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Design of PI & Sliding Mode Controllers for Buck Converters

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Abstract **— The operation of buck converter is stable until the load variation or the supply variation is within the limit. Beyond the range it will lose its stability. Not only the buck converter any system without controller or any stabilizer this will happen. So the stability of the system will come down automatically. The aim of this paper is to increase the stability of the buck converter for the large load variation. Here the PI and Sliding mode controllers are used to analyze the stability issue. MATLAB simu-links are used to solve the problem.**

Keywords **— Buck Converter, Sliding Mode Controllers, MATLAB Simu-links.**

I. Introduction

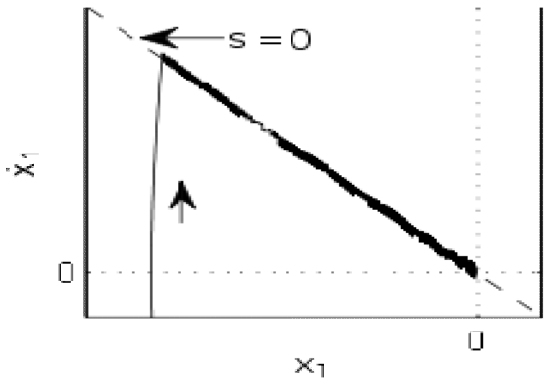
A. PI Controller

After including the PI controller in the buck converter the stability of the system will be increased to better level and the output voltage will be kept constant level. It will give better performance than the PID controller.

B. Sliding mode controller

The sliding mode control is a non-linear control method that alters the dynamics of a nonlinear system by application of a discontinuous control signal that forces the system to "slide" along a cross-section of the system's normal behavior. Hence, sliding mode control is a variable structure control method.

The figure shows Phase plane trajectory of a system being stabilized by a sliding mode controller .After the initial reaching phase, the system states "slides" along the line s = 0. The particular s = 0 surface is chosen because it has desirable reduced-order dynamics when constrained to it. Figure shows an example trajectory of a system under sliding mode control. The sliding surface is described by s = 0, and the sliding mode along the surface commences after the finite time when system trajectories have reached the surface. In the theoretical description of sliding modes, the system stays confined to the sliding surface and need only be viewed as sliding along the surface. Sliding mode control must be applied with more care than other forms of non-linear control that have more moderate control action. In particular, because actuators have delays and other imperfections, the hard sliding-mode-control action can lead to chatter, energy loss, plant damage, and excitation of un modeled dynamics.



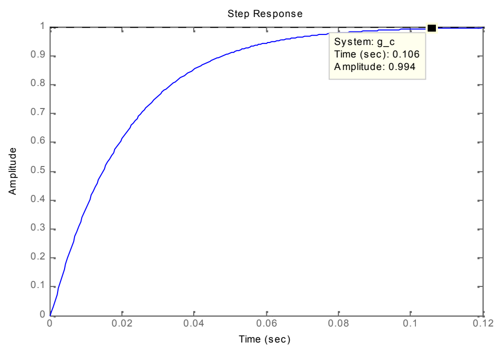
II. PI Controllers

$T_i=P_{cr}/1.2$
$P_{cr} = 79.22 \times 10^{-6}$
K_p= Taking initial value as 0.01 & the optimum can be computed from
the program given below.
$T_i= 79.22 \times 10^{-6}/1.2=6.031*10^{-5}$

A. Program to find Kp value for PI controller Output in Closed loop Buck converter

g=tf([3.638e^{-12}, 2.512e^{9}],[1,1.282e^{4},7.538e^{9}]);
K_p =0.035;
T_i=6.031e^{-5};
S=tf(s);
g_c =K_p*(1+1/t_i/s);
g_c=feedback (g*g_c,1)
step(g_c),held on

