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ROLL NO - M200203EE

BRANCH - POWER ELECTRONICS

SUBJECT - SMRC ASSIGNMENT - 3

Ques 1. Data for Buck Converter

$V_{ip} = 110V$ $\quad r_l = 0.3\Omega, \; r_s = 0.2\Omega, \; r_d = 0.2\Omega$

$V_{op} = 48V$ $\quad r_c = 0.5\Omega, \; V_r = 0.5V$

$I_o = 4.8A$ $\quad L = 540\mu H, \; C = 100\mu F$

$f_s = 50kHz$

$R = 10\Omega$

a) Set up state space Averaged Model and to evaluate d_o.

$$\begin{bmatrix} \Delta \dot{\bar{i}}_L \\ \Delta \dot{\bar{v}}_c \end{bmatrix} = \begin{bmatrix} \frac{-(r_c + d_o r_s + (1-d_o) r_d + r_L)}{L} & -\frac{1}{L} \\ \frac{1}{C} & 0 \end{bmatrix} \begin{bmatrix} \Delta \bar{i}_L \\ \Delta \bar{v}_c \end{bmatrix} + \begin{bmatrix} \frac{d_o}{L} & \frac{-(1-d_o)}{L} & \frac{r_c}{L} \\ 0 & 0 & -\frac{1}{C} \end{bmatrix} \begin{bmatrix} \Delta \bar{v}_{in} \\ 0 \\ \Delta \bar{i}_o \end{bmatrix}$$

$$+ \begin{bmatrix} \frac{(r_d - r_s)\bar{i}_L}{L} + \frac{\bar{v}_{in} + V_r}{L} \\ 0 \end{bmatrix} \Delta d(t)$$

$$[\Delta \bar{v}_o] = [r_c \quad 1] \begin{bmatrix} \Delta \bar{i}_L \\ \Delta \bar{v}_o \end{bmatrix} + [0 \quad 0 \quad -r_c] \begin{bmatrix} \Delta \bar{v}_{in} \\ 0 \\ \Delta \bar{i}_o \end{bmatrix}$$

$$\begin{bmatrix} \Delta \bar{i}_L \\ \Delta \bar{v}_c \end{bmatrix} = \begin{bmatrix} \frac{-[0.5 + d_o 0.2 + (1-d_o)0.2 + 0.3]}{540\mu} & -\frac{1}{540\mu} \\ \frac{1}{100\mu} & 0 \end{bmatrix} \begin{bmatrix} \Delta \bar{i}_L \\ \Delta \bar{v}_c \end{bmatrix} + \begin{bmatrix} \frac{d_o}{540\mu} & \frac{-[1-d_o]}{540\mu} & \frac{0.5}{540\mu} \\ 0 & 0 & -\frac{1}{100\mu} \end{bmatrix} \begin{bmatrix} \Delta \bar{v}_{in} \\ 0 \\ \Delta \bar{i}_o \end{bmatrix}$$

$$+ \begin{bmatrix} \frac{110 + 0.5}{540\mu} \\ 0 \end{bmatrix} \Delta d(t)$$

$$[\Delta \bar{v}_o] = [0.5 \quad 1] \begin{bmatrix} \Delta \bar{i}_L \\ \Delta \bar{v}_o \end{bmatrix} + [0 \quad 0 \quad -0.5] \begin{bmatrix} \Delta \bar{v}_{in} \\ 0 \\ \Delta \bar{i}_o \end{bmatrix}$$

We get,

$$V_o = d_o V_{in} + (1-d_o) V_r + [r_L + d_o r_s + r_d (1-d_o)] i_o$$

$$48 = d_o \times 110 + (1-d_o) 0.5 + [0.3 + 0.2 d_o + 0.2[1-d_o]] 4.8$$

$$\boxed{d_o = 0.412}$$

→ Steady state duty ratio.

b) To Evaluate —

$$\frac{\Delta \bar{v}_o(s)}{\Delta d(s)}, \quad \frac{\Delta \bar{v}_o(s)}{\Delta \bar{v}_{in}(s)}; \quad \frac{\Delta \bar{i}_L(s)}{\Delta d(s)} \text{ and } \frac{\Delta \bar{i}_L(s)}{\Delta \bar{v}_{in}(s)}$$

Solⁿ:-

$$\frac{\Delta \bar{V}_o(s)}{\Delta d(s)} = \frac{\left(\frac{V_{in} + V_r}{LC}\right)(1 + r_c s C)}{s^2 + \frac{r_{eff}}{L} s + \frac{1}{LC}}$$

$$r_{eff} = r_c + r_L + d_o r_s + (1-d_o) r_d$$

$$r_{eff} = 0.5 + 0.3 + 0.412 \times 0.2 + (1-0.412) 0.2$$

$$= 1 \Omega$$

$$\frac{\Delta \bar{v}_o(s)}{\Delta d(s)} = \frac{\left(\frac{110 + 0.5}{540\mu \times 100\mu}\right)(1 + 0.5 \times 100\mu s)}{s^2 + \frac{1}{540\mu} s + \frac{1}{540\mu \times 100\mu}}$$

$$\boxed{\frac{\Delta \bar{V}_o(s)}{\Delta d(s)} = \frac{2046.3 \times 10^6 [1 + 50\mu s]}{s^2 + 1851.85 s + 18.51 \times 10^6}}$$

$$\frac{\Delta \bar{V}_o(s)}{\Delta \bar{V}_{in}(s)} = \frac{\left(\frac{d_o}{LC}\right)(1 + r_c s C)}{s^2 + \frac{r_{eff}}{L} s + \frac{1}{LC}}$$

$$\frac{\Delta \bar{V}_o(s)}{\Delta \bar{V}_{in}(s)} = \frac{\left(\frac{0.412}{540\mu \times 100\mu}\right)\left[1 + 0.5 \times 100\mu s\right]}{s^2 + 1851.85\, s + 18.51 \times 10^6}$$

$$\boxed{\frac{\Delta \bar{V}_o(s)}{\Delta \bar{V}_{in}(s)} = \frac{7.629 \times 10^6 \left[1 + 50\mu s\right]}{s^2 + 1851.85 s + 18.51 \times 10^6}}$$

$$\frac{\Delta \bar{i}_L(s)}{\Delta d(s)} = \frac{\left\{\left(\frac{r_d - r_s}{L}\right) i_o + \left(\frac{V_{in} + V_r}{L}\right)\right\} s}{s^2 + \frac{r_{eff}}{L} s + \frac{1}{LC}}$$

$$\boxed{\frac{\Delta \bar{i}_L(s)}{\Delta d(s)} = \frac{0.204 \times 10^6\, s}{s^2 + 1851.85 s + 18.51 \times 10^6}}$$

$$\frac{\Delta \bar{i}_L(s)}{\Delta \bar{V}_{in}(s)} = \frac{\left(\frac{d_o}{L}\right) s}{s^2 + \frac{r_{eff}}{L} s + \frac{1}{LC}}$$

$$= \frac{\frac{0.412}{540\mu}\, s}{s^2 + 1851.85 s + 18.51 \times 10^6}$$

$$\boxed{\frac{\Delta \bar{i}_L(s)}{\Delta \bar{V}_{in}(s)} = \frac{762.96\, s}{s^2 + 1851.85 s + 18.51 \times 10^6}}$$

c) When duty ratio is suddenly increased by 5% of d_o.

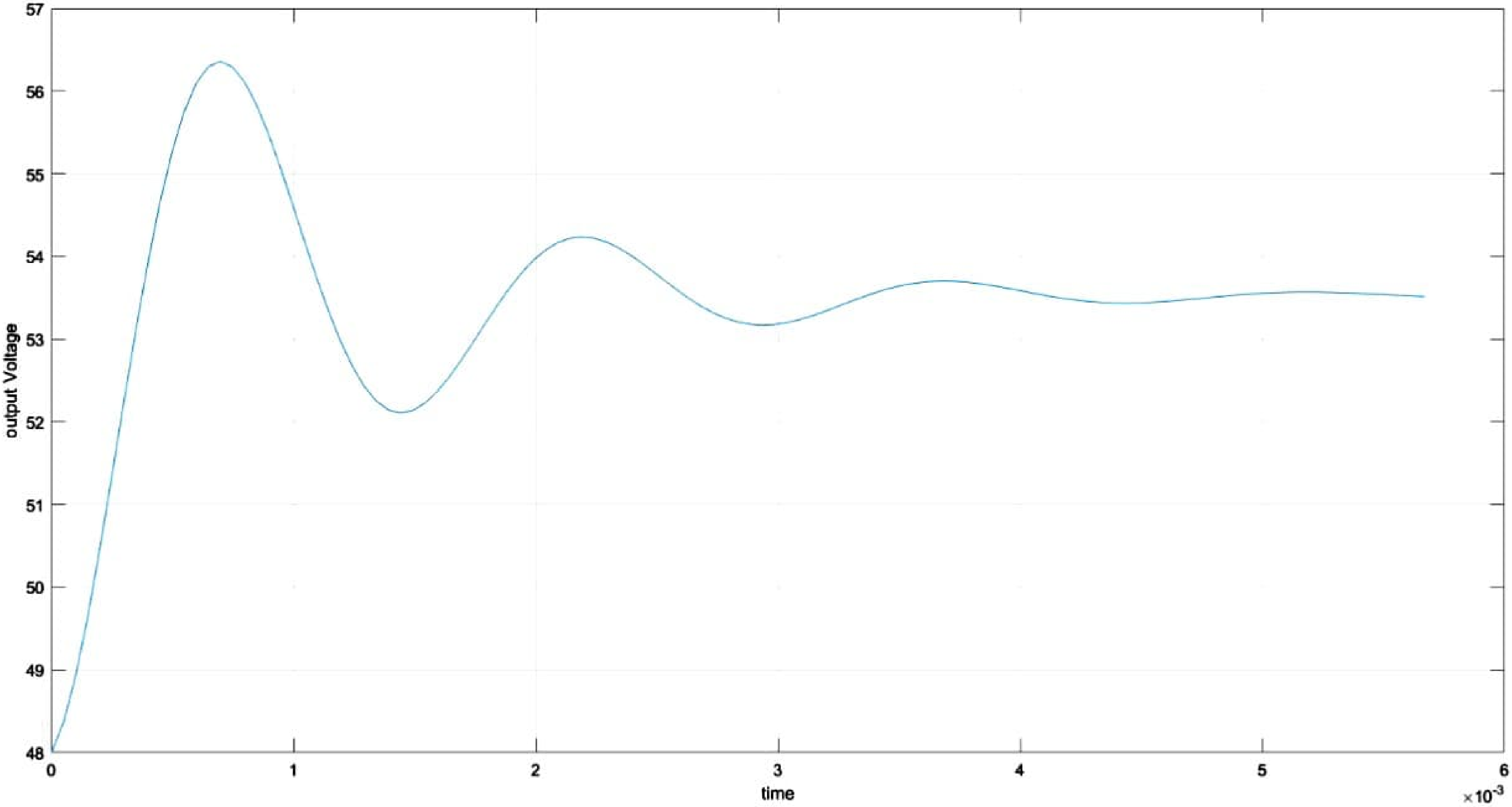
$$\frac{\Delta V_o(s)}{\Delta d(s)} = \frac{2.762 \times 10^6 s + 5.801 \times 10^{10}}{27 s^2 + 7700 s + 5.5 \times 10^6}$$

$$\frac{\Delta I_L(s)}{\Delta d(s)} = \frac{5.525 \times 10^6 s + 5.52 \times 10^9}{27 s^2 + 7700 s + 5.5 \times 10^6}$$

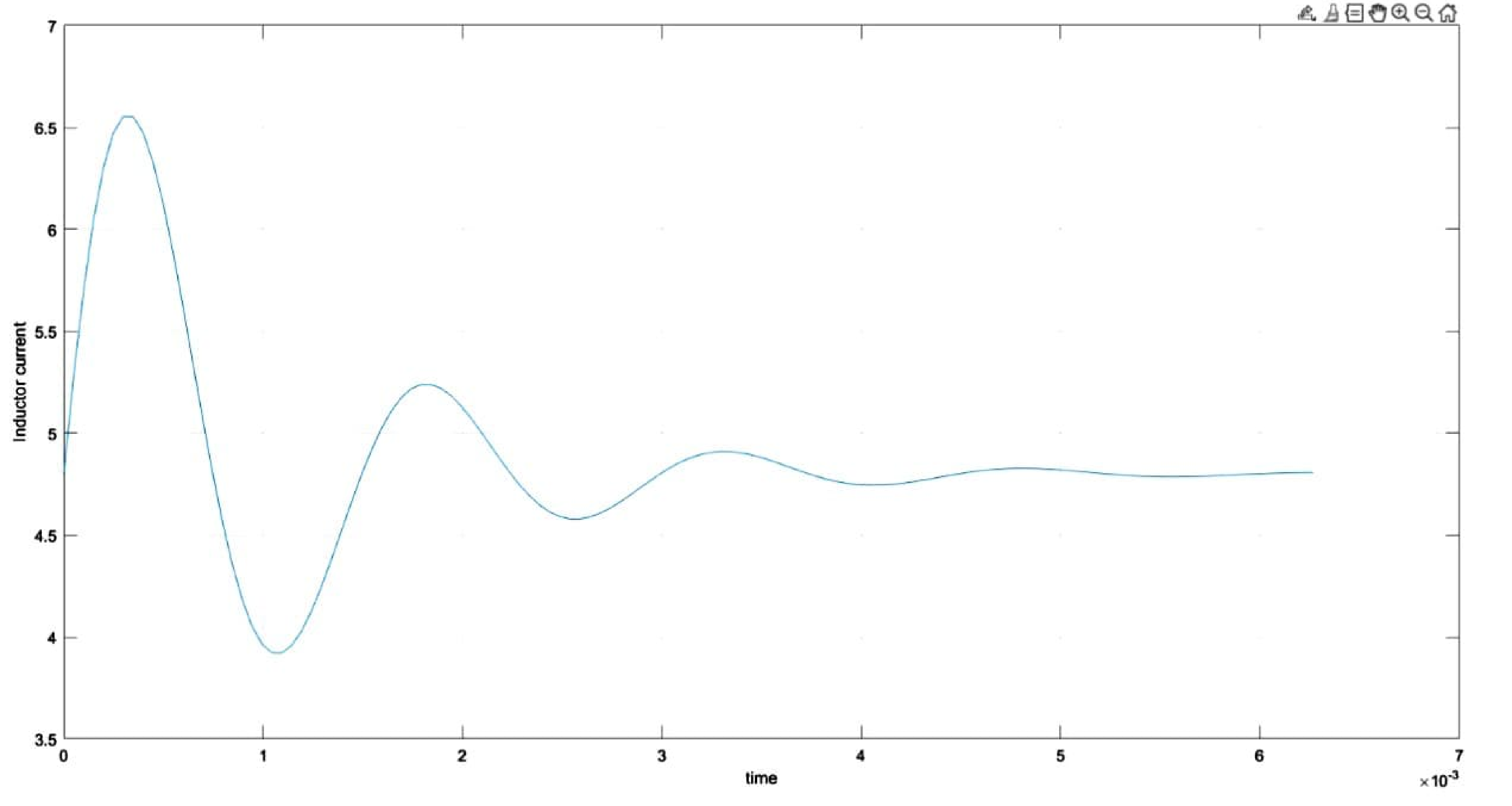
$$\Delta V_o(s) = \frac{(2.762 \times 10^6)s + 5.801 \times 10^{10}}{27s^2 + 7700s + 5.5 \times 10^8} \times \frac{0.05}{s}$$

$$\Delta I_L(s) = \frac{5.525 \times 10^6 s + 5.525 \times 10^9}{27s^2 + 7700s + 5.5 \times 10^8} \times \frac{0.05}{s}$$

Plot of Both is attached with this



57
56
55
54
53
52
51
50
49
48
output Voltage
0
1
2
3
4
5
6
time
×10-3



7
6.5
6
5.5
5
4.5
4
3.5
Inductor current
0
1
2
3
4
5
6
7
time
×10-3

d)

