}{T_2} = \frac{\frac{k S_1}{R_2}}{\frac{k S_2}{R_2'}} = \frac{N_1^2}{N_2^2} \Rightarrow \frac{\frac{0.045}{30.5 \times 10^{-3}}}{\frac{S_2}{(30.5+x) \times 10^{-3}}} = \left(\frac{477.5}{450}\right)^2$

$\Rightarrow 1.126 = \frac{1.475 \times 10^{-3}}{S_2}(30.5+x)$ —— (1)

Now, $(1-S_2) \Rightarrow \frac{N_{r2}}{N_s} \Rightarrow 1-S_2 = \frac{450}{500} \Rightarrow \boxed{S_2 = 0.1}$

Put this in Eq (1) we get

$1.126 = \frac{1.475 \times 10^{-3}}{0.1}(30.5+x) \Rightarrow \boxed{x = 45.84 m\Omega}$

Hence resistance to be added to rotor circuit to reduce the speed of 450 rpm of rotor is 45.84 mΩ.

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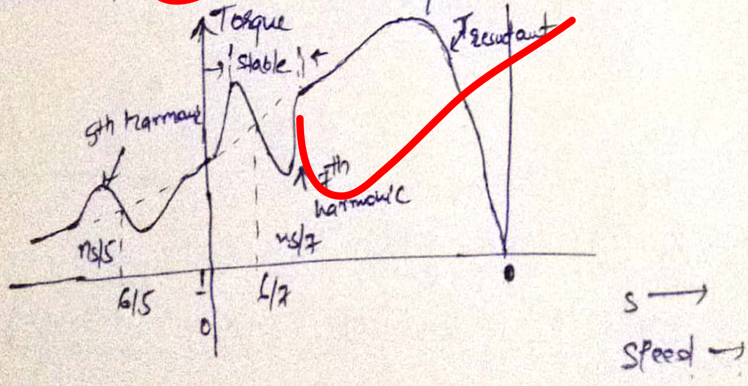
Ans 4(a)(ii) Cogging:→ When induction motor refuses to start at all. Sometimes it happens because of low supply voltage. But the main reason for starting problem in the motor is because of

Coggings in which the slots of stator gets locked up with the rotor slots. When the slots of rotor are equal in number with slots in the stator, they align themselves in such a way that both face to each other and at this stage the reluctance of magnetic path is minimum and motor refuse to start.

Crawling:→ It has been observed that induction motor have tendency to run at very low speed compared to it's synchronous speed this phenomenon is known as Crawling. The resultant speed is nearly 1/7th of its synchronous speed. This is due to the fact that harmonics flux produced in the air gap of the stator winding of odd harmonics like 3rd, 5th, 7th etc. and torque produced are in forward and backward direction.

- The torque produced by 5th harmonic rotates in backward direction. It works as a braking action is small in quantity. So it can be neglected.
- Torque produced by 7th harmonic produces a forward rotating torque at asynchronous speed of Ns/7. Hence net forward torque is sum of fundamental & 7th harmonic torque.

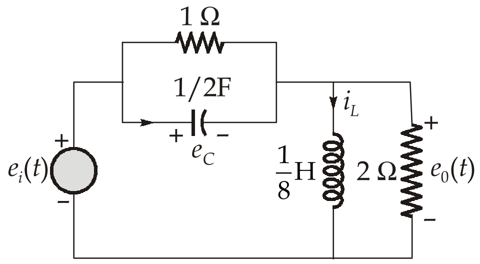


Q.4 (b) **(i)** Consider the system with two states and the state-space model matrices given by:

$$A = \begin{bmatrix} -6 & 1 \\ -5 & 0 \end{bmatrix}, \qquad B = \begin{bmatrix} 1 \\ K \end{bmatrix}, \qquad C = \begin{bmatrix} 1 & 0 \end{bmatrix}, \qquad K \in \Re$$

1. Form the observability matrix for the system. Is the system observable for all values of K?
2. Form the controllability matrix for the system. Is the system controllable for all values of K?

(ii) For the given circuit, obtain the state space representation using i_L and e_c as state variables, the input is $e_i(t)$ and output is $e_0(t)$.



[10 + 10 marks]

Ans 4(b) Given $A = \begin{bmatrix} -6 & 1 \\ -5 & 0 \end{bmatrix}$, $B = \begin{bmatrix} 1 \\ k \end{bmatrix}$, $C = \begin{bmatrix} 1 & 0 \end{bmatrix}$

$$[CA] = \begin{bmatrix} 1 & 0 \end{bmatrix} \begin{bmatrix} -6 & 1 \\ -5 & 0 \end{bmatrix} = \begin{bmatrix} -6 \\ 1 \end{bmatrix}$$

So $[CA]^T = \begin{bmatrix} -6 & 1 \end{bmatrix}$

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For observability, $|[O_{Matrix}]| \neq 0 \Rightarrow \begin{bmatrix}[C]\\ [CA]\end{bmatrix} = \begin{bmatrix}1 & 0\\ -6 & 1\end{bmatrix} = [O]_{Matrix}$

$\therefore\ |O| = \begin{vmatrix}1 & 0\\ -6 & 1\end{vmatrix} \Rightarrow 1 \neq 0$

Hence System is observable for all values of k.

2.