B. Output for Different values of Kp



Kp = 0.01

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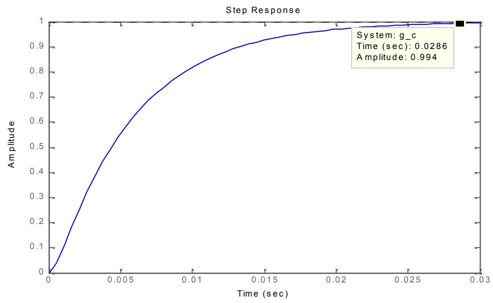
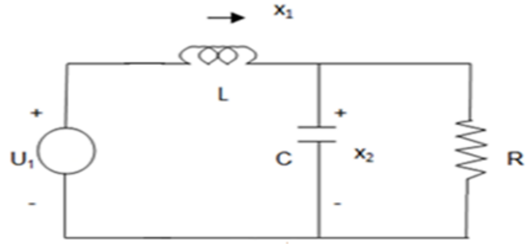
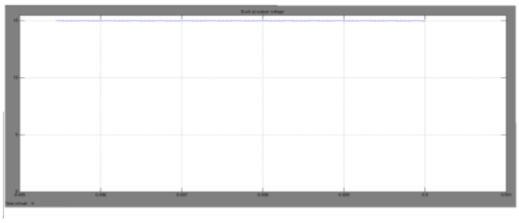


Kp = 0.035 (Optimum)

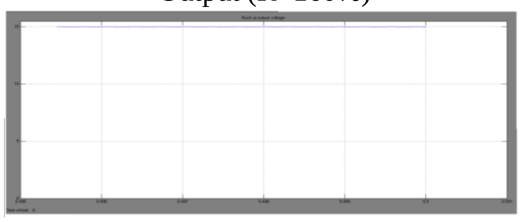
C. PI Controller Diagram



Output (R = 100%)



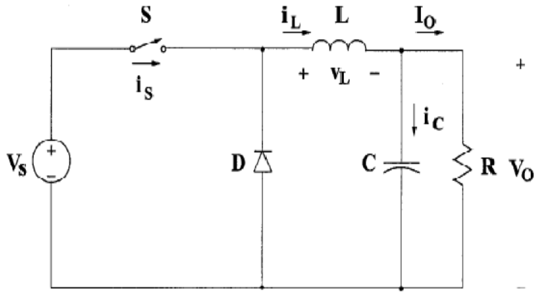
Output (R=160%)



III. Sliding Mode Controller

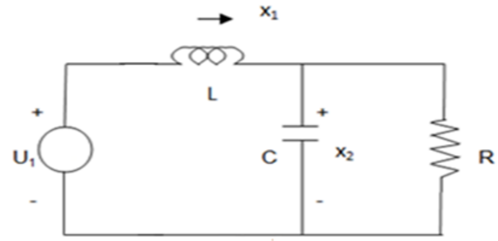
A. State-Space Models of Dc-Dc Converters

In this part, state-averaging techniques are used to derive steady state models for Buck converter



(a)

Mode. 1. Switch S_1 is ON, the equivalent circuit is shown



$X_1' = -X_2/L + U_1/L$

$X_2' = X_1/C - X_2/RC$

Mode 2: switch S_1 is OFF and switch S_2 is ON. The equivalent circuit is shown in fig.

$X_1^1 = -X_2/L$

$X_2^1 = X_1/C - X_2/RC$

State co-efficient matrix, A= $\begin{vmatrix} 0 & -\frac{1}{L} \\ 1/C & -1/RC \end{vmatrix}$

$$\begin{vmatrix} x'1 \\ x'2 \end{vmatrix} = \begin{vmatrix} 0 & -\frac{1}{L} \\ 1/C & -1/RC \end{vmatrix} \begin{vmatrix} x1 \\ x2 \end{vmatrix} + [\, vi/L \,]\ d \quad \text{------ (1)}$$