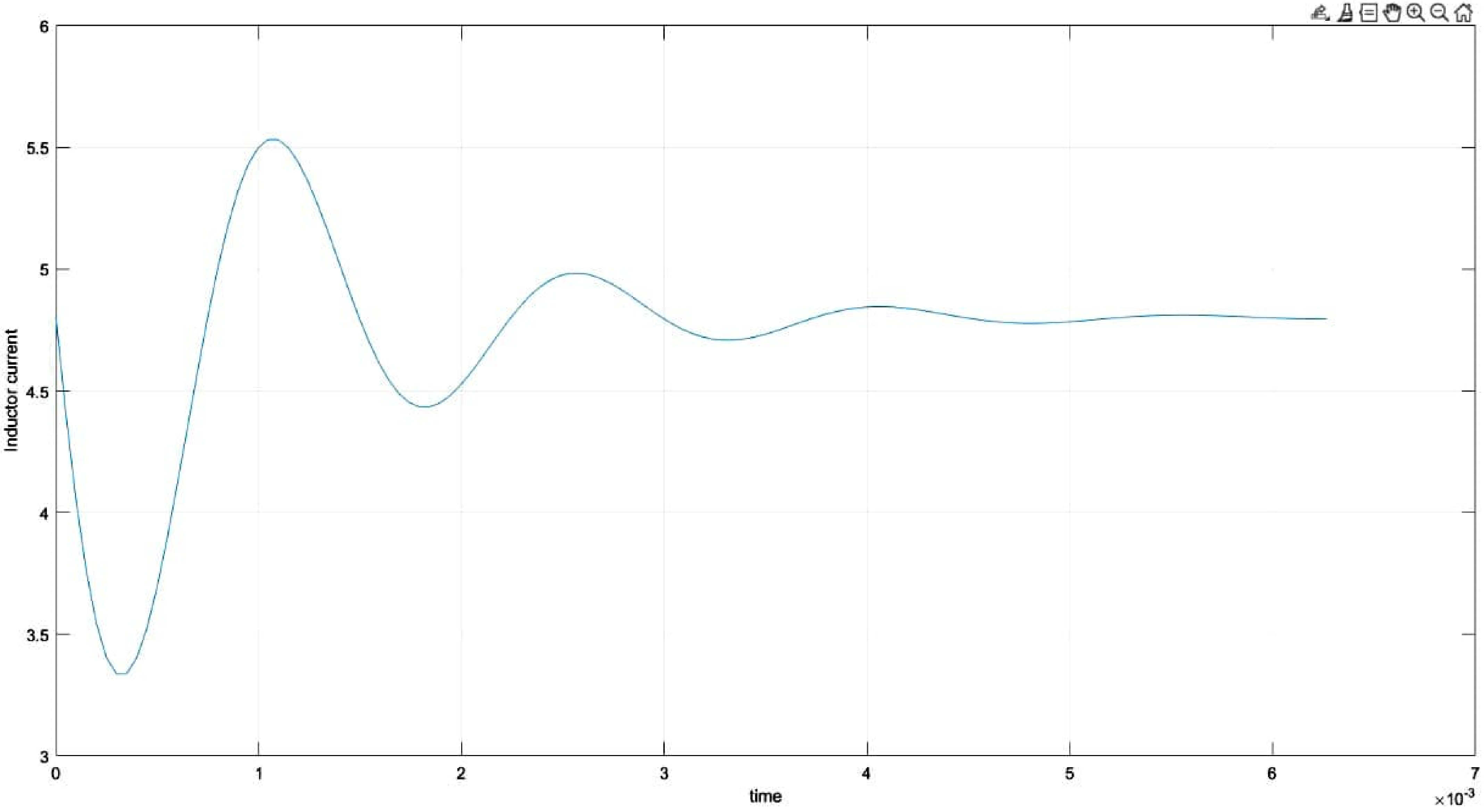
$$\frac{\Delta V_o(s)}{\Delta V_{in}(s)} = \frac{1.778\times10^{7}s + 3.73\times10^{11}}{41769s^2 + 1.191\times10^{8}s + 8.5\times10^{11}}$$

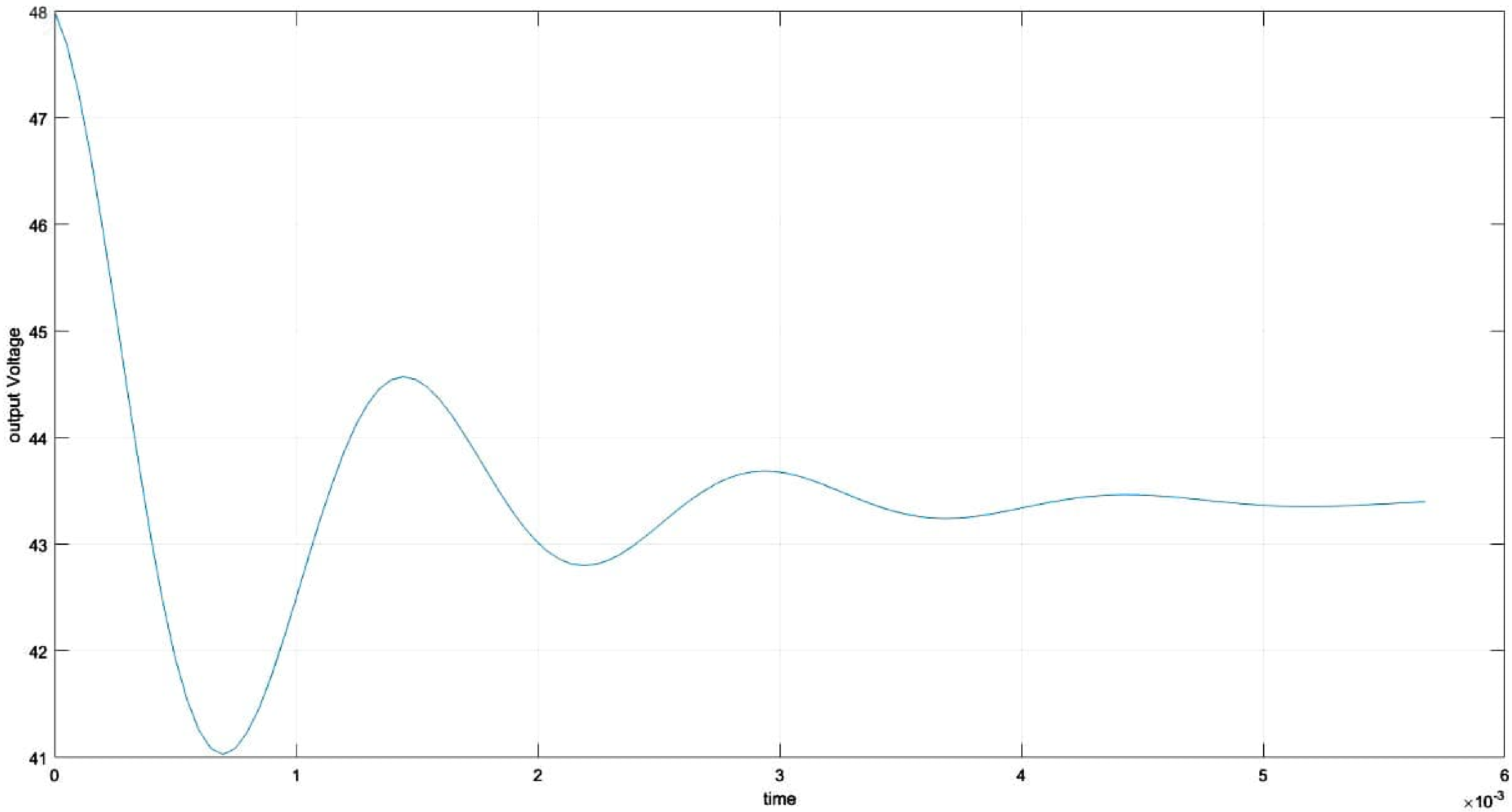
$$\Delta V_o(s) = \frac{1.778\times10^{7}s + 3.733\times10^{11}}{41769s^2 + 1.191\times10^{8}s + 8.5\times10^{11}} \times \frac{-10}{s}$$

$$\frac{\Delta I_L(s)}{\Delta d(s)} = \frac{3.55\times10^{7}s + 3.55\times10^{10}}{41769s^2 + 1.191\times10^{8}s + 3.508\times10^{11}}$$

$$\Delta I_L(s) = \frac{3.55\times10^{7}s + 3.55\times10^{10}}{41769s^2 + 1.191\times10^{8}s + 3.508\times10^{11}} \times \frac{-10}{s}$$

Plot of Both is attached with this


Inductor current
time
$\times 10^{-3}$
6
5.5
5
4.5
4
3.5
3
0
1
2
3
4
5
6
7



48
47
46
45
44
43
42
41
output Voltage
0
1
2
3
4
5
6
time
×10-3

e)

$$\frac{\Delta i_L(s)}{\Delta v_{in}(s)} = \frac{851.85\, s}{s^2 + 1851.85 s + 1.85 \times 10^7}$$

$$\omega = 2\pi \times 100$$
$$= 200\pi$$
$$= 628.31 \text{ rad/sec.}$$

At 628.31 rad/sec

Gain = -30.6 dB

$$20 \log \frac{\Delta i_o}{\Delta V_{in}} = -30.6$$

$$\frac{\Delta i_o}{\Delta V_{in}} = 10^{\frac{-30.6}{20}}$$

$$\frac{\Delta i_o}{\Delta V_{in}} = 0.04$$

$$\Delta i_o = 0.03 \times 5$$

$$\boxed{\Delta i_o = 0.15 A}$$

$$\Delta V_o(s) = \frac{425 s + 8.5 \times 10^6}{s^2 + 1851.85 s + 1.35 \times 10^4}$$

At 628.31 rad/sec

Gain = -6.58

$$\frac{\Delta V_o}{\Delta V_{in}} = 10^{\frac{-6.58}{20}}$$

$$\boxed{\Delta V_o = 2.34 V}$$

Ques 2. Bode plot $\frac{\Delta \bar{V}_o(s)}{\Delta d(s)}$

$$\frac{\Delta \bar{V}_o(s)}{\Delta d(s)} = \frac{\left(\frac{V_{in}+V_r}{LC}\right)(1 + r_c s c)}{s^2 + \frac{r_{eff}}{L} s + \frac{1}{LC}}$$

$$r_{eff} = r_c + r_L + d_o r_s + (1-d_o) r_d$$

$$V_o = [d V_{in} + (1-d) V_r] + [r_L + d r_s + r_d (1-d)] i_o$$

$$48 = d_o \times 110 + (1-d_o) 0.5 + [0.3 + d_o 0.2 + 0.2 (1-d_o)] 4.8$$

$$\boxed{d_o = 0.412}$$

$$\therefore r_{eff} = 0.5 + 0.3 + 0.412 \times 0.2 + (1-0.412) 0.2$$
$$= 1 \Omega$$

$$\frac{\Delta \bar{V}_o(s)}{\Delta d(s)} = \frac{\left(\frac{110+0.5}{540 \times 100 \mu\mu}\right)(1 + 0.5 \times 100\mu s)}{s^2 + \frac{1}{540\mu} s + \frac{1}{540\mu \times 100\mu}}$$

$$\boxed{\frac{\Delta \bar{V}_o(s)}{\Delta d(s)} = \frac{2046.3 \times 10^6 [1 + 50\mu s)}{s^2 + 1851.85 s + 18.51 \times 10^6}}$$

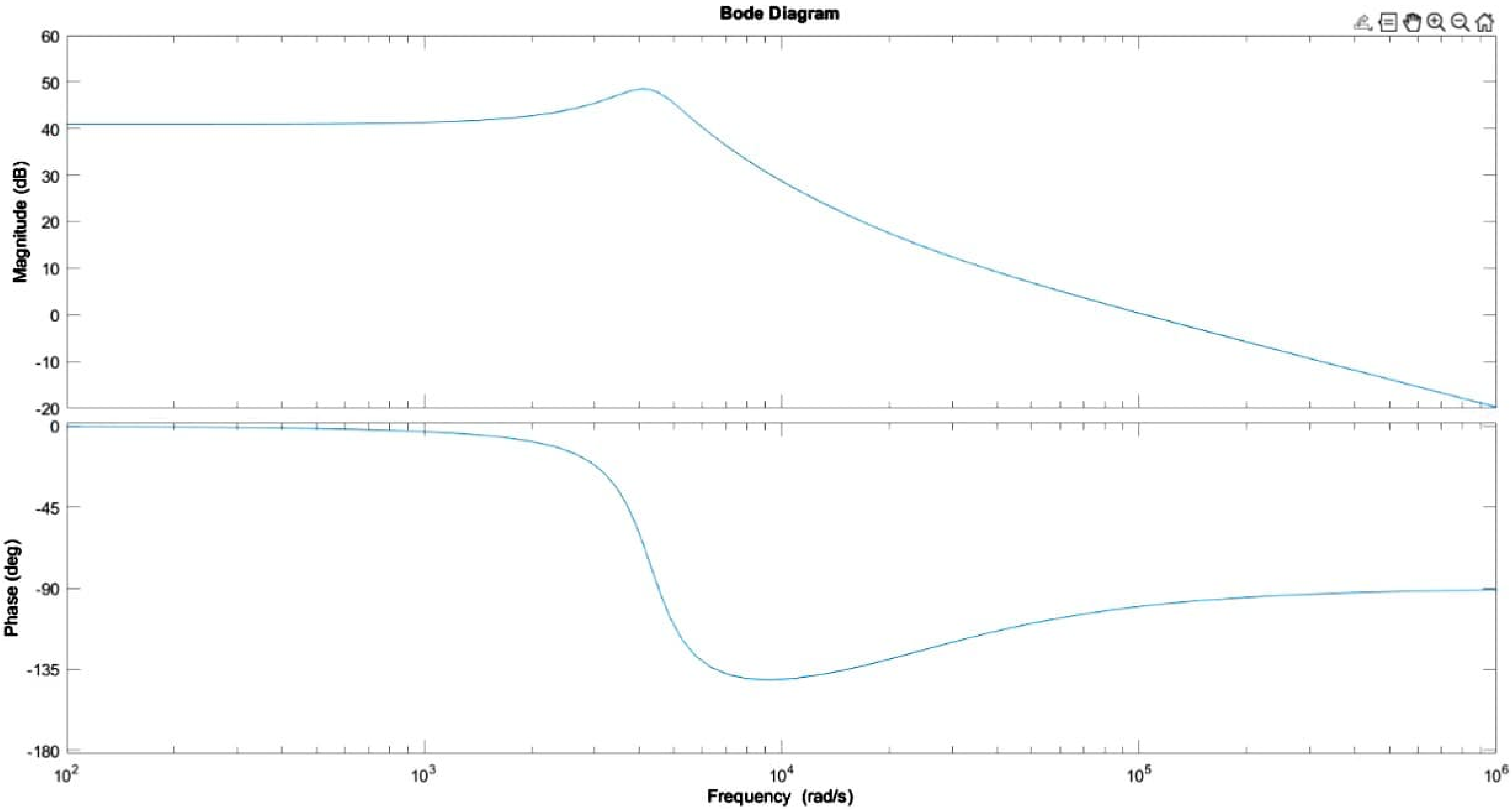
When we plot this transfer fn. on MATLAB then at $f_{co} = 5KHz$ ie, $\omega = 2\pi f = 2\pi \times 5K = 3.14 \times 10^4$ rad/sec we get phase delay of $G(s) = +119°$.

Phase delay Angle of $K'(j\omega_{co}) = 90° - \text{Phase delay } G(j\omega_{co}) - PM$

$$0 = 90° - 119° - PM$$

$$PM = -ve$$

Hence PM is Negative so, it is not possible to design at $f_{co} = 5KHz$.



Bode Diagram
Magnitude (dB)
60
50
40
30
20
10
0
-10
-20
Phase (deg)
0
-45
-90
-135
-180
10^2
10^3
10^4
10^5
10^6
Frequency (rad/s)

∴ Now, fixing $P.M = 45°$

∴ $0 = 90° -$ Phase delay of $G(j\omega_{co}) - 45°$

Phase delay of $G(j\omega_{co}) = 45°$

from the Bode plot we get the frequency corresponding to 45° phase which is 3.7k rad/sec.

$\omega_{co} = 3700$ rad/sec.

$G.M = 48$ dB

$20 \log |M| = 48$

$|M| = 251.18$

∴ $k = \frac{\omega_{co}}{|G(j\omega_{co})|} = \frac{3700}{251.18} = 14.73$

Hence our system becomes slow and sluggish ∴
So, Type 1 Compensator is not good for this transfer fn or for Buck Converter.

b) $f_{co} = ?$

$PM = 60°$ — Type 1 Compensator

∴ $0 = 90° -$ Phase delay of $G(j\omega_{co}) - PM$

$0 = 90° -$ Phase delay of $G(j\omega_{co}) - 60°$

Phase delay of $G(j\omega_{co}) = 30°$

So, from the Bode plot we get ω_{co} corresponding to phase delay of $G(j\omega_{co}) = 30°$ is

$\omega_{co} = 3.31$ krad/sec.