$[AB] = \begin{bmatrix}-6 & 1\\ -5 & 0\end{bmatrix}\begin{bmatrix}1\\ k\end{bmatrix} = \begin{bmatrix}-6+k\\ -5\end{bmatrix}$

For controllability, $[C] = [B \quad AB]$, $|C| \neq 0$

$[C] = \begin{bmatrix}1 & -6+k\\ k & -5\end{bmatrix}$ So $|[C]| = \begin{vmatrix}1 & -6+k\\ k & -5\end{vmatrix}$

$\Rightarrow |C| = -5 + 6k - k^2 = 0 \Rightarrow$ $\boxed{k = 5, 1}$

So Matrix C is controllable $\forall$ k∈R except k = 5, 1

i.e. [C] controllable $k = (-\infty, \infty)$ & $k \neq 5, 1$.

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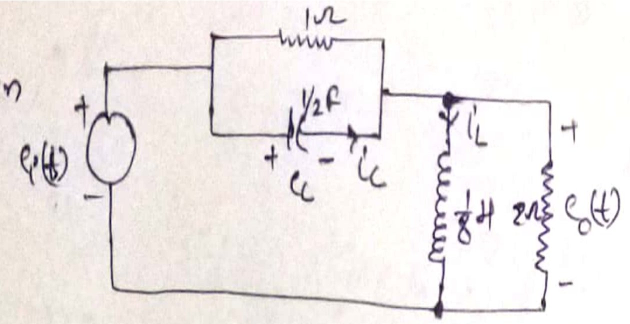
Ans 4(ii) Given



From the circuit, current through capacitor $= C\frac{de_c}{dt} = i_c$

$\Rightarrow i_c = \frac{1}{2}\frac{de_c}{dt} = i_L - \frac{e_c}{1} \Rightarrow$ So, $\frac{de_c}{dt} = -2e_c + i_L$ —— (1)

Voltage of Inductor, $V_L = L\frac{di}{dt} = \frac{1}{8}\frac{di_L}{dt} = e_i - e_c$

So $\frac{di_L}{dt} = -8e_c + 8e_i(t)$ —— (2)

Hence $\begin{bmatrix} \frac{de_c}{dt} \\ \frac{di_L}{dt} \end{bmatrix} = \begin{bmatrix} -2 & 1 \\ -8 & 0 \end{bmatrix} \begin{bmatrix} e_c \\ i_L \end{bmatrix} + \begin{bmatrix} 0 \\ 8 \end{bmatrix} e_i(t)$ —— (3)

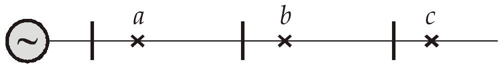
$\therefore e_o(t) = V_L = \frac{1}{8}\frac{di_L}{dt}$

also $e_o(t) = e_i(t) - e_c \Rightarrow -e_c + e_i(t)$

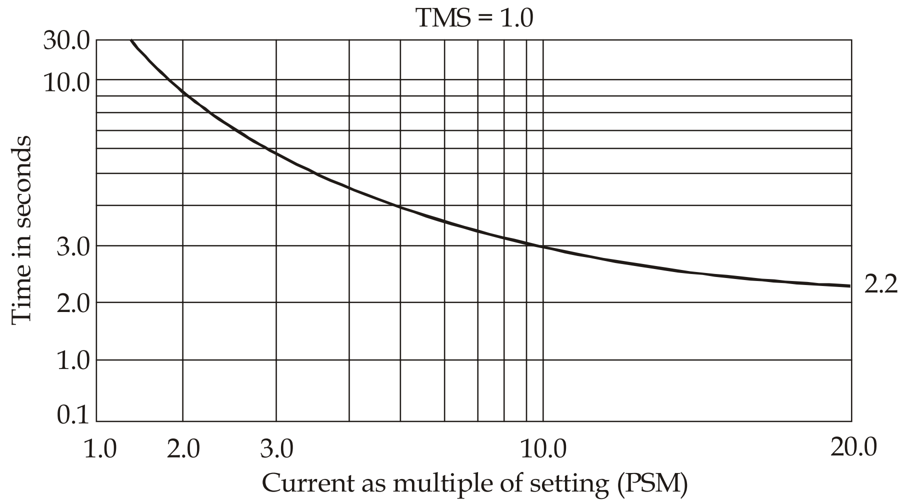
So, $e_o(t) = \begin{bmatrix} -1 & 0 \end{bmatrix} \begin{bmatrix} e_c \\ i_L \end{bmatrix} + e_i(t)$ —— (4)

Hence state space Presentation is made as per eq (3) & (4)

Q.4 (c) For the following system, estimate the time-current grading of each relay.



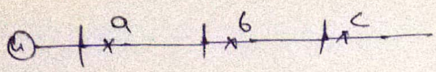
Relay Point	CT Ratio	Fault Current
a	400/5	6000 A
b	200/5	5000 A
c	200/5	4000 A



(Relay IDMT Curve)

[20 marks]

Ans 4(c) Given



Let us start our calculation from relay c and calculate operating time of relay b and relay a first. relay c.

$\therefore$ PSM = $\frac{\text{Secondary fault current}}{\text{Secondary pickup current}}$

$\therefore$ Pickup is not give so let us assume 100% pick up setting

So I_{pickup} = 5A.

