DIGITAL CONTROL – MINI PROJECT

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MEng-VLSI Systems

AIM:

The aim of this mini project is to design a Buck SMPS based on the specifications provided.

Digital Control

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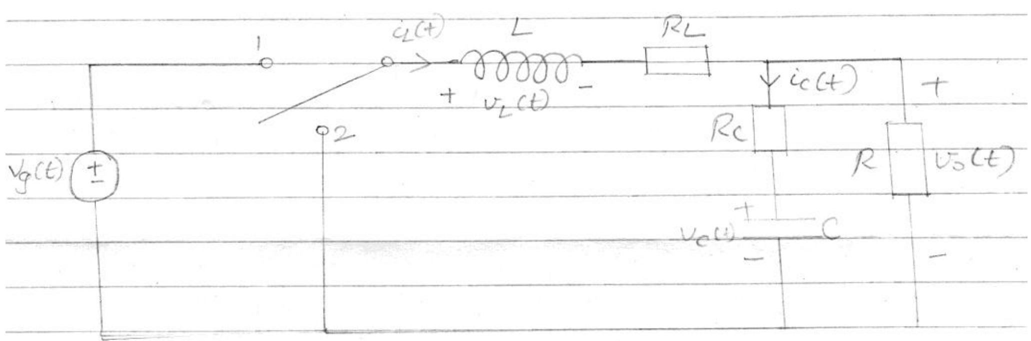
Consider the bulk SMPS Given:



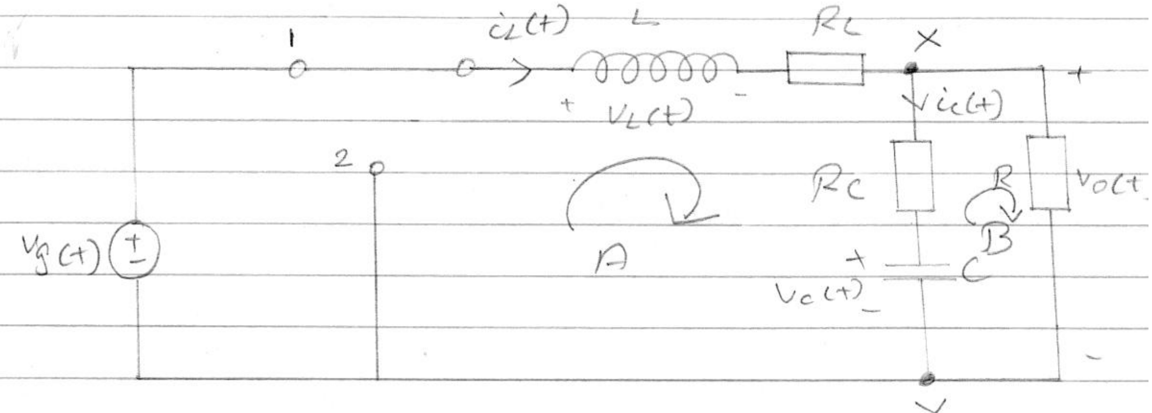
States, inputs and outputs are chosen as

$$x(t) = \begin{bmatrix} v_c(t) \\ i_L(t) \end{bmatrix}, \quad u(t) = v_g(t) \text{ or } u(t) = \alpha(t)$$

$$y(t) = v_o(t).$$

Case 1: Switch in ON position (1 position):

The given circuit can be re-drawn as,



The State space matrices are given by,

$$\dot{x} = Ax(t) + Bu(t)$$

$$y = Cx(t) + Du(t).$$

Here on analysing the above circuit and incorporating Kirchoff's voltage law, we can find that,

$$V_o = R(i_L - i_c)$$

$$V_o = Ri_L - Ri_c$$

$$V_o = Ri_L - R\left(C\frac{dv_c}{dt}\right) \quad \left(\because i_c = C\frac{dv_c}{dt}\right)$$

$\hookrightarrow$ (1)

But the voltage across the output Resistor R is the voltage across the Terminals X, Y which is given by

$$v_C + i_C R_C = v_O.$$

$$\therefore v_O = v_C + R_C\left(C\frac{dv_C}{dt}\right) \rightarrow (2)$$

Comparing (1), (2)

$$\Rightarrow v_C + R_C\left(C\frac{dv_C}{dt}\right) = Ri_L - R\left(C\frac{dv_C}{dt}\right)$$

$$R\left(C\frac{dv_C}{dt}\right) + R_C\left(C\frac{dv_C}{dt}\right) = Ri_L - v_C$$

$$C\frac{dv_C}{dt}\left\{R + R_C\right\} = -v_C + Ri_L$$

$$\boxed{\frac{dv_C}{dt} = \frac{-1}{C(R+R_C)}v_C + \frac{R}{C(R+R_C)}i_L}$$

$\rightarrow$ (a)

we know that,

$$V_O = Ri_L - RC\frac{dv_c}{dt} \quad (\text{from } ①)$$

Sub $\frac{dv_c}{dt}$ from (a),

$$V_O = Ri_L - R\left[C\left\{\frac{-1}{(R+R_C)\cdot C}v_c + \frac{R}{(R+R_C)\cdot C}i_L\right\}\right]$$

$$V_O = Ri_L - R\left[\frac{-v_c}{R+R_C} + \frac{Ri_L}{R+R_C}\right]$$

$$V_O = \frac{R}{R+R_C}\cdot v_c + \frac{R^2-R}{R+R_C}i_L$$

$$V_O = \frac{R}{R+R_C}v_c + \frac{R(1-R)}{R+R_C}i_L$$

$$\boxed{V_O = \frac{R}{R+R_C}v_c + \frac{R\,R_C}{R+R_C}i_L \quad (\because R+R_C=1)}$$

↳ (b)

