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QUESTIONS WITH DETAILED SOLUTIONS

ELECTRICAL ENGINEERING

(Paper-2)

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ELECTRICAL ENGINEERING

ESE MAINS 2025_PAPER – II

Questions with Detailed Solutions

SUBJECT WISE WEIGHTAGE

S.No	NAME OF THE SUBJECT	Marks
01	Analog and Digital Electronics	72
02	Systems and signal processing	72
03	Control systems	84
04	Electrical Machines	84
05	Power Systems	84
06	Power Electronics	84
	Total Marks	**480**

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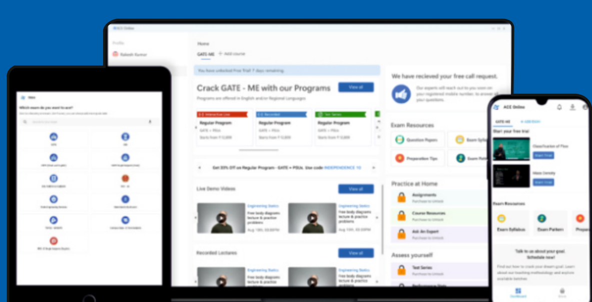

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SECTION – A

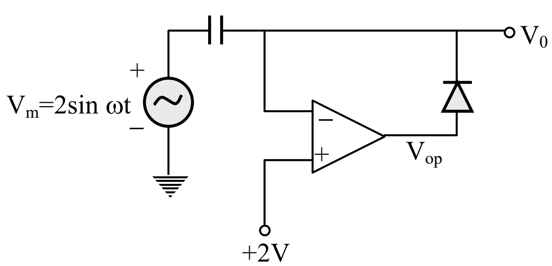
1[a] Give the circuit diagram of a negative peak clamper circuit using op-amp, and

(i) Considering V_{ref} = +2 V, sketch the output waveform for an input signal v_i = 2sin(1000t).

(ii) Provide conditions to achieve precision clamping and explain how will you protect op-amp against excessive discharge currents.

(iii) State how will you modify your circuit to achieve positive peak clamping [12M]

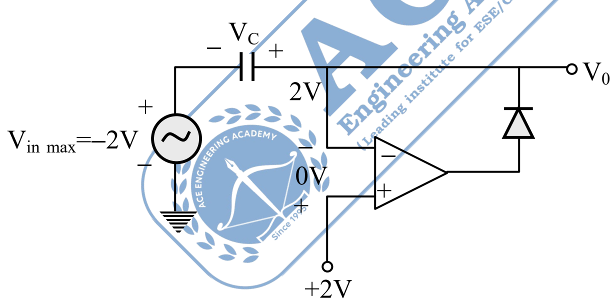
Solution



Let V_{op} is pos for diode ON

Step 1:

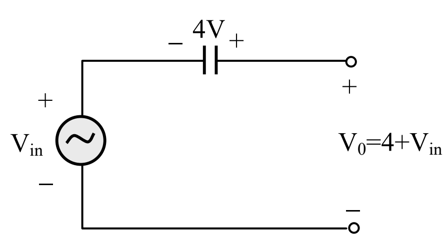
$V_{in} < 2$ V → V_{op} positive and capacitor charges

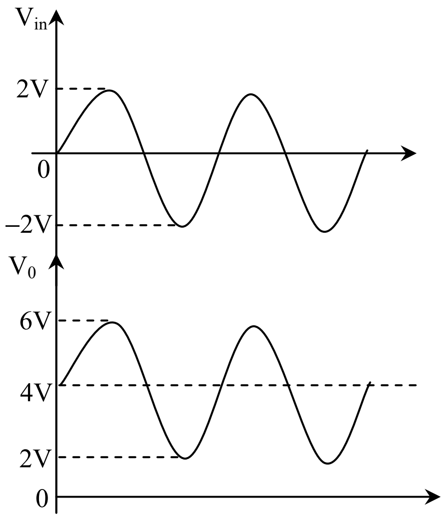


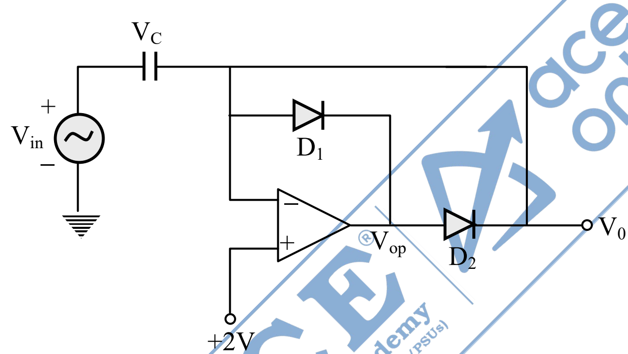
$V_{Cmax} = 2 -(-2) = +4$ V

Step 2:

After capacitor is fully charged the diode is R_B







In order to avoid V_{op} to reach saturation when D_2 is OFF, D_1 will be ON avoiding saturation at output.

1[b] A 7.5 kW, 440 V, 3-phase, star-connected, 50 Hz, 4-pole squirrel cage induction motor develops full load torque at a slip of 3% when operated at rated voltage and frequency. The leakage reactance of stator and rotor windings are five times the respective stator and rotor resistances. The ratio of stator to rotor winding is 3 : 5. Determine the percentage increase in stator reactance to limit starting current to 2.5 times the full load current. Assuming R_1 and R_2 are equal and of requisite amount, and motor has negligible magnetizing reactance and core losses. [12M]

Solution:

V_L = 440 V; Y-connected

$$V_L/ph = \frac{440}{\sqrt{3}} = 254.03 \text{ V}$$

Let $R_1 = R_2 = R$, $X_1 = 5$ R

$X_{20} = 5R$

$a = \frac{3}{5} = 0.6;\ R'_2 = R_2 a^2$

$= R \times 0.6^2$

$= 0.36\ R$

$X'_2 = 0.6^2 \times 5R = 1.8R$

$s_{fl} = 0.03$

Assuming the mechanical losses are neglected

$P_{im} = 7.5$ kW

$$P_{ag} = \frac{P_{im}}{1-s} = \frac{7.5\times10^3}{1-0.03}$$

$= 7.731$ kW

$$P_{ag} = 3\frac{V_1^2}{\left[\left(R+\frac{R'_2}{s}\right)\right]^2 + [X_1 + X'_2]^2} \times \frac{R'_2}{s}$$

$$= \frac{3\times 254.03^2}{\left[\left(R+\frac{0.36R}{0.03}\right)\right]^2 + [5R+1.8R]^2} \times \frac{0.36R}{0.03}$$

$= 7.731 \times 10^3$

Solving for R

$R = 1.4\ \Omega$

$$I_{fl} = \frac{V_1}{\sqrt{\left(R_1 + \frac{R'_2}{s}\right)^2 + (X_1 + X'_2)^2}}$$

$$= \frac{254.03}{\sqrt{\left(1.4 + \frac{0.36\times1.4}{0.03}\right)^2 + [5R+1.8R]^2}}$$

$$= \frac{254.03}{\sqrt{\left(1.4 + \frac{0.36\times1.4}{0.03}\right)^2 + (6.8\times1.4)^2}} = 12.36$$

Similarly

$$I_{st} = \frac{254.03}{\sqrt{\left(14 + \frac{0.36\times1.4}{1}\right)^2 + (6\times1.4)^2}} = 26.16\ \text{A}$$

$$\frac{I_{st}}{I_{fl}} = \frac{26.16}{12.36} \leq 2.116$$

Percentage increase should be zero.

1[c] In a short circuit test on a 3-pole, 110 kV circuit breaker, power factor of the fault was 0.4, the recovery voltage was 0.95 times full line value. The breaking current was symmetrical. The frequency of oscillation of restriking voltage was 15,000 cycles/sec. Estimate the average rate of rise of restriking voltage. The neutral is grounded and fault involves earth. [12M]

Solution:

$V_L = 110$ kV

$$V_{ph(rms)} = \frac{110}{\sqrt{3}} \text{kV}$$

$$V_m = \sqrt{2} \times \frac{110}{\sqrt{3}} \text{kV} = 89.814 \text{ kV}$$

$\cos\phi = 0.4 \Rightarrow \sin\phi = 0.917$

$K_1 = 0.95; K_2 = 1$

$$f = 15000 \text{ cycles/sec} = 15000 \text{ Hz} = \frac{1}{2\pi\sqrt{LC}}$$

$$RRRV_{avg} = \frac{2.ARV}{\pi\sqrt{LC}} \times \frac{2}{2}$$

$$= \frac{4 \times K_1.K_2 V_m \sin\phi}{2\pi\sqrt{LC}}$$

$$= 4 \times 0.95 \times (1) \times 89.814 \times 0.917 \times 10^3 \times 15000$$

$$= 4.69 \text{ kV}/\mu\text{sec}$$

1[d] The standstill impedances of the inner and outer cages of a double cage 3-ϕ induction motor rotor are given as Z_{ic} = (0.1 + j0.5) Ω and Z_{oc} = (0.05 + j0.1) Ω respectively. Assuming the stator impedance to be negligible, determine the approximate ratio of the torques produced by the output cage (T_{oc}) to the torque produced by the inner cage (T_{ic}) at a slip of s = 0.05? Also determine the net torque developed as a function of T_{oc} and comment on performance as compared to single cage motor. [12M]

Solution:

Given

$Z_{ic} = 0.01 + j0.5\ \Omega$

$R_{ic} = 0.01\ \Omega;\ X_{ic} = 0.5\ \Omega$

$Z_{oc} = 0.05 + j0.1\ \Omega$

$R_{oc} = 0.05;\ X_{oc} = 0.1\Omega$

Neglected, stator impedance

$$T_{em} = K'\frac{V_1^2 \times \frac{R_2'}{2}}{\left(\frac{R_2'}{s}\right)^2 + X_{oc}^2}$$

$$\frac{T_{oc}}{T_{ic}} = \frac{\dfrac{R_{oc}/s}{\left(\frac{R_{oc}}{s}\right)^2 + X_{oc}^2}}{\dfrac{\frac{R_{ic}}{s}}{\left(\frac{R_{ic}}{s}\right)^2 + X_{ic}^2}}$$

$$\frac{T_{oc}}{T_{ic}} = \frac{\dfrac{\frac{0.05}{0.05}}{\left(\frac{0.05}{0.05}\right)^2 + 0.1^2}}{\dfrac{\frac{0.01}{0.05}}{\left(\frac{0.01}{0.05}\right)^2 + 0.5^2}} = 1.436$$

Net torque

$T_{net} = T_{ic} + T_{oc}$

$= T_{ic} + 1.436\ T_{ic}$

$= 2.436\ T_{ic}$

Because of high resistance of output cage staring torque is high, because of low resistance of inner cage the running performance is good.

1[e] A 10 MVA, 13.8 kV turbo-generator having $X_d'' = X_2 = 15\%$ and $X_0 = 5\%$ is about to be connected to power system. The generator has current limiting reactor of 0.7 Ω in the neutral. Before the generator is connected to the system, its voltage is adjusted to 13.2 kV. When a double line to ground fault develops at terminal 'b' and 'c', find the initial symmetrical rms currents in the ground and in line 'b'. [12M]

Solution:

$S_{B(3-\phi)} = 10\text{MVA}$

$V_{BL} = 13.8 \text{ kV}$

$X_d'' = X_1 = X_2 = 0.15$

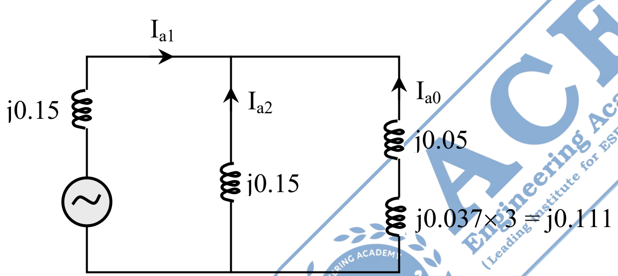
$X_0 = 0.05$

$X_n = 0.7\Omega$

$V_{PF} = 13.2 \text{ kV}$

$$X_{npu} = 0.7 \times \frac{10\times10^6}{(13.8\times10^3)^2}$$

$$= 0.037\text{PU}$$



$$I_{a1} = \frac{V_{PF}}{j(X_1 + (X_2 \parallel (X_0 + 3X_n)))}$$

$$V_{PF} = \frac{13.2}{13.8} = 0.957 \text{ PU}$$

$$\therefore\ I_{a1} = \frac{0.957}{j(0.15 + (0.15 \parallel (0.05 + 0.111)))}$$

$$= \frac{-j0.957}{0.15 + 0.078}$$

$$= -j4.197 \text{ PU}$$

$$\therefore\ I_{a0} = -I_{a1} \times \frac{j0.15}{j0.15 + j0.05 + j0.111}$$

$$= +j4.197 \times \frac{0.15}{0.311}$$

$I_{a0} = j2.02$ PU

$I_{a2} = j2.177$

$\therefore\ I_f = 3.I_{a0} = 3 \times j2.02 = j6.06$ PU

$I_b = I_{b0} + I_{b1} + I_{b2} = I_{a0} + K^2.\ I_{a1} + K.I_{a2}$

$= j2.02 + 1\angle{-120}\times 4.197\ \angle{-90} + 1\angle 120 \times 2.177\angle 90$

$= -5.52 + j3.03 = 6.29\angle 151.23$ PU

2[a] A 15 km long 3-phase overhead line delivers 5 MW at 11 kV at a power factor of 0.8 lagging. Line loss is 12% of the power delivered. Line inductance is 1.1 mH per km per phase.