$\omega_{co} = 2\pi f_{co}$

$f_{co} = \frac{3.31 \times 10^3}{2\pi}$

$\boxed{f_{co} = 527 \text{ Hz}}$

c) $f_{co} = ?$

$PM = 60°$ → by Type 2 Compensator

Phase delay Angle of $k'(j\omega_{co}) = 90° -$ Phase delay angle of $G(j\omega_{co}) - PM$

∴ Phase delay of $G(j\omega_{co}) + P.M \leq 170°$

Phase delay of $G(j\omega_{co}) = 170° - 60°$

$= 110°$

Now, from the Bode Plot we can get the ω_{co} corresponding to $110°$. i.e,

$\omega_{co} = 4.5$ k rad/sec.

$f_{co} = \frac{4500}{2\pi}$

$\boxed{f_{co} = 716.5 \text{ Hz}}$

d) $f_{co} = ?$

$PM = 60°$ → by Type III Compensator

Phase delay of $G(j\omega_{co}) + PM \leq 250°$

Phase delay of $G(j\omega_{co}) = 250° - 60$

$= 190°$

Now, from the Bode plot we can get the ω_{co} corresponding to the $190°$ i.e,

Here According to our design specification $f_s = 50 kHz$

$f_{co} = f_s/10 = \frac{50K}{10} = 5KHz$

∴ $\boxed{f_{co} = 5KHz}$

So, at this frequency, from the bode plot

Phase delay of $G(j\omega_{co}) = 119°$. and $G.M = 12.4 dB$

e) Designing the Compensator TOF in 'b', 'c', 'd'.

Designing Compensator for 'b' part i.e, Type 1.

$f_{co} = 527 \text{ Hz}$

$w_{co} = 3.31 \text{ k rad/sec.}$

$|G.M| = 46.1 \text{ dB}$

$20 \log |M| = 46.1$

$|M| = 201.83$

$$K = \frac{w_{co}}{|G(jw_{co})|} = \frac{33100}{201.83} = 163.99$$

$$\boxed{\text{Compensator} = \frac{K}{s} = \frac{164}{s}}$$

for 'c' port

$w_{co} = 4.5 \text{ k rad/sec.}$, Phase delay of $G(jw_{co}) = 110°$

$|G.M| = 48 \text{ dB}$ $\quad$ $PM = 60°$

$$K(s) = \frac{K(1+T_z s)}{s(1+T_p s)} = \frac{K}{s} \times K'(s)$$

$$w_z = \frac{w_{co}}{k} , \quad w_p = k\, w_{co}$$

$$k = \tan\left\{\frac{\text{Phase Delay angle of } G(jw_{co}) + PM}{2}\right\}$$

$$k = \tan\left\{\frac{110 + 60°}{2}\right\}$$

$$\boxed{k = 11.43}$$

$$|K'(jw_{co})| = \frac{\sqrt{1+k^2}}{\sqrt{1+1/k^2}} = k = 11.43$$

$$K \times 11.43 = \frac{w_{co}}{|G(jw_{co})|} = \frac{4500}{251.2}$$

$|M| = 48 \text{ dB}$

$20\log|M| = 48$

$|M| = 251.2$

$$\boxed{K = 1.567}$$

Now, $\tau_z = \frac{1}{\omega_{z}} = \frac{k}{\omega_{co}} = \frac{11.43}{4500} = 2.54 \times 10^{-3}$ sec. $= \tau_p$

$\omega_p = \frac{1}{\tau_p}$

$\therefore \tau_p = \frac{1}{\omega_p} = \frac{1}{k\omega_{co}} = \frac{1}{11.43 \times 4500} = 19.4 \times 10^{-6}$ sec.

$\therefore K(s) = \frac{K}{s} \frac{(1+\tau_z s)}{(1+\tau_p s)}$

$$\boxed{K(s) = \frac{1.567}{s} \frac{(1+2.54\times10^{-3}s)}{(1+19.4\times10^{-6}s)}} \rightarrow \text{Type II Compensator}$$

for 'd' part (Type III Compensator)

$f_{co} = 5\,kHz$

$\omega_{co} = 3.14 \times 10^4$ rad/sec.

Phase of $G(j\omega_o)$ delay $= 119°$

$G.M = 12.4\,dB$

$20 \log |M| = 12.4$ $\qquad$ PM $= 60°$

$|M| = 4.168$

$$K(s) = \frac{K}{s} \frac{(1+\tau_z s)^2}{(1+\tau_p s)^2}$$

$$K\,|K'(j\omega_{co})| = \frac{\omega_{co}}{|G(j\omega_{co})|}$$

$$K'(j\omega_{co}) = \frac{(1+jk)^2}{(1+j/k)^2}$$

ϕ (Phase Delay Angle) $= 180° - 4\tan^{-1} k$

$$k = \tan\left\{\frac{90° + \text{Phase delay of } G(j\omega_{co}) + PM}{4}\right\}$$

$$= \tan\left\{\frac{90° + 119° + 60°}{4}\right\} = 2.38$$

$$K \times |K'(j\omega_{co})| = \frac{\omega_{co}}{|G(j\omega_{co})|}$$

$$|K'(j\omega_{co})| = k^2 = (2.38)^2 = 5.68$$

$$\therefore \quad K = \frac{\omega_{co}}{5.68 \times |G(j\omega_{co})|}$$

$$K = \frac{31400}{5.68 \times 4.168} = 1326.3$$

$$\boxed{K = 1326.3}$$

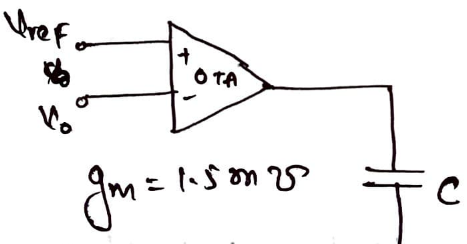
$$\tau_z = \frac{k}{\omega_{co}} = \frac{2.38}{31400} \qquad \tau_p = \frac{1}{k\omega_{co}} = \frac{1}{2.38 \times 31400}$$

$$\tau_z = 75.7 \times 10^{-6} \text{ sec.} \qquad \tau_p = 13.3 \times 10^{-6} \text{ sec.}$$

$$\therefore \quad K(s) = \frac{K}{s} \frac{(1+\tau_z s)^2}{(1+\tau_p s)^2}$$

$$\boxed{K(s) = \frac{1326.3}{s} \frac{(1+75.7\times10^{-6} s)^2}{(1+13.3\times10^{-6} s)^2}} \rightarrow \text{Type III Compensator.}$$

f) Type I and Type II Compensator → Design.



$g_m = 1.5\,m℧$

Type I

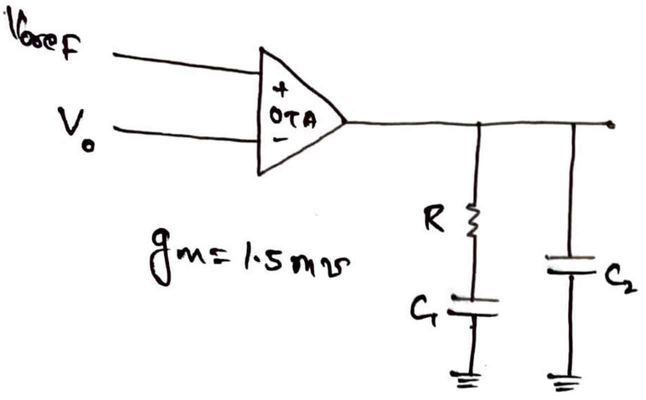
for Type I

As we know,

$$\frac{K}{s} = \frac{g_m}{sC}$$

$$C = \frac{g_m}{K} = \frac{1.5m}{164}$$

$$\boxed{C = 9.1\,\mu F}$$



$g_m = 1.5\,m℧$

Type II

$$H(s) = \frac{g_m}{\frac{C_1+C_2}{s}}\left[\frac{1+sRC_1}{1+Rs\frac{C_1C_2}{C_1+C_2}}\right]$$

$$\frac{g_m}{C_1+C_2} = K = 1.567$$

$$RC_1 = \tau_2 = 2.54\times10^{-3}$$

$$\frac{RC_2C_1}{C_1+C_2} = 19.4\times10^{-6} = \tau_p \quad \text{— (A)}$$

$$\cancel{C_2 = \frac{19.4\times10^{-6}}{2.54\times10^{-3}} = 7.63\times10^{-3}F}$$

$$\boxed{\cancel{C_2 = 7.637\,nF}}$$

$$\frac{g_m}{C_1+C_2} = 1.567$$

$$\cancel{\frac{1.5m}{C_1+7.63\times10^{-3}} = 1.567}$$

$$C_1+C_2 = \frac{1.5m}{1.567} = 0.957\,m$$

from A

$$\frac{\tau_2\times C_2}{C_1+C_2} = 19.4\times10^{-6}$$

$$C_2 = \frac{19.4\times10^{-6}\times0.957\times10^{-3}}{2.54\times10^{-3}}$$

$$\boxed{C_2 = 7.31\,\mu F}$$

$$K = \frac{g_m}{C_1 + C_2}$$

$$C_1 + C_2 = 0.957\,m$$

$$C_1 = 0.957\,m - 7.31\,\mu$$

$$\boxed{C_1 = 949\,\mu F}$$

$$RC_1 = 2.54 \times 10^{-3}$$

$$\boxed{R = 2.6\,\Omega}$$

g) Design → opamp Circuit
Type III Compensator arrived at part 'e'

$K = 1326.3$

$\tau_z = 75.7 \times 10^{-6}$ sec.

$\tau_p = 13.3 \times 10^{-6}$ sec

Choosing $C_2 = 0.1 \mu F$

$$K = \frac{1}{R_1 [C_1 + C_2]} , \quad \tau_z = R_2 C_2 = (R_1 + R_3) C_3$$

$$\tau_p = R_2 \frac{C_1 C_2}{C_1 + C_2} = R_3 C_3$$

$$\frac{V_o(s)}{V_{in}(s)} = -\frac{1}{R_1 [C_1 + C_2] s} \frac{(1 + s R_2 C_2)[1 + s (R_1 + R_3) C_3]}{(1 + s R_3 C_3)[1 + s R_2 \frac{C_1 C_2}{C_1 + C_2}]}$$

$\tau_z = R_2 C_2$

$75.7 \times 10^{-6} = R_2 \times 0.1 \mu$

$\boxed{R_2 = 0.75 k\Omega}$

$$\tau_p = R_2 \frac{C_1 C_2}{C_1 + C_2} \Rightarrow \frac{13.3 \times 10^{-6}}{0.75 k} = \frac{C_1 \times 0.1 \mu}{C_1 + 0.1 \mu}$$

$0.017 [C_1 + 0.1] = 0.1 C_1$

$C_1 + 0.1 = 5.88 C_1$

$0.1 = 4.88 C_1$

$\boxed{C_1 = 20.4 nF}$

Now, $K = \frac{1}{R_1 [C_1 + C_2]}$

$$1326.3 = \frac{1}{R_1 [20.4 n + 0.1 \mu]}$$

$\boxed{R_1 = 6.26 k\Omega}$

Now, $\tau_z = R_2 C_2 = [R_1 + R_3] C_3$

$= R_1 C_3 + R_3 C_3$

$\tau_z = R_1 C_3 + \tau_p \Rightarrow 75.7 \times 10^{-6} = 6.26k \times C_3 + 13.3 \times 10^{-6}$

$$\boxed{C_3 = 9.96\ nF}$$

Now, $I_2 = (R_1 + R_3)\, C_3$

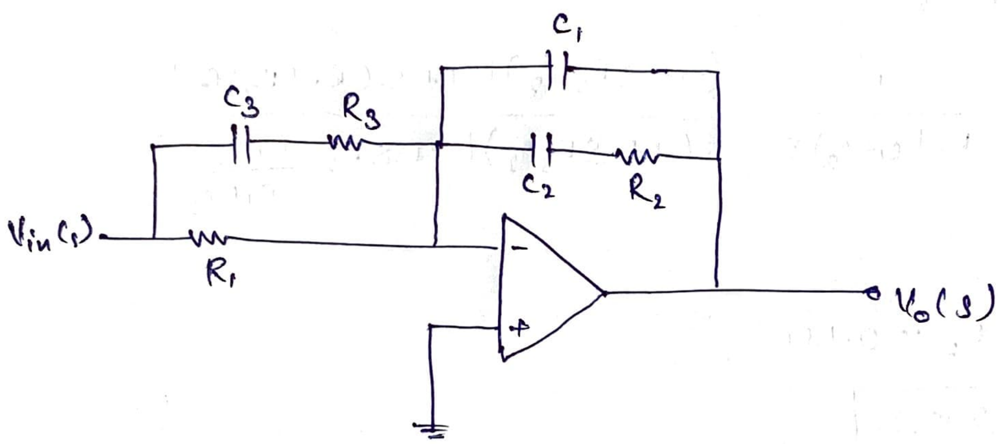
$$75.7 \times 10^{-6} = [6.26K + R_3] \times 9.96\,n$$

$$\boxed{R_3 = 1.34\ k\Omega}$$

$\therefore$ Design values are,

$R_1 = 6.26\,k\Omega$, $R_2 = 0.75\,k\Omega$, $R_3 = 1.34\,k\Omega$,

$C_1 = 20.4\,nF$, $C_2 = 0.1\,\mu F$, $C_3 = 9.96\,nF$



Type III Compensator.

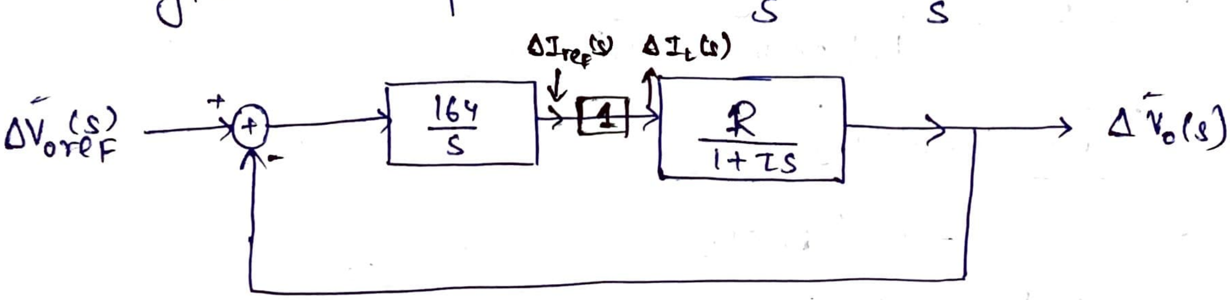
Ques 8. Type I Compensator with P.M = 60°

a) To obtain $\dfrac{\Delta \bar{V}_o(s)}{\Delta \bar{V}_{in}(s)}$, $\dfrac{\Delta \bar{V}_o(s)}{\Delta \bar{V}_{oref}(s)}$, $\dfrac{\Delta \bar{i}_L(s)}{\Delta \bar{V}_{in}(s)}$, $\dfrac{\Delta \bar{i}_L(s)}{\Delta V_{oref}(s)}$

for close loop Buck Converter

Soln: for 2 'e' part

Type I Compensator $= \dfrac{K}{S} = \dfrac{164}{S}$



$$\tau = RC = 10 \times 100\mu = 1\,\text{msec.} \qquad \therefore \frac{R}{1+\tau s} = \frac{10}{1+10^{-3}s}$$

$$\frac{\Delta \bar{V}_o(s)}{\Delta V_{oref}(s)} = \frac{\frac{164}{s} \times \frac{10}{1+10^{-3}s}}{1 + \frac{164}{s} \times \frac{10}{1+10^{-3}s}}$$

$$= \frac{1640}{s[1+10^{-3}s] + 1640} = \frac{1640}{10^{-3}s^2 + s + 1640}$$

$$\boxed{\frac{\Delta \bar{V}_o(s)}{\Delta \bar{V}_{oref}(s)} = \frac{1640000}{s^2 + 1000s + 1640000}}$$

$$\text{-lly} \quad \frac{\Delta \bar{i}_L(s)}{\Delta \bar{V}_{oref}(s)} = \frac{\frac{R}{1+\tau s}}{1 + \frac{K_i'}{s} \times \frac{R}{1+\tau s}}$$

