# Advance Control Techniques for DC/DC Buck Converter with Improved Performance

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**ABSTRACT**:A buck converter is a very common and useful device in modern power electronics. It has wide application in modern HVDC power system network. The common and effective technique to control the buck converter is PID controller. PID controller is widely used in modern automatic control system. More advance technique to control the converter is non-linear control. Sliding mode control is a non-linear control technique.Every control method has some advantages and drawbacks due to which that particular control method consider as a suitable control method under specific conditions, compared to other control methods. The control method that gives the best performances under any conditions is always in demand.

**KEYWORDS:**PID controller, Pulse Width Modulation (PWM), Sliding mode control, DC-DC buck converter, Transfer function, MATLAB, Simulink.

## I.INTRODUCTION

The switch mode DC-DC converter are some of the simplest circuit which converts power level of DC power effectively. It has wide application in modern computer, DC motor drive, power system, automotive, aircrafts etc. the commonly used control methods are pulse width modulation (PWM), voltage mode control, PWM current mode control with proportional (P), proportional integral (PI), and proportional integral derivative (PID) controller. But this control method cannot perform satisfactory under large load variation so non liner control technique is in picture.The dc-dc converters, which are non-linear and time variant system, and do not lend themselves to the application of linear control theory, can be controlled by means of sliding-mode (SM) control, Which is derived from the variable structure control system theory (VSCS).

## II.LITEARTURE SURVEY

The dc-dc switching converters are the widely used circuits in electronics systems. They are usually used to obtain a stabilized output voltage from a given input DC voltage which is lower (buck) from that input voltage, or higher (boost) or generic (buck–boost) [1]. Most used technique to control switching power supplies is Pulse-width Modulation (PWM) [2]. The conventional PWM controlled power electronics circuits are modelled based on averaging technique and the system being controlled operates optimally only for a specific condition [3]-[4]. The linear controllers like P, PI, and PID do not offer a good large-signal transient (i.e. large-signal operating conditions) [4]-[5].

Therefore, research has been performed for investigating non-linear controllers. The main advantages of these controllers are their ability to react immediately to a transient condition. The different types of non-linear analog controllers are: (a) hysteretic current-mode controllers, (b) hysteretic voltage-mode/V2 controllers, (c) sliding-mode/boundary controllers. Advantages of hysteretic control approach include simplicity in design and do not require feedback loop compensation circuit. M. Castilla [6]-[8] proposed voltage-mode hysteretic controllers for synchronous buck converter used for many applications. The analysis and design of a hysteretic PWM controller with improved transient response have been proposed for buck converter in 2004[9].

### III.BASIC PRINCIPLES

The buck converter circuit converts a higher dc input voltage to lower dc output voltage. The basic buck dc-dc converter topology is shown in figure. 1. It consists of a controlled switch $S_w$, an uncontrolled switch (diode) D, an inductor L, a capacitor C, and a load resistance R.
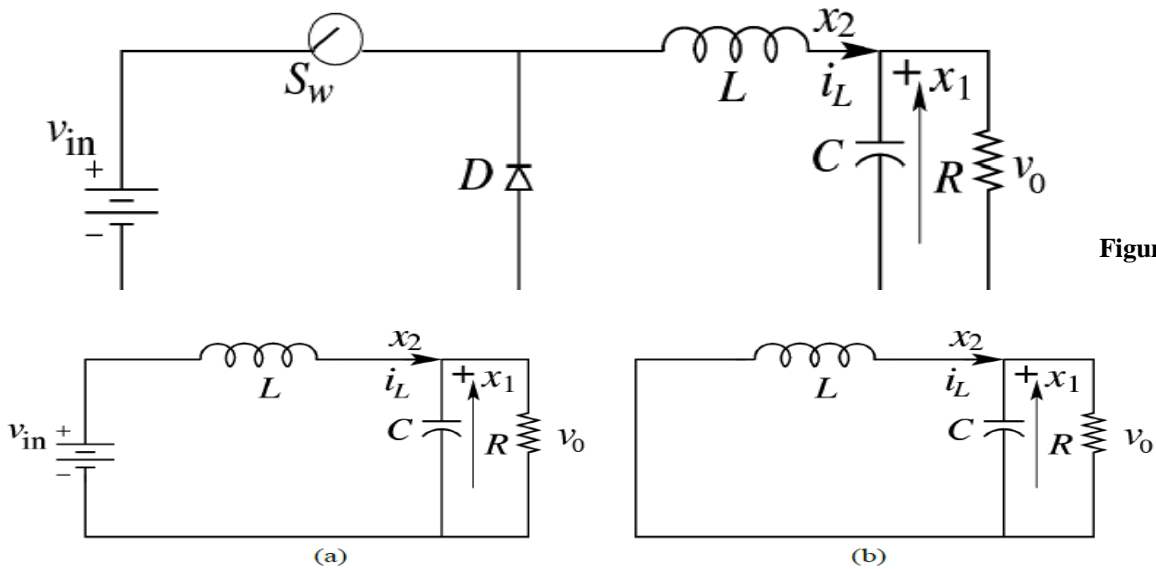