Calculate:

(i) Sending end voltage and voltage regulation **[15M]**

(ii) Power factor of the load to make voltage regulation zero. **[5M]**

Solution:

$\ell = 15$ km

$P_D = 5$MW

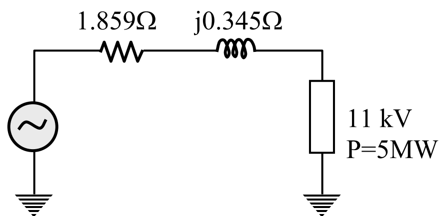
$V_{RL} = 11$ kV

$\cos\phi = 0.8$

$P_{Loss} = 0.12 \times 5$MW

$= 0.6$ MW

$L = 1.1$ mH/km



$$P_{3-\phi} = \sqrt{3}.V_{RL}.I_{RL}.\cos\phi$$

$$\therefore\ I_{RL} = I_{Rph} = \frac{5\times 10^6}{\sqrt{3}\times 11\times 10^3 \times 0.8} = 328\text{ A}$$

$P_{Loss(3-\phi)} = 3.I_R^2.R$

$$\frac{0.6\times10^6}{3\times(32P)^2} = R$$

$\therefore R = 1.859\Omega$

$\therefore Z = R + jX_L$

$= 1.859 + j0.345\ \Omega$

$= 1.89\angle10.51\Omega$

(i) $V_{S_{ph}} = V_{Rph} + I_R.Z$

$$= \frac{11}{\sqrt{3}}\angle0kV + 328\angle-36.86\times(1.89\angle10.51)$$

$= 6906.36 - j275.15$

$= 6.911\angle-2.28kV$

$\therefore V_{SL} = \sqrt{3}\times6.911$

$= 11.97\ kV$

$$\%\ V_{reg} = \frac{I_R.Z\cos(\theta-\phi_R)}{V_R}\times100$$

$$= \frac{328\times1.89\cos(10.51-36.86)}{(11/\sqrt{3})\times10^3}\times100$$

$= 8.74\%$

(ii) To have zero voltage regulation

$\theta + \phi_R = 90°$

$\phi_R = 90 - \theta = 90 - 10.51$

$= 79.49$

$\therefore \cos\phi = 0.182$

2[b] A 2200/220 V, single phase transformer has maximum possible voltage regulation of 6% and it occurs at a power factor of 0.3 lag. Find the load voltage at full load at a power factor of 0.8 lead. [20M]

Solution:

Given a 1-ϕ, $\frac{2200V}{220V}$

Maximum voltage Regulation = 6% = %z

At a pf of $\cos\phi = 0.3$

$$\cos\phi = \frac{\%R}{\%Z} = 0.3$$

$\Rightarrow \%R = 1.8\%$

$$\%X = \sqrt{\%Z^2 - \%R^2}$$

$$= \sqrt{6^2 - 1.8^2}$$

$\%X = 5.72\%$

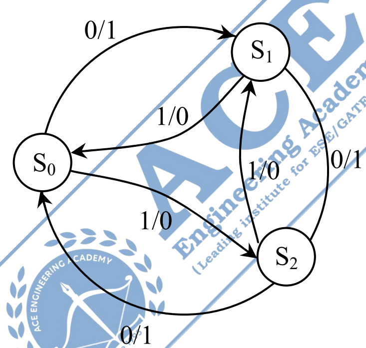
%Regulation at 0.8 pf lead

$$\%\ \text{Regulation} = (\%R)\cos\phi - (\%X)\sin\phi$$

$$= 1.8 \times 0.8 - 5.72 \times 0.6$$

$$= -1.99\%$$

2[c] (i) For the state diagram shown below, design the circuit using D-flip flops. Assume S_0 : 00, S_1 : 10 and S_2 : 01.



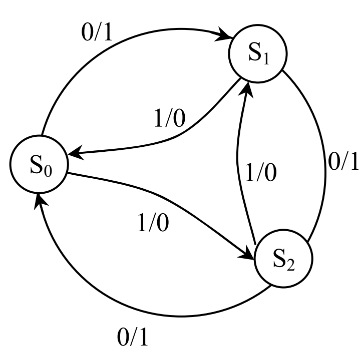
Realize the signal circuits with minimum number of NAND gates (More than two input NAND gates are allowed). [10M]

Solution:

S_0 : 0 0

S_1 : 1 0

S_2 : 0 1



PS	PI	NS	O/P
S_0	0	S_1	1
S_0	1	S_2	0
S_1	0	S_2	1
S_1	1	S_0	0
S_2	0	S_0	1
S_2	1	S_1	0

	PS $\theta_1\theta_2$	PI X	NS $\theta_1\theta_0$	FF i/ps D_1D_0	O/P Z
0	00	0	10	10	1
1	00	1	01	01	0
4	10	0	01	01	1
5	10	1	00	00	0
2	01	0	00	00	1
3	01	1	10	10	0

$D_1 = \sum m(0, 3)$

$D_0 = \sum m(1, 4)$

$Z = \sum m(0, 2, 4)$

θ_1 \ $\theta_0 x$	00	01	11	10
0	1		1	
1				

$$D_1 = \bar{\theta}_1\bar{\theta}_0\bar{x} + \bar{\theta}_1\theta_0 x$$

$$= \bar{\theta}_1(\theta_0 \odot x)$$

θ_1 \ $\theta_0 x$	00	01	11	10
0		1		
1	1			

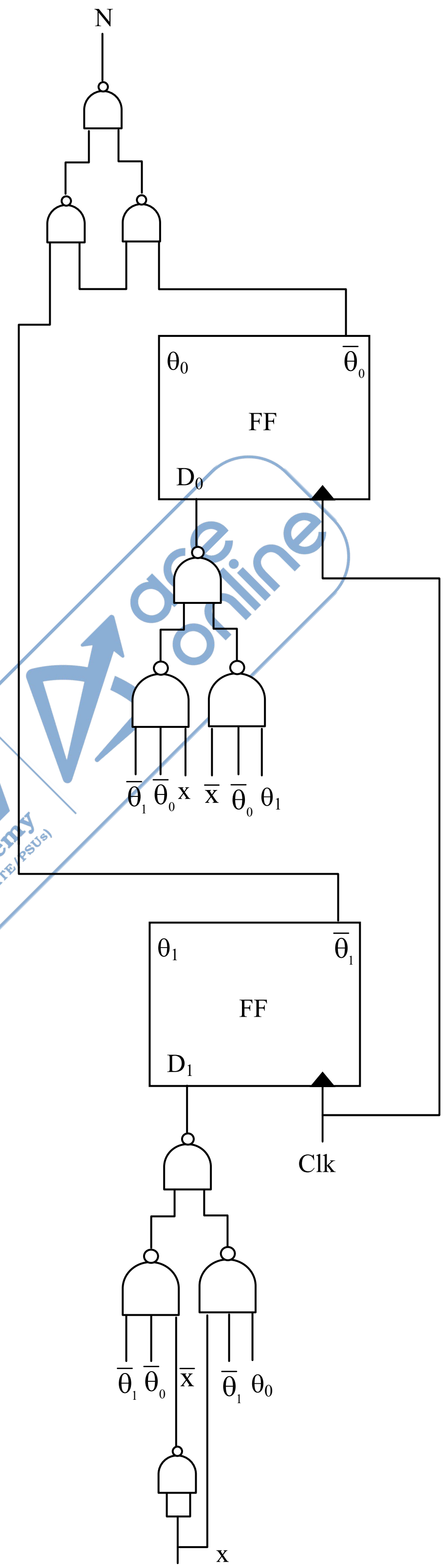
$D_0 = \bar{\theta}_1\bar{\theta}_0 x + \theta_1\bar{\theta}_0\bar{x}$

$= \bar{\theta}_0\,(\theta_1 \oplus x)$

θ_1 \ $\theta_0 x$	00	01	11	10
0	1			1
1	1			

$Z = \bar{\theta}_1\bar{x} + \bar{\theta}_0\bar{x}$

$= \bar{x}\left(\bar{\theta}_1 + \bar{\theta}_0\right)$



2[c] (ii) An angle modulated signal is given as

X(t)=20 cos(12000 t) for | t | ≤ 1

If the carrier wave frequency ω_c = 10000 rad/sec, determine

(A) Modulation index m(t), if X(t) were a PM (phase modulated) signal with K_p=500 over | t | ≤ 1.

(B) Modulation index m(t), if X(t) were a frequency modulated (FM) signal with K_f= 500 over | t | ≤ 1. **[10M]**

Solution:

$X(t) = 20\cos(1200t),\ |t| \le 1$ (or) $-1 \le t \le 1$

$\omega_c = 10000$ (rad/sec)

NOTE: This might be the message signal

A_m (or) $|m(t)|_{max} = 20$(volts)

$$f_{max} = \frac{1200}{2\pi}(\text{Hz})$$

(A) $$\beta_{PM} = \Delta\phi_{MAX} = K_p|m(t)|_{MAX}$$

$$= 500 \times 20$$

$$= 10000$$

(B) $$\beta_{FM} = \frac{\Delta f_{max}}{f_{max}} = \frac{K_f|m(t)|_{MAX}}{f_{max}}$$

$$= \frac{500 \times 20 \times 2\pi}{1200}$$

$$= \frac{5 \times 20 \times 2\pi}{12} = \frac{200\pi}{12} = 52.35$$

3[a] Give the circuit diagram of a second order highpass Butteworth filter circuit using op-amp. Evaluate the component values, such that the filter has lower cutoff frequency of 5 kHz and a pass band gain A_F = 2. Also give expression for voltage gain magnitude and sketch its frequency response. **[20M]**

Solution:

The normalized butterworth polynomial for second order is

$$S_n^2 + 1.414S_n + 1$$

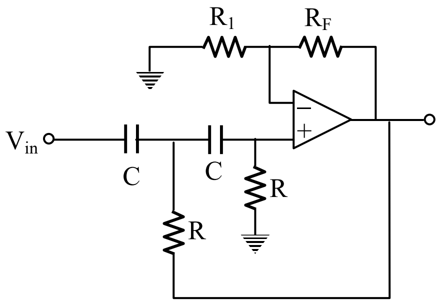
This is of the form

$$S_n^2 + (3 - A_0)S_n + 1 \text{ of the Salen – key filter drawn below}$$

$$\therefore 3 - A_0 = 1.414$$

$$\rightarrow \quad A_0 = 1.586$$

Second order high pass Butterwork filter



Given cutoff frequency $f_C = \frac{1}{2\pi RC} = 5$ kHz

Let $C = 0.1\ \mu F \rightarrow R = \frac{1}{2\pi(5K)(0.1\mu)}$

$R = 318.309\ \Omega$

Gain for Butterworth filter = 1.586

$\therefore\ 1.586 = 1 + \frac{RF}{R_1}$

Let $R_1 = 10\ k\Omega \rightarrow R_F = 5.86\ k\Omega$

3[b] A 50 Hz alternator is supplying 40% of the power that it is capable of delivering through a transmission line to an infinite bus. A fault occurs that increases the reactances between the generator and the infinite bus to 600% of the value before the fault. When the fault is isolated, the maximum power that can be delivered is 80% of the original maximum value, find critical clearing angle. [20M]

Solution:

$P_s = P_{e1} = 0.4\,P_{max_1}$

So, $\sin^{-1}\left(\frac{P_s}{P_{max_1}}\right) = \sin^{-1}(0.4) = 23.57 = 0.4113$ rad

$P_{max_2} = \frac{EV}{X_{2equ}} = \frac{EV}{6 \times X_{1equ}}$

$P_{max_2} = 0.167 \times P_{max_1}$

$P_{max_3} = 0.8P_{max_1} = 0.8 \times \frac{P_s}{0.4}$

$\therefore\ \frac{P_s}{P_{max_2}} = \frac{0.4}{0.8} = 0.5$

$$\therefore\ S_{max} = 180 - \sin^{-1}\left(\frac{P_s}{P_{max_3}}\right) = 180 - \sin^{-1}(0.5)$$

$$= 150$$

$$= 2.618 \text{ rad}$$

$$\therefore\ \delta_C = \cos^{-1}\left[\frac{P_s(\delta_{max} - \delta_0) + P_{max_3}\cos\delta_{max} - P_{max_2}\cos\delta_0}{P_{max_3} - P_{max_2}}\right]$$

$$= \cos^{-1}\left[\frac{0.4P_{max_1}(2.618 - 0.4113) + 0.8P_{max_1} \times \cos(150) - 0.167P_{max_1}\cos(23.57)}{0.8P_{max_1} - 0.167P_{max_1}}\right]$$

$$= \cos^{-1}\left[\frac{0.4 \times 2.2067 + 0.8 \times (-0.866) - 0.167 \times 0.917}{0.8 - 0.167}\right]$$

$$= \cos^{-1}(0.0580)$$

$$= 86.67$$

3[c] A 240 V D.C. series motor takes 40 A when giving its rated output at 1500 rpm. Its resistance is 0.3Ω. Calculate the value of resistance that must be added to obtain the rated torque

(i) during starting and

(ii) at 1000 rpm **[20M]**

Solution:

Given 240 V,

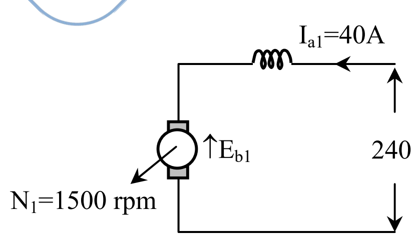
$I_{a1} = 40$ A at rated output

$N_1 = 1500$ rpm

$R = 0.3\ \Omega$

$E_{b1} = 240 - 40(0.3)$

$= 228$ V



(i) For rated torque $\Rightarrow I_{a2} = 40$ A

At starting $\Rightarrow I_a = \dfrac{V - 0}{R + R_e}$

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$$\Rightarrow 40 = \frac{240}{0.3 + R_e}$$

$$\Rightarrow R_e = 5.7\ \Omega$$

(ii) At rated torque, $I_{a2} = I_{a1} = 40$ A

For $N_2 = 1000$ rpm $\Rightarrow R_e = ?$

$E_{b2} = 240 - 40(R + R_e)$

$$\therefore \frac{N_2}{N_1} = \frac{E_{b2}}{E_{b1}} \times \frac{\phi_1}{\phi_2}$$

$$\Rightarrow \frac{1000}{1500} = \frac{240 - 40(0.3 + R_{ee})}{228} \times 1$$

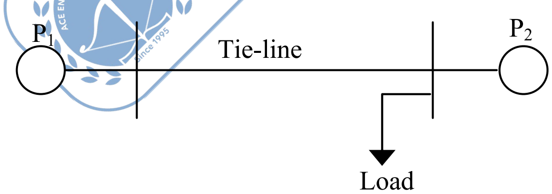
$$\Rightarrow R_e = 1.9\ \Omega$$

4[a] Figure shows a two bus system. If a power of 125 MW is transferred from plant 1 to load, a power loss of 15.625 MW occurs. Find generation schedule and load demand if cost of received power is ₹24 per MWh. The incremental production costs are

$$\frac{dF_1}{dP_1} = 0.025\ P_1 + 15$$

$$\frac{dF_2}{dP_2} = 0.05 P_2 + 20$$

Assume penalty factor of 2nd generator = 1. **[20M]**



Solution:

$P_1 = 125$ MW

$P_L = 15.625$ MW

$P_L = B_{11}.\ PG_1^2$

$15.625 = B_{11} \times (125)^2$

$\therefore B_{11} = 0.001\ MW^{-1}$

Penalty factor of plant–1

$$L_1 = \frac{1}{1 - \frac{\partial P_2}{\partial P_{G_1}}} \; ; \; \frac{\partial P_L}{\partial P_{G_1}} = 2.B_{11}.P_{G_1}$$

$$= \frac{1}{1 - 0.25} \qquad = 2 \times 0.001 \times 125$$

$$= 1.33 \qquad = 0.25$$

$L_2 I_{C2} = 24$

$0.05P_2 + 20 = 24$

$0.05\ P_2 = 4$

$$P_2 = \frac{4}{0.05} = 80MW$$

$\therefore$ Total power received $= P_1 + P_2 - P_L$

$= 125 + 80 - 15.625$

$= 189.375$ MW

4[b] (i) Give the block diagram of AM Receiver and FM Receiver. Also explain each block. [10M]

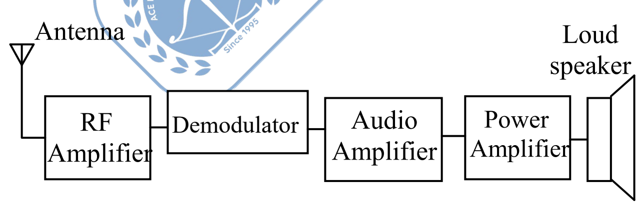
Solution:

AM Receivers:

(1) Tuned radio frequency (TRF) Receiver

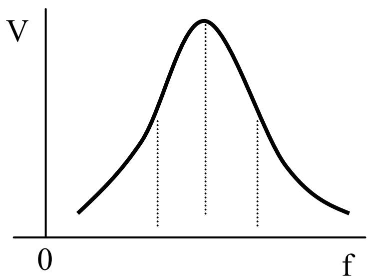
(2) Superheterodyne Receiver

TRF Receiver:



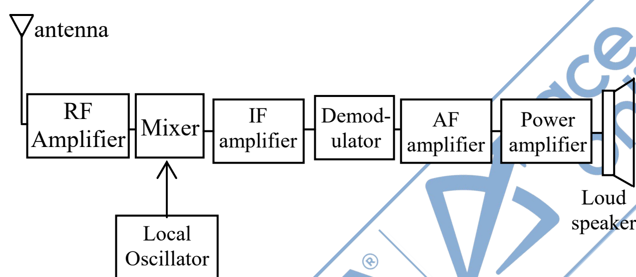
RF amplifier must be a low noise amplifier.

RF amplifier itself acts as a BPF. RF amplifier itself consists of a tuned circuit. Thus it is called tuned RF amplifier.



By tuning arrangement we are making the resonant frequency of the tuned circuit equal to the carrier frequency of the required channel.

Superheterodyne AM Receiver:



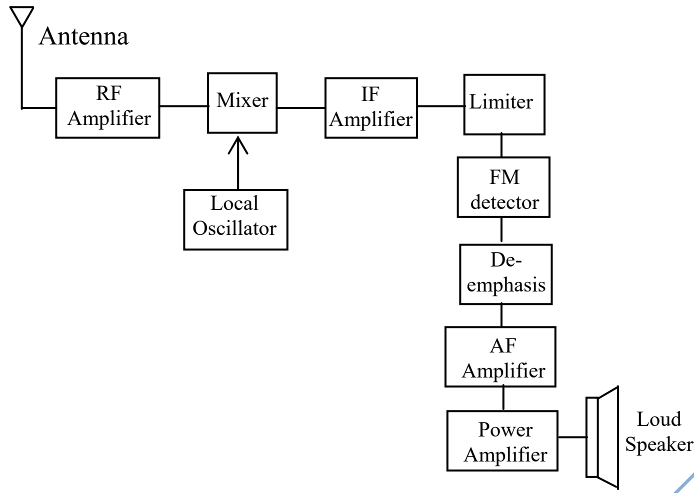
In the superheterodyne receiver the signal voltage is combined with the local oscillator voltage and converted into a signal of lower fixed frequency. The signal at this intermediate frequency contains the same modulation as the original carrier and is now amplified and detected to reproduce the original information. A constant frequency difference is maintained between the local oscillator and the RF circuits.

In mixer, down conversion is done with respect to the tuned circuit. Tuning means changing the local oscillator frequency. Mixer will change the carrier frequency from f_s to f_{IF}.

AM range $\rightarrow$ 550 kHz – 1650 kHz

IF $\rightarrow$ 455 kHz

FM receiver block diagram :



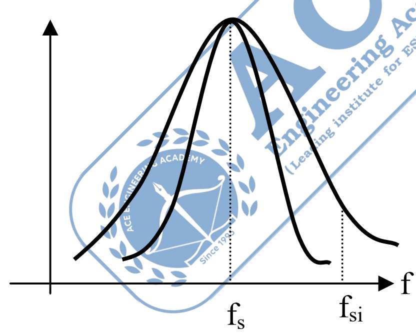
FM range $\rightarrow$ 88 MHz to 108 MHz

IF $\rightarrow$ 10.7 MHz

Image frequency:

$f_{si} = f_s + 2\text{ IF}$

Image (Frequency) Rejection Ratio:



$$\text{IRR} = \frac{\text{Gain at } f_s}{\text{Gain at } f_{si}}$$

By increasing the Intermediate frequency, IRR can be increased. By increasing the bandwidth, the gain at f_{si} can be decreased so that IRR increases.

$$\text{IRR} \propto \frac{1}{\text{B.W}}$$

A minimum of 10 kHz bandwidth should be maintained at the first tuned circuit that is placed before mixer.

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

$$\text{where } \rho = \frac{f_{si}}{f_s} - \frac{f_s}{f_{si}}$$

IRR should be as high as possible. If two tuned circuits are cascaded then the overall

$$IRR = \sqrt{1+Q_1^2\rho^2}\,.\sqrt{1+Q_2^2\rho^2}$$

4[b] (ii) What is the largest value of output voltage from an 8-bit DAC that produces 2.0 V for digital Input of 01110010 ? [10M]

Solution:

For a digital input 01110010,

the output voltage is 2 V

$V_0 = \Delta$(decimal equivalent of digital)

$2V = \Delta(0 \times 2^7 + 1 \times 2^6 + 1 \times 2^5 + 1.2^4 + 0 + 0 + 1 \times 2^1 + 0)$

$2V = \Delta\,(0 + 64 + 32 + 16 + 2)$

$2V = \Delta(114)$

$$\Delta = \frac{2V}{114}$$

Then the full scale voltage is

$V_0 = \Delta(255)$

$$V_0 = \frac{2V}{114}(255)$$

$= 4.4737$ V

4[c] A 3-phase, 6-pole, 500 kVA, 6600 V, 50 Hz star-connected synchronous motor having synchronous impedance of j 80 Ω per phase operates at unity power factor at rated conditions.

(i) Determine the mechanical torque driving capability for this motor at rated conditions, neglecting all mechanical losses.

(ii) At this rated torque, what are the required deviations from rated armature current and excitation (in terms of $E_f \angle\delta$) to produce a maximum torque of 1.26 times to the maximum rated torque for a leading power factor operation of motor.

(iii) Determine the value of the leading power factor for motor operation as stated in (ii) above.

[20M]

Solution:

A 3-phase, 6-pole, 500 kVA, 6600 V, 50 Hz, Y-connected synchronous motor, X_S = 80 Ω, operate at UPF at rated conditions.

$$V_L = 6600 \Rightarrow V_{Ph} = \frac{6600}{\sqrt{3}} = 3810.5\text{ V}$$

$$I_L = \frac{kVA}{\sqrt{3}V_L} = \frac{500\times10^3}{\sqrt{3}\times6600} = 43.74\text{ A} = I_{aph}\ \ (\because\text{ Y-connection})$$

At UPF, rated condition

P = kVA × PF = 500 × 1 = 500 kW

(i) Mechanical torque driving capacity for this motor at rated condition

$$T = \frac{P}{W} = \frac{500\times10^3}{2\pi\frac{N}{60}};\qquad N = \frac{120f}{P} = \frac{120\times50}{6} = 1000\text{ rpm}$$

$$= \frac{500\times10^3}{2\pi\times\frac{1000}{60}} = 4774.64\text{ Nm}$$

$\therefore$ T = 4774.64 Nm = 4.774 kNm

(ii) At rated condition, the excitation emf or back emf

$$E = V - I_aZ_S$$

$$= 3810.5\angle0 - 43.74\angle0 \times 80\angle90°$$

$$= 3810.5\angle0 - 3500\angle90°$$

$$= 3810.5 - j3500$$

$$E = 5173.9\angle-42.56°$$

The required deviation from rated condition of $E\angle\delta$ and armature current I_a to produce maximum torque of 1.26 times maximum rated torque as below

At maximum torque δ = 90°

$T_2 = 1.26\ T_1$

$$\frac{P_2}{W} = \frac{1.26P_1}{W}$$

$$\frac{E_2V}{X_sW}\sin90° = \frac{1.26E_1V}{X_sW}\sin90°$$

$\Rightarrow E_2 = 1.26E_1 = 1.26 \times 5173.9 = 6519\ 14$ V

$\therefore$ The deviation of induced emf from rated condition

$E_1 = 5173.9$ to $E_2 = 6519.14$ V

For leading power factor $E_2\cos\delta_2 > V$

$\therefore$ $6519.14\cos\delta_2 > 3810.5$

$\therefore$ $\cos\delta_2 > \dfrac{3810.5}{6519.14}$

$\therefore$ $\cos\delta_2 > 0.584$

$\delta_2 < 54.23°$

$\therefore$ The deviation from rated condition $\delta_1 = 42.56$ to $\delta_2 < 54.23°$

At maximum torque, power drop max

$\therefore$ $P_2 = 1.26P_1$

$VI_{a2}\cos\phi_2 = 1.26V\, I_{a1}\cos\phi_1$ [PF is UPF]

$I_{a2} \times 1 = 1.26 \times 43.74 = 55.1$ A

$\therefore$ $I_{a2} = 55.1$ A

The deviation of current from rated condition

$I_{a1} = 43.74$ A to $I_{a2} = 55.1$ A

(iii) In part let $E_2 = 6519.14$ V

$\delta_2 < 54.23°$, Let $\delta_2 = 30°$

Then $I_{a2} = \dfrac{V\angle 0 - E_2\angle -\delta_2}{X_s\angle\theta} = \dfrac{3810.5\angle 0 - 6519.14\angle -30°}{80\angle 90°}$

$$= \frac{3810.5 - (6519.14\cos 30 - j6519.14\sin 30)}{80\angle 90}$$

$$= \frac{3810.5 - (5645.14 - j3259.57)}{80\angle 90}$$

$$= \frac{-1834.64 + j3259.57}{80\angle 90}$$

$$= \frac{3740.41\angle -60.62°}{80\angle 90}$$

$I_{a2} = 46.75\angle 29.38°$

$\therefore$ Power factor $= \cos\phi = \cos 29.38$

$= 0.871$ lead

ACE Interview Guidance Program

Empowering Job Seekers to Succeed

- Job seekers confront a variety of challenges on their path to securing a job. Our ACE Interview Guidance programme has been carefully designed to provide thorough assistance in overcoming these challenges.
- With a team of seasoned experts at the helm, our focus is on empowering individuals with the intricate skills and extensive knowledge required to fully shine during interviews.
- Whether it's perfecting your presentation strategies or fine-tuning your overall interview skills, we are completely committed to improving your prospects of securing desired positions.
- ACE conducts comprehensive mock interviews with expert panel members, both in person and virtually. These simulations are designed to thoroughly prepare individuals for college admissions or job interviews.

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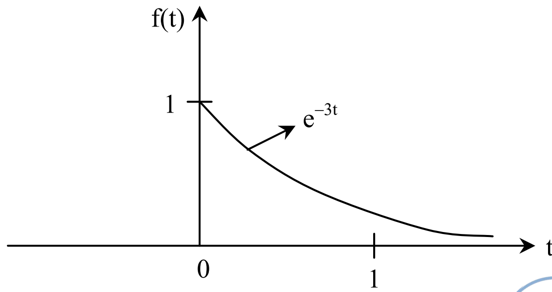
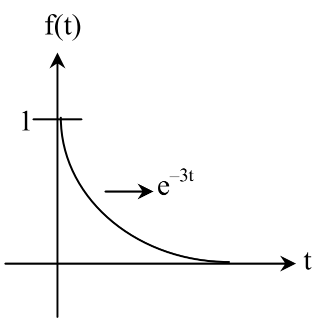
SECTION – B

5[a] An exponential function $f(t) = e^{-34}$ u(t) as shown in the following figure is delayed by 1 sec. Sketch and describe mathematically the delayed function. Also repeat the same if f(t) is advanced by 1 second.

