Controlling of Buck Converter Using Different Types of Sliding Mode Controllers

Mr. Thanikonda Yedukondalu, Dr S. Satya Narayana and M. Subba Rao

Abstract: **This paper presents the design and analysis of different types of sliding-mode control techniques for buck converter from a circuit design perspective. Different types namely voltage sliding mode control, current sliding mode control and adaptive sliding mode control are implemented. The ripple content in the output voltages for all the control techniques during both the input voltage change and load current change was tabulated. Simulation and experimental results show the performance of the converter with the best control technique. The design of such strategies is performed in two steps. In the first step, among different sliding surfaces it is selected that one providing the desired asymptotic behavior when the converter dynamics is forced to evolve over it. In the second step, the feedback circuit which addresses the converter dynamics to the sliding surface is designed**

Keywords: **Buck converter, Voltage mode sliding mode controller, current sliding mode controller, adaptive sliding mode controller.**

I. INTRODUCTION

Use of sliding-mode control techniques in variable structure systems(VSS) renders them very robust regarding to parameter variations and external disturbances. Switching converters constitute an important case of VSS, with several different sliding-mode strategies to control this class of circuits having been reported in the last two decades .The design of such strategies is performed in two steps. In the first step, among different sliding surfaces it is selected that one providing the desired asymptotic behavior when the converter dynamics is forced to evolve over it. In the second step, the feedback circuit which addresses the converter dynamics to the sliding surface is designed.

The main advantages of sliding-mode control over conventional PWM control are stability, even for large supply and load variations, robustness, good dynamic response, and simple implementation. However, sliding-mode control presents some drawbacks. First, the switching frequency depends on the working point, due to the control hysteretic nature. Second, steady-state errors can appear in the output response and a significant overshoot in the state variables might arise during the converter transient regime.

There are many commercial integrated circuits for dc-to-dc switching conversion control developed in the last years. Most of them can be chosen from catalogs according to power supply specifications, i.e., input and output voltage levels, converter topology, control strategy, output power, etc. A great number of these circuits perform PWM control in either voltage or current mode with both reference voltage and switching frequency externally adjustable. Another important technique is the PFM regulation which is a variable frequency control that results in low start-up currents, low quiescent currents in the feedback loop, and good efficiency for low output current operation. There are also some integrated controllers that use hysteresis comparators to generate the on/off power transistor control signal. In some cases, the power switch is also integrated in the same controller circuit. Nevertheless, the hysteresis width is fixed in all cases (around 10 mV) and, besides, external signal processing is required to close the control loop. Therefore, if sliding-mode control is implemented through these available hysteresis controllers, some drawbacks will arise, mainly due to the fixed hysteresis width and the need of designing external networks for voltage regulation

II. BUCK CONVERTER

Buck converter is a DC-DC step-down converter shown in Figure 1.and voltage and current changes are shown in Figure 2.the transistor turning ON will put voltage V_{in} on one end of the inductor. This voltage will tend to cause the inductor current to rise. When the transistor is OFF, the current will continue flowing through the inductor but now flowing through the diode.Initially assume that the current through the inductor does not reach zero, thus the voltage at V_x will now be only the voltage across the conducting diode during the full OFF time. The average voltage at V_x will depend on the average ON time of the transistor provided the inductor current is continuous.

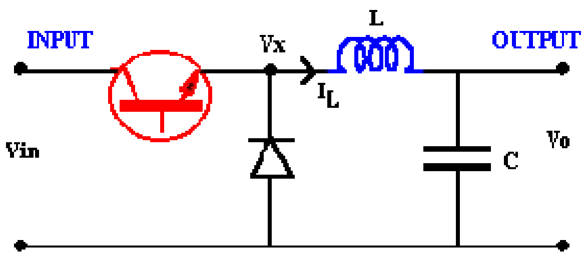

Figure 1: Buck Converter

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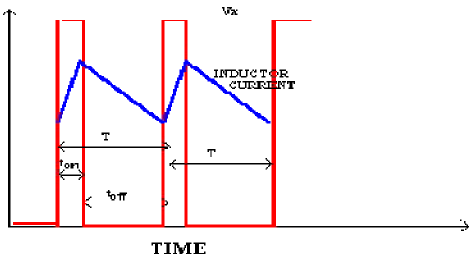