$$= \frac{\frac{10}{1+10^{-3}s}}{1 + \frac{164}{s} \times \frac{10}{1+10^{-3}s}} = \frac{10s}{s[1+10^{-3}s] + 1640}$$

$$\boxed{\frac{\Delta \bar{i}_L(s)}{\Delta \bar{V}_{oref}(s)} = \frac{10000\,s}{s^2 + 1000s + 1640000}}$$

$$\frac{\Delta \bar{V}_o(s)}{\Delta \bar{V}_{in}(s)} = \frac{\dfrac{\left(\frac{d_o}{LC}\right)(1+sCr_c)}{s^2 + \frac{r_{eff}}{L}s + \frac{1}{LC}}}{1 + \dfrac{K_i'}{s} \times \dfrac{\left(\frac{d_o}{LC}\right)(1+sCr_c)}{s^2 + \frac{r_{eff}}{L}s + \frac{1}{LC}}}$$

$$\frac{\Delta \bar{V}_o(s)}{\Delta \bar{V}_{in}(s)} = \frac{\left(\frac{0.412}{540\mu \times 100\mu}\right)\left[1 + 0.5 \times 100\mu\, s\right] s}{s(s^2 + 1851.85\,s + 18.51 \times 10^6) + 164\left(\frac{0.412}{540\mu \times 100\mu}\right)(1 + s \times 0.5 \times 100\mu)}$$

$$\boxed{\frac{\Delta \bar{V}_o(s)}{\Delta \bar{V}_{in}(s)} = \frac{7.63 \times 10^6 s\,[1 + 50\mu s]}{s^3 + 1851.85\,s^2 + 18.51 \times 10^6 s + 1251.25 \times 10^6 s\,[1 + 50\mu s]}}$$

$$\frac{\Delta \bar{i}_L(s)}{\Delta \bar{V}_{in}(s)} = \frac{\dfrac{\left(\frac{d_o}{L}\right) s}{s^2 + \frac{r_{eff}}{L} s + \frac{1}{LC}}}{1 + \dfrac{K_i}{s} \times \dfrac{\left(\frac{d_o}{L}\right) s}{s^2 + \frac{r_{eff}}{L} s + \frac{1}{LC}}}$$

$$= \frac{\left(\frac{0.412}{540\mu}\right) s^2}{s^3 + 1851.85\,s^2 + 18.51 \times 10^6 s + 164\left(\frac{0.412}{540\mu}\right) s}$$

$$= \frac{762.96\,s^2}{s^3 + 1851.85\,s^2 + 18.51 \times 10^6 s + 125125.9 \times 10^6 s}$$

$$\frac{\Delta \bar{i}_L(s)}{\Delta \bar{V}_{in}(s)} = \frac{762.96\,s}{s^2 + 1851.85\,s + 18.51 \times 10^6 + 125125.9 \times 10^6}$$

$$\boxed{\frac{\Delta \bar{i}_L(s)}{\Delta \bar{V}_{in}(s)} = \frac{762.96\,s}{s^2 + 1851.85\,s + 125144.4 \times 10^6}}$$

b) Time-domain response plot using MATLAB for $\bar{v}_o(t)$ and $i_L(t)$ when V_{oref} changes from 48V to 40V.

$$\frac{\Delta \bar{V}_o(s)}{\Delta \bar{V}_{ref}(s)} = \frac{1.64 \times 10^6}{s^2 + 1000\,s + 1.64 \times 10^6}$$

~~when $\Delta \bar{V}_{ref}(s) = 48V \rightarrow 48/s$~~

$$\cancel{\Delta \bar{V}_o(s) = \frac{1.64 \times 10^6 \times 48}{s^3 + 1000\,s^2 + 1.64 \times 10^6 s}}$$

Answer:

When Voref changes from 48V to 40V.

$$V_{oref}(t) = V(\infty) - [V(\infty) - V(0)]\, e^{-t/\tau}$$

$\tau = RC$
$= 10 \times 100\mu$
$= 1m$

$$= 48 - [48 - 40]\, e^{-t/1m}$$

$$= 48 - 8e^{-1000t}$$

$$V_{oref}(s) = \frac{48}{s} - \frac{8}{s+1000}$$

$$\therefore \Delta \bar{V}_o(s) = \frac{1.64\times10^6}{s^2+1000s+1.64\times10^6} \times \left[\frac{48}{s} - \frac{8}{s+1000}\right]$$

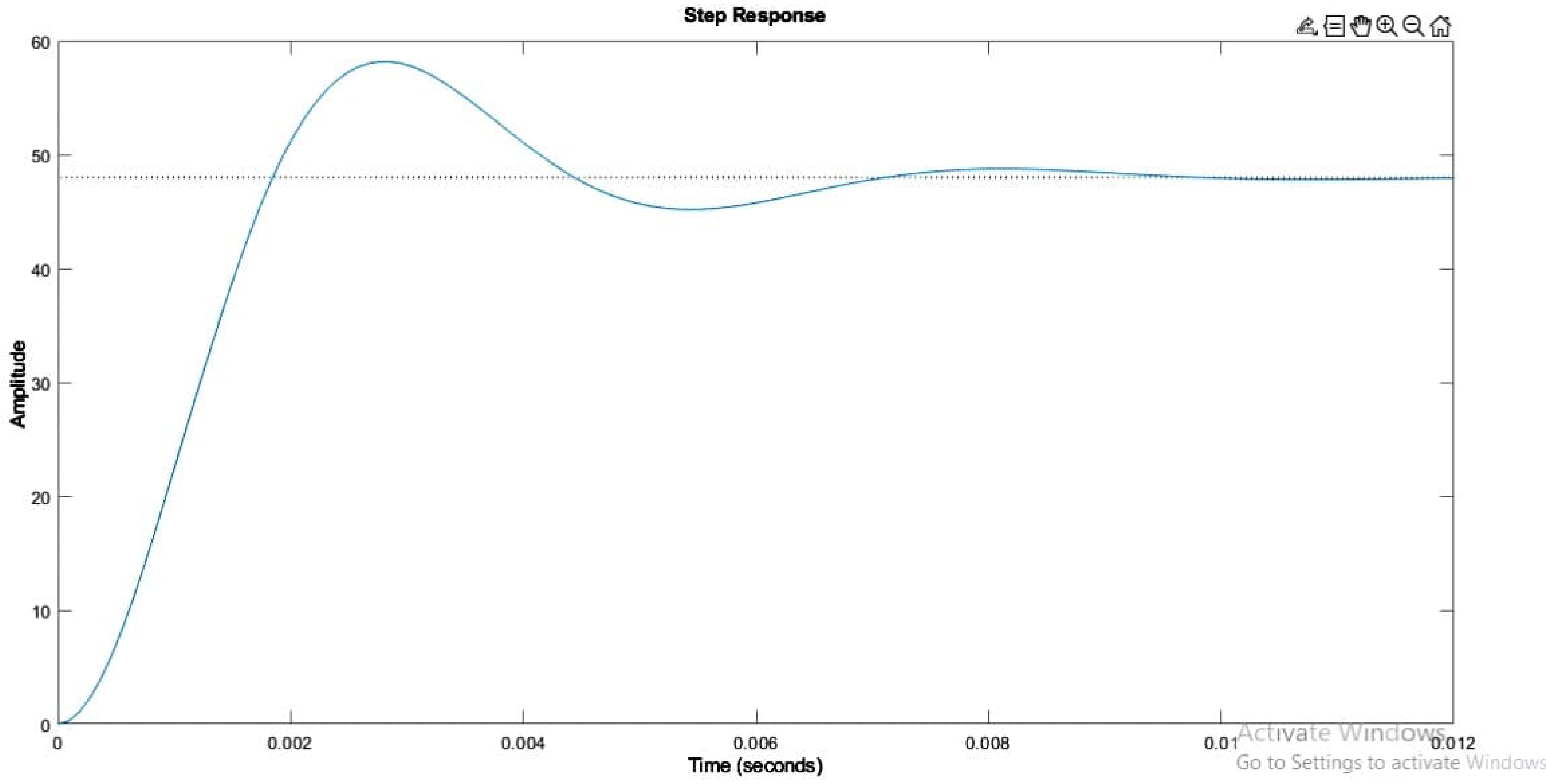
$$= \frac{1.64\times10^6}{s^2+1000s+1.64\times10^6} \left[\frac{48s+48000-8s}{s[s+1000]}\right]$$

$$\Delta \bar{V}_o(s) = \frac{1.64\times10^6\,[40s+48000]}{s^4+2000s^3+2.64\times10^6 s^2+1.64\times10^9 s}$$

$$= \frac{65600000s + 7872\times10^7}{s^4+2000s^3+2.64\times10^6 s^2+1.64\times10^9 s}$$

$$\boxed{\Delta V_o(t) = 280\sqrt{139}\,\sin(100\sqrt{139}\,t) - \frac{5560\cos(100\sqrt{139}\,t)}{139} \cdot e^{-500t} + 48 - 8e^{-1000t}}$$

Time Domain Response plot of $\bar{V}_o(t)$ is given by the MATLAB is attached with the page.



Step Response
Amplitude
Time (seconds)
0
10
20
30
40
50
60
0
0.002
0.004
0.006
0.008
0.01
0.012
Activate Windows
Go to Settings to activate Windows

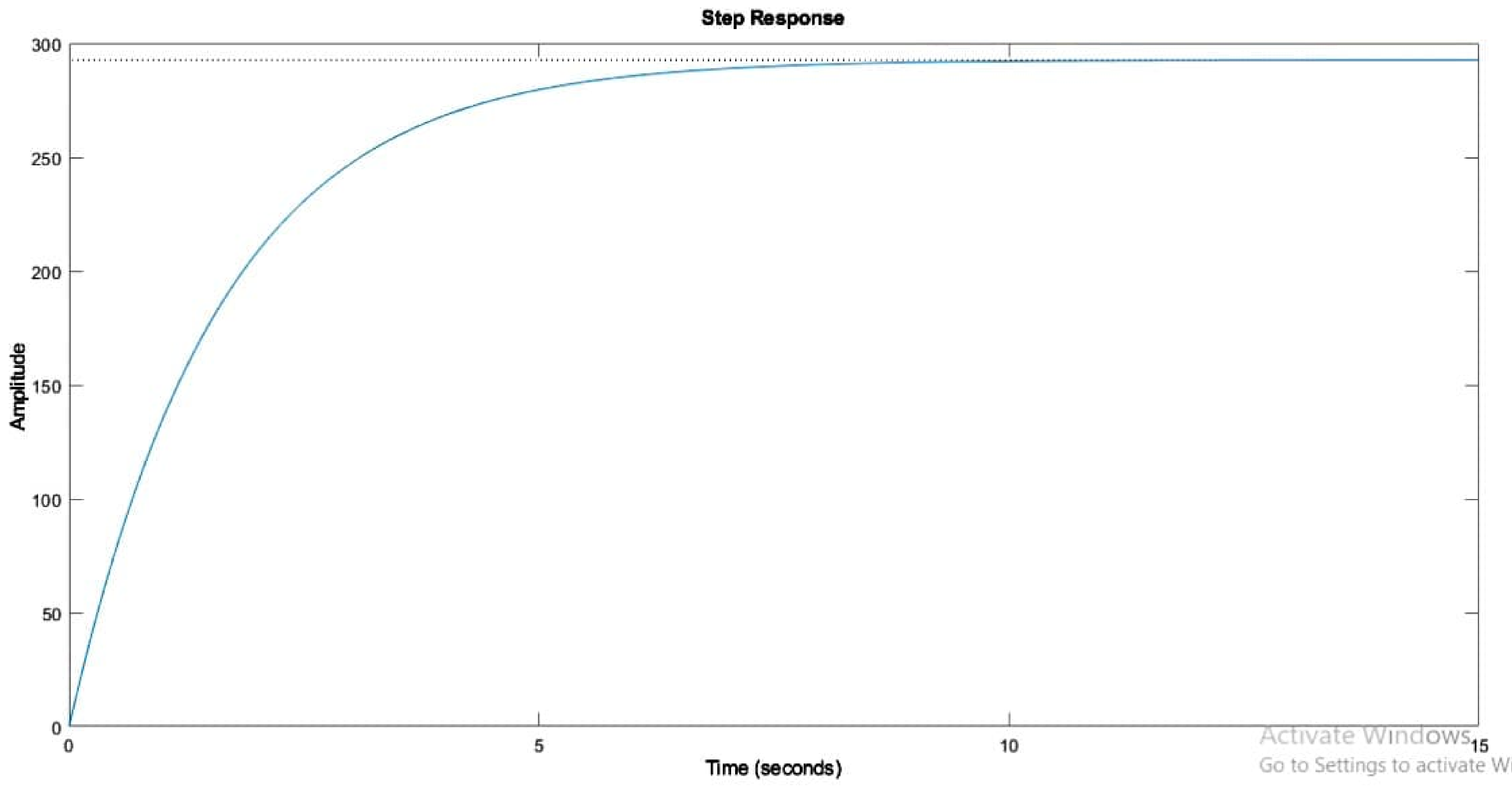
Hly $\dfrac{\Delta \hat{i}_L(s)}{\Delta \hat{V}_{ref}(s)} = \dfrac{10000\, s}{s^2 + 1000 s + 1640000}$

$$\Delta \bar{i}_L(s) = \frac{10^4 s}{s^2 + 10^3 s + 164 \times 10^4} \times \left[\frac{40s + 48000}{s\,[s+1000]} \right]$$

$$= \frac{10^4\,[40 s^2 + 48000 s]}{s^4 + 2\times10^3 s^3 + 2640000 s^2 + 164\times10^4 s}$$

$$\Delta \bar{i}_L(s) = \frac{10^4\,[40s + 48000]}{s^3 + 2\times10^3 s^2 + 2640000 s + 164\times10^4}$$

Time response plot using MATLAB is attached with this ques.


Step Response
Amplitude
Time (seconds)
0
50
100
150
200
250
300
0
5
10
15

c) To obtain time domain response plot for $\bar{V_o}(t)$ and $\bar{i_L}(t)$ for Vin suddenly changes from 110V to 100V.

Soln:

V_{in} = 110 to 100

$$V_{in}(t) = V(\infty) - [V(\infty) - V(0)]\, e^{-t/\tau}$$

$$= 110 - [110 - 100]\, e^{-1000t}$$

$$= 110 - 10 e^{-1000t}$$

$$V_{in}(s) = \frac{110}{s} - \frac{10}{s+1000} = \frac{110s + 11\times10^4 - 10s}{s(s+1000)}$$