S= $a i_{in} + b v_0 + m \int_0^t (vo - vr)\, dt$

$X_1 = i_{in}$

$X_2 = v_0$

$S = a x_1 + b\, x_2 + m \int_0^t (x2 - vr)\, dt = 0$

$S' = a x'_1 + b x'_2 + m\,(x_2 - v_r) = 0$

From equation (1)

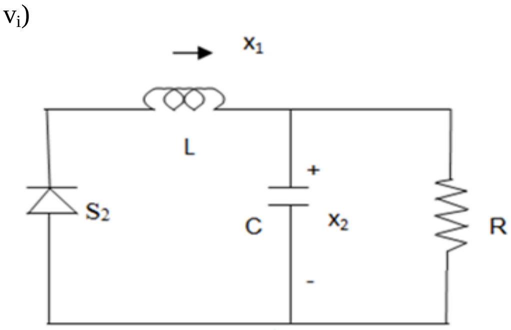
$x'_1 = (-\,x_2 / L) + (v_i/L)\, d_{eq}(t)$

$x'_2 = (x_1 / c) – (x_2 / RC)$

$S' = a[(-\,x_2 / L) + (v_i/L)\, d_{eq}(t)] + b[(x_1 / c) – (x_2 / RC)] + m\,(x_2 - v_r) = 0$ ------ (2)

$d_{eq}(t)=\{ (-b\, x_1 / c) + b(x_2 / RC) - m(x_2 - v_r) + (a\, x_2 / L)\}\ (L / a\, v_i)$

$d_{eq}(t) = \{(-bR\, x_1 L) + (b x_2 L) - mRCL(x_2 - v_r) + (a\, x_2 CR)\} / (aRC\, v_i)$



$d_{eq}(t) = \{(a\, x_2 CR) + Lb(x_2 - R\, x_1) + LRmC(v_r - x_2)\} / (aRC\, v_i)$ --------------- (3)

The equation (3) is substituted in equation (1), we get

$$\begin{vmatrix} x'1 \\ x'2 \end{vmatrix} = \begin{vmatrix} 0 & -\frac{1}{L} \\ 1/C & -1/RC \end{vmatrix} + [vi/L]\ x\ \{(aRCx_2) + [bL(x_2 - Rx_1)] + [LRmC(v_r - x_2)]\} / (aRCVi)$$

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$$= \begin{vmatrix} 0 & -\frac{1}{L} \\ 1/C & -1/RC \end{vmatrix} + [(x_2/L)+$$

$\{b[x_2-Rx_1]/aRC\} +[(M/a) (v_r - x_2)]$

$$\begin{vmatrix} -\frac{b}{aC} & (b-mRC)/aRC \\ \frac{1}{c} & -1/RC \end{vmatrix} \begin{vmatrix} mVr \\ 0 \end{vmatrix} \text{--(4)}$$

At steady state

$x_2 = V_0 = V_r$

$d_{eq}(t) = k = V_r / V_i$ ------------ (5)

The characteristics function is given by

$$\begin{vmatrix} \lambda + \frac{b}{aC} & (b-mRC)/aRC \\ \frac{1}{c} & \lambda + 1/RC \end{vmatrix} = 0$$

$\lambda^2 + \{ (b / ac) \}\lambda + \{(b/ac).(1/RC)\} – \{ (b-mRC)/ aRC^2 \}$

$\lambda^2 + \{ (b / ac) \}\lambda + (b/aR C^2) - (b/aR C^2) + (m / aC) = 0$

$\lambda^2 + \{ (b / ac) \}\lambda + (m / aC) = 0$ ------ (6)

We know

$i_c = x_1 – (x_2 / R)$ -------------------------(7)

Substitute equation (7) in (3)

$x_1 = i_c + (x_2 / R)$

$d_{eq}(t) = \{(a\, x_2CR) + Lb(x_2-R (i_c + (x_2 / R))+ LRmC(v_r - x_2)\} / (aRC\, v_i)$

$d_{eq}(t) = \{(a\, x_2CR) + Lb(x_2-R\, i_c -x_2)+ LRmC(v_r - x_2)\} / (aRC\, v_i)$

$d_{eq}(t) = (a\, x_2C) - Lbi_c + LmC(v_r - x_2)\} / (aC\, v_i)$

$d_{eq}(t) = \{(ac-LmC) x_2 + Lbi_c + LmCv_r\} / (aC\, v_i)$ ------------ (8)

Equation (8) is function applied to the gate circuit of MOSFET.