Figure 2: Voltage and current changes

To analyze the voltages of this circuit let us consider the changes in the inductor current over one cycle. From the relation

$$Vx - Vo = L\frac{di}{dt} \qquad (1)$$

the change of current satisfies

$$di = \int_{on}(Vx - Vo)dt + \int_{off}(Vx - Vo)dt \qquad (2)$$

For steady state operation the current at the start and end of a period T will not change. To get a simple relation between voltages we assume no voltage drop across transistor or diode while ON and a perfect switch change. Thus during the ON time $V_x = V_{in}$ and in the OFF $V_x = 0$. Thus

$$\int_0^{ton}(Vin - Vo)dt + \int_{ton}^{ton+toff}(-Vo)dt = di = 0 \qquad (3)$$

which simplifies to

$$(Vin - Vo)ton - (Vo)toff = 0 \qquad (4)$$

$$\frac{Vin}{Vo} = \frac{ton}{T} \qquad (5)$$

and defining "duty ratio" as

$$D = \frac{ton}{T} \qquad (6)$$

The voltage relationship becomes Vo=D Vin Since the circuit is lossless and the input and output powers must match on the average $V_o * I_o = V_{in} * I_{in}$. Thus the average input and output current must satisfy $I_{in} = D\, I_o$ These relations are based on the assumption that the inductor current does not reach zero.

III. Sliding Mode Control for DC/DC Converters

The most important features of the sliding mode regime in the VSS is the ability to achieve response that is independent of the system parameters. From this point of view, the DC/DC converter is particularly suitable for the application of the SMC, because of its controllable state ''the system is controllable if every state variable can be affected by an input signal''. The output voltage and its derivative are both continuous and accessible for measurement.For DC/DC converters used in practice, the motion rate of the current is much faster than the motion rate of the output voltage. The control problem can be solved by using cascaded control structure with two control loops: an inner current control loop, and an outer voltage control loop. The combined loops represent the SMC.

For DC/DC converters, the inductor current and the capacitor voltage are selected as the state variables

$$\begin{cases} x_1 = V_o - V_{ref} \\ x_2 = \dfrac{dx_1}{dt} = \dfrac{dv}{dt} = \dfrac{i_c}{C} \end{cases} , \qquad (7)$$

where *V*ref represents the reference voltage, *V*o is the output voltage, and *ic* denotes the capacitor current. Considering the CCM operation, the system equations in terms of the statevariables *x*1 and *x*2 can be written as follow

$$\begin{cases} \dot{x}_1 = x_2 \\ \dot{x}_2 = -\dfrac{x_1}{LC} - \dfrac{x_2}{R_L C} + \dfrac{V_{in}}{LC}u - \dfrac{V_{ref}}{LC} \end{cases} . \qquad (8)$$

In matrix form

$$\dot{x} = Ax + Bu + D, \qquad (9)$$

where *u* is the discontinuous input that can assume the value 0 or 1. In matrix form

$$A = \begin{bmatrix} 0 & 1 \\ -\frac{1}{LC} & -\frac{1}{R_L C} \end{bmatrix}, \quad B = \begin{bmatrix} 0 \\ \frac{V_{in}}{LC} \end{bmatrix}, \quad D = \begin{bmatrix} 0 \\ -\frac{V_{ref}}{LC} \end{bmatrix}. \qquad (10)$$

The phase trajectories corresponding to the substructures *u* = 0, 1 are shown in Figure 4.5 for different values of initial conditions.

It is convenient to select the sliding surface as a linear combination of the state variables since it results in simple-to-implement control systems and it allows the use of the equivalent control method to describe the system dynamics in the sliding mode, thus

$$\sigma(x) = c_1 x_1 + x_2 = C^T x = 0, \qquad (11)$$

The coefficient *c*2 was set to 1 without loss of generality. Equation (4.18)

describes a line in the phase plane passing through the origin, which represents a stable operating point for this converter (zero output voltage error and its zero derivative.

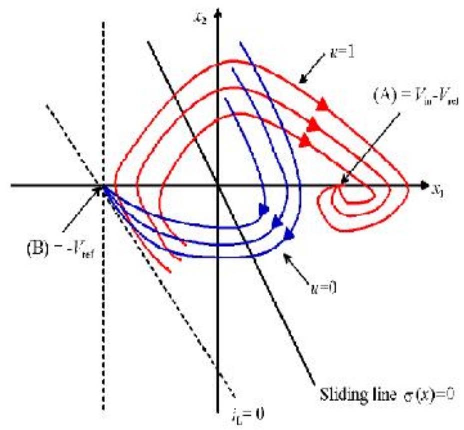

Figure 3. System trajectory and sliding line in the phase plane of a DC/DC Buck converter.