**Figure 1:**



**Dc-Dc Buck Converter Topology**
**Figure 2: Buck Converter Circuit When Switch: (A) Turns On (B) Turns Off**

In the description of converter operation, it is assumed that all the components are ideal and also the converter operates in CCM. In CCM operation, the inductor current flows continuously over one switching period. The switch is either on or off according to the switching function and this results in two circuit states. The first sub-circuit state is when the switch is turned on, diode is reverse biased and inductor current flows through the switch, which can be shown in figure 2(a). The second sub-circuit state is when the switch is turned off and current freewheels through the diode, which is shown figure 2(b).
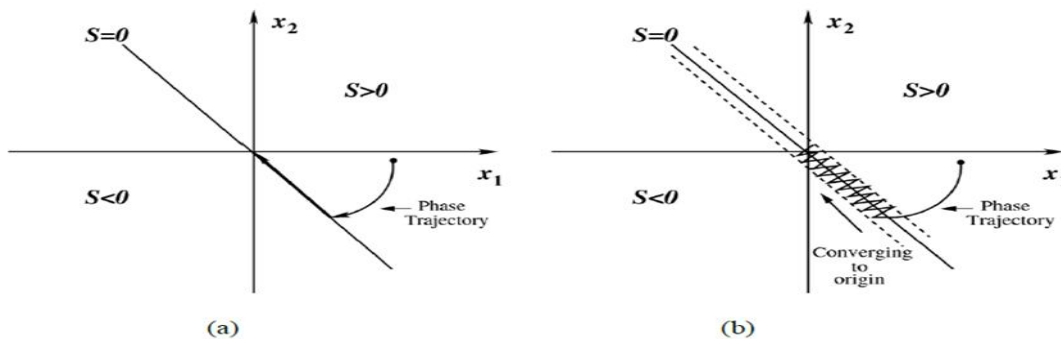


**Figure 3: Phase Plot for (a) ideal SM Control (b) actual SM control**

The basic idea of SM control is to design first a sliding surface in state space and then the second is to design a control law direct the system state trajectory starting from any arbitrary initial state to reach the sliding surface in finite time, and finally it should come to a point where the system equilibrium state exists that is in the origin point of the phase plane. The existence, stability and hitting condition are the three factors for the stability of sliding mode control. SM

control principle is graphically represented in Figure 3, where, represent the sliding surface and $x1$ and $x2$ are the voltage error variable and voltage error dynamics respectively. The sliding line (when it is a two variable SM control system in two-dimensional plane) divides the phase plane into two regions. Each region is specified with a switching state and when the trajectory arrives at the system equilibrium point, the system is considered as stable.

### IV.IMPLEMENTATION OF PID CONTROLLED BUCK CONVERTER

The simulation model of DC-DC buck converter consists of following parts:
**DC-DC Buck Converter:** ADC-DC buck converter is a power electronics device to convert high level of voltage to a lower level voltage. In this paper the buck converter is implemented in two forms. One is mathematical modelling and another is electrical modelling. A buck converter is consists of Inductance (L), Inductance Series Resistance (RL), Capacitance (C), and Capacitance Series Resistance (Rc).
The mathematical model of the system consists of two loop. 1st one is inductor current and 2nd is output voltage loop. To design this two loop general equation must have to derive from variable system structure model.
From the general model of buck converter we can assume:
The first loop is responsible for computing the Inductor current by solving the differential equation obtained from applying KVL