So PSM for relay c = $\frac{4000 \times \frac{5}{200}}{5}$ = 20

So PSM for relay c = 20.

From IDMT curve, operating time corresponding to PSM 20 = 2.2 sec

$\therefore$ TSM is not know let us assume if TSM = 0.2

So operating time for relay c = 2.2 × 0.2 = 0.44 sec.

Let us consider relay b as back up if fault at c is not cleared by relay c so consider a delay of 0.5 sec.

Hence relay be 6 operated at t = 0.5 + 0.44 = 0.94 sec.

So relay 6 operate as a back up relay if fault is near C. and operate at 0.94 sec.

When fault is near 6 So relay 6 now act as primary relay.
Assuming relay pickup setting of 125%. So Ipickup = 1.25×5 = 6.25 A

So PSM for relay 6 = $\frac{5000 \times \frac{5}{200}}{6.25} \approx 20$

So operating time corresponding to PSM = 20 is 2.2 sec.

Now actual operating time of relay 6 = TSM × operating time —(1)

We would calculated TSM corresponding to fault at location near C for relay 6.

So, PSM of relay 6 when fault is near C = $\frac{4000 \times 5/200}{6.25} = 16$

For PSM = 16, operating time from curve = 2.4 sec approx.
and operating time of relay 6 is 0.94 sec (Actual)

So TSM for relay 6 = $\frac{0.94}{2.4} = 0.39$

So, from Eq (1)
Actual operating time for relay 6 when acting as primary relay = 0.39 × 2.2
= 0.858 sec.

For relay a

So CT ratio = 400/5 which is high So
Let us consider a delay of for relay a when fault is near 6 w.r.t. relay 6

and Assume pick up setting for relay a is 100%.

So PSM for relay a when fault at location 6 = $\frac{5000 \times 5/400}{5} = 12.5$

For PSM = 12.5, operating time of relay a = 2.75 sec approx.

So, relay a operate actual at t = 0.858 + 0.25 = 1.108 sec.

So TMS of relay a = $\frac{1.108}{2.75}$ = 0.4

When fault is near a, the PSM will be = $\frac{6000 \times \frac{5}{400}}{5}$

= 15

Corresponding to PSM = 15, Operating time of relay a = 2.5 sec approx.

So, actual operating time of relay a = 2.5 × 0.4 = 1 sec approx.

Section-B

Q.5 (a) A 50 Hz, 400 V, 4-pole cylindrical synchronous generator has 36 slots, two-layer winding with full-pitch coils of 8 turns each. The mean air-gap diameter is 0.16 m, axial length 0.12 m and a uniform air-gap of 2 mm. Calculate the value of resultant AT/pole and the peak air-gap flux density.

[12 marks]

Ans 5(a) Given 50 Hz, 400 V, P = 4, S_{total} = 36 slots, 2 layer, 8 turn each, D = 0.16 m, axial length = 0.12 m, air gap = 2 mm

So Turns / phase, $N_{ph} = \frac{36 \times 8 \times 2}{2 \times 3} = \frac{\text{Number of conductor}}{\text{phase} \times 2}$

$= 96$

So, slot per pole per phase, $m = \frac{36}{4 \times 3} = 3$

and β = Angle between slots = $\frac{180°}{\left(\frac{36}{4}\right)} = 20°$

So, ∴ Kd, Distribution factor $= \frac{\sin(m\beta/2)}{m \sin(\beta/2)} = \frac{\sin\left(\frac{3 \times 20°}{2}\right)}{3 \sin(20°/2)}$

$K_d = 0.96$

So, Induced emf, $E = 4.44 f N_{ph} \phi_p K_d = 4.44 \times 50 \times 96 \times \phi_p \times 0.96 = \frac{400}{\sqrt{3}}$

⇒ $\phi_p = 0.0113$ Wb/pole

∴ Flux per pole, $\phi_p = \frac{\text{MMF/pole}}{\text{Reluctance}}$ ⇒ $\frac{AT}{Pole} = \phi_p \times \text{Reluctance}$

So $\frac{AT}{Pole} = 0.0113 \times \frac{1}{4\pi \times 10^{-7}} \times \frac{2 \times 10^{-3}}{2\pi \times \left(\frac{0.16}{2}\right) \times 0.12}$

$\frac{AT}{Pole} = 298.16$

Pole area $= \frac{2\pi r l}{Pole} = \frac{2\pi \times \left(\frac{0.16}{2}\right) \times 0.12}{4} = 0.0151\ m^2$

Hence Magnetic field, $B = \frac{\phi_p}{Area} = \frac{0.0113}{0.0151} = 0.749\ T$ ⇒ Average field.

∴ B, Average field $= \frac{2 B_{(peak)}}{\pi}$ ⇒ $B_{(peak)} = \frac{\pi}{2} \times B = \frac{\pi}{2} \times 0.749$

So Peak flux density = 1.18 T.

12

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Q.5 (b) The fuel inputs per hour of plants 1 and 2 are given as

$$F_1 = 0.2P_1^2 + 40P_1 + 120 \text{ Rs./hr.}$$

$$F_2 = 0.25P_2^2 + 30P_2 + 150 \text{ Rs./hr.}$$

Determine the economic operating schedule and the corresponding cost of generation if the maximum and minimum loading in each unit is 100 MW and 25 MW, the demand is 180 MW, and the transmission losses are neglected. If the load is equally shared by both the units, determine the saving obtained by loading the units as per equal incremental production cost.