Substituting equations leads to

$$\sigma(x) = c_1 x_1 + \dot{x}_1 = 0, \tag{12}$$

which describes the system dynamics in the sliding mode. Thus if the existence and the reaching condition of the SMC are satisfied, a stable system is obtained by choosing a positive value of $c1$.According to equations (4.5), and (4.7) and by choosing the following control law.

$$u = \begin{cases} 0 & \text{for} \quad \sigma(x) > 0 \\ 1 & \text{for} \quad \sigma(x) < 0 \end{cases},$$

then both the existence and the reaching conditions are satisfied. In fact, it can be easily seen that in this control law, for both sides of the sliding line, the phase trajectories of the corresponding substructures are directed toward the sliding line (at least in small region around it). It is shown in Figure 4.5 that the real structure has a physical limitation due to the rectifying characteristic of the free-wheeling diode.

In fact, when the switch is off the inductor current (iL) can only assume a nonnegative value.In practice, when iL goes to zero it remains zero and the output capacitor discharges exponentially to zero. This situation corresponds to the DCM and poses a constraint to the state variable. The boundary of this region can be derived from the constraint iL = 0 and is given as

$$x_2 = \frac{1}{R_L C} x_1 \quad \frac{V_{ref}}{R_L C} \tag{13}$$

which corresponds to the straight line with a negative slope equal to -1/RLC and passing through the point (-Vref, 0), as it is shown in Figure 4.5. It is also shown that the line $x1$ = -Vref defines another not physically accessible region of the phase plane, i.e. Vo < 0.

IV. SIMULATION CIRCUITS AND RESULTS

matlab/simulink model of buck converter with different types of sliding mode controllers are shown in figures. Figure() is the Voltage mode SMC matlab/simulink model.Figure() is the respective voltage and current waveforms with load and voltage change. Figure() is the Voltage mode SMC matlab/simulink model.Figure() is the respective voltage and current waveforms with load and voltage change. Figure() is the Voltage mode SMC matlab/simulink model.Figure() is the respective voltage and current waveforms with load and voltage change.

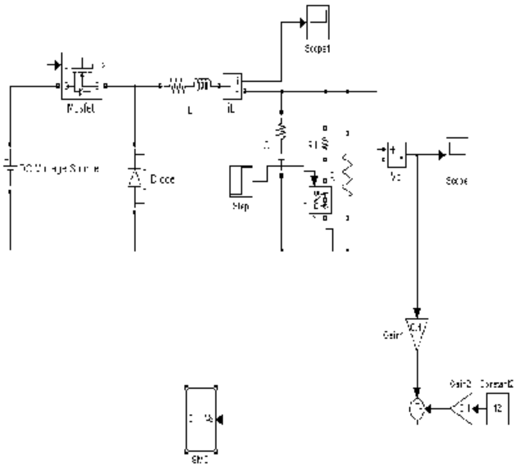

Figure: 4 Voltage mode SMC buck converter.

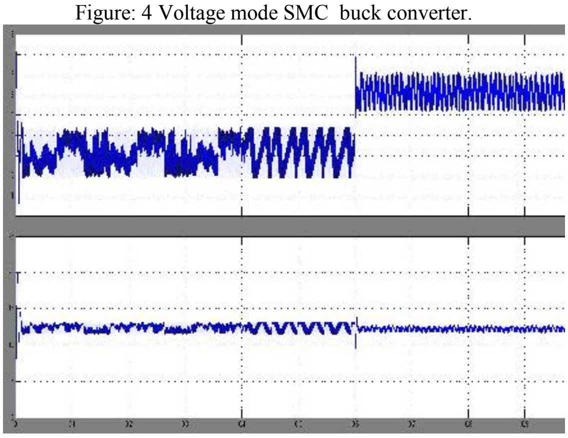

Figure 5. Output Current and voltage Waveforms for the step change in input voltage from 48V to 30V at 0.25sec and for load change from 3A to 6A at 0.6sec.