$$V_{in}D = L\frac{di_L}{dt} + i_L R_L + V_0 \ldots\ldots 1$$

$$L\frac{di_L}{dt} = V_{in}D - i_L R_L - V_0 \ldots\ldots 2$$

$$i_L = \frac{i}{L}\int (V_{in}D - i_L R_L - V_0)\ dt \ldots\ldots 3$$

Where, $V_{in}$= Input Voltage of the Buck Converter, D=1 when Duty Cycle is ON and D=0 when Duty Cycle is OFF, $i_L$= Inductor Current, $R_L$=Effective Series Resistance of Inductance, $V_0$=Output Voltage of the Buck Converter, L=Inductance Value in Henry.
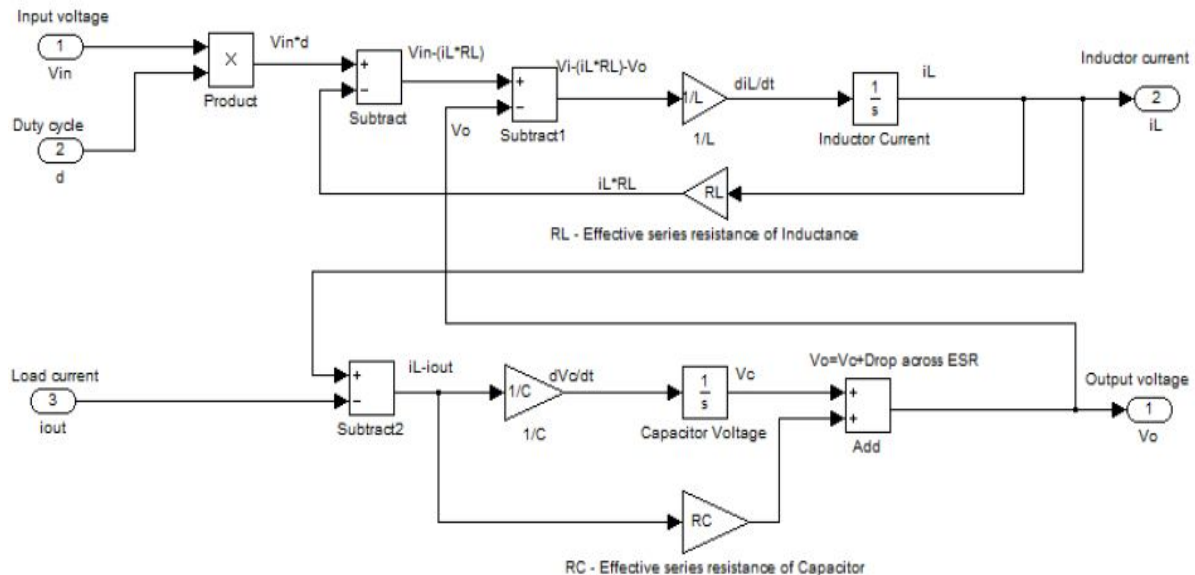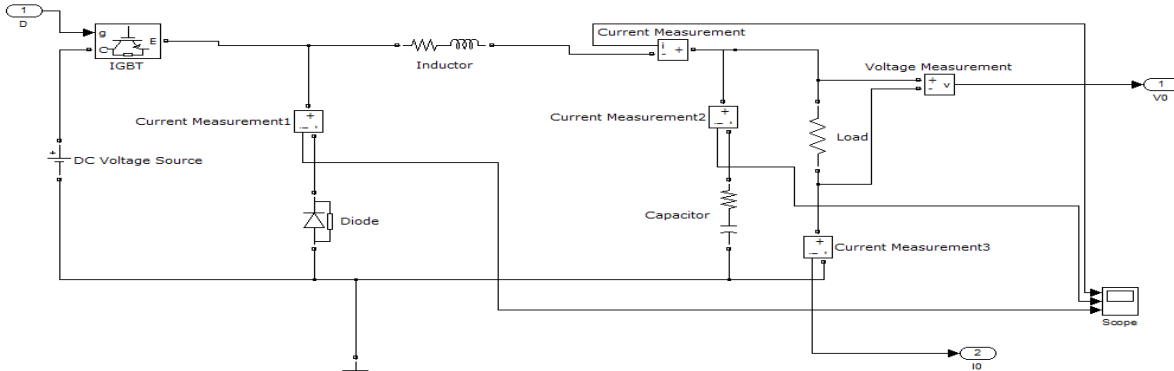