[12M]



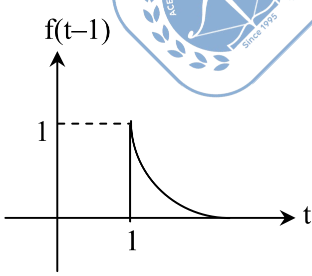
Solution:



The delayed function delayed by 1 sec is

$f(t-1) = e^{-3(t-1)}$ $\quad t > 1$

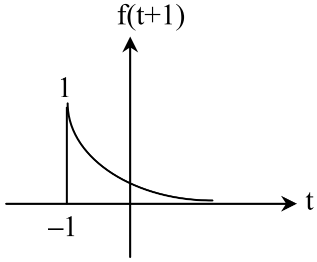
$= 0$ $\quad t < 1$



The advanced function advanced by 1 sec is

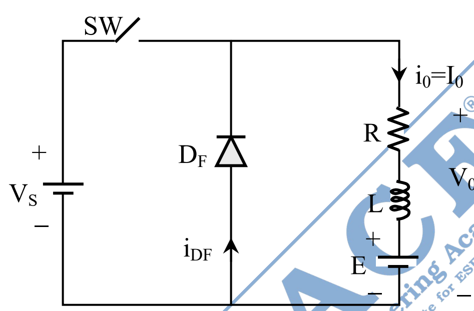
$f(t+1) = e^{-3(t+1)}$ $\quad t > -1$

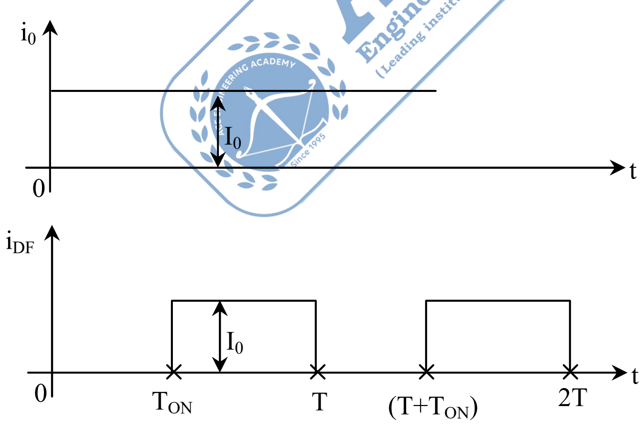
$= 0$ $\quad t < -1$



5[b] A step-down DC-DC convertor is feeding an RLE load with a freewheeling diode across the load. Assuming a ripple free load current, derive the expression for maximum duty cycle in terms of supply voltage V_s and back emf of the load E for which the RMS current through the freewheeling diode has maximum value. [12M]

Solution:





$$i_{DF\ RMS} = \left[\frac{1}{T}\int_{T_{ON}}^{T} I_0^2 dt\right]^{\frac{1}{2}}$$

$$= I_0\left[\frac{T - T_{ON}}{T}\right]^{\frac{1}{2}}$$

$i_{DF\ RMS} = \sqrt{1-D}\,I_0$ ………. (1)

$$I_0 = \frac{V_0 - E}{R}$$

$$I_0 = \frac{DV_s - E}{R}$$

Put "I_0" in equation (1)

$$i_{DF\ RMS} = \sqrt{(1-D)}\left[\frac{DV_s - E}{R}\right]$$

Using maximum theorem, $\frac{d}{dD}\left(i_{DF\ RMS}\right) = 0$

$$\frac{d}{dD}\left[\sqrt{(1-D)}\left\{\frac{DV_s - E}{R}\right\}\right] = 0$$

$$\frac{d}{dD}\left[\sqrt{(1-D)}.\{DV_s - E\}\right] = 0$$

$$\sqrt{(1-D)}.V_s + (DV_s - E).\left[\frac{-1}{2\sqrt{1-D}}\right] = 0$$

$$\sqrt{(1-D)}.V_s - \frac{(DV_s - E)}{2\sqrt{1-D}} = 0$$

$$\sqrt{(1-D)}.V_s = \frac{(DV_s - E)}{2\sqrt{(1-D)}}$$

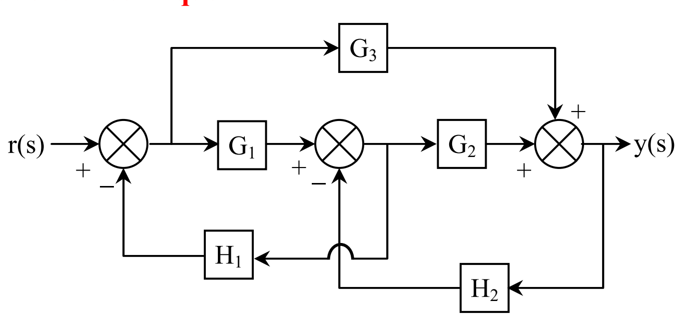
$2(1–D)V_S = DV_S – E$

$2 – 2DV_S = DV_S – E$

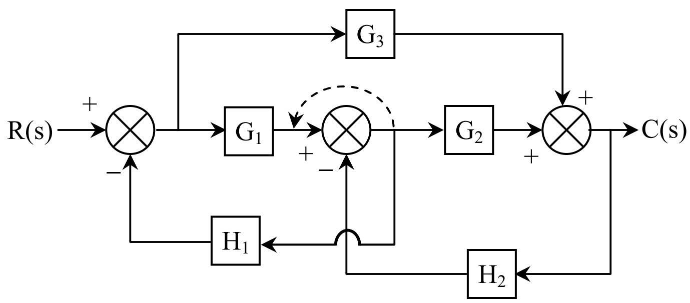
$2 + E = 3DV_S$

$$\therefore D = \frac{(2+E)}{3V_s}$$

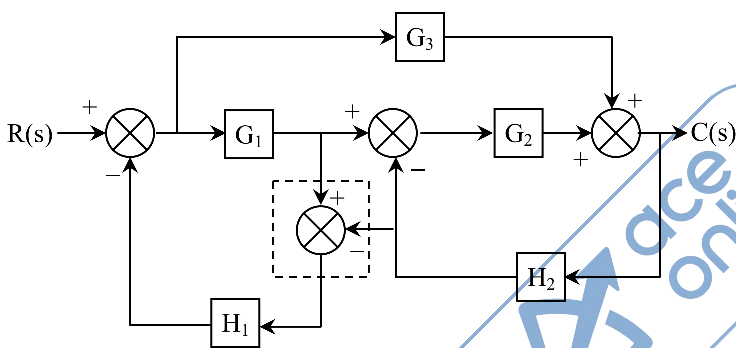
5[c] The block diagram of a system is as shown below. Find the overall transfer function of the system using block diagram reduction technique. [12M]



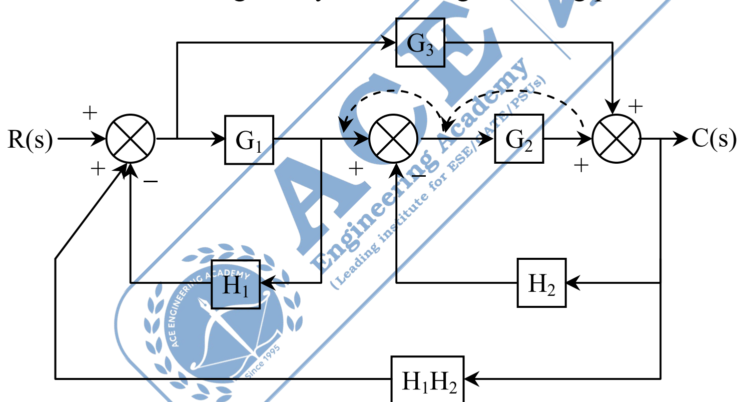
Solution:



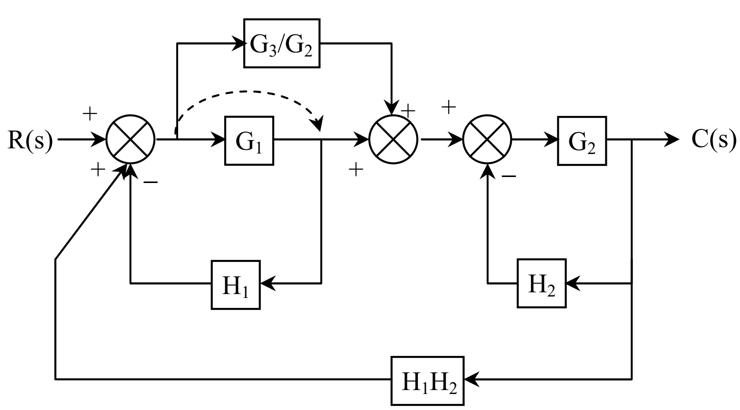
S1: Shift take—off point a head of summing point. The equivalent block diagram as follows.



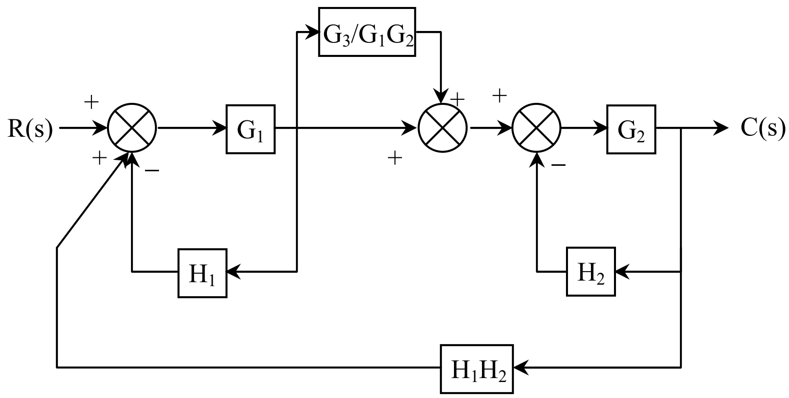
S2: Redraw the above block diagram by eliminating summing point.



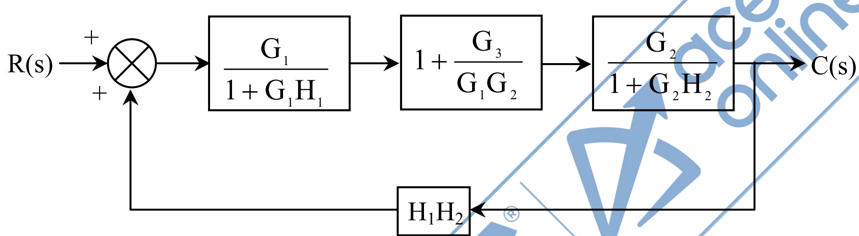
S3: Shift summing point a head of G_2, the equivalent diagram as follows.



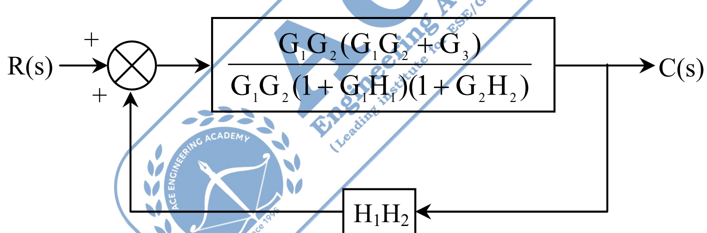
S4: Shift take-off point after G_1, the equivalent diagram as follows.



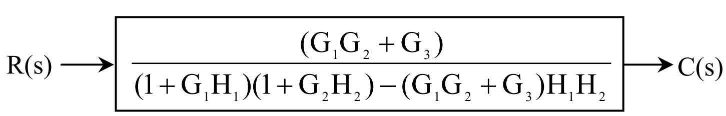
S5: Simplifying feedback & parallel combinations.



S6: Simplifying series combinations.



S7: Simplifying feedback,



$$\frac{C(s)}{R(s)}=\frac{(G_1G_2+G_3)}{1+G_1H_1+G_2H_2+G_1H_1G_2H_2-G_1G_2H_1H_2-G_3H_1H_2}$$

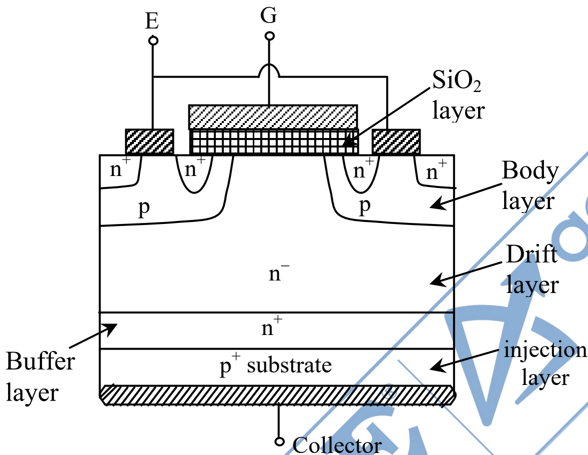
$$\frac{C(s)}{R(s)}=\frac{(G_1G_2+G_3)}{1+G_1H_1+G_2H_2-G_3H_1H_2}$$

5[d] (i) Draw the silicon cross-section view of IGBT and identify the distinguishing feature from MOSFET with reference to the conductivity modulation. Also, state its impact on IGBT operation and performance. [8M]

(ii) Draw 2-transistor and simplified equivalent circuits with proper labels and their significance. [4M]

Solution:

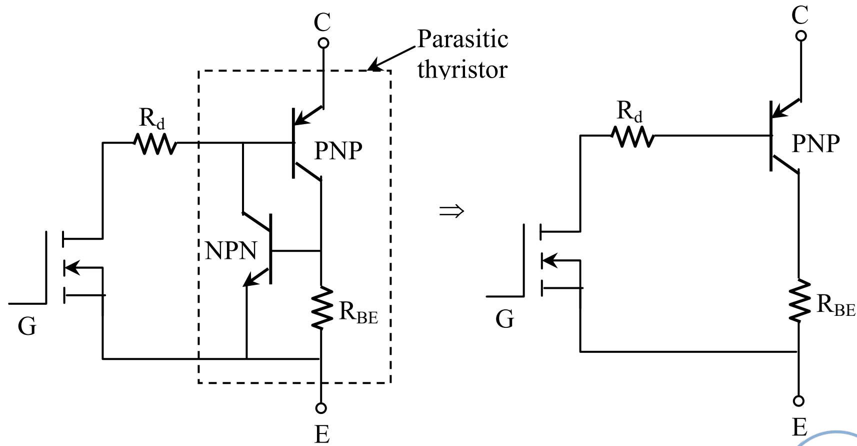
(i)



IGBT is constructed in the same manner as a power MOSFET, there is however a major difference in the substrate. The n^+ layer substrate at the drain in a power MOSFET is now substituted in the IGBT by a p^+ layer substrate called collector 'C'.