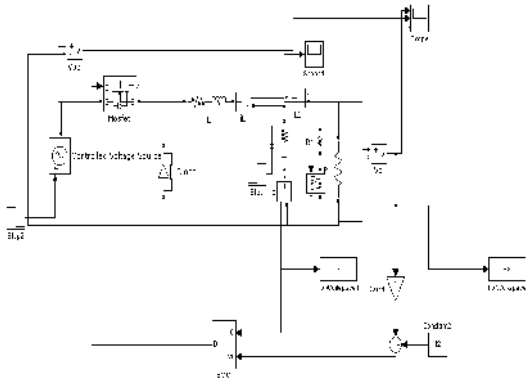

Figure 6. Current SMC DC-DC Buck Converter .

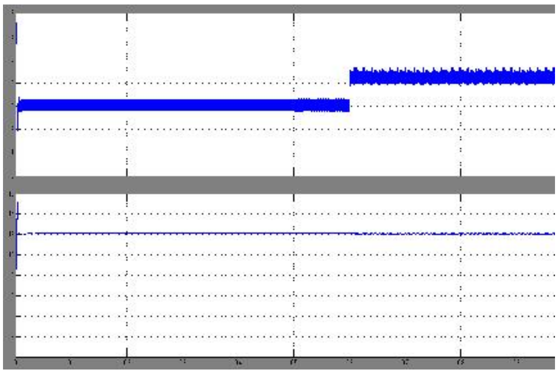

Figure 7. Output Current and voltage Waveforms for the step change in input voltage from 48V to 30V at 0.5sec and for load change from 3A to 6A at 0.6sec.

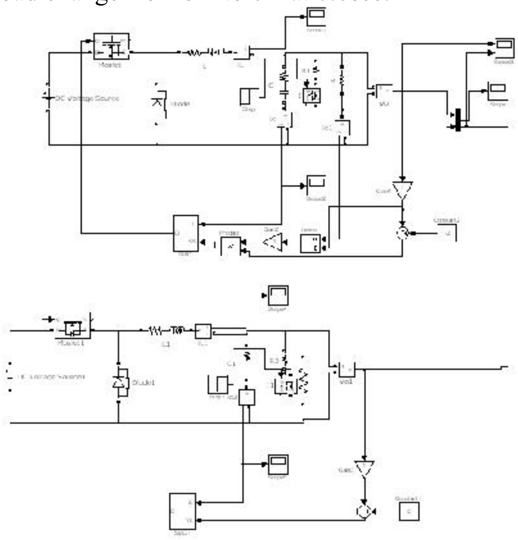

Figure 8. Adaptive SMC DC-DC Buck Converter.

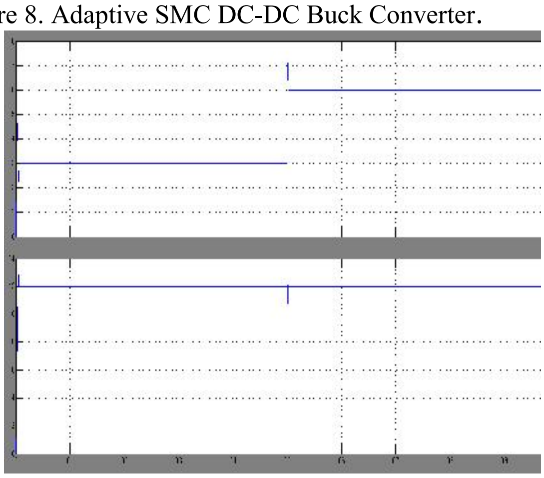

Figure 9. Output Current and voltage Waveforms for the step change in input voltage from 48V to 30V at 0.25sec and for load change from 3A to 6A at 0.6sec.

V. CONCLUSION

This paper presents different types of sliding mode control techniques have been implemented. In comparison with current sliding mode control, the ripple content in voltage sliding mode control is high and hence in order to reduce the ripple, current sliding mode control is implemented in which the both current and voltage are taken in to account and the ripple is reduced. Adaptive sliding mode control is implemented with adaptive control to reduce the ripple content further. The difference in both adaptive and current mode control techniques are shown clearly through waveforms. The ripple contents in all the three control techniques were tabulated.

Table(1) compression of different sliding mode controllers

Name of the mode	**Voltage Mode Control**	**Current Mode Control**	**Adaptive Sliding Mode**
Voltage change	0.25	0.034	0.0006
Load change	0.13	0.025	0.0005

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