[12 marks]

Ans 5 (b) $F_1 = 0.2P_1^2 + 40P_1 + 120$ Rs/hr

So $\frac{dF_1}{dP_1} = 0.4P_1 + 40$ Rs/MW-hr $= \lambda$ —— (1)

also $F_2 = 0.25P_2^2 + 30P_2 + 150$ Rs/hr

$\Rightarrow \frac{dF_2}{dP_{g2}} = 0.5P_2 + 30 = \lambda \frac{Rs}{MW\text{-}hr}$ —— (2)

So, Given $P_1 + P_2 = 180$ MW —— (3) and $P_{max} = 100$ MW and $P_{min} = 25$ MW

from Economic load dispatch

$\frac{dF_1}{dP_{g1}} = \frac{dF_2}{dP_{g2}}$

$\Rightarrow 0.4P_1 + 40 = 0.5P_2 + 30 \Rightarrow 0.4P_{g1} - 0.5P_{g2} = -10$

$\Rightarrow 4P_1 - 5P_2 = -100$ —— (4)

from Eq (3) & (4) we get

$\Rightarrow P_1 = 88.88$ MW and $P_2 = 91.12$ MW [$\because 25\,MW < P_1, P_2 < 100\,MW$]

Case 2 If $P_1' = P_2' = 90$ MW then saving obtained $= ?$

old cost of generation $= F_1 + F_2 = 0.2(88.88)^2 + 40(88.88) + 120 + 0.25(91.12)^2 + 30(91.12) + 150$

$\Rightarrow C_1 =$ Rs 10214.44/hr

New cost of generation, $C_2 = F_1' + F_2'$

$C_2 = 0.2(90)^2 + 40(90) + 120 + 0.25(90)^2 + 30(90) + 150$

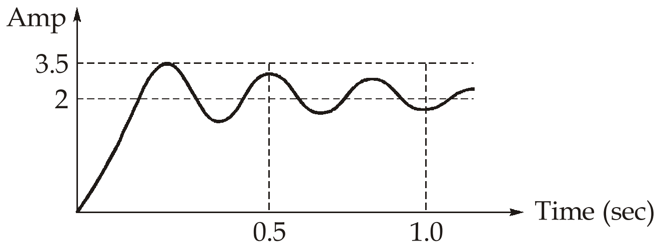
$=$ Rs 10215/hr

So saving will be $C_2 - C_1 = 10215 - 10214.44$

Hence saving will be $=$ Rs 0.56/hr.

12

Q.5 (c) Given below is the transient response of a second order system for a unit step input.



Find:

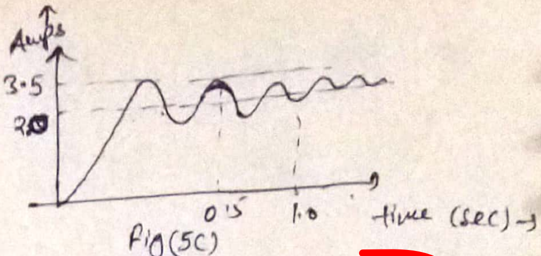
1. Natural frequency
2. Rise time
3. Peak time
4. Setting time (2% tolerance band)

[12 marks]

Ans 5(c) Given from graph

$C(t_p) = 3.5$ Amps

$C(\infty) = 2$ Amps



So % overshoot $(M_p) = \frac{C(t_p) - C(\infty)}{C(\infty)} \times 100 = \frac{3.5 - 2}{2} \times 100 = 75\%$

$\therefore M_p = e^{-\pi \xi / \sqrt{1-\xi^2}} = 0.75 \Rightarrow \xi = 0.0912$

Hence Damping factor, $\xi = 0.0912$.

From figure (5C) 1.5 cycle takes 0.5 sec

$\Rightarrow 1.5 \times \frac{2\pi}{\omega_d} = 0.5 \Rightarrow$ Damped frequency, $\omega_d = 18.85$ rad/sec

1. So, Natural frequency $\omega_n = \frac{\omega_d}{\sqrt{1-\xi^2}} = \frac{18.85}{\sqrt{1-0.0912^2}} = 18.928$ rad/sec.

2. Rise time, $t_r = \frac{\pi - \tan^{-1}\left(\frac{\sqrt{1-\xi^2}}{\xi}\right)}{\omega_d} = \frac{\pi - \tan^{-1}\left(\frac{\sqrt{1-0.0912^2}}{0.0912}\right)}{18.85}$

So rise time, $t_r = 0.0882$ sec

3. Peak time, $t_p = \frac{\pi}{\omega_d} = 0.167$ sec.

4. Settling time, $t_s = \frac{4}{\xi \omega_n} = \frac{4}{0.0912 \times 18.928}$

$= 2.317$ sec.

12

Q.5 (d) A single-phase ac voltage controller, connected to 230 V, 50 Hz source, is feeding a series load $R = 3\ \Omega$ and $X_L = 5\ \Omega$. For a firing angle delay of 120°, calculate the extinction angle and rms value of output voltage.

