PRACTICAL IMPLEMENTATION OF A SLIDING MODE CONTROL FOR BUCK CONVERTER

Pathuri Nagatimmaiah[1],Sri. P. Deepak Reddy[2]

Pathuri Nagatimmaiah,M.Tech scholar, Lakireddy Balireddy College of Engineering, Mylavaram, India
Sri. P. Deepak Reddy M-Tech (Ph.D), Assistant Professor, ,Lakireddy Balireddy College of Engineering, Mylavaram, India

ABSTRACT- **In this project, practical implementation of a sliding mode control for buck converter, operating in continuous conduction mode has been developed. A detailed analysis of the design principle of a sliding mode control for buck converter is studied. The performance of the sliding line for an ideal controller has been compared with the sliding line for practical controller and necessary results are presented to validate the sliding line for an ideal & practical controller.**

Keywords: **Buck converter, sliding mode control**

I.INTRODUCTION

DC-DC converter is the circuits which convert sources of direct current (DC) from one voltage level to another. There are six basic DC-DC converters. Buck, boost, buck-boost, cuk, Sepik, & zeta. DC-DC converters are nonlinear system. Therefore they represent a big challenge for control system. As classical control methods are designed at one operating point, they doesn't give satisfactory performance under operating point variations, large parameter variations & load variations.

Buck converter converts an input (DC) voltage to lower output (DC) voltage by changing the duty cycle of the main switches in the circuit. Buck converters are used in battery powered devices, where the circuit requires a higher operating voltage than the battery can supply, e.g. laptops, mobile phones, camera flashes & battery powered vehicles.

Pulse width modulation is a modulation technique that conforms the width of a pulse, formally the pulse duration, based on modulator signal information. It is used to allow the control of power supplied to electrical devices, especially to internal loads such as motors. The average value of voltage fed to the load is controlled by turning the switch between supply and load. The longer the switch is on compared to the off periods, the power supplied to the load is high. Advantage of PWM is that power loss in switching devices is very low. When a switch is off practically there is no current, and when it is on, there is no voltage drop across switch. Power loss, being the product of voltage and current, is thus in both cases close to zero. PWM has also been used in communication systems where its duty cycle has been used to convey information over a communication channel. It also used in motor drives for fans, pumps robotic servos, electric stoves and lamp dimmers.

Sliding mode control or SMC is a nonlinear method of control. It alters the dynamics of any nonlinear system by application of a discontinuous control signal. State feedback control law is a discontinuous function of time. Hence it switches from one continuous structure to another. Hence sliding mode control is a variable structure control method. Discontinuous signal forces the system to slide along cross section of the system's normal behavior. The multiple control structures are designed so that trajectories always move toward adjacent region with a different control structure so, ultimate trajectory will not exist entirely within one control structure, but it will slide along the boundaries of control structures. The motion of system that slides along the boundaries is called sliding mode and geometrical locus consisting of the boundaries is called sliding surface. Concurrently, there was also an alternative approach of limiting the switching frequency, which is through the incorporation of a constant ramp function into the controller to determine the switching of the converter. The main advantage of this approach is that the switching frequency is constant under all operating conditions, and it is easily controllable through varying the ramp signal. Basically, there are two methods of implementing this constant frequency operation. The first method is to encode the ramp signal into the discontinuous SM switching function of the controller. In these sliding mode controllers, two types of controllers are there Voltage sliding mode controller and current sliding mode controller. In this voltage sliding mode controller, control operation depends on only output voltage. And the current sliding mode controllers, control operation depends on output voltage and capacitor current also.

II. CONTROL TECHNIQUES USED INDC-DC BUCK CONVERTER

A control technique suitable for DC-DC converter must match with their nonlinearity and input voltage and load variations, ensuring stability in any operating condition. There are various control techniques such as, fuzzy logic controller, artificial neural network (ANN) controller, sliding mode controller (SMC), PI controller, PID controller, P controller. But here for DC-DC buck converter of sliding mode control method.