Again from the figure we can find that,

$$V_g = L\frac{di_L}{dt} + R_L i_L + R_C \cdot C\frac{dv_c}{dt} + v_c$$

$$L\frac{di_L}{dt} = -v_C - R_C \cdot C\frac{dv_C}{dt} - R_L i_L + V_g$$

$$L\frac{di_L}{dt} = -v_C - R_C \cdot \left[C\left[\frac{-v_C}{(R+R_C)C} + \frac{R i_L}{(R+R_C)C}\right]\right] - R_L i_L + V_g \quad \left[\because \frac{dv_C}{dt} \text{ from (a)}\right]$$

$$L\frac{di_L}{dt} = -v_C - R_C\left[\frac{-v_C}{(R+R_C)} + \frac{R i_L}{(R+R_C)}\right] - R_L i_L + V_g$$

$$L\frac{di_L}{dt} = v_C\left[\frac{R_C}{R+R_C} - 1\right] - i_L\left[\frac{R_C R}{R+R_C} + R_L\right] + V_g.$$

$$\boxed{\frac{di_L}{dt} = \left[\frac{-R}{(R+R_C)L}\right]V_g - \left[\frac{R_C R}{R+R_C} + R_L\right]\frac{i_L}{L} + \frac{V_g}{L}}$$

$\longrightarrow$ (c).

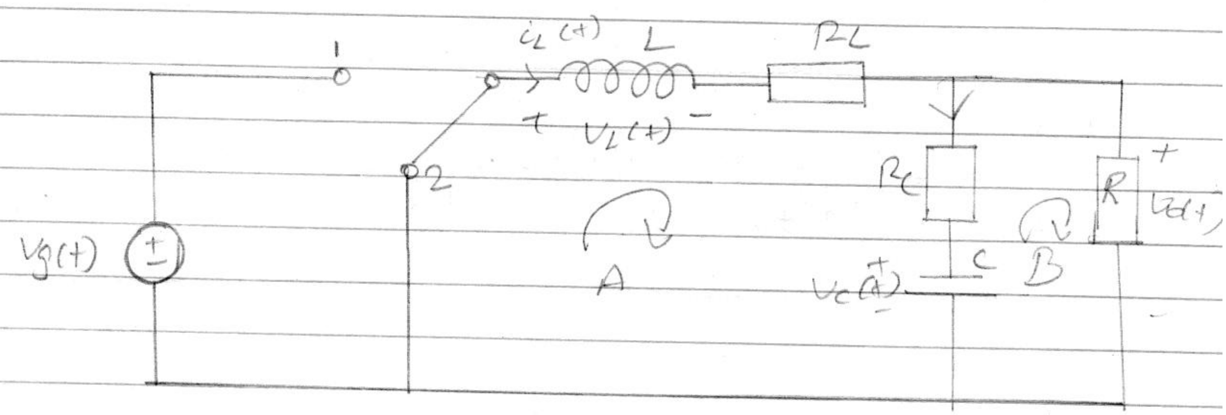
The State matrices for position (1) is given by from (a), (b), (c) as.

$$A_1 = \begin{bmatrix} \dfrac{-1}{(R+R_C)C} & \dfrac{R}{(R+R_C)C} \\[2ex] \dfrac{-R}{(R+R_C)L} & -\left(R_L + \dfrac{R_C R}{R_C + R}\right)\dfrac{1}{L} \end{bmatrix}$$

$$B_1 = \begin{bmatrix} 0 \\ 1/L \end{bmatrix} \qquad C_1 = \begin{bmatrix} \dfrac{R}{R+R_C} & \dfrac{R_C R}{R+R_C} \end{bmatrix}$$

$$D_1 = [0]$$

Case 2: OFF Position (Position 2)



Since the Switch is in OFF position, i.e Position 2, there will be no input voltage applied.

$\therefore$ B matrix is O

$$\Rightarrow B_2 = [\,0\,]$$

But on examining, we can find the there will be flow of current in the Loop A.

therefore (a), (c), (b) applies in this case also.

$\therefore$ we can write directly the state matrices of A, B, C, D in the OFF position as

$$A_2 = \begin{bmatrix} \dfrac{-1}{(R+R_C)C} & \dfrac{R}{(R+R_C)C} \\ \dfrac{-R}{(R+R_C)L} & -\left(R_L + \dfrac{R_C R}{R+R_C}\right)\dfrac{1}{L} \end{bmatrix}, \quad B_2 = \begin{bmatrix} 0 \end{bmatrix}$$

$$C_2 = \begin{bmatrix} \dfrac{R}{R+R_C} & \dfrac{R_C \cdot R}{R+R_C} \end{bmatrix}, \quad D = \begin{bmatrix} 0 \end{bmatrix}$$

(b),

$$B_c = (A_1 - A_2)x + (B_1 - B_2)v_g$$

Here from our Results $A_1 = A_2, B_2 =$

$\therefore B_c = B_1 v_g.$

$$\Rightarrow B_c = \begin{bmatrix} 0 \\ 1/L \end{bmatrix} v_g$$

$$\boxed{B_c = \begin{bmatrix} 0 \\ v_g/L \end{bmatrix}}$$

(c), state transition Procedure.

$$\phi(t) = e^{At} \approx I + At$$

$$\Rightarrow \phi(t) = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} + \begin{bmatrix} \frac{-1}{(R+R_C)C} & \frac{R}{(R+R_C)C} \\ -R/(R_C+R)L & -\left(R_L + \frac{R_C R}{R_C+R}\right)\frac{1}{L} \end{bmatrix} \cdot t$$

$$= \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} + \begin{bmatrix} \dfrac{-t}{(R+R_C)C} & \dfrac{Rt}{(R+R_C)C} \\ -Rt/(R_C+R)L & -\left(R_L + \dfrac{R_C R}{R_C+R}\right)\dfrac{t}{C} \end{bmatrix}$$

$$= \begin{bmatrix} 1 - t/(R+R_C)C & \dfrac{Rt}{(R+R_C)C} \\ -Rt/(R_C+R)L & 1 - \left(R_L + \dfrac{R_C R}{R_C+R}\right)\dfrac{t}{L} \end{bmatrix}$$

$$= \begin{bmatrix} 1 - \dfrac{t}{RC} & \dfrac{\cancel{R}t}{\cancel{R}C} \\ \dfrac{-\cancel{R}t}{\cancel{R}L} & 1 - (R_L + R_C)\dfrac{t}{L} \end{bmatrix}$$

$$\boxed{\phi(t) = \begin{bmatrix} 1 - \dfrac{t}{RC} & \dfrac{t}{C} \\ \dfrac{-t}{L} & 1 - (R_L + R_C)\dfrac{t}{L} \end{bmatrix}}$$