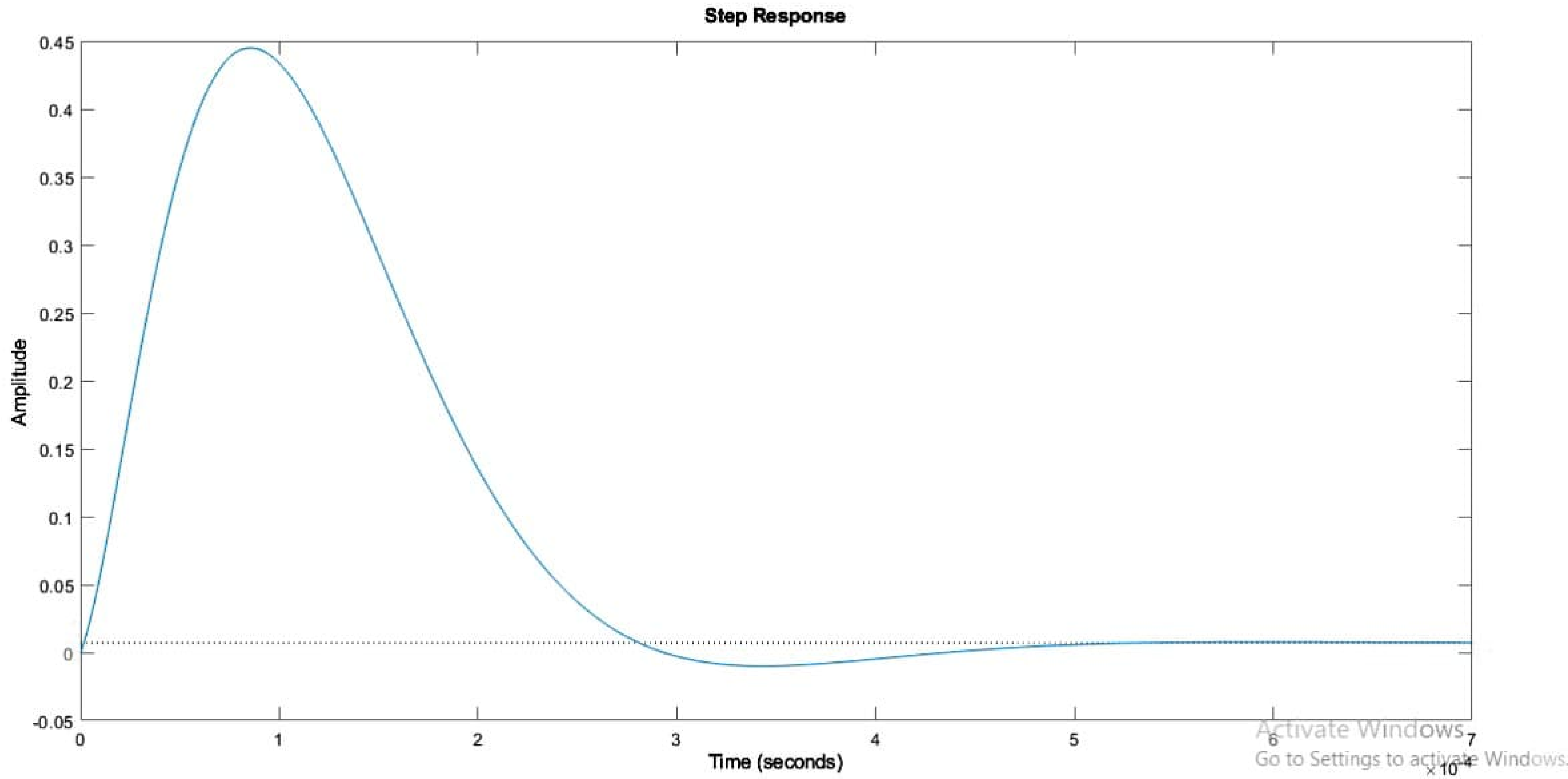
$$= \frac{100s + 11\times10^4}{s(s+1000)}$$

$$\frac{\Delta \bar{V_o}(s)}{} = \frac{7.63\times10^6\, \cancel{s}\,[1+50\mu s]}{s^3 + 1851.85 s^2 + 18.51\times10^6 s + 1251.25\times10^6 s[1+50\mu s]} \times \frac{100s+11\times10^4}{\cancel{s}(s+1000)}$$

$$= \frac{7.63\times10^6\, [1+50\mu s][100s + 11\times10^4]}{(s^3 + 1851.85 s^2 + 18.51\times10^6 s + 1251.25\times10^6 s + 62562.5 s^2)(s+10^3)}$$

$$\Delta \bar{V_o}(s) = \frac{3815 s^2 + 76719.65\times10^4 s + 8.93\times10^{10}}{s^4 + 65414.35 s^3 + 1333.4\times10^6 s^2 + 1269\times10^9 s}$$

Time Response plot using MATLAB is attached with this ques.



Step Response
Amplitude
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
-0.05
0
1
2
3
4
5
6
7
Time (seconds)
×10^-4
Activate Windows
Go to Settings to activate Windows.

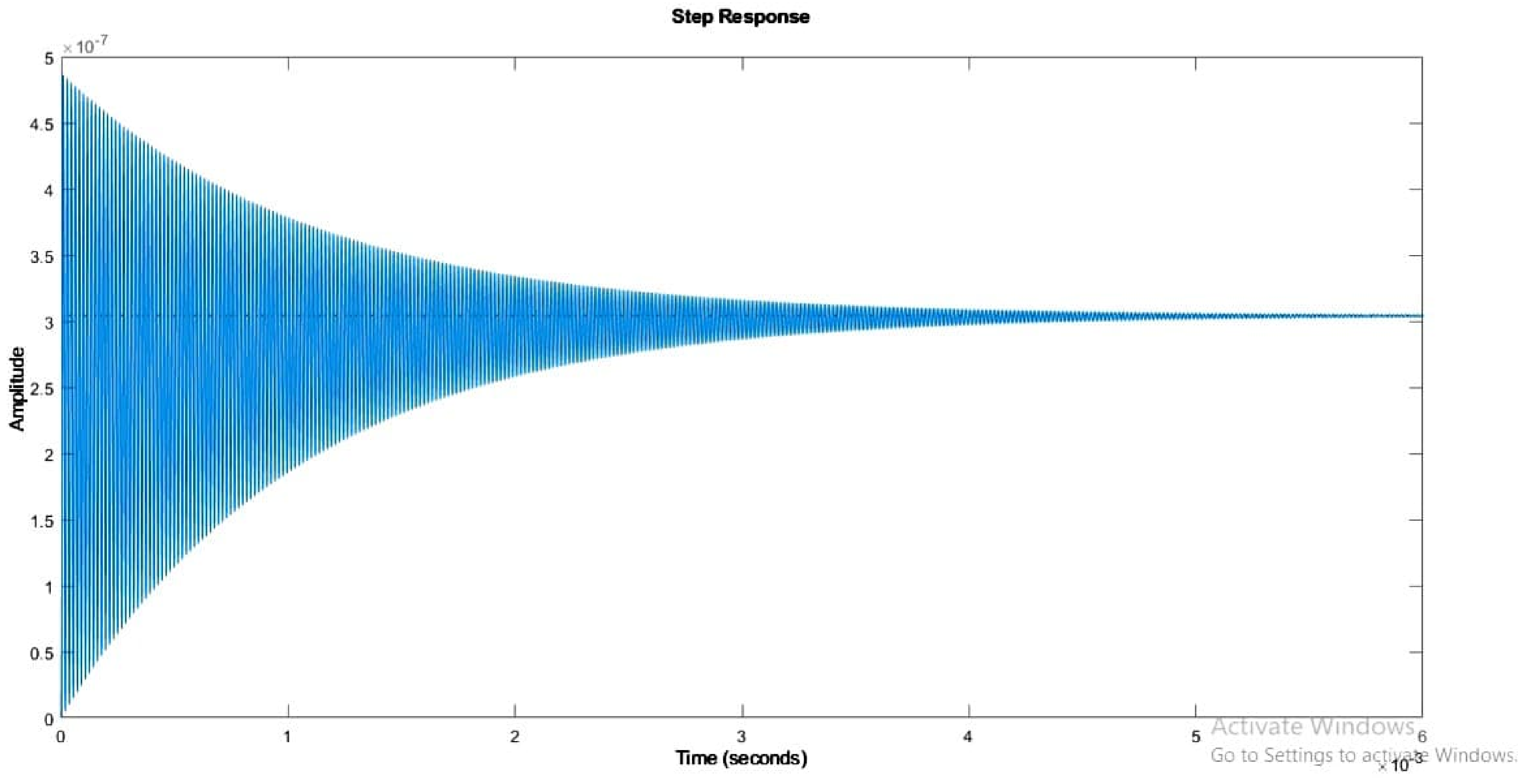
-lly $\frac{\Delta i_L(s)}{\Delta v_{in}(s)} = \frac{762.96\, s}{s^2 + 1851.85\, s + 125144.4 \times 10^6}$

$$\Delta i_L(s) = \frac{762.96\, \cancel{s}}{s^2 + 1851.85 s + 125144.4 \times 10^6} \times \frac{40s + 48000}{\cancel{s}\,[s + 10^3]}$$

$$= \frac{762.96\,[40s + 48000]}{s^3 + 1851.85 s^2 + 125144.4 \times 10^6 s + 1000 s^2 + 1851.85 \times 10^3 s + 125144.4 \times 10^9}$$

$$\Delta i_L(s) = \frac{762.96\,[40s + 48000]}{s^3 + 2851.85 s^2 + 125.14 \times 10^9 s + 125.14 \times 10^{12}}$$

Time response plot using MATLAB is attached with this ques.


Step Response
×10^-7
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
Amplitude
0
1
2
3
4
5
6
Time (seconds)
×10^-3

Ques 4.

a) Buck Converter Controlled using Current Mode Control

$i_{L\,peak} = 6A$

gain $= 0.5\,V/A$

To Design → PI Controller for outer Voltage Control loop,

$t_r = 1m\,sec$

Soln:- rise time $= t_r = \frac{1}{a}$

$$a = \frac{1}{t_r} = \frac{1}{1m} = 1000$$

$$\boxed{a = 1000}$$

$$K_p = \frac{a\tau}{R}$$

$\tau = RC$

$= 10 \times 100\mu$

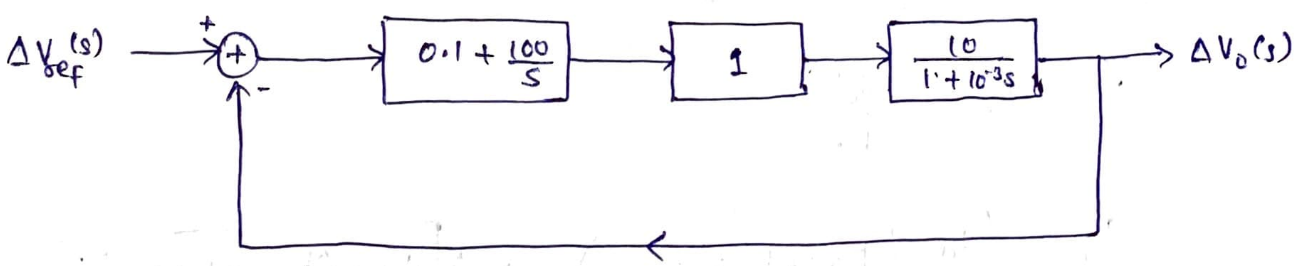
$\tau = 1m\,sec$

$$K_p = \frac{1000 \times 1m}{10}$$

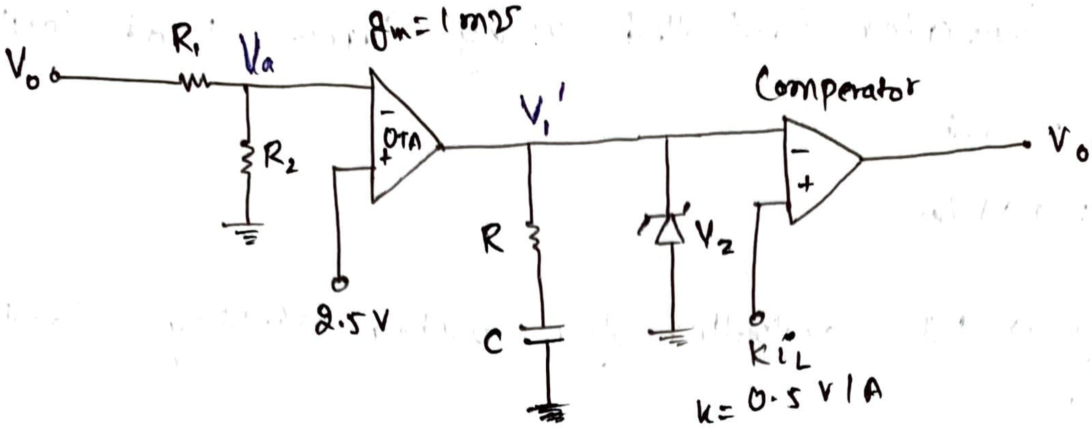
$$\boxed{K_p = 0.1}$$

$$K_i = \frac{a}{R} = \frac{1000}{10} = 100$$

$$\boxed{K_i = 100}$$



b



$$\cancel{H(s) = -\frac{R_2}{R_1+R_2} \times g_m \times \left[R + \frac{1}{C_o s}\right]}$$

$$\cancel{f_z = \frac{1}{2\pi R C}}$$

$$H(s) = -\frac{R_2 g_m}{R_1+R_2} \times R \times \frac{1+\frac{1}{SRC}}{1+SRC}$$

$$= \frac{-R_2 g_m}{R_1+R_2} \times R \times \frac{1+\frac{1}{RCS}}{1+SRC}$$

$$f_z = \frac{1}{2\pi R C}$$

$$f_p = \frac{C_f}{2\pi R_2 C}$$

$$|G(f_c)| = G_o \frac{\sqrt{1+\left(\frac{f_z}{f_c}\right)^2}}{\sqrt{1+\left(\frac{f_c}{f_p}\right)^2}}$$

$$\therefore f_z = \frac{f_c^2}{f_p}$$

$$f_p = \left\{\tan\left(\text{boost} \times \frac{\pi}{180}\right) + \sqrt{\tan\left(\text{boost} \times \frac{\pi}{180}\right)^2 + 1}\right\} \times f_c$$

$$= 27.5\ \text{kHz}$$

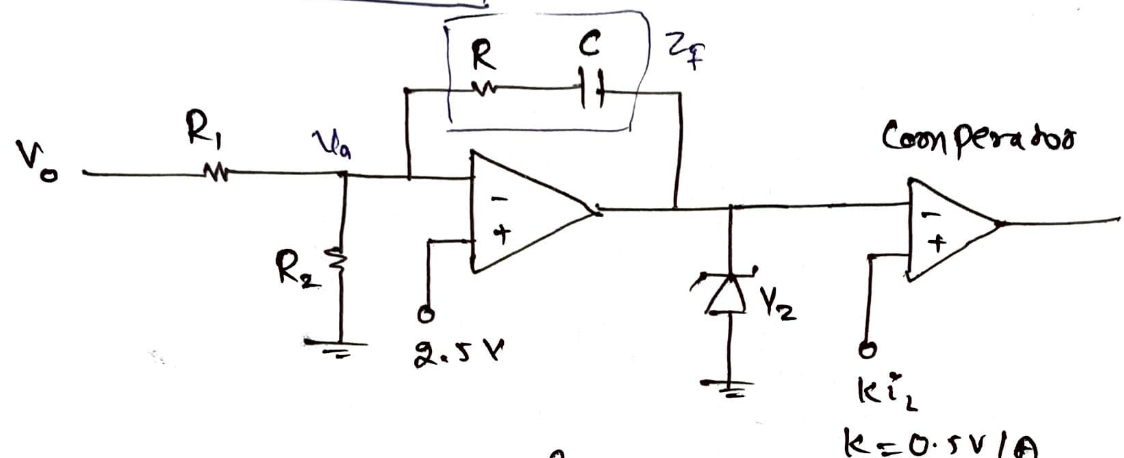
| for Boost $\theta = 50°$

$$f_2 = \frac{f_c^2}{f_p} = 3.64\,kHz$$ { from the OTA plot,

$\therefore$ $\boxed{R = 1.685\,k\Omega}$

$\boxed{C = 25.95\,nF}$

c)



Component values = ?

$$H(s) = \frac{Z_f}{Z_i} = -\frac{\frac{R * \frac{1}{Cs}}{R + \frac{1}{Cs}}}{R_1} \times \frac{R_2}{R_1 + R_2}$$

$$H(s) = \frac{1 + CRs}{C_1 R_1 s + R_1 C_1 R s^2}$$

$$f_{p_1} = \frac{1}{2\pi R}$$

$$f_{z_1} = -\frac{1}{2\pi RC}$$

$\therefore$ $\boxed{C = \frac{1}{2\pi R f_{z_1}}}$

$\boxed{R = \frac{f_{po} * R_1}{f_{z_1}}}$

$s^2 R_1 C_1 R + s R_1 C_1 = 0$

$s R_1 C_1 R + R_1 C_1 = 0$

$s = -\frac{\cancel{R_1 C_1}}{R_1 C_1 R}$

$\omega = \frac{1}{R}$

$f_p = \frac{1}{2\pi R}$

By putting all the values from the OTA Results we get

$\boxed{R = 1.2 k\Omega}$

$\boxed{C = 2.2 nF}$

Boost Converter Data

$V_{ip} = 48\,V$, $V_{op} = 110\,V$, $I_{op} = 4\,A$, $f_s = 50\,kHz$

$L = 270\,\mu H$, $C = 330\,\mu F$, $r_L = 0.3\,\Omega$, $r_s = 0.1\,\Omega$, $r_d = 0.1\,\Omega$

$R_L = 27.5\,\Omega$, $r_c = 0.1\,\Omega$

$V_r = 0.5\,V$

Ques 1.