We know L= 1mH, C=10µF, R = 10Ω

(The value of R, L & C are determined from the PID Method of calculation. When

Load = 22.5W, V_0 =15V, V_s=48V, K= 0.3125, f= 3.5KHz)

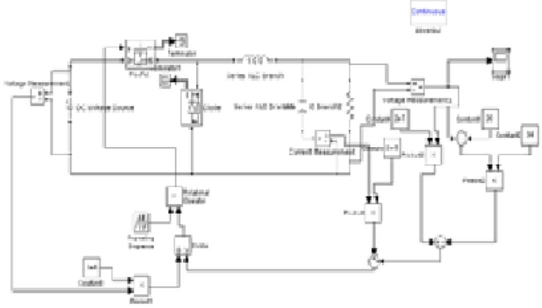
From equation (6), the stability of the system can be verified

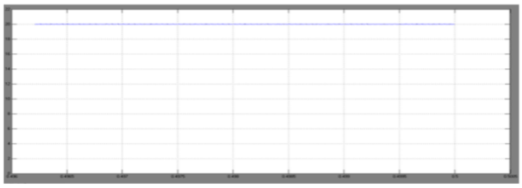
From equation (6)

$\lambda^2 + \{ (b / ac) \}\lambda + (m / aC) = 0$ ------ (6)

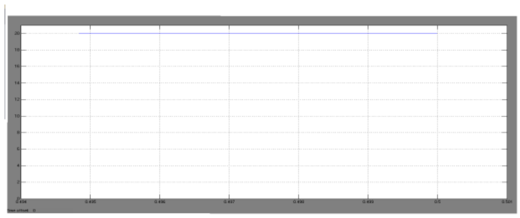
All the co-efficient of the above secondorder system are positive value, so the roots are lies on the left half of the s-plane. Therefore the system is stable.

B. Sliding Mode Controller Diagram

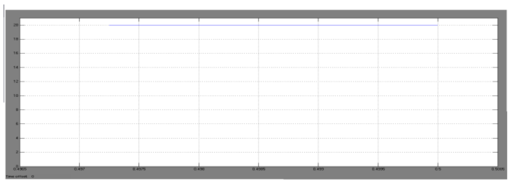




Output (R = 100%)



Output (R = 500 %)



Output (R = 40 %)

C. Advantages of Sliding Mode Controller

- Mode dc to dc converters are used to convert the unregulated dc input into a controlled dc output at a desired voltage level.
- It can maintain constant output voltage even for large scale variations.

IV. APPLICATIONS

This method can be used in SMPS-Switched Mode Power Supply or transferring energy between two dc sources.

Comparision of PI & PID Controllers

S.No.	Sliding Mode Controller	PI Controller
1	Output did not vary even for 500% of load	Output remains constant up to 140% of R and oscillates for 160% of R.

2	Output did not vary for 40% of load(R).	Output remain constant up to 60% of R and varies for less than 60% of R.

From the above table it is concluded that the Sliding mode controller gives best performance than the PI controller.

V. Conclusion

The DC-DC converter is non – linear system. We can't get constant output in open loop system. If there is a change in the load and source, it reflect in the output. So we go for the closed loop method. The most familiar closed loop method is PI controller and PID controllers.

The performance of Sliding mode controller was studied. It is possible to maintain the output as constant even for the large scale variations which is not at all possible by other methods like PID controllers and PI controllers. In this paper, the PI controller has been chosen for the comparison. I concluded the Sliding mode controller gave the best result than the PI controller.

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