Consider the Expression,

$$1-(R_L+R_C)\frac{t}{L}$$

Now Add and subtract R to R_C

$$\therefore 1-(R_L+R_C+R-R)\frac{t}{L}$$

$$1-(R_L+\cancel{R}-\cancel{R})\frac{t}{L} \quad (\because R_C+R \simeq R)$$

$$1-R_L\frac{t}{L}$$

$$\therefore \boxed{\phi_c(t) = \begin{bmatrix} 1-t/RC & t/C \\ -t/L & 1-R_L\frac{t}{L} \end{bmatrix}}$$

Discrete State space Matrix Estimation:

The Discrete State space matrices of A, B, C, D can be estimated as follows.

i) The Discrete State space matrix of A is given by,

$$A_d = [\phi(T)]$$

$$\therefore \boxed{A_d = \begin{bmatrix} 1 - T/RC & T/C \\ -T/L & 1 - R_L \frac{T}{L} \end{bmatrix}}$$

ii) Similarly, the discrete state space matrix of B can be found by

$$B_d = \int_0^{T} \phi(t) \cdot dt \cdot B$$

$$= \int_0^T \begin{bmatrix} 1 - t/RC & t/C \\ -t/L & 1 - R_L t/L \end{bmatrix} \cdot dt \begin{bmatrix} 0 \\ Vg/L \end{bmatrix}$$

$$= \left[\begin{matrix} t - \frac{t^2}{2RC} & \frac{t^2}{2C} \\ -\frac{t^2}{2L} & t - \frac{R_L t^2}{2L} \end{matrix} \right]_0^T \begin{bmatrix} 0 \\ Vg/L \end{bmatrix}$$

$$= \begin{bmatrix} T - \frac{T^2}{2RC} & \frac{T^2}{2C} \\ -\frac{T^2}{2L} & T - \frac{R_L T^2}{2L} \end{bmatrix} \begin{bmatrix} 0 \\ vg/L \end{bmatrix}$$

$$\therefore \boxed{B_d = \begin{bmatrix} \frac{T^2}{2C} \cdot \frac{vg}{L} \\ \left(T - \frac{R_L T^2}{2L}\right) \cdot \frac{vg}{L} \end{bmatrix}}$$

iii) The Discrete state space matrix of C and D are same as their continuous state space matrix.

$$\therefore C_D = \begin{bmatrix} 1 & R_C \end{bmatrix}$$

$$D_d = \begin{bmatrix} 0 \end{bmatrix}$$

(d) Choosing appropriate L and C:
The condition for the Buck SMPS to operate in continuous conduction mode is given by

$$\boxed{K > K_{Crit}(D)}$$

where, $K = \frac{2L}{RT_S}$; $K_{crit}(D) = 1 - D$.

For the Buck SMPS, D is given by

$$D = \frac{V_O}{V_g}$$

From the Table provided, we can find that $V_O = 1.44V$ and $V_g = 12V$.

$$\therefore D = \frac{1.44}{12} \qquad \boxed{D = 0.12}$$

$$\therefore K_{crit}(D) = 1 - D$$
$$= 1 - 0.12 \qquad \therefore \boxed{K_{crit}(D) = 0.88}$$

Therefore inorder to ensure that the SMPS works in CCM mode, we have to make sure that the value of K must be higher than the $K_{crit}(D)$.

Case(i): $L = 440nH$; $R_L = 25m\Omega$; $C = 470\mu F$;
$R_C = 8m\Omega$; $R = 1\Omega$; $T_S = 10^{-6}$

$$\therefore K = \frac{2L}{RT_S} = \frac{2 \times 440 \times 10^{-9}}{1 \times 10^{-6}}$$

$$K = 0.88.$$

Here $K = 0.88$ and $K_{crit}(D) = 0.88$. Hence the condition is not satisfied. Hence we cannot use these values for our further calculation.

Case (ii) $L = 528\,nH$; $R_L = 30\,m\Omega$; $C = 520\,\mu F$
$R_C = 5\,m\Omega$; $R = 1\,\Omega$; $T_S = 10^{-6}$

$$K = \frac{2L}{RT_S} = \frac{2 \times 528 \times 10^{-9}}{1 \times 10^{-6}} = 1.056.$$

Hence in this case the condition

$$\underset{(1.056)}{K} > \underset{0.88}{K_{crit}(D)}$$

is satisfied.

Case (iii) $L = 760\,nH$; $R_L = 30\,m\Omega$; $C = 610\,\mu F$
$R_C = 3\,m\Omega$; $R = 1\,\Omega$; $T_S = 10^{-6}$

$$K = \frac{2L}{RT_S} = \frac{2 \times 760 \times 10^{-9}}{1 \times 10^{-6}} = 1.52$$

Hence the condition $\underset{(1.52)}{K} > \underset{0.88}{K_{crit}(D)}$

is satisfied.

Thus from the above calculation, we could find that the case (ii) and case (iii) satisfies the condition for the SMPS TO operate in the CCM mode. Here we are using Case (ii) for our further analysis.