In IGBT, p^+ substrate is called injection layer because it injects holes into n^- layer. When gate is made positive with respect to emitter by voltage V_G, with gate emitter voltage more than the threshold voltage V_{GET} of IGBT, an n-channel is framed in the upper part of p region just beneath the gate. This n-channel short circuit the n^- region with n^+ emitter regions. Electrons from n^+ emitter begin to flow to n drift region through n-channel. Also p^+ collector region injects holes into n^- drift region. In short n^- drift region is flooded with electrons from n^+ region and holes from p^+ collector region, with this, injection carrier density in n^- drift region increases and conductivity of n^- region enhances, this will reduce ON state resistance of IGBT is less than power MOSFET.

(ii)



Equivalent Circuit   Simplified Equivalent Circuit

An IGBT is made of four alternate PNPN layers and could latch like a thyristor given the necessary condition ($\alpha_{NPN} + \alpha_{PNP}$) > 1. Two transistor model of an IGBT provides a simplified representation of its internet structure and behavior. It combines a BJT and a MOSFET to explain how IGBT operates. This model helps to understand how the IGBT combines the advantages both transistor types: high input impedance and fast switching from the MOSFET and low on state voltage drop from the BJT.

5[e] The overall transfer function of a unity feedback system is given by

$$G_{CL}(S) = \frac{Ks + b}{s^2 + as + b}$$

(i) Calculate the open loop transfer function of the system and its type.

(ii) If the overall system with K= 0, admits a unity normalized bandwidth, and a settling time of 4 seconds for 2% tolerance band, compute position, velocity and acceleration error constants. Assume unity DC gain.

(iii) Compute the sensitivity and complimentary sensitivity function value at ω = 1 rad/sec. Consider K= 1.

(iv) Discuss the effect of having a non-zero value of K on the behavior of the system in comparison to that with K= 0. **[12M]**

Solution:

Overall TF $\Rightarrow G_{CL}(s) = \left(\frac{Ks + b}{s^2 + as + b}\right)$

(i) $\text{OLTF} = \dfrac{G_{CL}(s)}{1-G_{CL}(s)} = \dfrac{\dfrac{Ks+b}{(s^2+as+b)}}{1-\left(\dfrac{Ks+b}{s^2+as+b}\right)}$

$$= \frac{(Ks+b)}{(s^2+as+b)-(Ks+b)} = \frac{(Ks+b)}{s^2+s(a-K)}$$

$$\Rightarrow \text{OLTF} = \frac{(Ks+b)}{s^1(s+(a-K))},\quad H(s)=1$$

Type – 1 System

(ii) $G_{CL}(s) = \dfrac{Ks+b}{s^2+as+b}$

If $K=0 \Rightarrow G_{CL}(s) = \dfrac{b}{s^2+as+b}$, $t_s = 4$ sec($\pm 2\%$)

$\Rightarrow$ Compare with standard form of second order system $\left(\dfrac{\omega_n^2}{s^2+2\xi\omega_n s+\omega_n^2}\right)$

$$\omega_n = \sqrt{b}\ \text{rad/sec},\quad 2\xi\omega_n = a$$

±2%: $t_s = \dfrac{4}{\xi\omega_n} = 4\ \text{sec} \Rightarrow \xi\omega_n = 1$

$\Rightarrow$ Unity normalized bandwidth $\omega_n = 1$ rad/sec $a = 2\xi\omega_n = 2$ and $b = 1$

Error constants:

When $K=0$: $\text{OLTF} = \dfrac{G_{CL}(s)}{1-G_{CL}(s)} = \dfrac{\dfrac{b}{(s^2+as+b)}}{1-\dfrac{b}{(s^2+as+b)}}$

$$\text{OLTF} = \left(\frac{b}{s^2+as+b-b}\right)$$

$$\text{OLTF} = \frac{b}{s^2+as} = \frac{b}{s(s+a)}$$

$G(s) = \text{OLTF} = \dfrac{b}{s(s+a)}$, $H(s) = 1$

Position Error constant:

$$\Rightarrow K_p = \underset{s\to 0}{\text{Lt}}\, G(s) = \underset{s\to 0}{\text{Lt}}\, \frac{b}{s(s+a)} = \infty$$

Velocity error constant:

$$K_v = \underset{s\to 0}{Lt}\, sG(s) = \underset{s\to 0}{Lt}\, s\left(\frac{b}{s(s+a)}\right) = \frac{b}{a}$$

Acceleration Error Constant:

$$K_a = \underset{s\to 0}{Lt}\, s^2G(s) = \underset{s\to 0}{Lt}\, s^2\left(\frac{b}{s(s+a)}\right) = 0$$

(iii) $G_{CL}(s) = \left(\dfrac{Ks+b}{s^2+as+b}\right)$

When K = 1 → $G_{CL}(s) = \dfrac{(s+b)}{(s^2+as+b)}$

Sensitivity of CLTF with G(s) ⇒ $S_G^T = \dfrac{1}{1+G(s)}$

$$\text{OLTF} \to G(s) = \frac{(s+b)}{(s^2+as+b)-(s+b)}$$

$$G(s) = \frac{(s+b)}{s^2+as+b-s-b} = \frac{(s+b)}{s^2+s(a-1)}$$

$$S_G^T = \frac{1}{1+G(s)} = \frac{1}{1+\left(\dfrac{(s+b)}{s^2+s(a-1)}\right)}$$

$$S_G^T = \frac{s^2+s(a-1)}{s^2+as-s+s+b} \Rightarrow S_G^T = \frac{s^2+s(a-1)}{s^2+as+b}$$

$$S_G^T\Big|_{S=j1} = \frac{-1+j(a-1)}{-1+aj+b} = \left(\frac{-1+j(a-1)}{(b-1)+aj}\right)$$

Complimentary sensitivity function :

Sensitivity + Complementary sensitivity = 1

Complimentary sensitivity = (1 – Sensitivity) = $1-\left[\dfrac{-1+j(a-1)}{(b-1)+aj}\right]$

$$= \frac{(b-1)+aj+1-ja+j}{(b-1)+aj} = \left(\frac{b+j}{(b-1)+aj}\right)$$

(iv) $K \neq 0$

⇒ If K is non-zero, then the damping ratio and natural frequency of oscillations are affected. Hence the transient response characteristics affected. Rise time, setting time, overshoot are affected.

$\Rightarrow$ Error constants $\Rightarrow K_p$ remains ∞

$$\Rightarrow K_v = \underset{s\to 0}{Lt}\, sG(s) = \underset{s\to 0}{Lt}\, s\left(\frac{Ks+b}{s(s+(a-K))}\right)$$

$$K_v = \left(\frac{b}{a-K}\right)$$

$\Rightarrow K_a$ remains 0

6[a] A single phase AC controller operating on phase control is supplied from a 230 V, 50 Hz AC supply. If the controller is feeding a purely resistive load of 10Ω at a firing angle of 45°; then determine

(i) the RMS output voltage V_0 rms (phase) of the phase controlled AC controller.

(ii) the equivalent duty cycle (K) of an integral cycle AC controller that would produce the same RMS output voltage.

(iii) If the integral cycle controller operates with a total of 100 cycles for one complete operation, determine the number of 'ON' cycles and 'OFF' cycles for the same as in (ii).

(iv) The input power factor of the integral duty cycle AC controller operating at equivalent duty cycle.

(v) The RMS Thyristor current $I_{T,\,rms}$ for the integral cycle controller operating at this equivalent duty cycle.

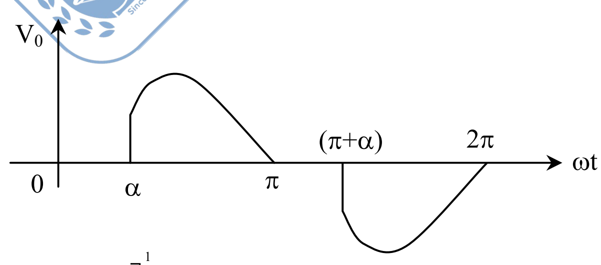
Derive the formula used for integral cycle AC controllers as used in above parts. [20M]

Solution:

1-ϕ AC voltage controller:

$V_{S\,RMS}$ = 230 V, R = 10 Ω, α = 45°

(i) Phase control:



$$V_{0\,RMS} = \left[\frac{1}{\pi}\int_{\alpha}^{\pi} V_m^2 \sin^2(\omega t)\,d\omega t\right]^{\frac{1}{2}}$$

$$= V_m\left[\frac{1}{\pi}\int_{\alpha}^{\pi}\frac{1-\cos(2\omega t)}{2}\,d\omega t\right]^{\frac{1}{2}}$$

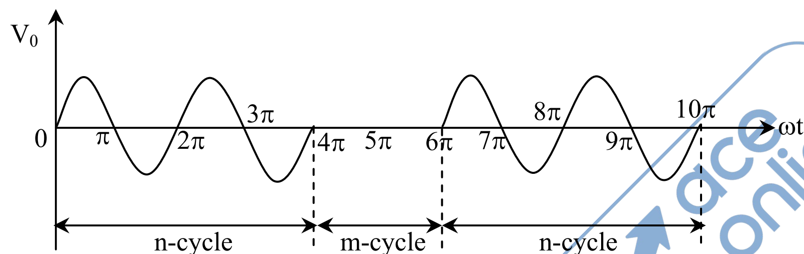
$$= \frac{V_m}{\sqrt{2\pi}}\left[\left\{\omega t - \frac{\sin(2\omega t)}{2}\right\}_{\alpha}^{\pi}\right]^{\frac{1}{2}}$$

$$V_{0\,RMS} = \frac{V_m}{\sqrt{2\pi}}\left[(\pi-\alpha)+\frac{\sin(2\alpha)}{2}\right]^{\frac{1}{2}}$$

$$\therefore\ V_{0\,RMS} = \frac{230\sqrt{2}}{\sqrt{2\pi}}\left[\left(\pi-\frac{\pi}{4}\right)+\frac{\sin(2\times 45°)}{2}\right]^{\frac{1}{2}}$$

$V_{0\,RMS} = 219.3$ V

(ii) Integral cycle control



$$V_{0\,RMS} = \left[\frac{n}{(m+n)2\pi}\int_0^{2\pi} V_m^2 \sin^2(\omega t)d\omega t\right]^{\frac{1}{2}}$$

$$= \sqrt{\frac{n}{(m+n)}}\,V_{SRMS}$$

$V_{0\,RMS} = = \sqrt{K}V_{S\,RMS}$; where $K = \frac{n}{m+n} \Rightarrow$ Duty cycle

$219.3 = \sqrt{K} \times 230$

$\therefore\ K = 0.909$

(iii) $m + n = 100$

$K = 0.909$

$$\frac{n}{(m+n)} = 0.909$$

$$\frac{n}{100} = 0.909$$

$n = 90.9 \approx 91$

$m + n = 100$

$m + 91 = 100$

$\therefore\ m = 9$

$\therefore$ Number of ON cycles $n = 91$

Number of OFF cycles m = 9

(iv) Input power factor [$\cos(\phi_S)$]:

$P_{input} = P_{output}$

$V_{S\,RMS}\,.i_{SRMS}\cos(\phi_S) = V_{0RMS}\,i_{0RMS}$

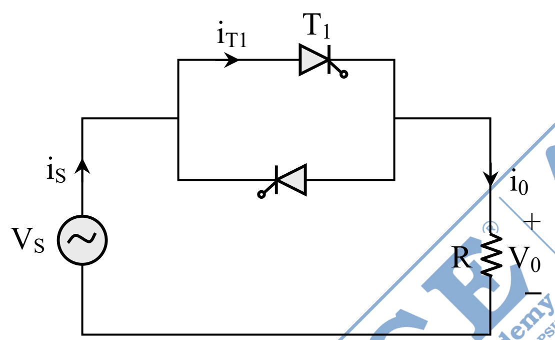
$$\therefore \cos\phi_S = \frac{V_{0RMS}}{V_{SRMS}}$$

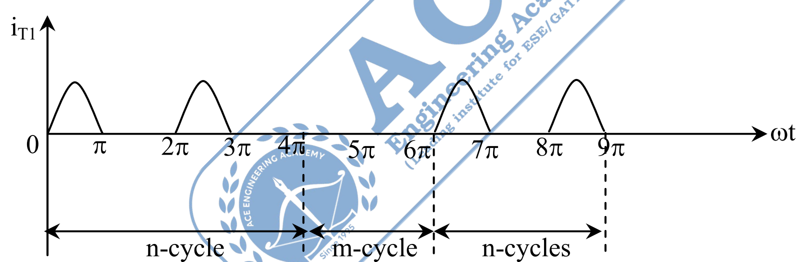
$$= \frac{\sqrt{K}V_{SRMS}}{V_{SRMS}}$$

$$\therefore \cos(\phi_S) = \sqrt{K}$$

$\therefore$ Input power factor = $\sqrt{0.909}$ = 0.9534 (lagging)

(v)





$$i_{TRMS} = \left[\frac{n}{(m+n)}.\frac{1}{2\pi}\int_0^{\pi}\frac{V_m^2\sin^2(\omega t)}{R^2}d\omega t\right]^{\frac{1}{2}}$$

$$= \sqrt{\frac{n}{(m+n)}}.\frac{V_m}{\sqrt{2\pi}}\times\frac{1}{R}\left[\int_0^{\pi}\frac{1-\cos(2\omega t)}{2}d\omega t\right]^{\frac{1}{2}}$$

$$= \sqrt{K}\,\frac{V_m}{\sqrt{\pi}.2R}\left[\left(\omega t-\frac{\sin(2\omega t)}{2}\right)_0^{\pi}\right]^{\frac{1}{2}}$$

$$= \frac{\sqrt{K}.V_m}{\sqrt{\pi}.2R}[\pi-0]^{\frac{1}{2}}$$

$$i_{TRMS} = \frac{\sqrt{K}.V_m}{2R} = \sqrt{0.9}\times\frac{230\sqrt{2}}{2\times10}$$

$$i_{TRMS} = 15.43 \text{ A}$$

6[b] (i) Derive the even and odd decomposition of a general signal x(t) by applying the definitions of even and odd signals. [10M]

Solution:

Any general signal x(t) can be expressed as sum of it's even part and odd part.

$$x(t) = x_e(t) + x_o(t) \text{ ....(1)}$$

Where $x_e(t)$ is even part of x(t)

$X_o(t)$ is odd part of x(t)

Now, $x(-t) = x_e(-t) + x_o(-t)$

From the definition of even and odd signals

$x_e(-t) = x_e(t)$ and

$x_o(-t) = -x_o(t)$

So, $x(-t) = x_e(t) - x_o(t)$ ....(2)

Add equation (1) & (2)

$$x(t) + x(-t) = 2x_e(t)$$

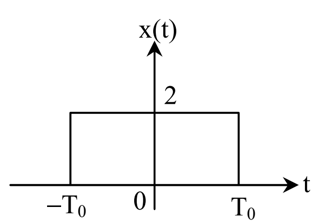
$$x_e(t) = \frac{x(t)+x(t)}{2}$$

Subtract equation (1) & (2)

$$(1) - (2) \Rightarrow x(t) - x(-t) = 2x_o(t)$$

$$x_o(t) = \frac{x(t)-x(-t)}{2}$$

6[b] (ii) Find Fourier Transform of x(t), which is given by following rectangular pulse, as shown in figure. [10M]



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RANK 1 CE
Venkat Reddy
MEGA MOCK TEST
Selected in Public Health, MA & UD Dept. Govt. of TG.