2.1 **Sliding Mode Control for Buck Converter**

2.1.1 System Modeling

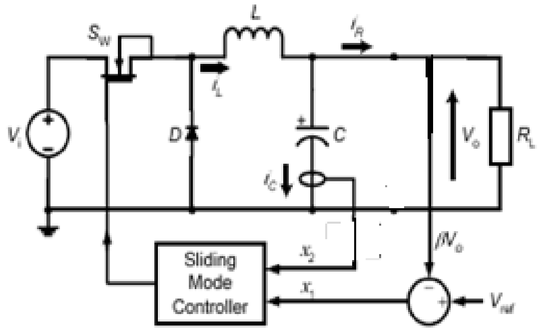


Fig.1 schematic diagram of a sliding mode control for buck converter

Here, the voltage error, X_1, is

$$x_1 = V_{ref} - \beta V_0 \quad 1$$

Where V_{ref} is the constant reference voltage and $\beta = R_2/(R_1 + R_2)$ is the sensing ratio of the output voltage. The rate of change of voltage error, X_2, is

$$x_2 = \dot{x}_1 = -\beta \frac{dV_0}{dt} = -\beta \frac{i_C}{C} \quad 2$$

Where $I_C = C\,(dVo/dt)$ is the capacitor current, and C is the capacitance. Since $I_C = I_L - I_R$, where I_L and I_R represent the inductor and load currents respectively, differentiation of above equation with respect to time gives

$$\dot{x}_2 = \frac{\beta}{C}\frac{d(i_R - i_L)}{dt} \quad 3$$

Using $I_R = Vo/R_L$ where R_L is the load resistance, and the averaged equation of a CCM inductor current

$$i_L = \int \frac{uV_i - V_0}{L} dt \quad 4$$

Where V_i is the input voltage, L is the inductance, and u = 1 or 0 is the switching state, we have

$$\dot{x}_2 = \frac{\beta}{R_L C}\frac{dV_0}{dt} + \frac{\beta}{C}\left(\frac{V_0 - uV_i}{L}\right)$$

$$= -\frac{x_2}{R_L C} + \frac{V_{ref}}{LC} - \frac{x_1}{LC} - u\frac{\beta V_i}{LC} \quad 5$$

Finally, from (2) and (5), a state space model describing the system is derived as

$$\begin{bmatrix}\dot{x}_1 \\ \dot{x}_2\end{bmatrix} = \begin{bmatrix} 0 & 1 \\ -\frac{1}{LC} & -\frac{1}{R_L C}\end{bmatrix}\begin{bmatrix}x_1 \\ x_2\end{bmatrix} + \begin{bmatrix}0 \\ -\frac{\beta V_i}{LC}\end{bmatrix} u + \begin{bmatrix}0 \\ \frac{V_{ref}}{LC}\end{bmatrix} \quad 6$$

2.1.2 Design of an Sliding Mode Control

In sliding mode control, this control employs a sliding surface to decide its input states, u, to the system. For sliding mode voltage control, the switching states, u, which corresponds the turning on and off of the power converter's switch, is decided by the sliding line

$$S = \alpha x_1 + x_2 \quad 7$$

Where α is a positive quantity, **J** = [α, 1] and $x = [x_1, x_2]^T$. It has been derived in that

$$\alpha = \frac{1}{R_L C} \quad 8$$

Graphically, this is simply a straight line on a $X_1 - X_2$ phase plane with gradient α However, the implication of α is more than a 'decision maker'. It actually determines the dynamic response of the system in SM with a first order time constant: $\tau = \frac{1}{\alpha}$. To ensure that a system follows its

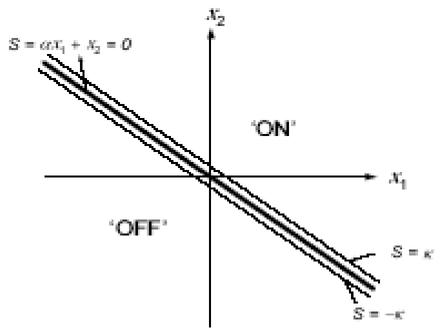


Fig.2 Sliding line on $X_1 - X_2$ phase-plane.