(e) Determination of Discrete time state space matrices for our buck Converter:

As said earlier, we are using our case(ii) values for our further Analysis. Hence,

$L = 528\,nH$; $R_L = 30m\Omega$; $C = 520\mu F$
(% Variation = ± 10%) (% Variation = ±15%)
$R = 1\Omega$ (% Variation = ±20%) ; $T_s = 10^{-6}$

On substituting these values in the discrete time state space matrix expressions we have found earlier, we can get,

$$A_d = \begin{bmatrix} 1 - \dfrac{10^{-6}}{1 \times 520 \times 10^{-6}} & \dfrac{10^{-6}}{520 \times 10^{-6}} \\[2ex] \dfrac{-10^{-6}}{528 \times 10^{-9}} & 1 - \dfrac{30 \times 10^{-3} \times 10^{-6}}{528 \times 10^{-9}} \end{bmatrix}$$

$$\boxed{A_d = \begin{bmatrix} 0.9980 & 0.001923 \\ -1.8939 & 0.9432 \end{bmatrix}}$$

Similarly,

$$B_D = \begin{bmatrix} \dfrac{(10^{-6})^2}{2\times 520\times 10^{-6}} \times \dfrac{12}{528\times 10^{-9}} \\ \left(10^{-6} - \dfrac{30\times 10^{-3}\times (10^{-6})^2}{2\times 528\times 10^{-9}}\right) \cdot \dfrac{12}{528\times 10^{-9}} \end{bmatrix}$$

$$\boxed{B_d = \begin{bmatrix} 0.0218 \\ 22.082 \end{bmatrix}}$$

$$\boxed{\begin{aligned} C_d &= \begin{bmatrix} 1 & 5\times 10^{-3} \end{bmatrix} \\ D_d &= \begin{bmatrix} 0 \end{bmatrix} \end{aligned}}$$

(f) Pole placement Using Ackermann Algorithm:

To find the pole placement using Ackermann algorithm, let us first consider the values of ζ and ω_n. Here we assume

$$\zeta = 0.8 \qquad \omega_n = 1.8 \text{ rad/sec}$$

$s = \zeta \omega_n \pm j\omega_n (1-\zeta^2)^{1/2}$

$= (0.8)(1.8) \pm j\,(1.8)(1 - (0.8)^2)^{1/2}$

$$\boxed{s = -1.44 \pm j1.08}$$

$z = e^{sT}$

Here, let us consider $T = 0.3\,s$.

$\therefore z = e^{(-1.44 \pm j1.08)\,0.3}$

$r = e^{-(1.44 \times 0.3)} = 0.65$

$\theta = \omega_n T = 1.08 \times 0.3 = 0.324$.

Now,

$z = 0.65(\cos 0.324 \pm j \sin 0.324)$

$$\boxed{z = 0.62 \pm j0.204}$$

The characteristic equation can be calculated as

$(z - 0.62 + j\,0.204)(z - 0.62 - j\,0.204) = 0$

$$\Rightarrow \boxed{z^2 - 1.24z + 0.4264 = 0} \longrightarrow (1)$$

This is our required characteristic equation for the ζ and ω_n we defined.

The discrete estimate of the system difference equation are given by

$$x(k+1) = Ax(k) + Bu(k)$$

$$y(k) = Cx(k) + Du(k).$$

In the Ackermann algorithm, we augment the control input $u(k)$ with a linear combination of the states at any instant. Here,

$$\text{System input} = u(k) - K_1 x_1(k) - K_2 x_2(k)$$

If we assume that there is no external input to the system then,

$$\text{System input} = -K_1 x_1(k) - K_2 x_2(k) = -Kx$$

Thus a "closed-loop" is represented as,

$$x(k+1) = \begin{bmatrix} 0.9980 & 0.001923 \\ -1.8939 & 0.9132 \end{bmatrix} x(k) + \begin{bmatrix} 0.0218 \\ 22.082 \end{bmatrix} [-K_1 x_1(k) - K_2 x_2$$

$$\begin{vmatrix} Z - 0.9980 + 0.00218K_1 & -0.001923 + 0.00218K_2 \\ 1.8939 + 22.082K_1 & Z - 0.9432 + 22.082K_2 \end{vmatrix} = 0$$

$$(Z - 0.9980 + 0.00218K_1)(Z - 0.9432 + 22.082K_2)$$
$$- \left((-0.001923 + 0.00218K_2)(1.8939 + 22.082K_1)\right) = 0$$

$$Z^2 - 0.9432Z + 22.082K_2 Z - 0.9980Z + 0.9413$$
$$- 22.038K_2 + 0.00218K_1 Z - 0.00206K_1$$
$$+ 0.0481K_1K_2$$
$$- \left[-0.003642 - 0.0425K_1 + 0.00413K_2 + 0.048K_1K_2\right] = 0$$

$$\Big\{Z^2 - \left[0.9432 + 22.082K_2 + 0.9980 - 0.00218K_1\right]$$
$$+ 0.9413 - 22.038K_2 - 0.00206K_1 + \cancel{0.0048K_1K_2}$$
$$- \{ 0.003642 + 0.0425K_1 - 0.00413K_2 - \cancel{0.048K_1K_2}$$
$$= 0$$

$$Z^2 - Z\left[1.9412 - 22.082K_2 - 0.00218K_1\right] - 22.042K_2$$
$$+ 0.04044K_1 + 0.945 = 0.$$

$$\boxed{Z^2 - \left[1.9412 - 22.082K_2 - 0.00218K_1\right] Z - 22.042K_2 + 0.0404K_1 + 0.945 = 0}$$

$\rightarrow$ (2)

we are now comparing the equation that we derived here, with the characteristic equation, that we derived earlier and equating thier co-efficients.

Hence,

$$1.9412 - 22.082K_2 - 0.00218K_1 = 1.24$$

$$-22.082K_2 - 0.00218K_1 = 1.24 - 1.9412$$

$$\Rightarrow 22.082K_2 + 0.00218K_1 = 0.7012 \rightarrow (a)$$

Similarly,

$$-22.042K2 + 0.0404K_1 + 0.945 = 0.4264$$

$$-22.042K2 + 0.0404K_1 = -0.5186 \rightarrow (b)$$

Now equating (a), (b) to find K_1 and K_2.

$$22.082K2 + 0.00218K_1 = 0.7012 \rightarrow (a)$$

$$-22.042K2 + 0.0404K_1 = -0.5186 \rightarrow (b).$$

$$(b) \times 1.0018 \Rightarrow -22.\cancel{082}K_2 + 0.0405K_1 = -0.5195$$

$$(a) \times 1 \Rightarrow 22.\cancel{082}K2 + 0.00218K_1 = 0.7012$$

$$0.04268K_1 = 0.1817$$

$$\boxed{K_1 = 4.26}$$

Substituting K_1 in a,

$$22.082K_2 + 0.00218(4.26) = 0.7012$$

$$22.082K_2 = 0.692$$

$$\boxed{K_2 = 0.0313}$$

Now substituting the value of K_1, K_2 in 2,

$$\therefore Z^2 - [1.9412 - 22.082(0.0313) - 0.00218(4.26)]Z$$
$$- 22.042(0.0313) + 0.0404(4.26) + 0.945 = 0$$