RANK 3 EE
Devarakonda Sathwik
CLASSROOM COACHING
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RANK 4 EE
Sangem Ravi Kumar
CLASSROOM COACHING
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RANK 4 CE
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M Dheeraj Reddy
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RANK 16 EE
Jangili Rajashekar
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RANK 18 EE
Malka Kiran
CLASSROOM COACHING
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RANK 19 EE
Sowmya
CLASSROOM COACHING
Selected in Irrigation & CAD Dept., Govt. of TG.

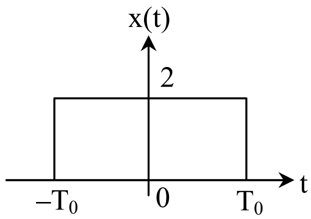
RANK 20 CE
Md. Azmatullah
MEGA MOCK TEST
Selected in Transport, R&B Dept., Govt. of TG.

AND MANY MORE...

500+ SELECTIONS

CE : 434 | EE : 61 | ME : 20

Solution:



The F.T of x(t) is $X(\omega) = \int_{-\infty}^{\infty} x(t) e^{-j\omega t} dt$

So, $X(\omega) = \int_{-T_0}^{T_0} 2e^{-j\omega t} dt$

$$X(\omega) = \left. \frac{2e^{-j\omega t}}{-j\omega} \right|_{-T_0}^{T_0}$$

$$X(\omega) = -\frac{2}{j\omega}\left[e^{-j\omega T_0} - e^{j\omega T_0}\right]$$

$$X(\omega) = -\frac{2}{j\omega}\left[-2j\sin(\omega T_0)\right]$$

$$X(\omega) = \frac{4}{\omega}\sin(\omega T_0)$$

$$X(\omega) = \frac{4}{\omega}\left[\frac{\sin(\omega T_0)}{\omega T_0}\right]\omega T_0$$

$$X(\omega) = 4T_0\left[\frac{\sin(\omega T_0)}{\omega T_0}\right]$$

We know that $Sa(x) = \frac{\sin(x)}{x}$

So, $X(\omega) = 4T_0\, Sa[\omega T_0]$

6[c] A unity feedback system has open loop transfer function.

$$G(s) = \frac{K.e^{-0.5s}}{(s^2 + \alpha s + \beta)}$$

G(s) has a DC gain of K/16, and has a decay rate of 2 nepers per second. Using first-order Pade approximation for the delay, sketch the root locus plot of G(s) and find the range of K for which the unity feedbacked system remains stable. [20M]

Solution:

$$G(s)=\frac{K.e^{-0.5s}}{(s^2+\alpha s+\beta)}$$

$\Rightarrow$ Given DC gain $\Rightarrow \dfrac{K}{16}$

Decay rate = 2 nepers/second

$$\Rightarrow \text{DC gain of } G(s)\big|_{s=0}=\frac{Ke^0}{0+0+\beta}=\frac{K}{\beta}=\frac{K}{16}$$

$\beta = 16$

$\rightarrow$ Decay rate gives real part of pole $\Rightarrow$ That is –2.

$$\xrightarrow{CE} s^2+\alpha s+\beta=0$$

$$s_1,s_2=\frac{-\alpha\pm\sqrt{\alpha^2-4\times1\times\beta}}{2\times1}$$

$$=\left(\frac{-\alpha}{2}\pm\frac{\sqrt{\alpha^2-4\beta}}{2}\right)$$

$$\text{Real part of pole}=-\frac{\alpha}{2}=-2\Rightarrow\alpha=4$$

$\Rightarrow$ First-order pade approximation for $e^{-0.5s}$,

$$e^{-0.5s}\approx\frac{\left(1-\frac{0.5s}{2}\right)}{\left(1+\frac{0.5s}{2}\right)}=\frac{(1-0.25s)}{(1+0.25s)}$$

$$\Rightarrow \text{Substitute all the values, then } G(s)=\frac{K\left(\frac{1-0.25s}{1+0.25s}\right)}{(s^2+4s+16)}$$

$$\Rightarrow G(s)=\frac{K(1-0.25s)}{(1+0.25s)(s^2+4s+16)}=\frac{K(4-s)}{(4+s)(s^2+4s+16)}$$

$$\xrightarrow{Poles}(s+4)(s^2+4s+16)=0$$

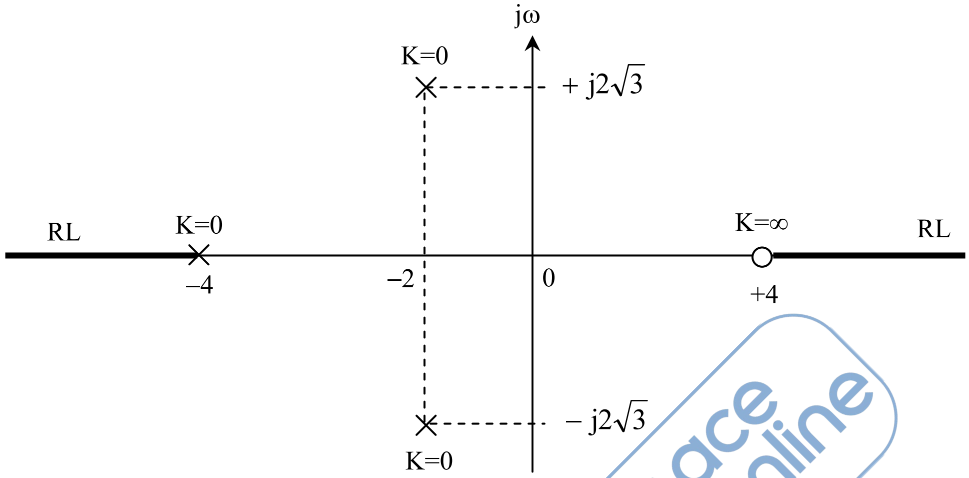
$$s=-4,\ s=\frac{-4\pm\sqrt{16-4\times1\times16}}{2}$$

$$s=-4,\ s=-2\pm j2\sqrt{3}$$

$$\xrightarrow{Zero}(4-s)=0\Rightarrow s=+4$$

$$G(s) = \frac{-K(s-4)}{(s+4)(s+2-j2\sqrt{3})(s+2+j2\sqrt{3})}, \; H(s) = 1$$

Real axis root locus:



Number of Assymptotes:

$$N = (P - Z)$$
$$= 3 - 1 = 2$$

$$\theta = \frac{(29)180°}{(P-Z)} \Rightarrow q = 0 \Rightarrow \theta = 0°$$

$$\Rightarrow q = 1 \Rightarrow \theta = \frac{2 \times 180°}{2} = 180°$$

Break Point:

$$\xrightarrow{CE} (s+4)(s^2+4s+16) + K(4-s) = 0$$

$$\xrightarrow{CE} (s^3+8s^2+32s+64) + K(4-s) = 0$$

$$K = \frac{(s^3+8s^2+32s+64)}{(s-4)}$$

$$\xrightarrow{BP} \frac{dK}{ds} = 0$$

$$\frac{dK}{ds} = \frac{(3s^2+16s+32)(s-4) - (s^3+8s^2+32s+64).1}{(s-4)^2} = 0$$

$$\Rightarrow 2s^3 - 4s^2 - 64s - 192 = 0$$

$$\Rightarrow s = 7.72, -2 \pm j2.04$$

Valid BP is 7.72

Intersection point with Imaginary axis:

$$\xrightarrow{CE} 1 + G(s) = 0$$

$$\xrightarrow{CE} s^3 + 8s^2 + s(32 - K) + (64 + 4K) = 0$$

Routh Array:

$$\begin{array}{c|cc} s^3 & 1 & (32 - K) \\ s^2 & 8 & (64 + 4K) \\ s^1 & \dfrac{(256 - 8K - 64 - 4K)}{8} & \\ s^0 & (32 - K & \end{array}$$

$\Rightarrow$ For marginal stability

$(256 - 8K - 64 - 4K) = 0$

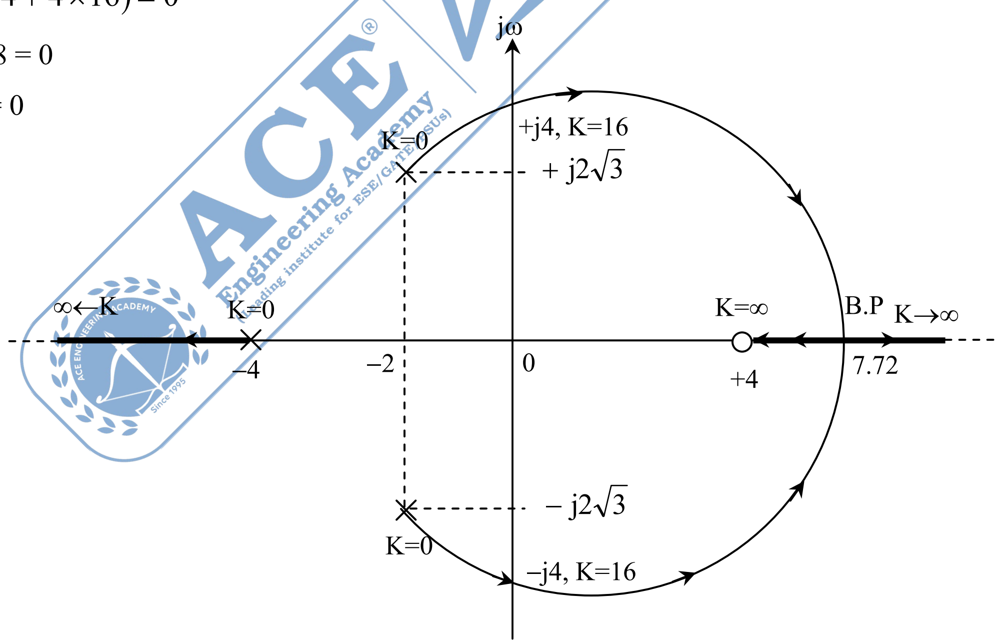
$\Rightarrow (192 - 12K) = 0 \Rightarrow K_{mar} = 16$

$\Rightarrow \xrightarrow{AE} 8s^2 + (64 + 4 \times 16) = 0$

$8s^2 + 128 = 0$

$s^2 + 16 = 0$

$s = \pm j4$



$\Rightarrow$ Condition for CL stability

$0 < K < 16$

$\Rightarrow K = 16$ closed loop system is marginal stable

$\Rightarrow$ When K = 16, the frequency of oscillations $\omega_n = 4$ rad/sec

Hearty Congratulations

To our students CIVIL ENGINEERING

Selected in SSC JE - 2024


HARSHIT KHARE
Roll No. 3008100089
Selected in: **CPWD**


RAMSWRUP
Roll No. 2404100567
Selected in: **CPWD**


LAKSHIT BHARDWAJ
Roll No. 3206106390
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M V SIVA RAM REDDY
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SUNIL SHARMA
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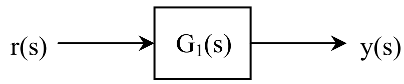
RINKESH KUMAR
Roll No. 6204103361
Selected in: **MES**

& many more..

Total 150+ Selections | **CE-98** | **EE-29** | **ME-24**

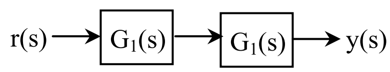
7[a] A second order system $G_1(s)$ as shown in figure has no zeros, and has unity DC gain.



The unit step response of $G_1(s)$ has a decay rate of 2.5 nepers/sec and has undamped natural frequency of $\sqrt{6}$ rad/sec

(i) Compute the observable canonical state representation of $G_1(s)$ and obtain its state transition matrix using Cayley-Hamilton approach.

(ii) Now another identical $G_1(s)$ is placed in cascade with earlier $G_1(s)$, as shown below.