**Figure 4: Buck Converter Subsystem**

**Figure 5: Buck Converter Subsystem Electrical Model**

The second loop calculates the Output Voltage which is the sum of the Capacitor Voltage and the drop across the Capacitor Series Resistance (Rc). Applying KCL at the capacitor node we get:

$$C \frac{dv_c}{dt} = i_L - i_{out} \dots\dots 4$$

$$V_c = \frac{1}{C} \int (i_L - i_{out}) dt \dots\dots 5$$

$$V_0 = V_C + Drop\ across\ Capacitor \dots\dots 6$$

$$V_0 = V_C + R_C (i_L - i_{out}) \dots\dots 7$$

Where $i_{out}$ = Load Current, C = Capacitance in Farad, $V_c$=Voltage across Capacitor, $R_C$ = Effective Series resistance of the Capacitor.

**PWM generator:** The PWM generator produce switching frequency for the desire output by varying the duty cycle of the converter. The converter has two operating mode. The duty interval, when switch is on ($T_{on}$) and freewheeling mode, when switch is off ($T_{off}$).
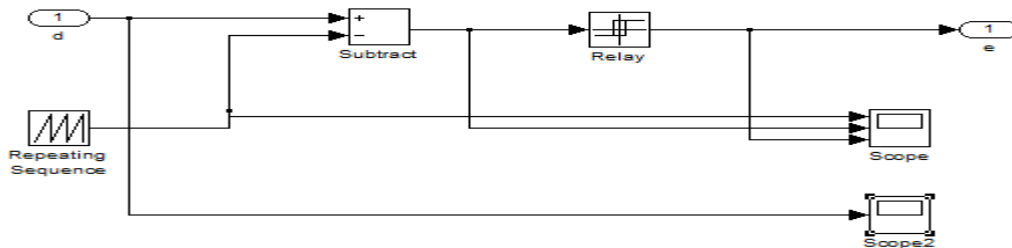


**Figure 6: PWM Subsystem**

To implement a PWM subsystem a relay is necessary to provide output. The input of the relay is the difference of duty cycle and saw tooth waveform. By varying the duty cycle the turn off and turn on period varies. With that the output of the relay also changes. A very simple PWM generator is designed in this paper. The time value of saw tooth is [0 0.1/fs], where fs is switching frequency. The only relay parameter 'output when on' value is 1 rest of that all value is 0.

**PID Controller:** To design a PID controller successfully first have to design a transfer function of the system with respect to duty cycle.
By applying Laplace Transform to Eqn (2), we get:

$$V_{in}D = Li_L s + i_L R_L + V_0 \dots\dots 8$$

Let us assume $V_c$=$V_0$ by neglecting the drop across Rc. Using Laplace Transform on Eqn (9) and rearranging the terms, we get

$$i_L = \frac{V_0}{R} + CV_0 s \dots\dots 9$$

By substituting the value of iL in Equation (10) and rearranging the terms, we obtain the open loop transfer function of the Buck Converter:

$$\frac{V_0}{D} = \frac{\frac{V_{in}}{LC}}{s^2 + s\left(\frac{1}{R_oC} + \frac{R_L}{L}\right) + \left(\frac{1}{LC} + \frac{R_L}{R_oLC}\right)} \dots \dots 10$$