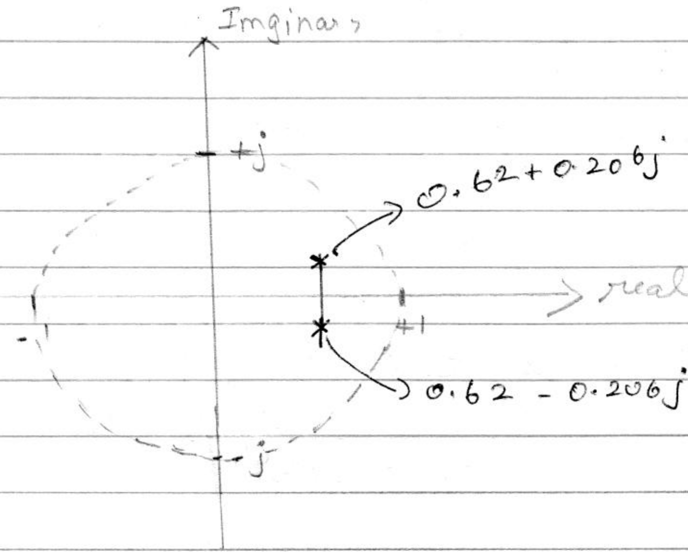
$$Z^2 - [1.9412 - 0.6912 - 0.00929]Z$$
$$- 0.6899 + 0.1721 + 0.945 = 0$$

$$\boxed{Z^2 - 1.24071Z + 0.4272 = 0}$$

$$Z = \frac{1.24071 \pm \sqrt{(1.24071)^2 - 4(1)(0.4272)}}{2(1)}$$

$$Z = \frac{1.24071 \pm j.4116}{2}$$

$$\therefore \boxed{Z = 0.62 \pm j0.206}$$



From the above diagram, we can find that the poles that we derived through the Ackermann Algorithm, lies within the unit circle. Hence the system is stable. Thus the selection of poles are justified succesfully.

Step Response:

In order to find the step response, we must find the Transfer function of our system.

The Transfer function of the system is given by,

$$\frac{Y(Z)}{U(Z)} = C(ZI - A)^{-1}B + D.$$

solving accordingly,

$$ZI - A = \begin{bmatrix} Z & 0 \\ 0 & Z \end{bmatrix} - \begin{bmatrix} 0.9980 & 0.001923 \\ -1.8939 & 0.9432 \end{bmatrix}$$

$$= \begin{bmatrix} Z - 0.9980 & -0.001923 \\ 1.8939 & Z - 0.9432 \end{bmatrix}$$

$$[ZI - A]^{-1} = \frac{1}{|ZI - A|} \cdot \text{adj}' [ZI - A].$$

$$|ZI - A| = \begin{vmatrix} Z - 0.9980 & -0.001923 \\ 1.8939 & Z - 0.9432 \end{vmatrix}$$

$$= (Z - 0.9980)(Z - 0.9432) - ((-0.001923)(1.8939))$$

$$= (Z^2 - 0.9432Z - 0.9980Z + 0.9413) - (-0.003642)$$

$$= Z^2 - 1.9412Z + 0.9413 + 0.003642$$

$$\boxed{|ZI - A| = Z^2 - 1.9412Z + 0.9449}$$

$$\operatorname{adj}(ZI - A) = \begin{bmatrix} Z - 0.9432 & 0.001923 \\ -1.8939 & Z - 0.998 \end{bmatrix}$$

$$[ZI - A]^{-1} B$$

$$= \frac{1}{Z^2 - 1.9412Z + 0.945} \begin{bmatrix} Z - 0.9432 & 0.001923 \\ -1.8939 & Z - 0.998 \end{bmatrix} \begin{bmatrix} 0.0218 \\ 22.082 \end{bmatrix}$$

$$= \frac{1}{Z^2 - 1.9412Z + 0.945} \begin{bmatrix} (Z - 0.9432)\,0.0218 + (0.001923)(22.082) \\ (-1.8939)(0.0218) + (Z - 0.998)(22.082) \end{bmatrix}$$

$$= \frac{1}{Z^2 - 1.9412Z + 0.945} \begin{bmatrix} 0.0218Z - 0.0206 + 0.004246 \\ -0.0413 + 22.082Z - 22.0378 \end{bmatrix}$$

$$= \frac{1}{Z^2 - 1.9412Z + 0.945} \begin{bmatrix} 0.0218Z - 0.0163 \\ 22.082Z - 22.0791 \end{bmatrix}$$

$$C[ZI - A]^{-1} B = \begin{bmatrix} 1 & 5 \times 10^{-3} \end{bmatrix} \left[\frac{1}{Z^2 - 1.9412Z + 0.945} \begin{bmatrix} 0.0218Z - 0.0163 \\ 22.082Z - 22.0791 \end{bmatrix} \right]$$

$$= \frac{1}{Z^2 - 1.9412Z + 0.945}\left[1(0.218Z - 0.0163) + 5\times10^{-3}(22.082Z - 22.0791)\right]$$

$$= \frac{1}{Z^2 - 1.9412Z + 0.945}\left[0.218Z - 0.0163 + 0.11041Z - 0.1104\right]$$

$$= \frac{1}{Z^2 - 1.9412Z + 0.945}\left[0.32841Z - 0.1267\right]$$

$$\therefore \boxed{\frac{Y(Z)}{U(Z)} = \frac{0.32841Z - 0.1267}{Z^2 - 1.9412Z + 0.945}}$$

For step response,

$$Y(Z) = U(Z)\left(\frac{0.32841Z - 0.1267}{Z^2 - 1.9412Z + 0.945}\right)$$

Here $U(Z) = \frac{Z}{Z-1}$ for step.