Obtain the state space representation of overall cascaded system using previously computed observable canonical representation of $G_1(s)$ **[20M]**

Solution:

Given Decay rate = 2.5 nepers/sec, unity dc gain

Decay rate for second order system = $\xi\omega_n = 2.5$

$$= \omega_n = \sqrt{16}\,\text{rad/sec}$$

$$\text{Second order TF} \Rightarrow G_1(s) = \frac{K\omega_n^2}{s^2 + 2\xi\omega_n s + \omega_n^2}$$

$$G(s) = \left(\frac{K6}{s^2 + 5s + 6}\right)$$

$$\text{Unity dc gain} \Rightarrow G_1(s)\Big|_{s=0} = \frac{K6}{6} = 1 \Rightarrow K = 1$$

$$G_1(s) = \left(\frac{6}{s^2 + 5s + 6}\right)$$

$$G_1(s) = \frac{Y(s)}{R(s)} = \left(\frac{6}{s^2 + 5s + 6}\right)$$

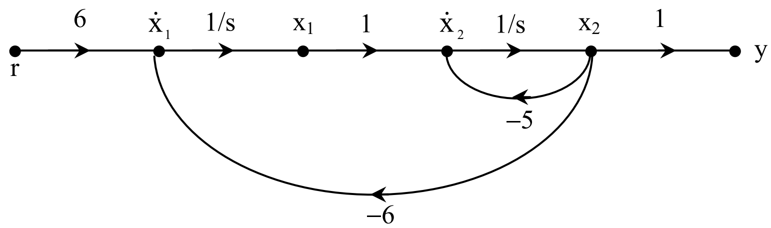
Divide numerator & denominator with $\left(\frac{1}{s^2}\right)$

$$\frac{Y(s)}{R(s)} = \left(\frac{6/s^2}{1 + 5/s + 6/s^2}\right) \Rightarrow \text{Compare with mason's gain formula } P_1 = 6/s^2$$

$$L_1 = -5/s$$

$$L_2 = -6/s^2$$

State diagram of OCF:



$\dot{x}_1 = 6r - 6x_2$ …….(1)

$\dot{x}_2 = x_1 - 5x_2$ …….(2)

$y = x_2$ …….(3)

$$\begin{bmatrix}\dot{x}_1\\ \dot{x}_2\end{bmatrix} = \begin{bmatrix}0 & -6\\ 1 & -5\end{bmatrix}\begin{bmatrix}x_1\\ x_2\end{bmatrix} + \begin{bmatrix}6\\ 0\end{bmatrix}[r], \quad [y] = [0 \quad 1]\begin{bmatrix}x_1\\ x_2\end{bmatrix}$$

Cayley – Hamilton Approach for state transition matrix

$$\xrightarrow{CE} |\lambda I - A| = \begin{vmatrix}\lambda & 6\\ -1 & \lambda+5\end{vmatrix} = 0$$

$$\lambda(\lambda + 5) + 6 = 0$$

$$\xrightarrow{CE} \lambda^2 + 5\lambda + 6 = 0 \Rightarrow (\lambda+2)(\lambda+3) = 0$$

$$\lambda_1 = -2, \lambda_2 = -3$$

$\Rightarrow$ By Cayley-Hamilton theorem

$\Rightarrow A^2 + 5A + 6I = 0$

The state transition matrix

$\phi(t) = e^{At} = \alpha_0 I + \alpha_1 A$

In terms of eigen value $\Rightarrow e^{-\lambda t} = \alpha_0 + \alpha_1\lambda$

Substituting eigen values $\Rightarrow e^{-2t} = (\alpha_0 - 2\alpha_1)$……..(4)

$e^{-3t} = (\alpha_0 - 3\alpha_1)$………(5)

Solve equation (4) & (5)

$\alpha_1 = (e^{-2t} - e^{-3t})$

$\alpha_0 = (3e^{-2t} - 2e^{-3t})$

$\phi(t) = \alpha_0 I + \alpha_1 A$

$$= \left(3e^{-2t} - 2e^{-3t}\right)\begin{bmatrix}1 & 0\\ 0 & 1\end{bmatrix} + \left(e^{-2t} - e^{-3t}\right)\begin{bmatrix}0 & -6\\ 1 & -5\end{bmatrix}$$

$$\phi(t)=\begin{bmatrix}3e^{-2t}-2e^{-3t} & 0\\ 0 & 3e^{-2t}-2e^{-3t}\end{bmatrix}+\begin{bmatrix}0 & -6e^{-2t}+6e^{-3t}\\ e^{-2t}-e^{-3t} & -5e^{-2t}+5e^{-3t}\end{bmatrix}$$

$$\phi(t)=\begin{bmatrix}3e^{-2t}-2e^{-3t} & -6e^{-2t}+6e^{-3t}\\ e^{-2t}-e^{-3t} & -2e^{-2t}+3e^{-3t}\end{bmatrix}$$

(ii) $\dfrac{Y(s)}{r(s)}=G_1(s).G_1(s)$

$$=\left(\frac{6}{s^2+5s+6}\right)\left(\frac{6}{s^2+5s+6}\right)$$

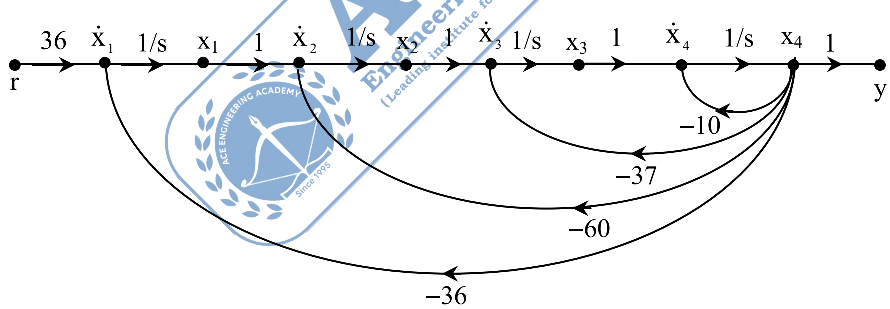
$$\frac{Y(s)}{r(s)}=\frac{36}{(s^4+10s^3+37s^2+60s+36)}$$

Divide numerator & denominator with $\left(\dfrac{1}{s^4}\right)$

$$\frac{Y(s)}{r(s)}=\frac{36/s^4}{\left(1+\frac{10}{s}+\frac{37}{s^2}+\frac{60}{s^3}+\frac{36}{s^4}\right)}$$

Compare with mason's gain formula

$$P_1=\frac{36}{s^4},\ L_1=-\frac{10}{s},\ L_2=-\frac{37}{s^2},\ L_3=-\frac{60}{s^2},\ L_4=-\frac{36}{s^4}$$



$\dot{x}_1=36-36x_4$

$\dot{x}_2=x_1-60x_4$

$\dot{x}_3=x_2-37x_4$

$\dot{x}_4=x_3-10x_4$

$y=x_4$


Hearty Congratulations
to our students GATE - 2025
84 TIMES AIR 1st IN GATE
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AIR 1 EE Pradip Chauhan
AIR 1 IN Kailash Goyal
AIR 2 EE Kailash Goyal
AIR 2 ME Gollangi Sateesh
AIR 2 ES Jitesh Choudhary
AIR 3 ME Nimesh Chandra
AIR 3 ME Sanket Tupkar
AIR 3 PI Sadhan Anumala
AIR 3 XE Rohan Biswal
AIR 3 PI Aditya Kumar Prasad
AIR 4 CE Harshil Maheshwari
AIR 5 EC Mohammed Nafeez
AIR 5 IN Sachin Yadav
AIR 5 ME Uday G.
AIR 5 PI Kuldeep Singh naruka
AIR 6 CE Nimish Upadhyay
AIR 6 CE Shivanand Chaurasia
AIR 6 EE Shivam Kumar Gupta
AIR 6 EE Puneet Soni
AIR 6 EC P Jaswanth Bhavani
AIR 6 PI Kaushal Kumar Kaushik
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AIR 7 ME Abhinn Srivastava
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AIR 7 CS Hemanth Reddu P
AIR 7 PI Waleed Shaikh
AIR 7 XE Sanket Tupkar
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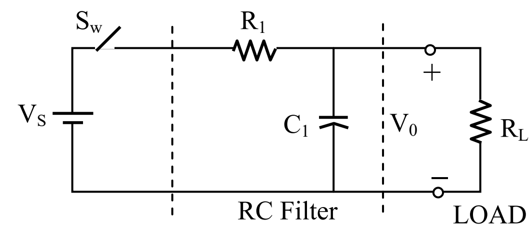
AIR 8 IN Pushpendra Payal
AIR 8 CS Rishi Sharma
AIR 9 EC Sai Charan Chilukuri
AIR 9 ME Rahul Paliwal
AIR 9 PI Anish Vanapalli
AIR 10 EE Neelava Mukherjee
AIR 10 ME Ashutosh kumar
AIR 10 ME Jetti Ganateja
AIR 10 ME Pitchika Kumar Vasu
AIR 10 CE Adnan Quasain
& mamy more....

$$\begin{bmatrix}\dot{x}_1\\ \dot{x}_2\\ \dot{x}_3\\ \dot{x}_4\end{bmatrix}=\begin{bmatrix}0&0&0&-36\\1&0&0&-60\\0&1&0&-37\\0&0&1&-10\end{bmatrix}\begin{bmatrix}x_1\\x_2\\x_3\\x_4\end{bmatrix}+\begin{bmatrix}36\\0\\0\\0\end{bmatrix}[r]$$

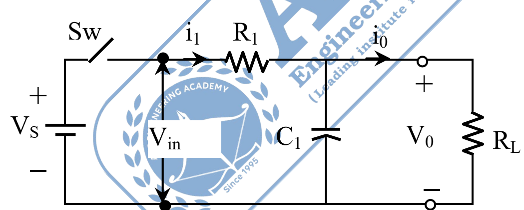
$$[y]=\begin{bmatrix}0&0&0&1\end{bmatrix}\begin{bmatrix}x_1\\x_2\\x_3\\x_4\end{bmatrix}$$

7[b] A buck converter with RC filter is shown in figure with a load resistance R_L..



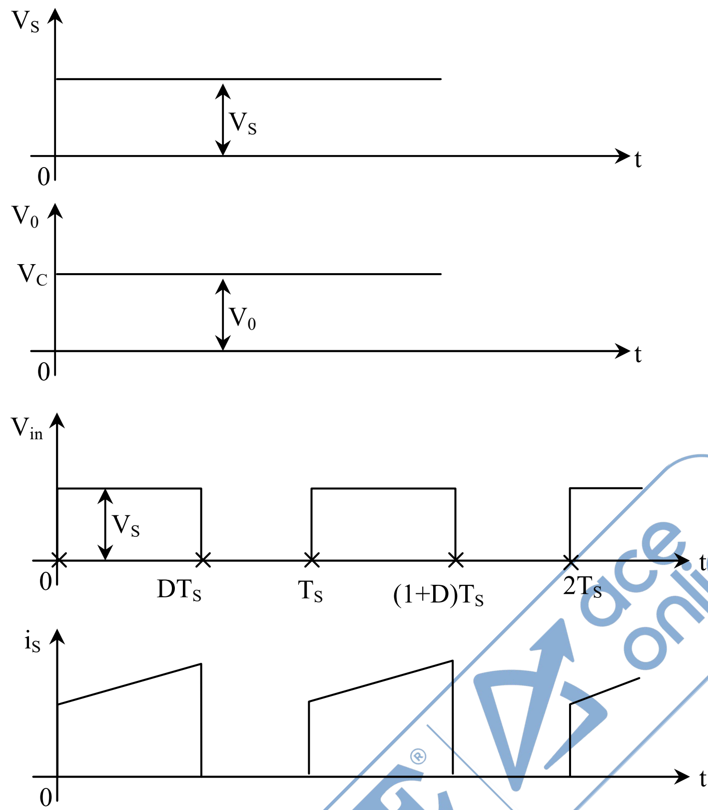
The switch S_w is operated with DT_S time ON and $(1 – D)\ T_S$ time OFF, cyclically with a time period of T_S. Draw the relevant waveforms and derive the expression for output voltage V_0 as a function of duty ratio 'D'. Assume the switching frequency to be high. [20M]

Solution:



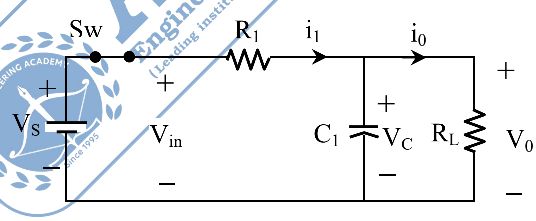
Assumption:

1. Capacitor value is high
2. Due to high switching frequency and high capacitor ripple in output voltage is neglected.
3. V_0 and i_0 are ripple free constant.