a) State space Averaged Model

$$\begin{bmatrix} \Delta \dot{\bar{i}}_L \\ \Delta \dot{\bar{V}}_c \end{bmatrix} = \begin{bmatrix} \dfrac{-[r_L + d_o r_s + (1-d_o)(r_d + r_c)]}{L} & -\dfrac{[1-d_o]}{L} \\ \dfrac{1-d_o}{C} & 0 \end{bmatrix} \begin{bmatrix} \Delta \bar{i}_L \\ \Delta \bar{V}_c \end{bmatrix} + \begin{bmatrix} \dfrac{1}{L} & \dfrac{-[1-d_o]}{L} & \dfrac{(1-d_o) r_c}{L} \\ 0 & 0 & -\dfrac{1}{C} \end{bmatrix} \begin{bmatrix} \Delta \bar{V}_{in} \\ V_r \\ \Delta \bar{i}_o \end{bmatrix}$$

$$+ \begin{bmatrix} \dfrac{(r_d - r_s + d_o r_c)}{(1-d_o)L} I_o + \dfrac{V_o + V_r}{L} \\ -\dfrac{I_o}{(1-d_o)C} \end{bmatrix} [\Delta d(t)]$$

$$[\Delta \bar{V}_o] = [(1-d_o) r_c \quad 1] \begin{bmatrix} \Delta \bar{i}_L \\ \Delta \bar{V}_c \end{bmatrix} + [0 \quad 0 \quad -r_c] \begin{bmatrix} \Delta \bar{V}_{in} \\ V_r \\ \Delta \bar{i}_o \end{bmatrix} + \left[\dfrac{-r_c I_o}{1-d_o} \right] [\Delta d]$$

$$\begin{bmatrix} \Delta \dot{\bar{i}}_L \\ \Delta \dot{\bar{V}}_c \end{bmatrix} = \begin{bmatrix} \dfrac{-[0.3 + 0.1 d_o + (1-d_o)(0.2)]}{270\mu} & -\dfrac{[1-d_o]}{270\mu} \\ \dfrac{1-d_o}{330\mu} & 0 \end{bmatrix} \begin{bmatrix} \Delta \bar{i}_L \\ \Delta \bar{V}_c \end{bmatrix} + \begin{bmatrix} \dfrac{1}{270\mu} & \dfrac{-[1-d_o]}{270\mu} & \dfrac{(1-d_o)0.1}{270\mu} \\ 0 & 0 & \dfrac{-1}{330\mu} \end{bmatrix} \begin{bmatrix} \Delta \bar{V}_{in} \\ V_r \\ \Delta \bar{i}_o \end{bmatrix}$$

$$+ \begin{bmatrix} \dfrac{0.1 d_o \times 4}{(1-d_o)270\mu} + \dfrac{48.5}{270\mu} \\ \dfrac{-4}{(1-d_o)330\mu} \end{bmatrix} [\Delta d(t)]$$

Steady state duty ratio 'd_o'

$$V_o = \left(\frac{V_{in}}{1-d_o} - V_r \right) - I_o \left\{ \frac{r_L + d_o r_s}{(1-d_o)^2} + \frac{r_d + d r_c}{1-d_o} \right\}$$

$$110 = \left(\frac{48}{1-d_o} - 0.5 \right) - 4 \left\{ \frac{0.3 + 0.1 d_o}{(1-d_o)^2} + \frac{0.1 + 0.1 d_o}{1-d_o} \right\}$$

$$\boxed{d_o = 0.6043}$$

b) Evaluate,

$$\frac{\Delta \bar{v}_o(s)}{\Delta d(s)}, \quad \frac{\Delta \bar{v}_o(s)}{\Delta \bar{v}_{in}(s)}, \quad \frac{\Delta \bar{i}_L(s)}{\Delta d(s)}, \quad \frac{\Delta \bar{i}_L(s)}{\Delta \bar{v}_{in}(s)}$$

Soln:-

$$\frac{\Delta \bar{v}_o(s)}{\Delta d(s)} = \frac{\left(\frac{(1-d_o)V_o}{LC}\right)\left[1 - \frac{sLI_o}{(1-d_o)^2 V_o}\right]}{s^2 + \frac{r_{eff}}{L}s + \frac{(1-d_o)^2}{LC}}$$

Where
$$r_{eff} = r_L + d_o r_s + (1-d_o)(r_d + r_c)$$
$$= 0.3 + 0.6043 \times 0.1 + (1-0.6043)[0.2]$$
$$= 0.4396$$

$$\frac{\Delta \bar{v}_o(s)}{\Delta d(s)} = \frac{\left(\frac{(1-0.6043)\times 110}{270\mu \times 330\mu}\right)\left[1 - \frac{s \times 270\mu \times 4}{(1-0.6043)^2 \times 110}\right]}{s^2 + \frac{0.4396}{270\mu}s + \frac{(1-0.6043)^2}{270\mu \times 330\mu}}$$

$$\boxed{\frac{\Delta \bar{v}_o(s)}{\Delta d(s)} = \frac{488.51 \times 10^6 \left[1 - 62.7 \times 10^{-6} s\right]}{s^2 + 1628.14 s + 1.75 \times 10^6}}$$

$$\frac{\Delta \bar{i}_L(s)}{\Delta d(s)} = \frac{\alpha s + \left(\frac{1-d_o}{\beta L}\right)}{s^2 + \frac{r_{eff}}{L}s + \frac{(1-d_o)^2}{LC}}$$

$$\alpha = \frac{r_d - r_s + d_o r_c}{(1-d_o)L} + \frac{V_o + V_F}{L}$$

$$\alpha = \frac{0.6043 \times 0.1}{(1-0.6043)270\mu} + \frac{110.5}{270\mu} = 0.409 \times 10^6$$

$$\frac{\Delta \tilde{i}_L(s)}{\Delta d(s)} = \frac{0.409\times10^6\, s - \left[\dfrac{1-0.6043}{\beta\times 270\mu}\right]}{s^2 + \dfrac{0.4396}{270\mu}s + \dfrac{(1-0.6043)^2}{270\mu\times330\mu}}$$

$$\beta = \frac{-I_o}{(1-d_o)C} = \frac{-4}{(1-0.6043)\times330\mu} = -0.306\times10^6$$

$$\frac{\Delta \tilde{i}_L(s)}{\Delta d(s)} = \frac{0.409\times10^6 s - \left[\dfrac{1-0.6043}{-306\times10^6\times270\mu}\right]}{s^2 + 1628.14s + 1.75\times10^6}$$

$$\boxed{\frac{\Delta \tilde{i}_L(s)}{\Delta d(s)} = \frac{0.409\times10^6 s + 4.7\times10^{-6}}{s^2 + 1628.14s + 1.75\times10^6}}$$

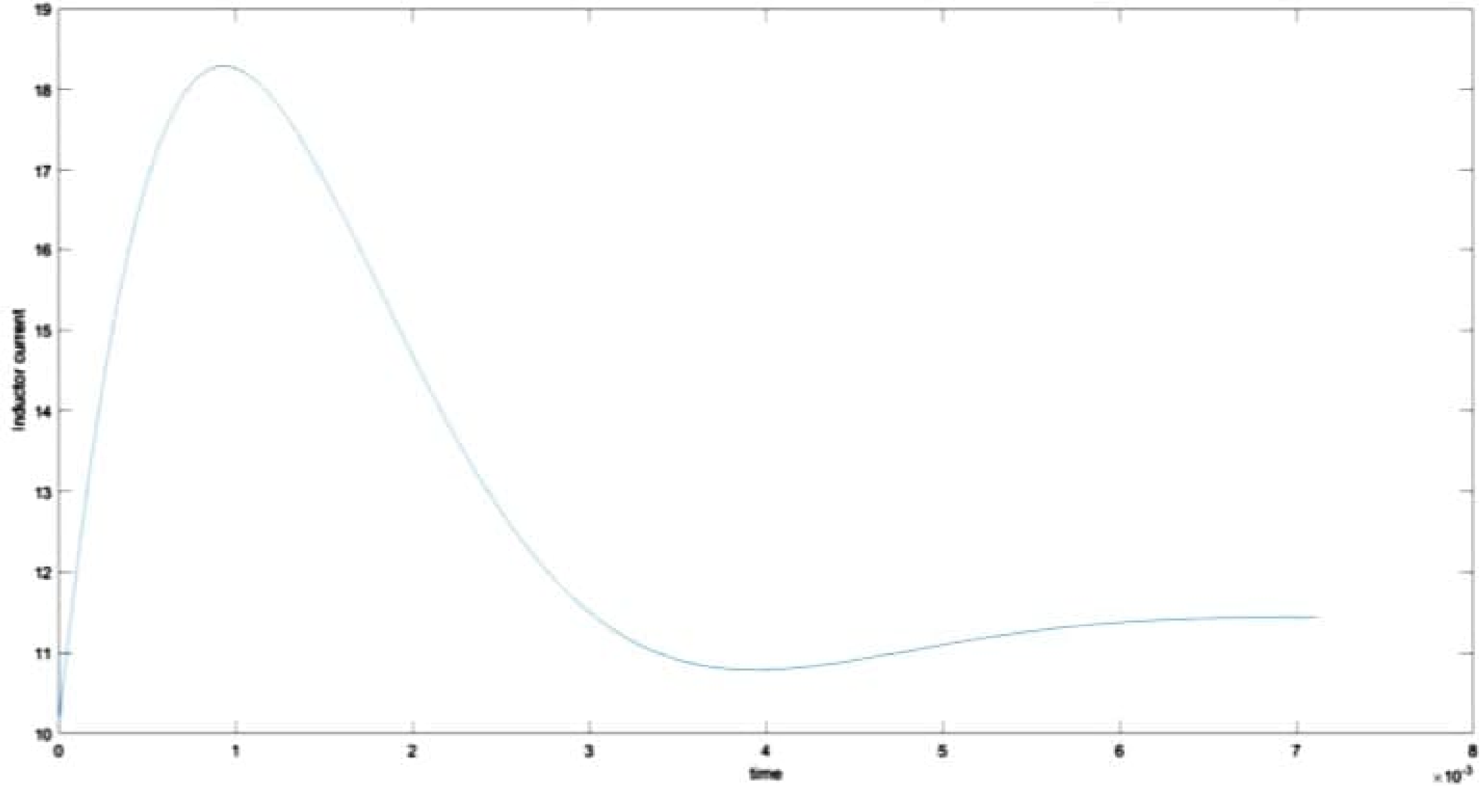
$$\boxed{\frac{\Delta I_L(s)}{\Delta V_{in}(s)} = \frac{1.934\times10^{30}\, s}{5.223\times10^{26}s^2 + 8.5\times10^{27}s + 3.66\times10^{23}}}$$

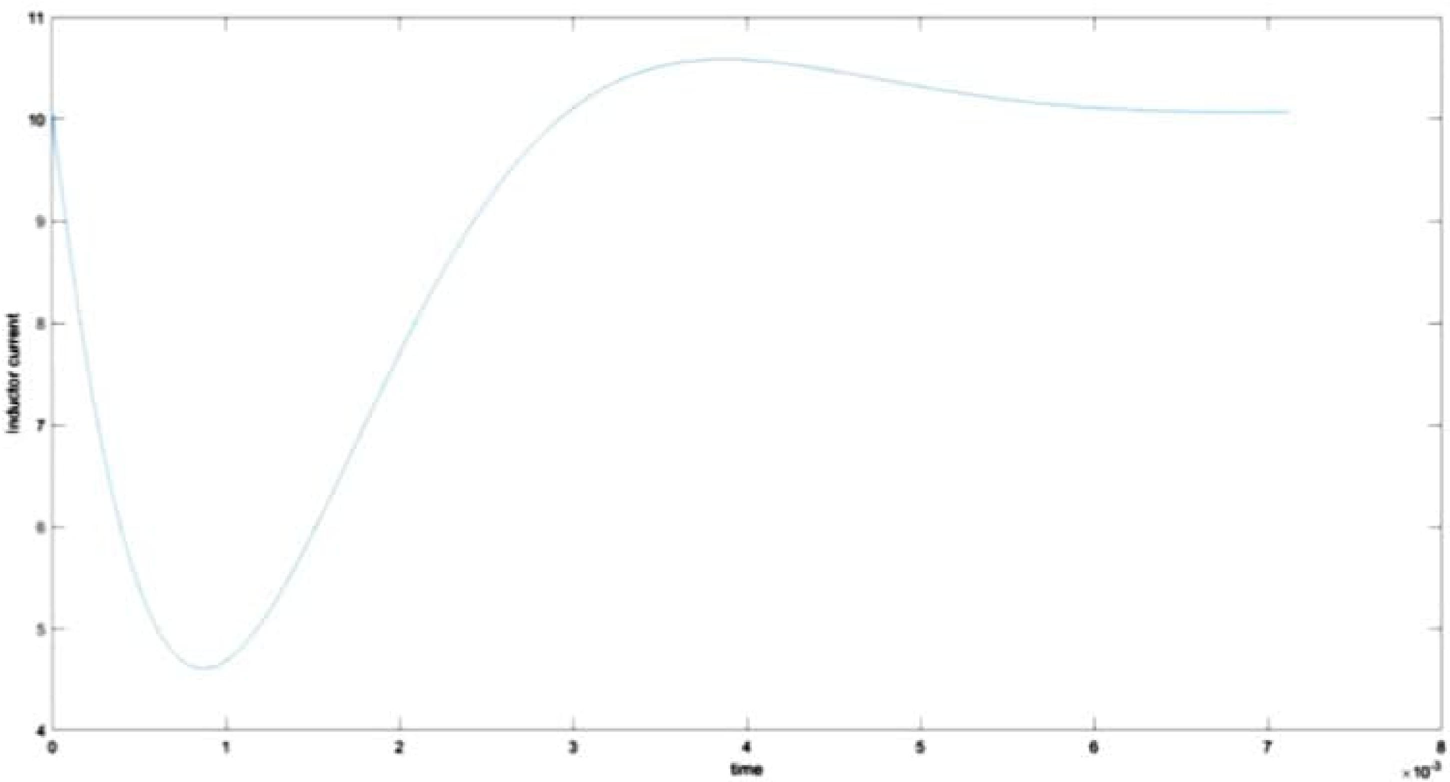
$$\boxed{\frac{\Delta V_o(s)}{\Delta V_{in}(s)} = \frac{7.652\times10^{28}s + 2.319\times10^{33}}{5.223\times10^{26}s^2 + 8.5\times10^{29}s + 9.143\times10^{32}}}$$

c)

$$\Delta V_o(s) = \frac{-1.674\times10^{46}s^2 - 265\times10^{50}s + 7.343\times10^{54}}{1.65\times10^{46}s^2 + 2.69\times10^{49}s + 2.908\times10^{52}} \times\frac{0.05}{s}$$

$$\Delta I_L(s) = \frac{8.597\times10^{32}s + 9.378\times10^{34}}{2.089\times10^{27}s^2 + 3.4\times10^{40}s + 3.66\times10^{23}} \times\frac{0.05}{s}$$