By applying different tuning technique like Ziegler– Nichols, Cohen–Coon the value of $K_p$, $K_d$, $K_i$ can be derived for the system.
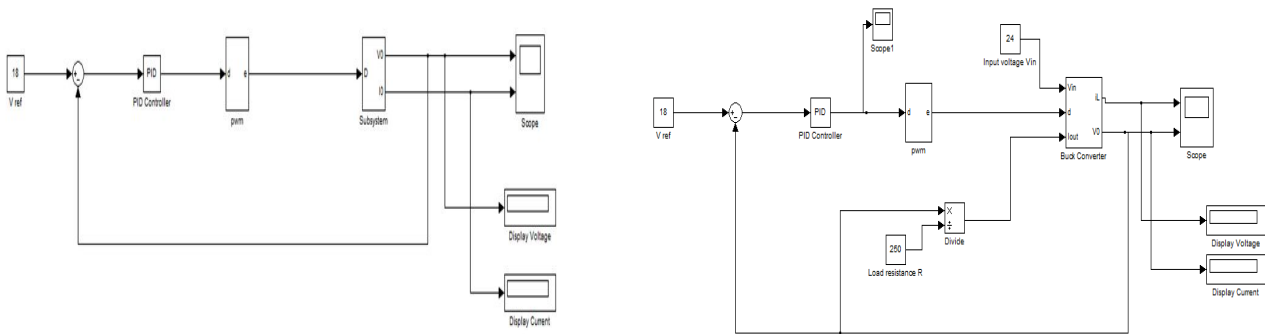
The proposed system is as follows:



**Figure 7: The Proposed Buck Converter's Electrical Model and Mathematical Model**

The parameters of the model is input voltage $V_{in}$ = 24 volt, reference voltage $V_{ref}$ = 18 volt, inductance L = 0.001H, capacitance C = 0.75μC, leakage inductance $R_L$ = 0.08 Ω, leakage capacitance $R_C$ = 0.03 Ω.
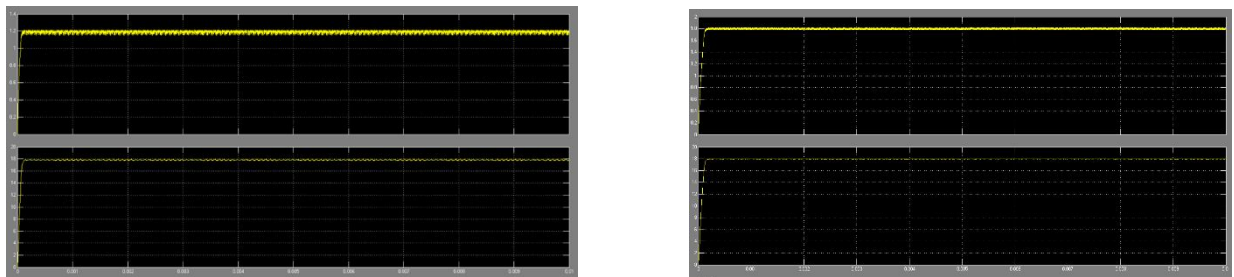


**Figure 8: Output Waveform Of The Proposed Electrical&Mathematical Model 1st Output Current 2nd Output Voltage**

In this model of buck converter the reference voltage $V_{ref}$ is 18 volt constant supply. The load resistance is 10 Ω. Input voltage of the converter is $V_{in}$ is 24 volt dc supply. The output voltage of this converter is $V_{out}$ and it is 17.66 volt and current $I_{out}$ 1.794 amp. Both are rippled and fluctuating but magnitude is moderate.

## V.SLIDING MODE CONTROL FOR BUCK CONVERTER

To design a sliding mode controller for Buck converter, the voltage error, X1, is

$$x1 = Vref - \beta V0 \dots \dots 11$$

Where Vref is the constant reference voltage and β = R2/ (R1 + R2) is the sensing ratio of the output voltage. The rate of change of voltage error, X2, is

$$x2 = \dot{x}1 = -\beta\frac{dV_0}{dt} = -\beta\frac{i_c}{c} \dots \dots 12$$

Where IC = C (dVo/dt) is the capacitor current, and C is the capacitance. Since IC = IL − IR, where IL and IR represent the inductor and load currents respectively, differentiation of above equation with respect to time gives

$$\dot{x}2 = \frac{\beta Cd(iR-iL)}{dt} \dots \dots 13$$

Using IR = Vo/RL where RL is the load resistance, and the averaged equation of a CCM inductor current

$$iL = \int \frac{uV_i - V_0}{L} L dt \dots \dots 14$$

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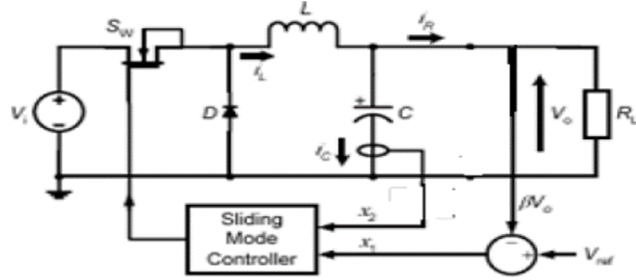