Equation (7) describes a line in the phase plane passing through the origin, which represents a stable operating point for this converter (output voltage error and its derivatives).

$$S = \alpha x_1 + \dot{x_1} = 0 \quad 9$$

This describes the system dynamics in the sliding mode. Thus if the existence and the reaching condition of the sliding mode control is satisfied, a stable system is obtained by choosing a Positive value of α Sliding surface, a control law must be imposed. In our system, the control law is defined as

$$u = \begin{cases} 1 = 'ON' & \text{when } s > k \\ 0 = 'OFF' & \text{when } s < -k \end{cases} \quad 10$$

$$S = K_1 (V_{ref} - \beta V_O) + K_2 i_C \quad 11$$

Where $K_1 = \frac{1}{R_L C}$ and $K_2 = -\frac{\beta}{C}$. From the equation, the terms $(V_{ref} - \beta V_O)$ and Ic are the

$$S = \frac{C}{\beta}\alpha x_1 + \frac{C}{\beta}\alpha x_2 = Qx \quad 12$$

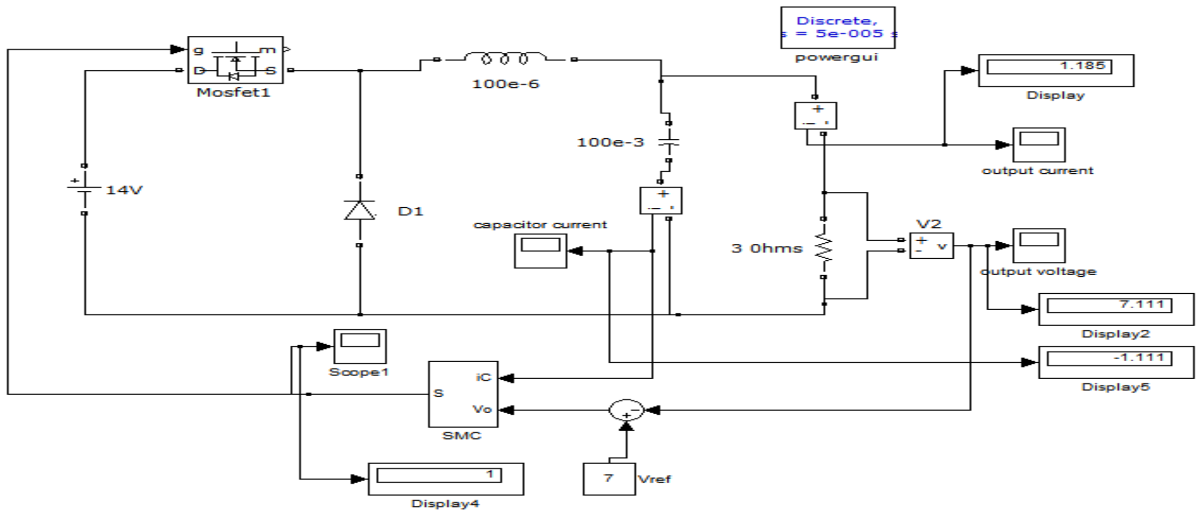
Where

$$Q = [(\frac{C}{\beta})\alpha, \frac{C}{\beta}]; \text{ and } X = [X_1, X_2]^T \quad 13$$

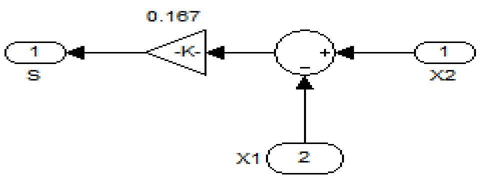
From (12), we get

$$S = \frac{1}{\beta R_L}(V_{ref} - \beta V_O) - i_C \qquad (14)$$

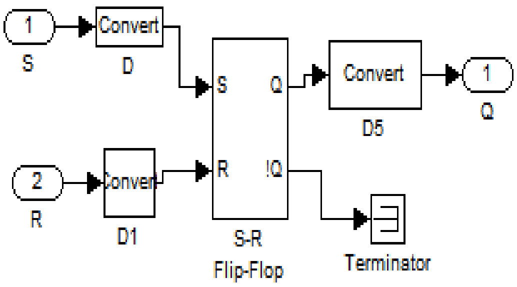
Equation (14) is known as a sliding surface



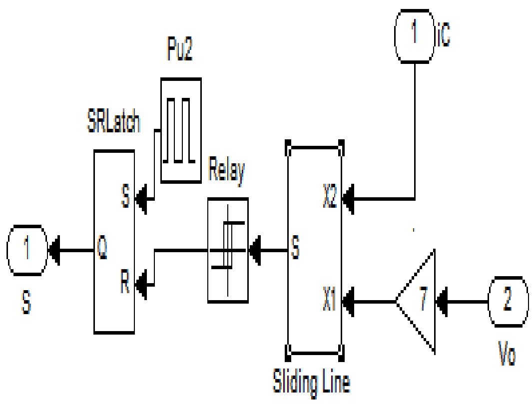
Simulation diagram of sliding mode control for buck converter