[12 marks]

Ans 5(d) ∴ $i_0 = \frac{V_m}{Z}\left[\sin(\omega t-\theta) - [\sin(\alpha-\theta)]\, e^{-\frac{(\omega t-\alpha)}{\omega \tau}}\right]$

Given $\alpha = 120°$ or $2\pi/3$ rad. and $\theta = \tan^{-1}\left(\frac{X_L}{R}\right) = \tan^{-1}(5/3)$

and $X_L = 5\Omega$, $R = 3\Omega$ So, $\theta = 59.04$ or 1.03^r.

∴ $\alpha > \theta$ So, $\beta > 180°$ So discontinous mode

Now, $i_0 = 0$

Ans 5(d)

$\frac{V_m}{Z}\left[\sin(\omega t-\theta) - \sin(\alpha-\theta)\, e^{-\frac{R}{X_L}(\beta-\alpha)}\right] = 0$ ∵ $\omega\tau = \frac{X_L}{R}$ and $\omega t = \beta$

⇒ $\sin(\beta-\theta) = \sin(\alpha-\theta)\, e^{-\left(\frac{R}{X_L}\right)(\beta-\alpha)}$

⇒ $\sin(\beta-1.03) = \sin(120-59.04)\, e^{-\left(\frac{3}{5}\right)(\beta-2\pi/3)} = 0.8745\, e^{+0.6\left(\frac{2\pi}{3}\right)} \cdot e^{-0.6\beta}$

⇒ $\sin(\beta-1.03) = 3.0726\, e^{-0.6\beta}$

On solving approximately we get $\beta = 221.5°$ or 3.866 rad. by trial method.

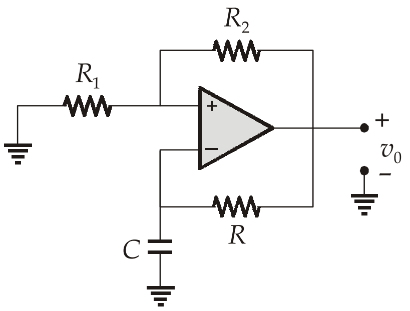
Now RMS value of output $V_{or} = V_m\left[\frac{1}{2\pi}(\beta-\alpha) + \frac{1}{2}(\sin 2\alpha - \sin 2\beta)\right]^{1/2}$

$V_{or} = 230\sqrt{2}\left[\frac{1}{2\pi}\left[(3.866-2.0944) + 0.5\,[\sin(240) - \sin(443)]\right]\right]^{1/2}$

⇒ RMS Voltage output $V_{or} = 119.67$ Volts.

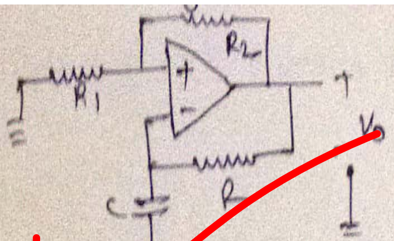
12

Q.5 (e) For the given opamp circuit, let the op-amp saturation voltages be ±10 V, R_1 = 100 kΩ, $R_2 = R$ = 1 MΩ and C = 0.01 μF. Find the frequency of oscillation.



[12 marks]

Ans5(e)



(Schmitt trigger)

Given $R_1 = 100k\Omega$, $R_2 = R = 1M\Omega$

$C = 0.01\mu F$

$V_{out} = \pm 10V$

For an astable multivibrator, $T = 2\tau \ln\left(\frac{1+\beta}{1-\beta}\right)$

where β = feed back factor $= \frac{R_1}{R_1+R_2} = \beta = \frac{100\times10^3}{100\times10^3 + 1\times10^6} = 1/11$

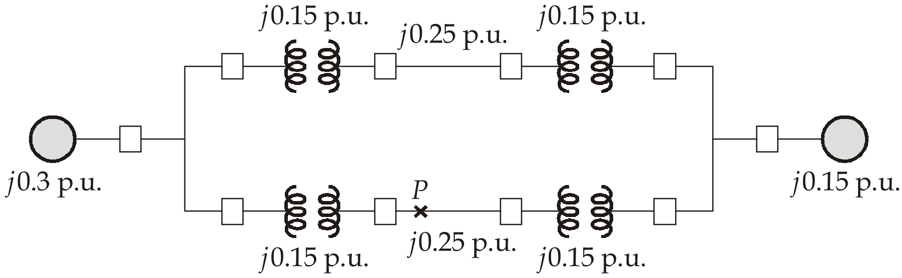
and $\tau = RC = 1\times10^{+6} \times 0.01\times10^{-6} = 0.01$ sec.

So, Time period $T = 2\times0.01 \ln\left(\frac{1+1/11}{1-1/11}\right)$

$= 3.6464\times10^{-3}$ sec

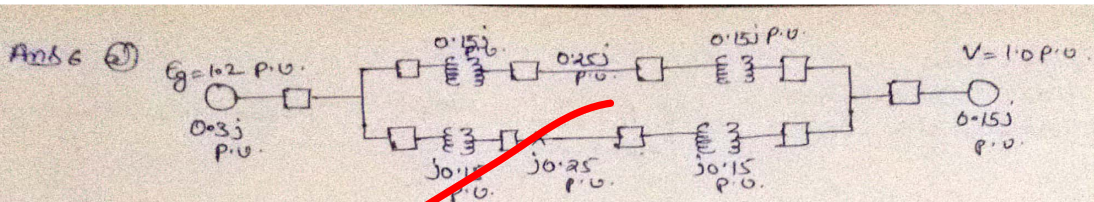
Hence $\boxed{\text{frequency} = 1/T = 274.2 Hz}$ frequency of oscillation

Q.6 (a) The single line diagram shows a generator connected to the metropolitan system (infinite bus) through high voltage lines. Determine the critical clearing angle for the generator for a 3-phase fault at the point P when the generator is delivering 1.0 p.u. power. Assume that the voltage behind transient reactances is 1.2 p.u. for the generator and that the voltage at the infinite bus is 1.0 p.u.. Breakers adjacent to a fault on both sides are arranged to clear simultaneously.