$$\therefore \boxed{Y(Z) = \frac{Z}{Z-1}\left(\frac{0.32841Z - 0.1267}{Z^2 - 1.9412Z + 0.945}\right)}$$

The remaining part of the report provides the matlab codings and their results for our required solutions. The codings and results can be seen below.

```
clc;
clear all;
close all;

 L_min = 0.000000528-0.10*0.000000528; % 10% variation of the inductor value
 L_max = 0.000000528+0.15*0.000000528;

 % we dont concentrate on the value of the capacitor as it does not affect
 % the system prerformance..this is because from the equation k=2*l/rts we
 % can find that c has no effect on the system performance. hence we are
 % considering and concentrating on L only

L = 0.000000528; %value of L for case (ii)
C = 0.000520;
R = 1;
Rc = 0.005;
Rl = 0.03;
fs = 1000000;  %given sampling frequency
ts = 1/fs;
Vg = 12;    %input voltage
A_d = [1-ts/(R*C) ts/C; -ts/L 1-(Rl)/L*ts];
B_d = [0; Vg*ts/L];
C_d = C_c;
D_d = D_c;

sys_c = ss(A_c,B_c,C_c,D_c)   %produces the state space variable of the
continuous time systems
sys_discrete = c2d (sys_c,ts) %produces the corresponding discrete state
variable of our continuous system..%c2d is used to convert continuous to
discrete
sys_d = ss(A_d,B_d,C_d,D_d,ts)      %produces corresponding state space
variable of our discrete system

sys_cl = feedback(sys_d,1);          %feedback is provided..this ensures the
system is now in a closed loop

step(sys_d);                         %providing a step input to our discrete
stste variable system
figure(2)
rlocus(sys_d)                        %providing the root locus of our
discrete state system
figure(3)
step(sys_cl);                        %providing the step response to our
closed loop feedback system
p = [0.62+0.204j 0.62-0.204j];       %assigning the poles from our
calculation
K = place(A_d,B_d,p)                 %providing the eigen values to the
system

new_A = A_d-B_d*K;                   %calculating the response of the new
variable A
```

```
new_sys = ss(new_A,B_d,C_d,D_d,ts);  %provides the state space variables for our newly designed system

sys_gain = zpk([],[],7.28);          %providing the zero pole gain to the system, here the gain of the system is found

sys = series(sys_gain,new_sys);      %makes the series connection of our gain along with the new system

figure(4)
step(new_sys)                        %step response of the new system
figure(5)
rlocus(new_sys)                      %root locus of the new system

sys_Ack_cl = feedback(new_sys,1);    %providing the ackerman control algorithm
figure(6)
step(sys_Ack_cl);                    %step response of the ackerman algorith


num=[0.32841 -0.1267]               %numerator of our transfer function from the calculation
den = [ 1 -1.9412 0.945]            %denominator of our transfer function from our calculation
newsys = tf(num,den,-1);            %provides the transfer function of the new system
```

RESULTS:

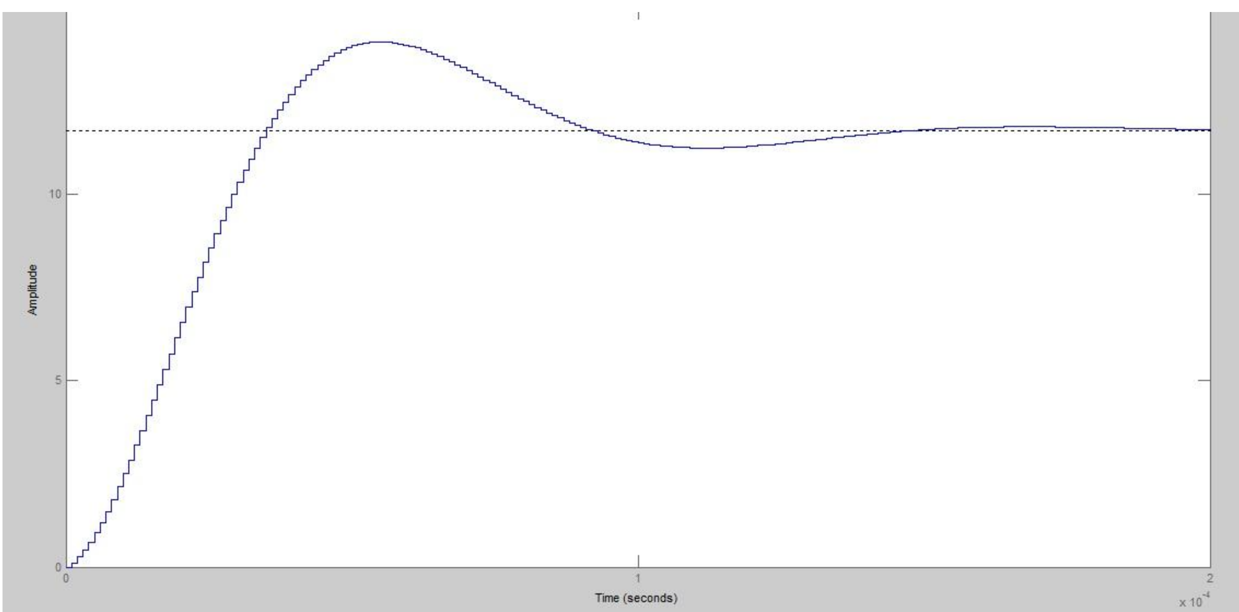


Figure-1: Step response of our discrete time system

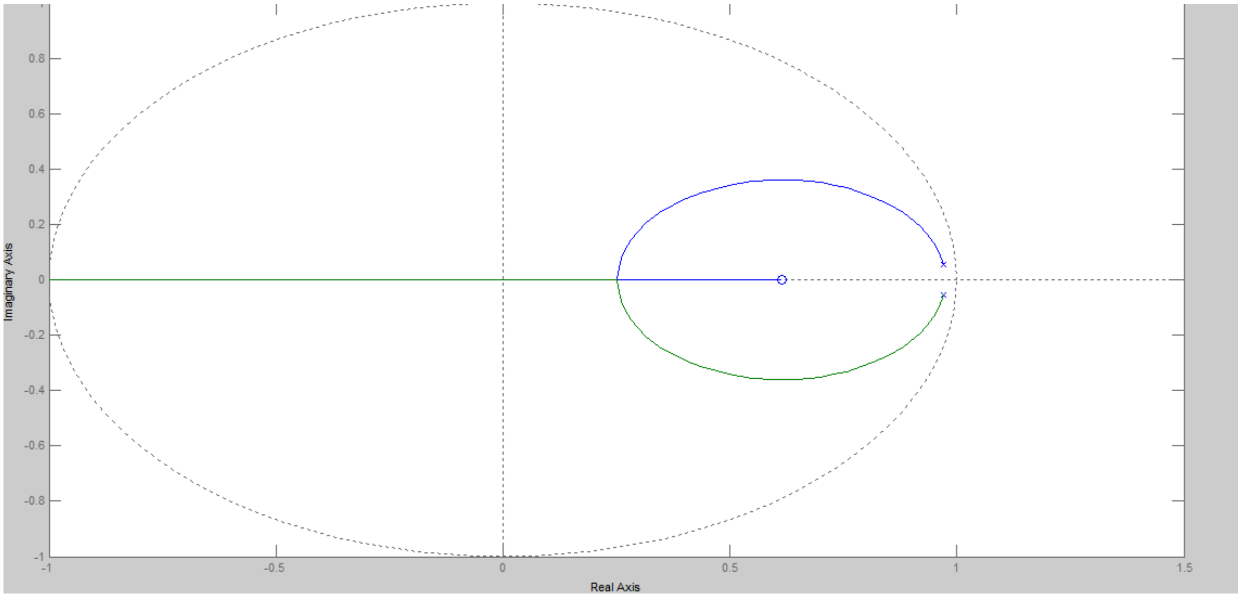


Figure-2: Root Locus of our discrete time system

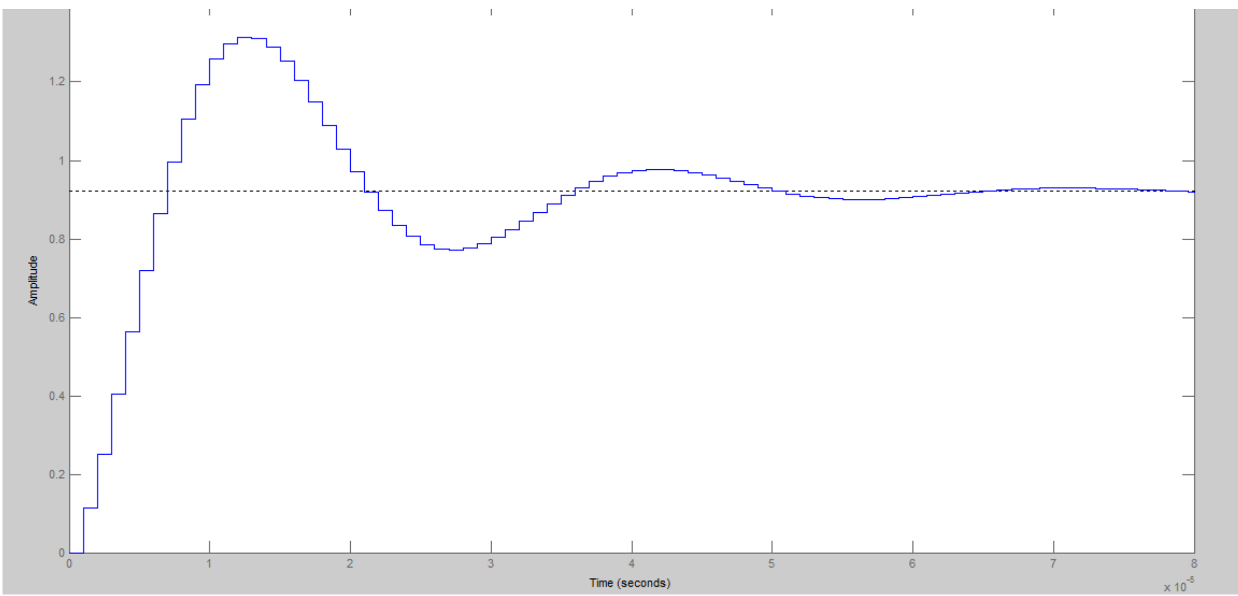


Figure-3: step response of our closed loop system

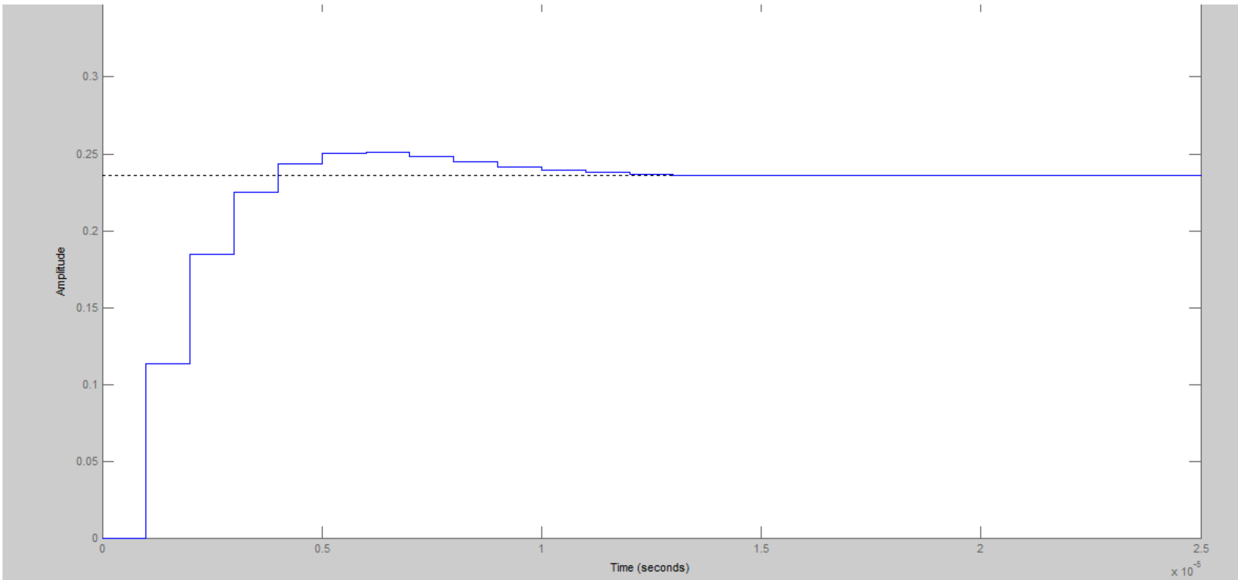


Figure-4: step response of the system with gain

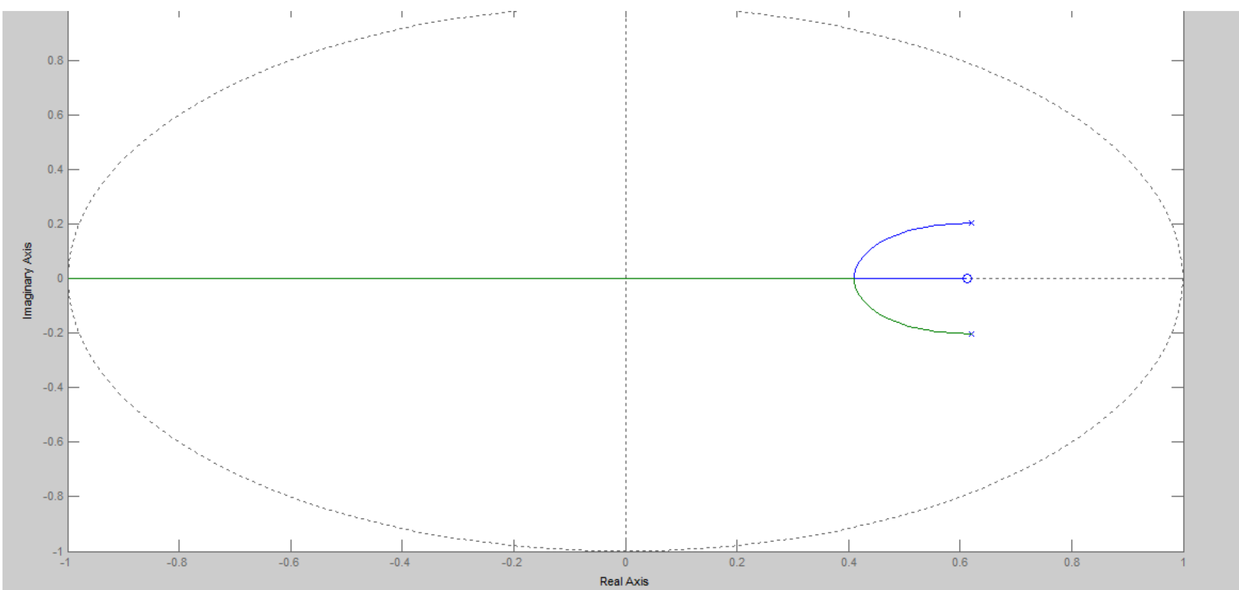


Figure-5: root locus of the system

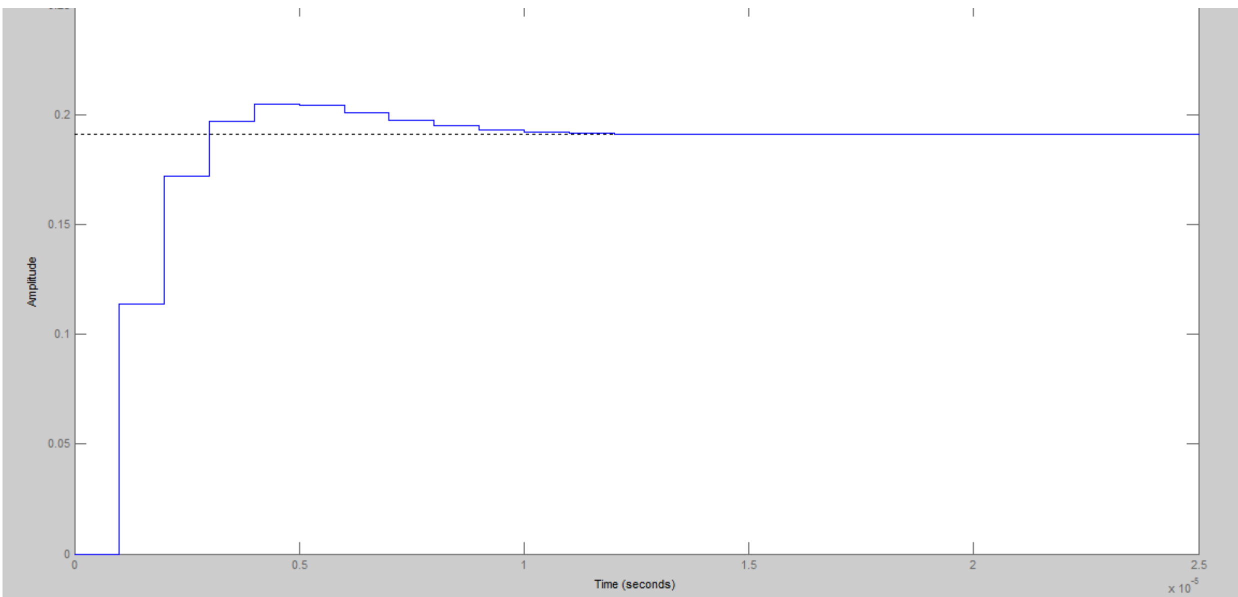


Figure-6: step response of the transfer function system.

Thus from the above figures we can show the stability of our system and also from the step response of the system we have proved that the output overshoot of the system is less than 15%.

The following are some of the other results obtained from the matlab. They provides the value of our state space matrices and also k1 and k2. These can be used for the verification of our manual calculation.

CONCLUSION:

Thus we have clearly understood the concepts of a bulk smps and its design methodologies.