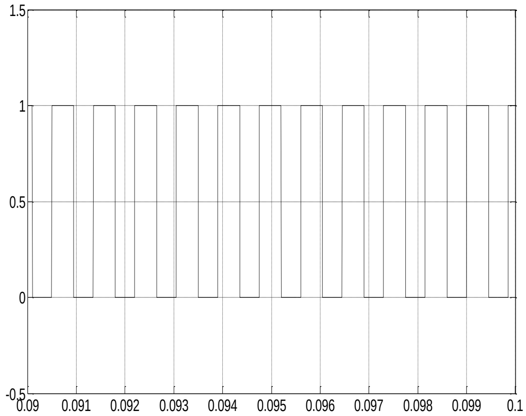
Sliding line



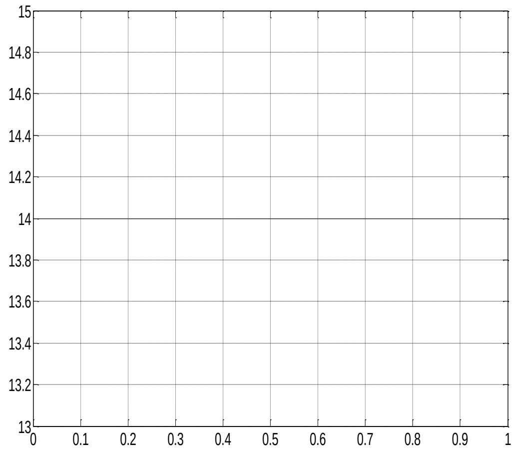
Internal diagram of SR latch



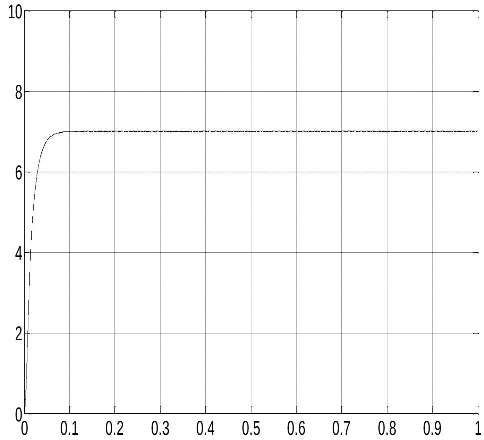
Sliding mode control



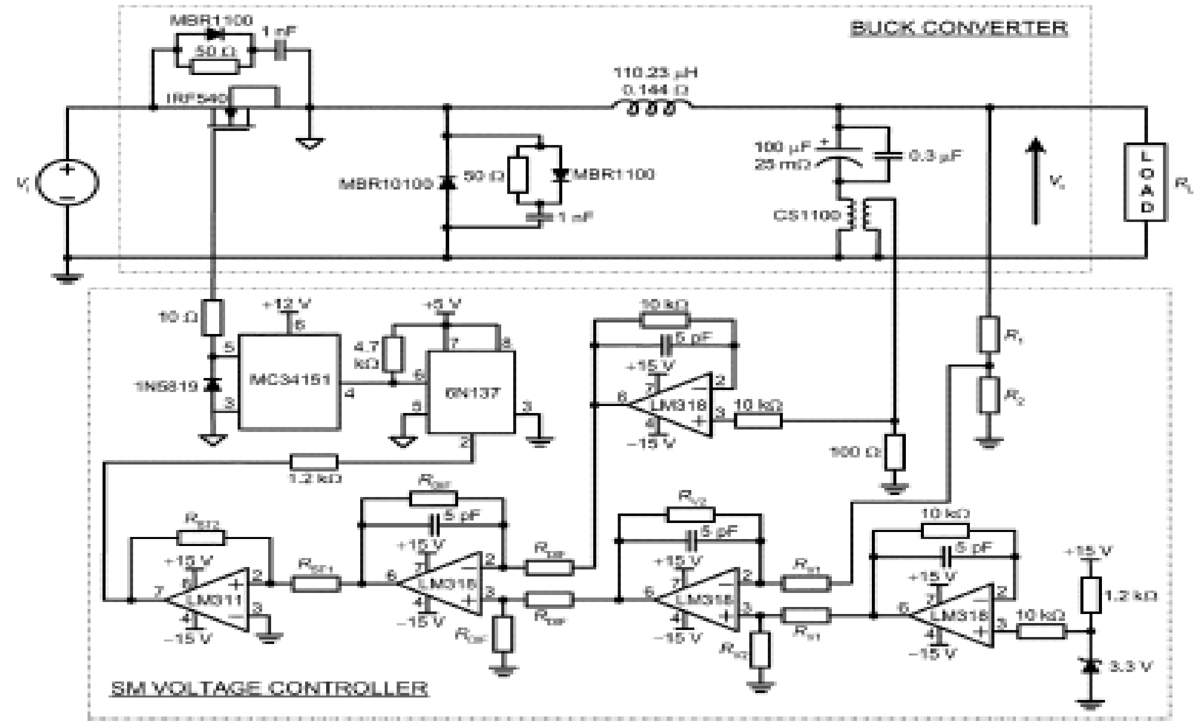
Sliding mode control pulse wave form



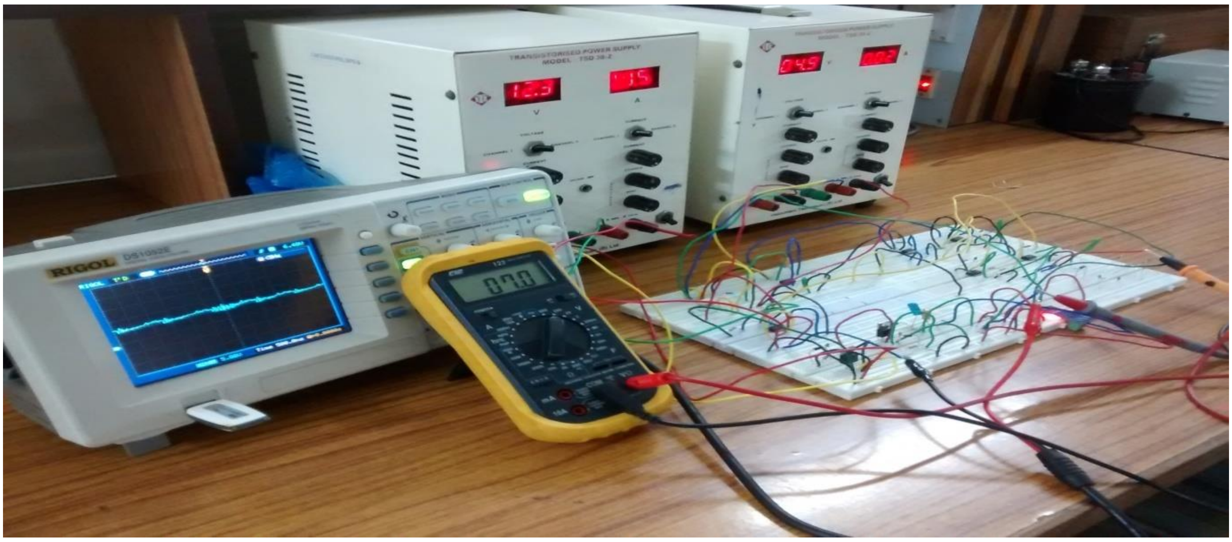
Buck converter input voltage wave form



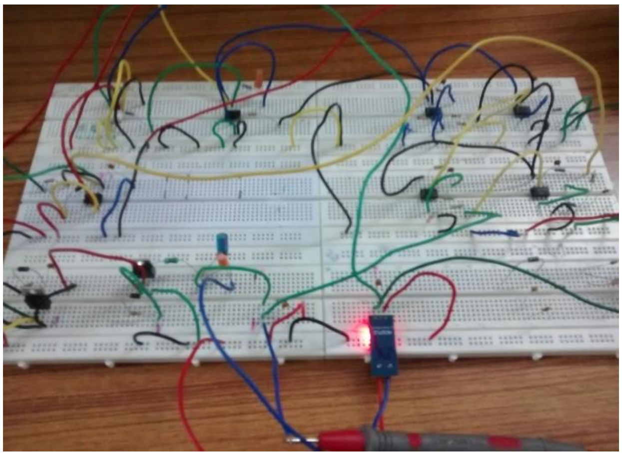
Buck converter output voltage wave form



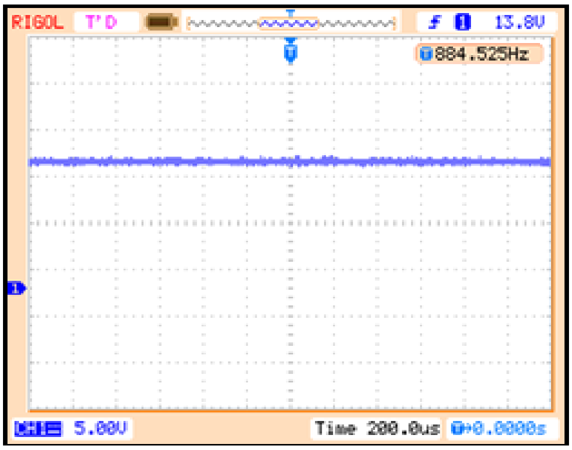
Hard ware diagram of the SMC buck converter



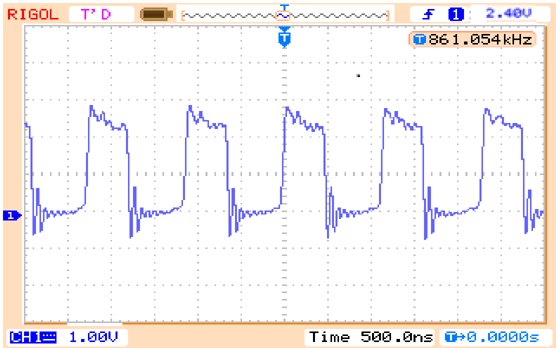
Hard ware implementation of sliding mode control buck converter



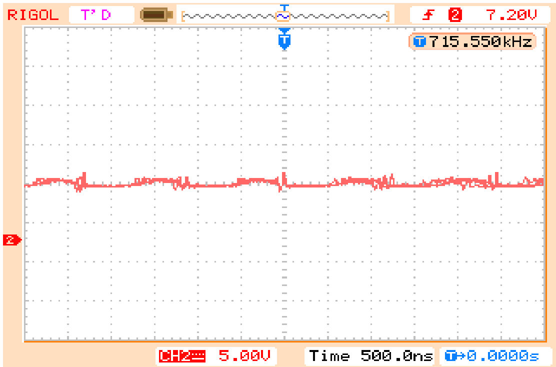
Hard ware connection of SMC buck converter



Buck converter input voltage wave form



Sliding mode control pulse wave form



Buck converter Output voltage wave form