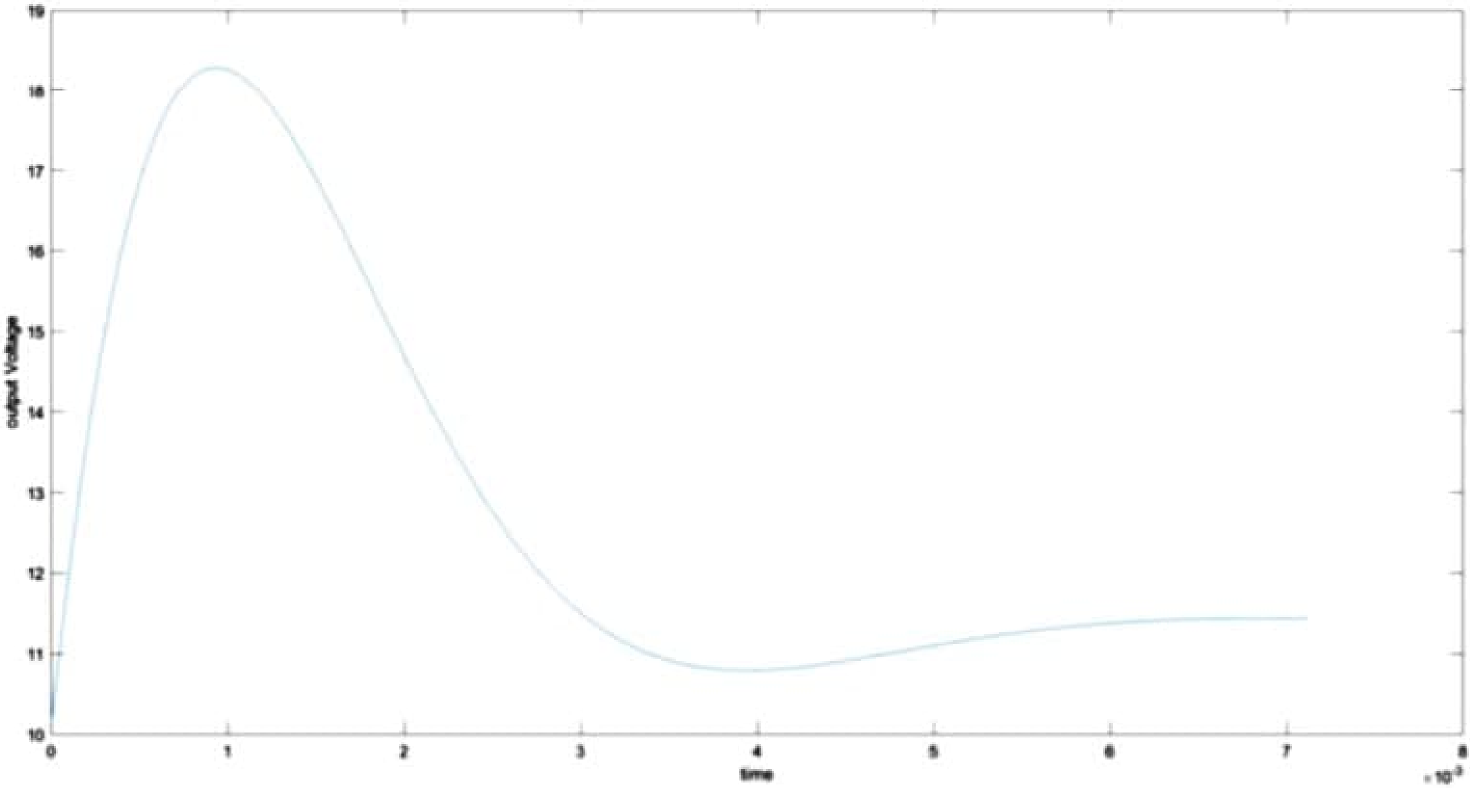

Inductor current
time
×10⁻³

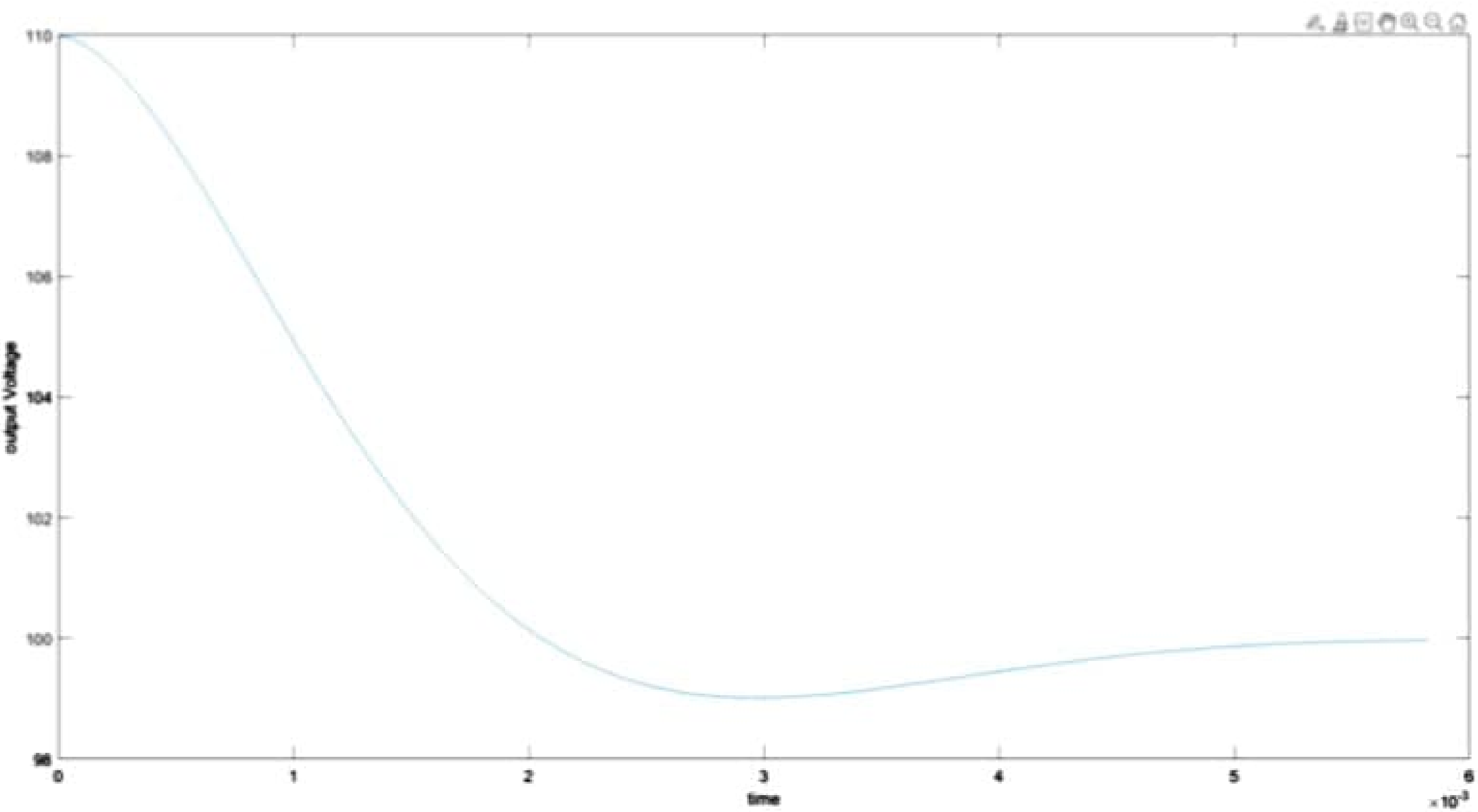

Inductor current
time
×10⁻³

d.)

$$\Delta V_o(s) = \frac{7.652 \times 10^{28} s + 2.31 \times 10^{33}}{5.22 \times 10^{26} s^2 + 8.5 \times 10^{29} s + 9.17 \times 10^{32}} \times \frac{-4}{s}$$

$$\Delta I_L(s) = \frac{1.934 \times 10^{30} s}{5.23 \times 10^{26} s^2 + 8.502 \times 10^{29} s + 9.17 \times 10^{32}} \times \frac{-4}{s}$$


output Voltage
time
19
18
17
16
15
14
13
12
11
10
0
1
2
3
4
5
6
7
8


output Voltage
time
110
108
106
104
102
100
98
0
1
2
3
4
5
6

Ques 2.

a)
$$\frac{\Delta \bar{V}_o(s)}{\Delta d(s)} = \frac{488.51 \times 10^6 \left[1 - 62.7 \times 10^{-6} s\right]}{s^2 + 1628.14 s + 1.75 \times 10^6}$$

$f_{co} = 5\,kHz$, $PM = 45°$ → Bode plot.

Type I $= \frac{K}{s} = K(s)$

Phase Delay Angle of $K'(j\omega_{co})$ = $90°$ − Phase delay of $G(j\omega_{co})$ − PM

$|K'(j\omega_{co})| = 1$

angle $= 0°$

$(\omega_{co} = 2\pi f = 3.14 \times 10^4$ rad/sec$)$

∴ for $f_{co} = 5\,kHz$, the angle $G(j\omega_{co}) = -122°$

∴ Phase delay of $G(j\omega_{co}) = 122°$

∴ $0 = 90° - 122° - PM$

$PM = -32°$

∴ Type I design is not possible if the cross over is specified at 5 kHz since PM is usually specified between 45° to 60°.

b) To find f_{co} for Type I Compensator having PM=60°

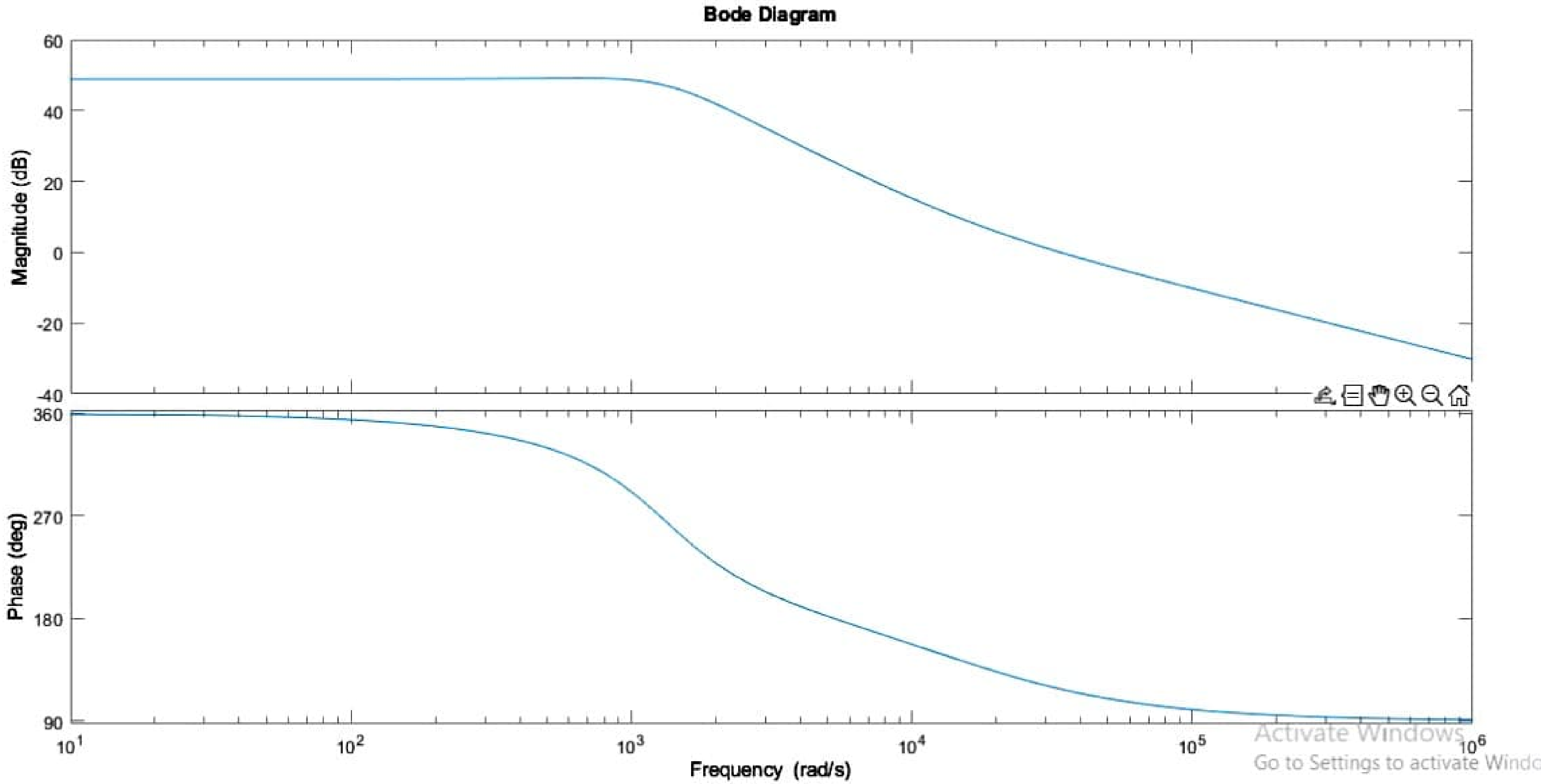
$0 = 90°$ − Phase delay of $G(j\omega_{co})$ − $60°$

Phase Delay of $G(j\omega_{co})$ = $30°$

∴ from the Bode plot, Phase having 30°, the corresponding cross over frequency is

$f_{co} = 80.9$ Hz

$\omega_{gc} = 508.3$ rad/sec.


Bode Diagram
Magnitude (dB)
60
40
20
0
-20
-40
Phase (deg)
360
270
180
90
10^1
10^2
10^3
10^4
10^5
10^6
Frequency (rad/s)
Activate Windows
Go to Settings to activate Windo

c) $f_{co} = ?$ for Type II Compensation, PM = 60°

Phase delay of $G(j\omega_{co}) = 170° - PM$

$= 170 - 60$

$= 110°$

Now from the Bode Plot we can get the f_{co} corresponding to 110° i.e, (360° - 110° = 250°)

$f_{co} = 250$ Hz

$\therefore \omega_{co} = 2\pi f = 1570$ rad/sec.

d) $f_{co} = ?$

PM = 60° → Type III Compensator

Phase delay of $G(j\omega_{co}) + PM \leq 250°$

Phase delay of $G(j\omega_{co}) = 250 - 60°$

$= 190°$

Now, from the Bode plot we can get the f_{co} corresponding to 190°

Phase = 360° - 190° = 170°

f_{co} corresponding to 170° = 1.1 KHz

$f_{co} = 1100$ Hz.

$\therefore \omega_{co} = 2\pi \times 1100 = 6908$ rad/sec.

e) To Design Compensator TOF in 'b', 'c', 'd' part.

for 'b' part

$f_{co} = 81$ Hz

$w_{co} = 509$ rad/sec.

$|G.M| = 49$ dB

$20 \log |M| = 49$ dB

$|M| = 281.83$

$\therefore \quad K = \dfrac{w_{co}}{|G(jw_{co})|} = \dfrac{509}{281.83} = 1.81$

$\therefore \quad \boxed{K(s) = \dfrac{1.81}{s}} \rightarrow$ Type I compensation.

for 'c' part

$w_{co} = 1570$ rad/sec.

$|G.M|_{dB} = 46$ dB

$20 \log |M| = 46$

$|M| = 200$

Phase delay $= 110°$

$PM = 60°$

$$K(s) = \frac{K}{s}\frac{(1+\tau_z s)}{(1+\tau_p s)} = \frac{K}{s} \times K'(s)$$

$$w_z = \frac{w_{co}}{k}, \quad w_p = k\, w_{co}$$

$$k = \tan\left\{\frac{\text{Phase Delay angle of } G(jw_{co}) + PM}{2}\right\}$$

$$k = \tan\left\{\frac{110° + 60°}{2}\right\}$$

$k = 11.43$

$\therefore \quad |K'(j\omega_{co})| = k = 11.43$

$$K \times 11.43 = \frac{\omega_{co}}{|G(j\omega_{co})|}$$

$$K = \frac{1570}{11.43 \times 200}$$

$$\boxed{K = 0.687}$$

$$\tau_2 = \frac{k}{\omega_{co}} = \frac{11.43}{1570} \qquad \tau_p = \frac{1}{k\omega_{co}} = \frac{1}{1570 \times 11.43}$$

$\tau_2 = 7.2$ msec. $\qquad \tau_p = 55.7$ μsec

$$\therefore \quad K(s) = \frac{K}{s} \frac{(1+\tau_2 s)}{(1+\tau_p s)}$$

$$\boxed{K(s) = \frac{0.687}{s} \frac{(1+7.2\times10^{-3}s)}{(1+55.7\times10^{-6}s)}} \rightarrow \text{Type II Compensation}$$

"for d part"

$f_{co} = 1100$ Hz $\qquad$ Phase delay $= 190°$

$\omega_{co} = 6908$ rad/sec.