[20 marks]

Ans 6 (a)



Given generator delivering power $P_1 = 1.0$ p.u.

Maximum Power supplied $P_{max} = \frac{EV}{|X_{net}|}$ —— (1)

Now $X_{net} = 0.3j + (0.15j + 0.25j + 0.15j) \| (0.15j + 0.25j + 0.15j) + 0.15j$

$= 0.725j$ p.u.

So, $P_{max} = \frac{1.2 \times 1}{|0.725j|} = 1.655$ p.u.

As we know that $P_m = P_{max} \sin\delta \Rightarrow P_1 = P_{max} \sin\delta_0$

So $\delta_0 = \sin^{-1}\left(\frac{P_1}{P_{max}}\right) = \sin^{-1}\left(\frac{1}{1.655}\right) = 37.173° = 0.649^r$

During fault, $P_2 = 0$ p.u.

After fault, P_3 is Max Power supplied by the generator

X_{net} new $= 0.3j + 0.15j + 0.25j + 0.15j + 0.15j$

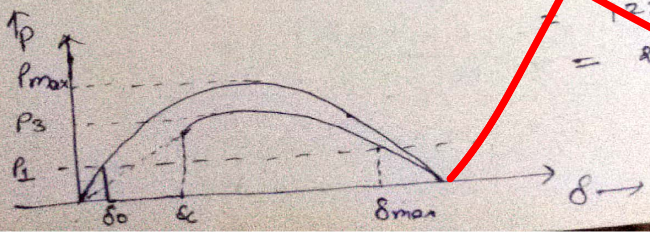
$= 1j$

So, P_3 = Max Power supplied by generator $= \frac{1.2 \times 1}{|j|} = 1.2$ p.u.

So, $\delta_{max} = \pi - \sin^{-1}\left(\frac{P_m}{P_3}\right) = \pi - \sin^{-1}\left(\frac{1}{1.2}\right)$

$= 123°.57'$ (degree)

$= 2.156^r$ (radian)



As we know that critical Clearing angle, $\delta_c = \cos^{-1}\left[\frac{P_1[\delta_{max}-\delta_0]\frac{\pi}{180} + P_3\cos\delta_{max} - P_2\cos\delta_0}{P_3 - P_2}\right]$

$\Rightarrow \delta_c = \cos^{-1}\left[\frac{1\times(2.156 - 0.[illegible]) + 1.2\cos 123.57 - 0}{1.2 - 0}\right]$

$\Rightarrow \boxed{\delta_c = 45.34^\circ}$

Hence critical clearing angle is 45.34° (degree)

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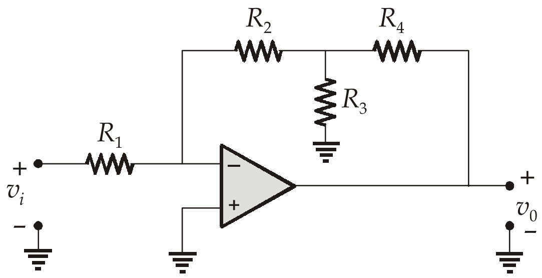
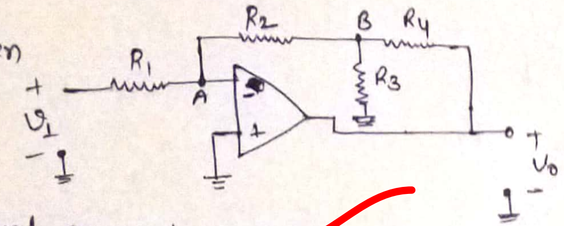
Q.6 (b) For the given op-amp circuit, derive the expression for closed-loop gain v_0/v_i. Hence, determine the resistance R_1, R_2, R_3 and R_4 to obtain a gain of 100 and input resistance of 1 MΩ (Resistance must not be greater than 1 MΩ).