During t = 0 to DT_S:

SW – ON, C – Charges

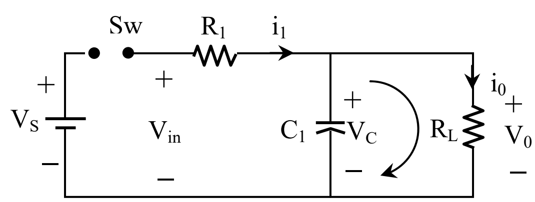


$V_{in} = V_S \Leftarrow$ Input voltage to filter

Current through R_1 increases, capacitor charging and supplying R_L

During t = DT_S to T:

SW-OFF, C – Discharging through load



Input voltage to filter

$V_{in} = 0, i_1 = 0$

Average voltage at input of RC filter

$$V_{in\ avg} = \frac{DT_s.V_s}{T_s}$$

$V_{in\ avg} = DV_S$

As the RC filter averages this pulsating input voltage and provides DC output voltage

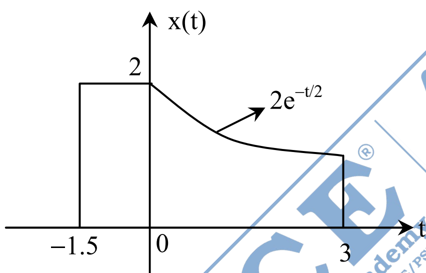
$\therefore$ We can write

$$V_0 = V_{in\ avg} = DV_S$$

7[c] Consider a single x(t) shown in following figure. Sketch and describe mathematically the signal x(t)

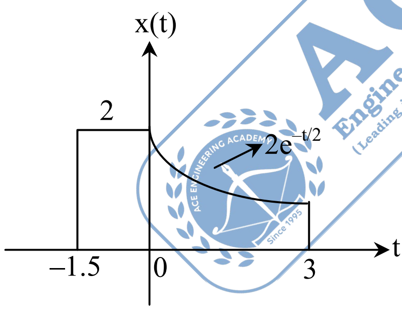
(i) If time-compressed by factor 5

(ii) Repeat the problem for same signal time-expanded by factor 3. [10+10M]



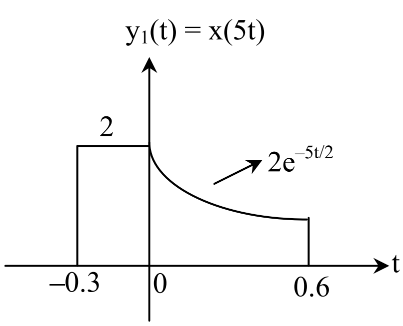
Solution:

Given



(i) Time compressed by a factor of '5'

The resultant signal is $y_1(t) = x(5t)$

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35
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AIR 1 EE Rajan Kumar
AIR 1 ME Munish Kumar
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AIR 2 EE SATYAM CHANDRAKANT
AIR 2 ME RAJESH KASANIYA
AIR 3 CE LAXMIKANT
AIR 3 E&T UNNATI CHANSORIA
AIR 3 EE PRIYANSHU MUDGAL
AIR 3 ME GOLLANGI SATEESH
AIR 4 CE MADHAN KUMAR
AIR 4 E&T RAJIV RANJAN MISHRA
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AIR 6 CE SANCHIT GOEL
AIR 6 E&T CHANDRIKA GADGIL
AIR 6 EE RITVIK KOK
AIR 6 ME CHANDAN JOSHI
AIR 7 E&T DEBARGHYA CH
AIR 7 EE MANTHAN SHARMA
AIR 7 ME DINESH KUMAR S
AIR 8 CE ROHIT KUMAR
AIR 8 E&T VIDHU SHREE
AIR 8 EE MAYANK JAIMAN
AIR 8 ME SHAILENDRA SINGH
AIR 9 CE ANKIT MEENA
AIR 9 E&T T PIYUSH DAYANAND
AIR 9 EE ANMOL SINGH
AIR 9 ME KRISHNA KUMAR D
AIR 10 CE RAJESH BADUGU
AIR 10 E&T RAJVARDHAN SHARMA
AIR 10 ME AKSHAY VIDHATE
TOTAL 36 SELECTIONS IN TOP 10
CE: 09 | ME: 10 | EE: 08 | E&T: 09

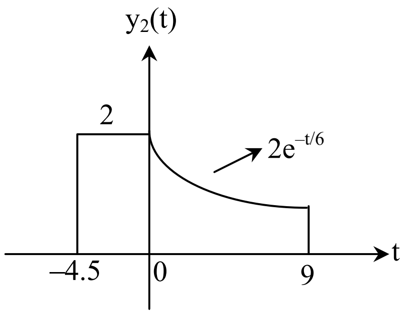
$y_1(t) = 2 \quad -0.3 < t < 0$

$= 2e^{-\frac{5t}{2}} \quad 0 < t < 0.6$

$= 0 \quad$ Otherwise

(ii) Time expanded by factor '3'.

The resultant signal is $y_2(t) = x(t/3)$



$y_2(t) = 2 \quad -4.5 < t < 0$

$= 2e^{-t/6} \quad 0 < t < 9$

$= 0 \quad$ Otherwise

8[a] Find the solution of following second order differential equation by using Transform method. The differential equation is

$$\frac{d^2y(t)}{dt^2} + 7\frac{dy(t)}{dt} + 12y(t) = \frac{dx(t)}{dt} + x(t)$$

with initial conditions $y(0^-) = 2$ and $\dot{y}(0^-) = 1$ and $x(t) = e^{-5t}u(t)$ and $x(0^-) = 0$ [20M]

Solution:

Given $\quad \frac{d^2y(t)}{dt^2} + 7\frac{dy(t)}{dt} + 12y(t) = \frac{dx(t)}{dt} + x(t)$

$\Rightarrow y''(t) + 7y'(t) + 12y(t) = x'(t) + x(t)$

$L\{y''(t)\} + 7L\{y'(t)\} + 12L\{y(t)\} = L\{x'(t)\} + L\{x(t)\}$

$\Rightarrow \{s^2y(s) - sy(0^-) - y'(0^-)\} + 7\{sy(s) - y(0^-)\} + 12y(s) = sx(s) - x(0^-) + x(s)$ ……. (1)

$L\{x(t)\} = L\{e^{-5t}u(t)\} = \frac{1}{s+5}$

$x(s) = \frac{1}{s+5}$

$$(1) \Rightarrow (s^2 y(s) - 2(s) - 1) + 7\{sy(s) - 2\} + 12y(s) = \frac{s}{s+5} + \frac{1}{s+5}$$

$$\Rightarrow (s^2 + 7s + 12)\, y(s) - 2s - 1 - 14 = \frac{s+1}{s+5}$$

$$\Rightarrow (s^2 + 7s + 12)y(s) = (2s+15) + \frac{s+1}{s+5}$$

$$\Rightarrow (s+3)(s+4)y(s) = 2s+15 + \frac{s+1}{s+5}$$

$$\Rightarrow y(s) = \frac{2s+15}{(s+3)(s+4)} + \frac{s+1}{(s+3)(s+4)(s+5)} \qquad \ldots\ldots\ldots\ldots (2)$$

$$\frac{2s+15}{(s+3)(s+4)} = \frac{A}{s+3} + \frac{B}{s+4}$$

$$A = \frac{2(-3)+15}{(-3+4)} = 9$$

$$B = \frac{2(-4)+15}{(-4+3)} = -7$$

$$\frac{2s+15}{(s+3)(s+4)} = \frac{9}{s+3} + \frac{7}{s+4}$$

Now, $\dfrac{s+1}{(s+3)(s+4)(s+5)} = \dfrac{A}{s+3} + \dfrac{B}{s+4} + \dfrac{C}{s+4}$

$$A = \frac{-3+1}{(-3+4)(-3+5)} = -1$$

$$B = \frac{-4+1}{(-4+3)(-4+5)} = 3$$

$$C = \frac{-5+1}{(-5+3)(-5+4)} = -2$$

$$\frac{s+1}{(s+3)(s+4)(s+5)} = \frac{-1}{s+3} + \frac{3}{s+4} - \frac{2}{s+5}$$

Substituting in eqn. (2)

$$y(s) = \frac{9}{s+3} + \frac{7}{s+4} - \frac{1}{s+3} + \frac{3}{s+4} - \frac{2}{s+5}$$

$$y(s) = \frac{8}{s+3} + \frac{10}{s+4} - \frac{2}{s+5}$$

$$L^{-1}\{y(s)\} = L^{-1}\left(\frac{8}{s+3}+\frac{10}{s+4}-\frac{2}{s+5}\right)$$

$y(t) = 8e^{-3t} + 10e^{-4t} - 2e^{5t}$

8[b] The open-loop transfer function of a unity feedback system is given as

$$G(s) = \frac{10}{(s-1)(s+5)}$$

Sketch the Bode plot for the system and calculate Gain and Phase margins [20M]

Solution:

$$G(s) = \frac{10}{(s-1)(s+5)},\quad H(s) = 1$$

$$G(s) = -\frac{2}{(1-s)\left(1+\frac{s}{5}\right)}$$

Corner frequencies are (1, 5) rad/sec

$$s \to j\omega \Rightarrow G(j\omega) = \frac{-2}{(1-j\omega)\left(1+\frac{j\omega}{5}\right)}$$

Magnitude:

$$|G(j\omega)| = \frac{2}{\sqrt{1+(\omega)^2}\sqrt{1+\left(\frac{\omega}{5}\right)^2}} \Rightarrow M(dB) = 20\log|G(j\omega)|$$

$$\Rightarrow M_{\omega=0.1} = 20\log 2 \approx 6dB$$

Phase:

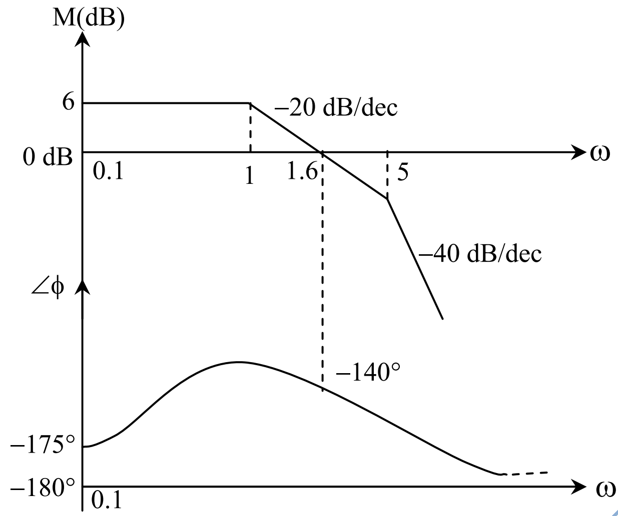
$$\Rightarrow \angle G(j\omega) = \frac{\angle -2}{\angle(1-j\omega)\angle(1+j\omega/5)}$$

$$\angle\phi = \angle G(j\omega) = -180° - (-\tan^{-1}(\omega) - \tan^{-1}(\omega/5)$$

$$\angle\phi = -180° + \tan^{-1}(\omega) + \tan^{-1}\left(\frac{\omega}{5}\right) \Rightarrow \phi|_{\omega=0.1} = -175°$$

$$\phi|_{\omega=1} = 146°$$

$$\phi|_{\omega=1.6} = -140°$$



From Plot,

$\Rightarrow \omega_{pc} = \infty$

$$M(dB)\big|_{\omega_{pc}} = -\infty dB$$

$$GM = -20\log(M)\big|_{\omega_{pc}} = -(M(dB))\big|_{\omega_{pc}} = -(-\infty) = \infty dB$$

$\Rightarrow \omega_{gc} = 1.6$ rad/sec

$\Rightarrow PM = 180° + \angle\phi\big|_{\omega_{gc}}$

$$\Rightarrow PM = 180° + \left[-180° + \tan^{-1}(\omega_{gc}) - \tan^{-1}\left(\frac{\omega_{gc}}{5}\right)\right]$$

$$PM = \tan^{-1}(1.6) - \tan^{-1}\left(\frac{1.6}{5}\right)$$

$$PM = +40°$$

8[c] Design a UJT triggering circuit for a 220 V, 50 Hz ac source fed single phase half controlled rectifier using BT 151 – 500 R SCR and 2N2646 UJT having following parameters:

2N2646 UJT: $\eta = 0.65$, $R_{BB} = 7\ k\Omega$, $I_P = 5\ \mu A$, $V_V = 3\ V$, $I_V = 4\ mA$

BT 151 – 500 R SCR: $V_{GT} = 0.8\ V$ (typical), 1.5 V (max)

$I_{GT} = 5\ mA$ (typical, 15 mA

$V_{DRM} = 500\ V$

Assume the triggering circuit be fed from 24 V DC

Take V_{BB} of 20 V for design and pulse width of triggering pulse of 30 μs. Draw relevant circuits and show the component values with power ratings [20M]

Solution:

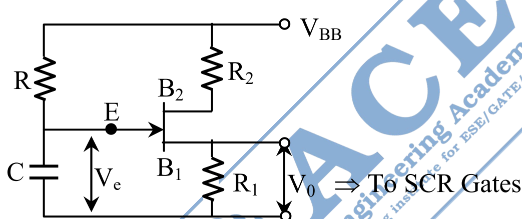
Given,

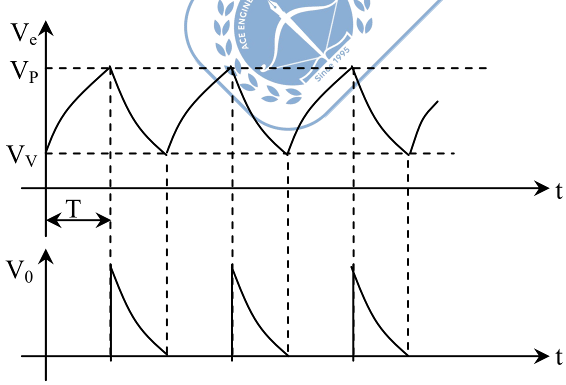
UJT: $\eta = 0.65$, $R_{BB} = 7\ k\Omega$, $I_P = 5\ \mu A$, $V_V = 3\ V$, $I_V = 4\ mA$

SCR: $V_{GT} = 0.8\ V$

$I_{GT} = 5\ mA$

$V_{BB} = 20\ V$, $T = 30\ \mu sec$





$V_P = \eta V_{BB} + V_D$

Assume $V_D = 0\ V$

$\therefore\ V_P = \eta V_{BB} = 0.65 \times 20 = 13\ V$

$$R_2 = \frac{10^4}{\eta . V_{BB}} = \frac{10^4}{0.65 \times 20} = 769.23\ \Omega$$

$$\frac{V_{BB}.R_1}{(R_{BB} + R_1 + R_2)} < V_{GT}$$

$$\frac{20 \times R_1}{(7000 + R_1 + 769.23} < 0.8$$

$\therefore\ 20R_1 < 0.8(7000 + R_1 + 769.23)$

$$\frac{20R_1}{0.8} < (7000 + R_1 + 769.23)$$

$25R_1 < (7769.23 + R_1)$

$24R_1 < 7769.23$

$$\therefore\ R_1 < \frac{7769.23}{24}$$

$\therefore\ R_1 < 323.71\ \Omega$

Maximum value of 'R' is

$$R_{max} = \frac{V_{BB} - V_P}{I_P} = \frac{20 - 13}{5 \times 10^{-6}} = 1.4\ M\Omega$$

Minimum value of 'R' is

$$R_{min} = \frac{V_{BB} - V_V}{I_V} = \frac{2. - 3}{4 \times 10^{-3}} = 4.25\ k\Omega$$

Taking $R = R_{min} = 4.25\ k\Omega$

$$R = \frac{T}{C.\ln\left[\frac{1}{1-\eta}\right]}$$

$$4.25 \times 10^3 = \frac{30 \times 10^{-6}}{C.\ln\left[\frac{1}{1-0.65}\right]}$$

$\therefore\ C = 6.72 \times 10^{-9}\ F$