$$K(s) = \frac{K}{s} \frac{(1+\tau_2 s)^2}{(1+\tau_p s)^2}$$

$$K|K'(j\omega_{co})| = \frac{\omega_{co}}{|G(j\omega_{co})|}$$

$$|K'(j\omega_{co})| = k^2$$

$$k = \tan\left\{\frac{90° + \text{Phase delay of } G(j\omega_{co}) + PM}{4}\right\}$$

$$k = \tan\left\{\frac{90 + 190° + 60}{4}\right\}$$

$$\boxed{\mathcal{K} = 11.43}$$

$|G(j\omega_{co})|_{dB} = 23dB$

$20\log|M| = 23$

$|M| = 14.12$

$$|K'(j\omega_{co})| = \mathcal{K}^2 = (11.43)^2 = 130.64$$

$$K = \frac{\omega_{co}}{|K'(j\omega_{co})|\,|G(j\omega_{co})|}$$

$$K = \frac{6908}{130.64 \times 14.12}$$

$$\boxed{K = 3.74}$$

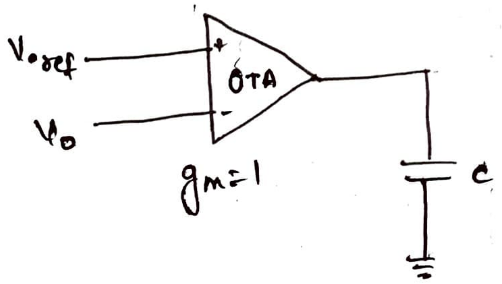
$$\tau_z = \frac{\mathcal{K}}{\omega_{co}} = \frac{11.43}{6908} = 1.6\,msec$$

$$\tau_p = \frac{1}{\mathcal{K}\omega_{co}} = \frac{1}{11.43 \times 6908} = 12.6\,\mu sec.$$

$$\therefore K(s) = \frac{K}{s}\,\frac{(1+\tau_z s)^2}{(1+\tau_p s)^2}$$

$$\boxed{K(s) = \frac{3.74}{s}\,\frac{(1+1.6\times10^{-3}s)^2}{(1+12.6\times10^{-6}s)^2}} \rightarrow \text{Type III Compensation}$$

f) Design Circuits



Type I

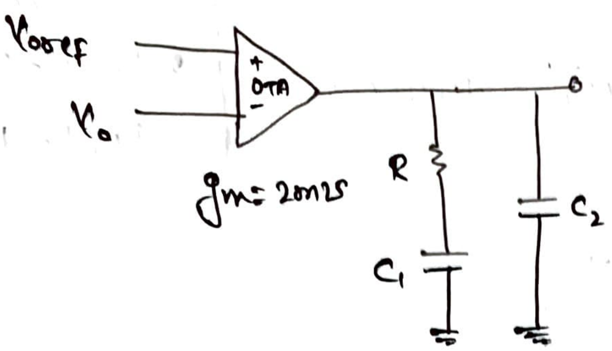
As we know,

$$\frac{K}{\cancel{s}} = \frac{g_m}{\cancel{s}.C}$$

$$K = \frac{g_m}{C}$$

$$C = \frac{g_m}{K} = \frac{1m}{1.81}$$

$$\boxed{C = 552.4\,\mu F}$$



Type II

$$H(s) = \frac{gm}{\frac{C_1+C_2}{s}} \left[\frac{1 + sRC_1}{1 + sR\frac{C_1C_2}{C_1+C_2}} \right]$$

$$\frac{gm}{C_1+C_2} = 0.733$$

$$RC_1 = 7.13 \times 10^{-3}$$

$$\frac{R_2C_2C_1}{C_1+C_2} = 54.6 \times 10^{-6}$$

$$C_1+C_2 = \frac{2m}{0.733} = 2.728 \times 10^{-3}$$

$$C_2 = \frac{54.4 \times 10^{-6} \times 2.728 \times 10^{-3}}{7.13 \times 10^{-3}}$$

$$\boxed{C_2 = 20.89\mu F}$$

$$\boxed{C_1 = 2707\mu F}$$

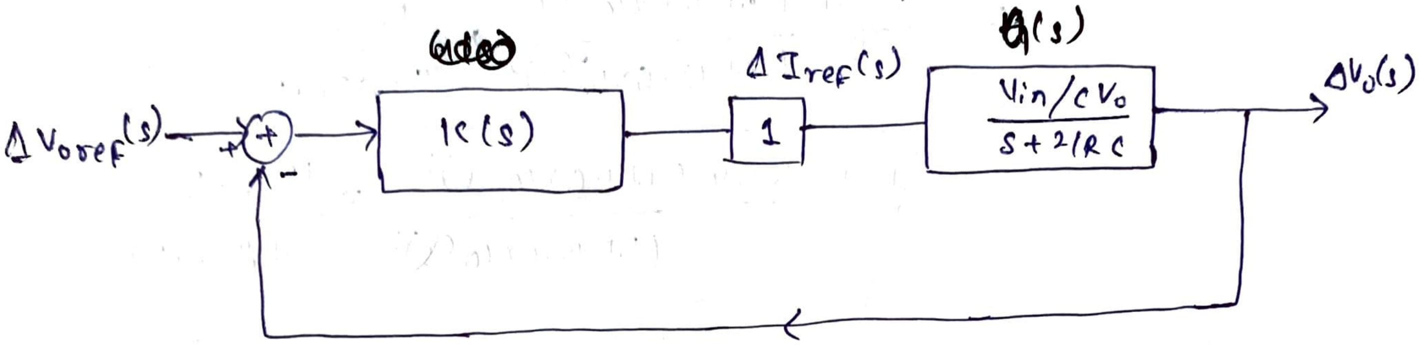
$$R = \frac{7.13 \times 10^{-3}}{2707 \times 10^{-6}}$$

$$\boxed{R = 2.63\Omega}$$

Ques 3. a) Type III Compensator, PM = 60°

2'e', Close loop Control block diagram in MATLAB.

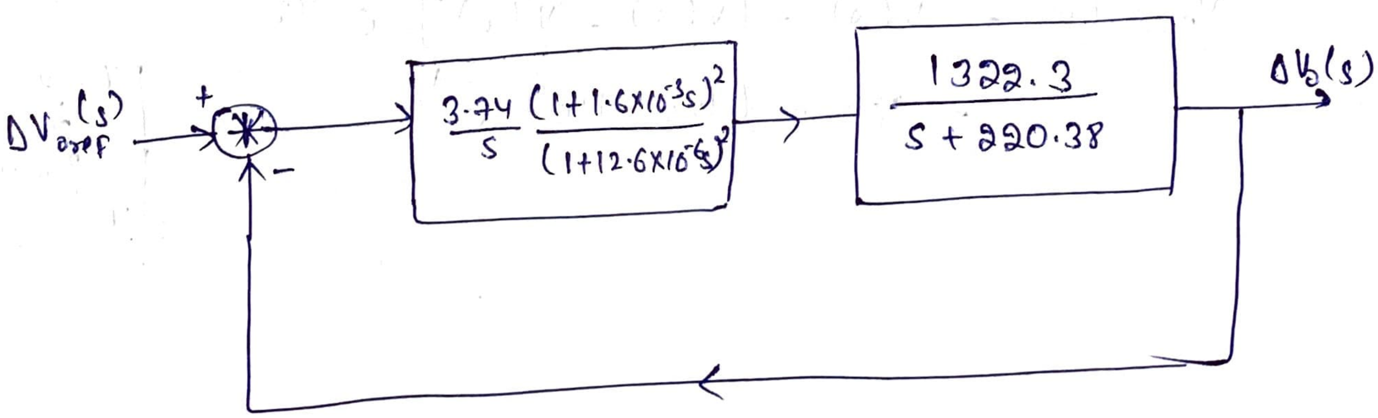
Soln:- $K(s) = \frac{3.74}{s} \frac{(1+1.6\times10^{-3}s)^2}{(1+12.6\times10^{-6}s)^2}$



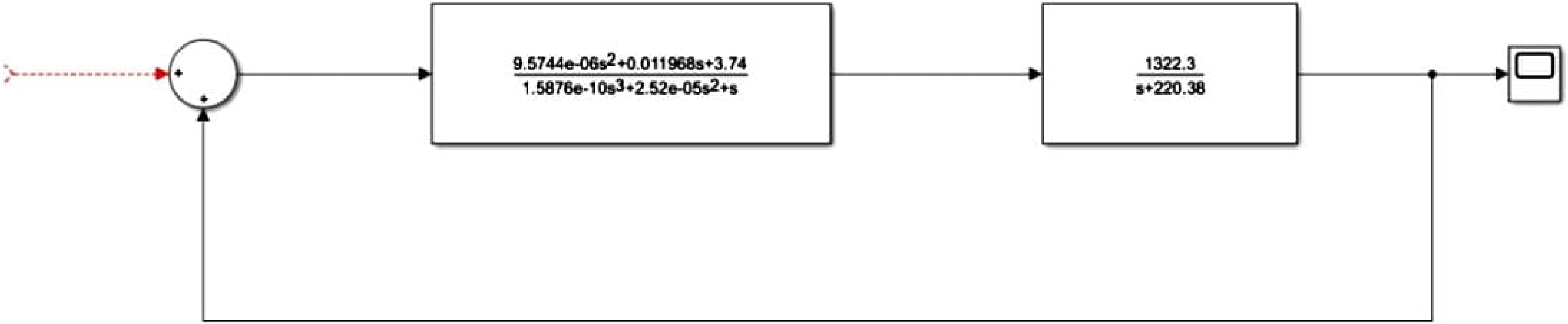
$$G(s) = \frac{V_{in}/CV_o}{s+2/RC} = \frac{\frac{48}{330\mu}\times110}{s+\frac{2}{27.5\times330\mu}}$$

$$= \frac{0.0013\times10^6}{s+\frac{2}{9075\mu}}$$

$$= \frac{1322.3}{s+220.38}$$

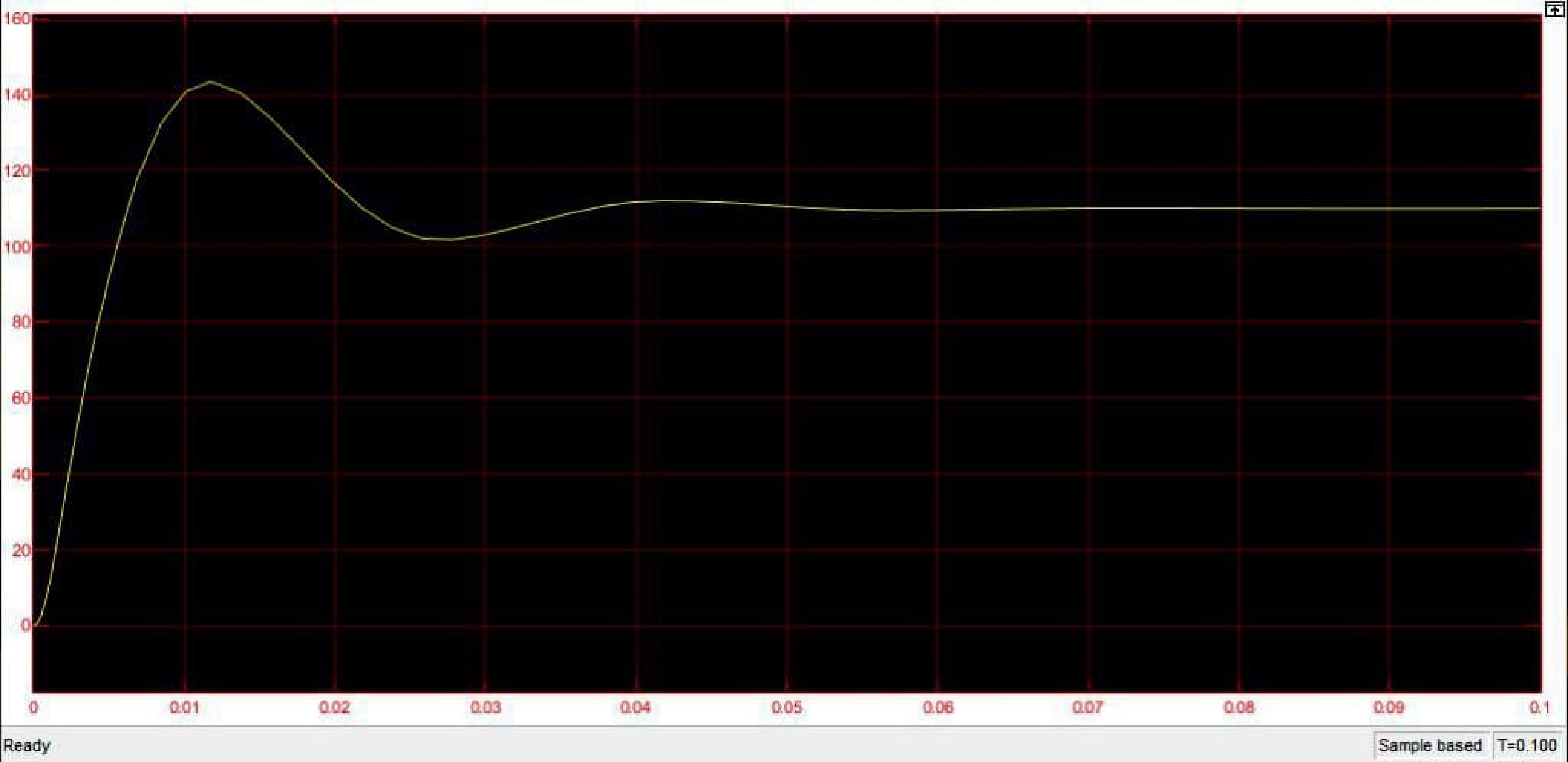


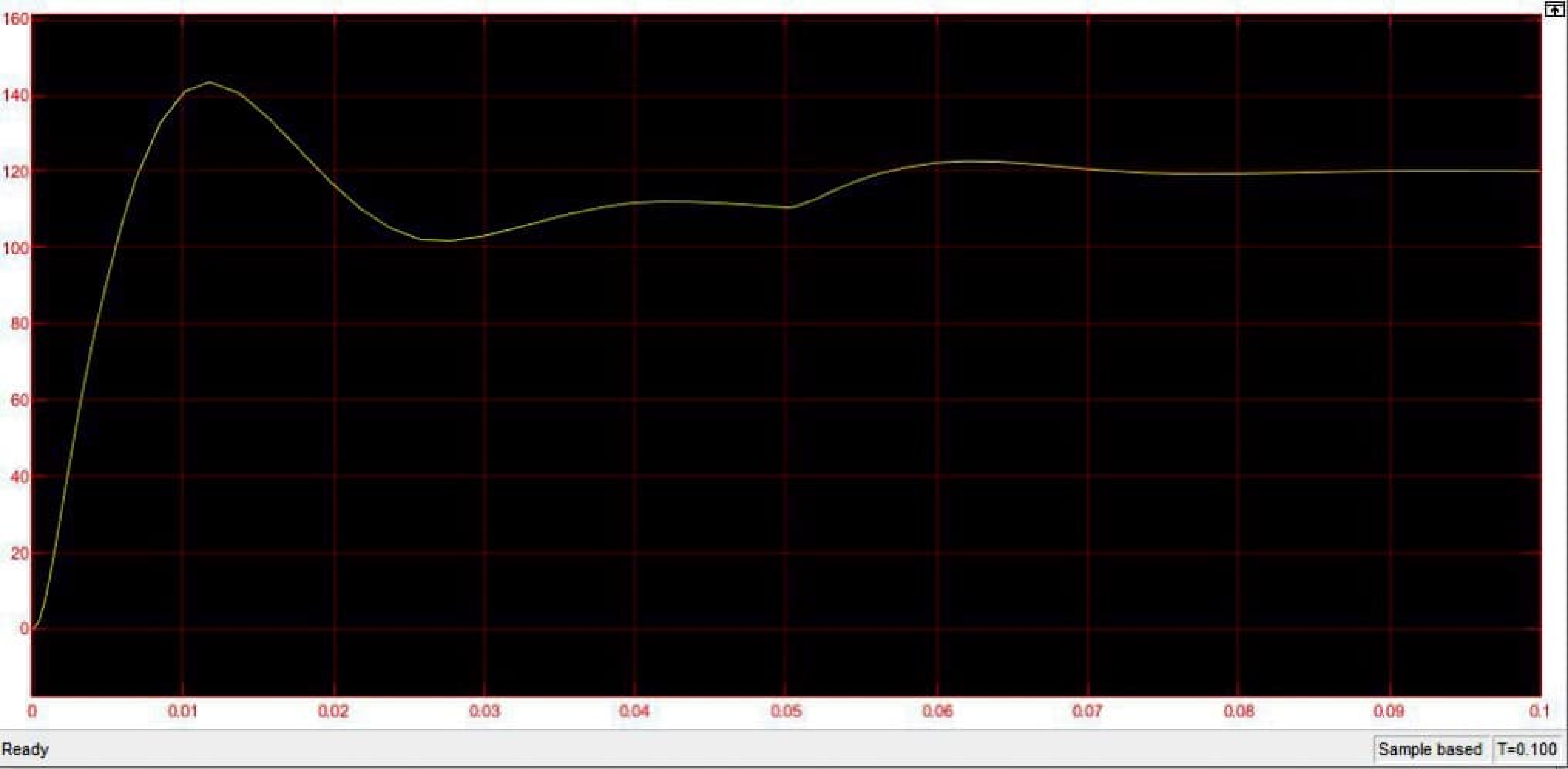
Close loop Block diagram with MATLAB Model is attached with this.


+
+
9.5744e-06s2+0.011968s+3.74
1.5876e-10s3+2.52e-05s2+s
1322.3
s+220.38

Ques 3.

b and c part waveforms are shown using MATLAB.


160
140
120
100
80
60
40
20
0
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.1
Ready
Sample based
T=0.100


160
140
120
100
80
60
40
20
0
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.1
Ready
Sample based
T=0.100