[20 marks]

Ans 6 (b) Given



Due to virtual ground concept, $V_A = 0V$

Applying KCL at Node A

$$\frac{0-V_i}{R_1} + \frac{0-V_B}{R_2} = 0 \Rightarrow -V_i\frac{R_2}{R_1} = V_B \quad \text{—— (1)}$$

$[\because V_A = 0V]$

Applying KCL at Node B

$$\frac{V_B - V_A}{R_2} + \frac{V_B}{R_3} + \frac{V_B - V_o}{R_4} \Rightarrow V_B\left[\frac{1}{R_2} + \frac{1}{R_3} + R_4\right] = \frac{V_o}{R_4}$$

⇒ From Eq (1) we have

$$-V_i\frac{R_2}{R_1}\left[\frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4}\right] = \frac{V_o}{R_4}$$

Do not write in this margin

$\Rightarrow \dfrac{V_o}{V_i} = -\dfrac{R_2}{R_1}\left[\dfrac{R_4}{R_2} + \dfrac{R_4}{R_3} + 1\right]$, Now input resistance, $R_i = 1M\Omega$

So, $\dfrac{V_i}{i_i} = R_1 = 1M\Omega$ (Max. limit)

Given, gain $= \dfrac{V_o}{V_i} = 100 = |A_V|$

Let us choose $R_2 = 1M\Omega$

So $\left[1 + \dfrac{R_4}{R_3} + \dfrac{R_4}{R_2}\right] = 100 \Rightarrow \dfrac{R_4}{R_3} + \dfrac{R_4}{R_2} = 99$

$\Rightarrow \dfrac{R_4}{R_3} + \dfrac{R_4}{1} = 99$; If we assume $R_4 = 1M\Omega$

then $\dfrac{1}{R_3} + 1 = 99 \Rightarrow \dfrac{1}{R_3} = 98 \Rightarrow R_3 = 10.20\,k\Omega$

$\therefore$ Maximum limit of resistance $= 1M\Omega$ So R_3 value is acceptable.

Hence, $R_1 = 1M\Omega = R_2 = R_4$ and $R_3 = 10.20\,k\Omega$.

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Q.6 (c) For the ideal type-A chopper feeding RLE load, show that the average input current is given by,

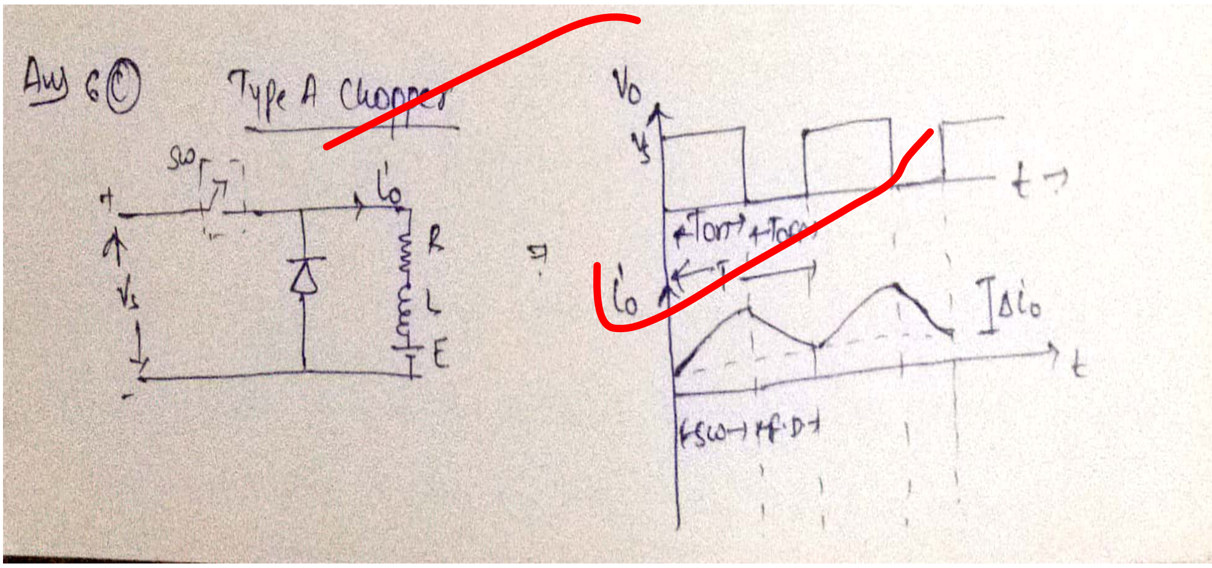
$$I_{av} = \frac{\alpha(V_s - E)}{R} - \frac{fL}{R}(\Delta I_0)$$

Where, V_S : Supply voltage, α : Duty cycle;

f : Switching frequency, ΔI_0 : Load current peak to peak ripple

Also, find the expression for average current in freewheeling diode. Assume continuous conduction mode.

[20 marks]



During Ton: $V_s = L\frac{di_0}{dt} + E + Ri_0$ and $i_s = i_0$

So, $Ri_s + L\frac{di_s}{dt} = V_s - E$

Integrating both sides we get and taking average

$$\frac{R}{T}\int_0^{t_{on}} i_s dt + \frac{L}{T}\int_0^{t_{on}} \frac{di_s}{dt}dt = \frac{1}{T}\int_0^{T_{on}} (V_s - E)dt$$

$$\Rightarrow R I_{average} + L\frac{\Delta I_0}{T} = (V_s - E)\frac{T_{ON}}{T}$$

$$\text{So } I_{avg.} = \frac{\alpha(V_s - E)}{R} - \frac{Lf\Delta I_0}{R} \quad \text{where } \alpha = T_{ON}/T$$

During toff period.