Conclusion:

In this project work, sliding line for an ideal control for buck converter has been developed and it is implemented under mat lab / simulink environment & sliding line for an practical control for buck converter has been implemented in hardware. The performance of a practical implementation sliding mode voltage control for buck converter operating in continuous conduction mode has been tested and found that its performance in quite satisfactory. From the results, sliding line for an ideal control for buck converter, observes that pulse, input voltage, output voltage waveforms are analyzed and sliding line for a practical control for buck converter, observes that pulse, input voltage, output voltage wave forms are analyzed.

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Pathuri Nagatimmaiah was born in kurnool, Andhra Pradesh in 1991 and he completed B.Tech in Electrical and Electronics Engineering from KITS Engineering College, Affiliated to JNTU KAKINADA, A.P in the year 2012. He is doing M.Tech in Power Electronics and Drives from Lakkireddy Balireddy College of Engineering, Mylavaram, A.p. His area of interest power Electronics, Control systems, Electrical circuits.

P.Deepak Reddy received the B.Tech from JNT University, Hyderabad. M.Tech from Vellore Institute of Technology, Deemed University, Vellore and Pursuing Ph.D from GITAM University, Hyderabad. Currently he is working as an Sr Assistant Professor in Dept. of EEE in Lakireddy Bali Reddy College, Mylavaram. He has published three International Journals. His area of interest is DC-DC Converters-Controlling, improvement of power factor, ZVS Converters, PWM techniques.