$Ri_0' + L\frac{di_0}{dt} + E = 0$, also freewheeling conduction.

$$\Rightarrow \boxed{i_{FD} = i_0'}\left(\frac{T_{off}}{T}\right)$$

take average both side.

$$\frac{R}{T}\int_{T_{on}}^{T} i_0 dt + \frac{L}{T}\int_{T_{ON}}^{T}\frac{di_0}{dt}dt + \frac{E}{T}\int_{T_{ON}}^{T} dt = 0$$

$$\Rightarrow \frac{R}{T} T_{off} \cdot i_0 + \frac{L}{T}(-\Delta I_0) + \frac{E}{T}T_{off} = 0$$

$$\Rightarrow \text{So, } R\, I_{FD} + Lf(-\Delta I_0) + (1-D)E = 0$$

$$\Rightarrow \boxed{I_{FD} = \frac{fL(\Delta I_0)}{R} - \frac{E(1-D)}{R}}$$

where $D = \frac{T_{ON}}{T_{ON} + T_{off}}$

or $\boxed{D = \alpha}$

18

Q.7 (a) **(i)** Give transfer function of a causal system

$$H(s) = \frac{2s+3}{s^2+2s+5}$$

1. Find the mark the location of its zeros and poles in s-plane.
2. Sketch the ROC.
3. Is the system BIBO stable? Explain.
4. Write the differential equation relating output $y(t)$ to the input $x(t)$.
5. Find the system's impulse response.

(ii) Signal $x(t)$ is given as

$$x(t) = te^{-|t|},\ t \in \left[-\frac{1}{2}, \frac{1}{2}\right]$$

$$x(t) = x(t+1)$$

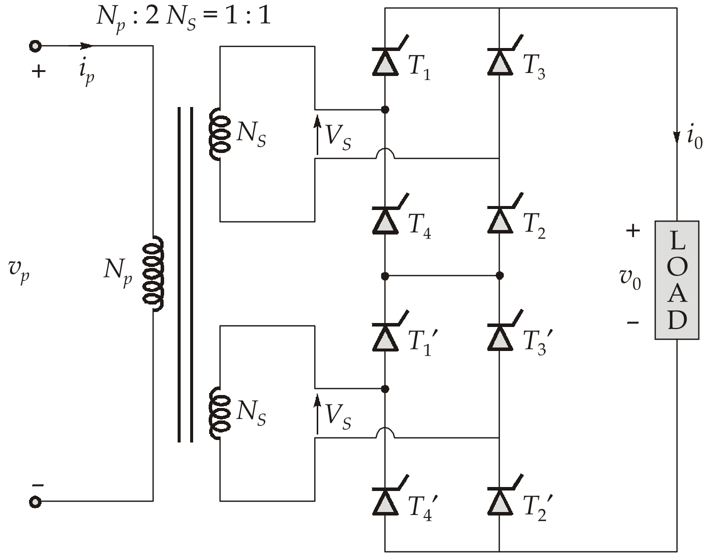
Compute the trigonometric fourier series coefficients of $x(t)$.

[10 + 10 marks]

Q.7 (b) For the given series full converter, the load current is continuous and constant at I_0. The converters operate in rectification mode such that $\alpha_1 = 0$ and $\alpha_2 = \pi/2$.

(i) Draw the waveforms of output voltage and supply current.

(ii) If input voltage is 120 V, calculate the values of average output voltage, rms output voltage, harmonic factor, displacement factor and input power factor.



[20 marks]

Q.7 (c) For the given open loop transfer function $G(s) = \dfrac{K(s^2+2s+2)}{s(s^2+1)}, K > 0$. Plot the root locus on a graph paper and obtain:

(i) Open loop poles and zeros, centroid, asymptotes, real and imaginary axis portion part of root locus.

(ii) Angle of departure and arrival of all OL poles and zeros.

(iii) Break-away and break-in point.

(iv) Gain value K for damping ratio $\xi = 0.5$.

[20 marks]

Q.8 (a) **(i)** What is bubble memory?

(ii) 2 kB RAM, 2 kB ROM, one input and one output device are to be interfaced with 8085 microprocessor. Employ memory mapped I/O scheme to execute the above.

(iii) How many ports are there in 8255 and what are they?

[4 + 12 + 4 marks]

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Q.8 (b) Using Radix-2 Decimation-in-frequency FFT algorithm to find the discrete frequency-domain samples of a signal, $s[n] = \{0, 4, -4j, 0, 0, 4j, -4, 0\}$.

[20 marks]

Q.8 (c) **(i)** A 50 kVA, 2400/240 V single-phase transformer has a short circuit test performed on its high-voltage side. An open-circuit test is performed on low voltage side. The following test results were obtained:

Open Circuit Test	**Short Circuit Test**
$V_{OC} = 240$ V,	$V_{SC} = 48$ V
$I_{OC} = 5.4$ A,	$I_{SC} = 20.8$ A
$P_{OC} = 186$ W,	$P_{SC} = 620$ W

1. Draw the transformer equivalent circuit referred to HV side. Find R_e, X_e, R_c, X_m.
2. Determine its voltage regulation and efficiency at rated load, 0.8 power factor lagging, and rated voltage at the secondary terminals.

(ii) A transformer has its maximum efficiency of 0.98 at 15 kVA at upf. Compute the all-day efficiency for the load cycle of full load for 4 hours/day and 0.4 full-load rest of the day. Assume load to operate on upf all day.

[12 + 8 marks]

❍❍❍❍

Space for Rough Work

Space for Rough Work

Space for Rough Work

Space for Rough Work