**Figure 9: Schematic Diagram Of A Sliding Mode Control For Buck Converter**

$$\dot{x}_2 = \frac{\beta}{R_L C}\frac{dV_0}{dt} + \frac{\beta}{C}\left(\frac{V0 - uVi}{L}\right) \dots \dots 15$$

$$= -\frac{x_2}{R_L C} + \frac{Vref}{LC} - \frac{x_1}{LC} - u\frac{\beta Vi}{LC} \dots \dots 16$$

Finally, from (4.4) and (4.6), a state space model describing the system is derived as

$$\begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ \frac{-1}{LC} & \frac{-1}{R_L C} \end{bmatrix}\begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + \begin{bmatrix} 0 \\ \frac{-\beta Vi}{LC} \end{bmatrix} u + \begin{bmatrix} 0 \\ \frac{Vref}{LC} \end{bmatrix} \dots \dots 17$$

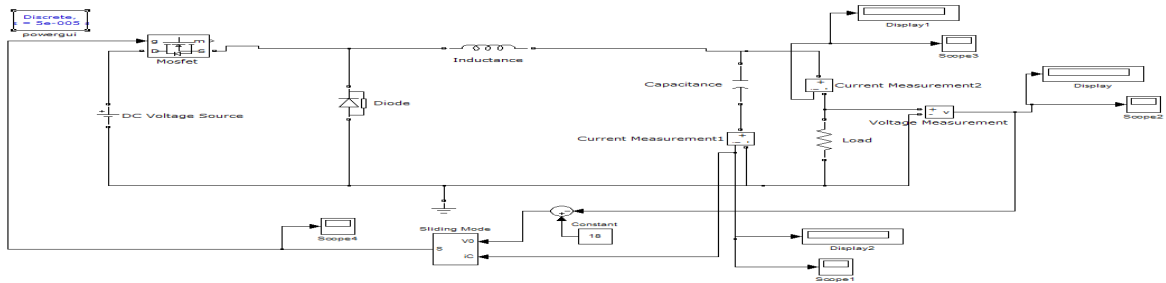The proposed model for buck converter is as follows:



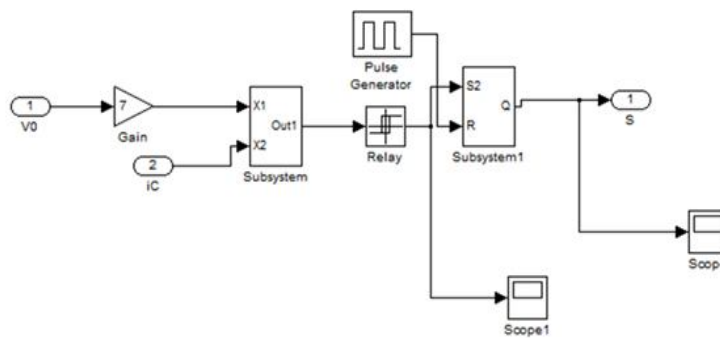**Figure 10: Simulink Model Of The Sliding Mode Control For Buck Converter**



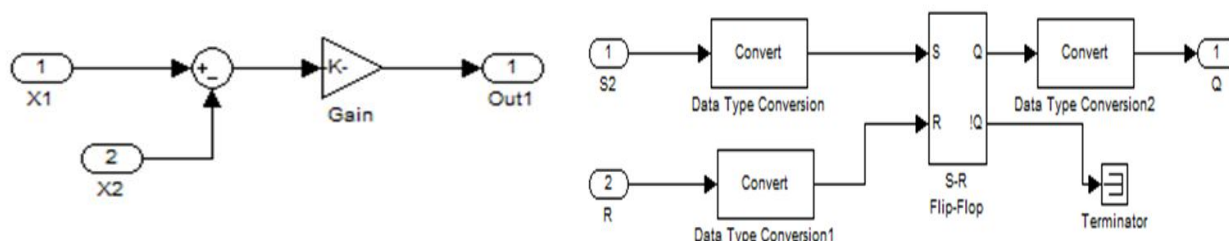**Figure 11: Sliding Surface Block Diagram**

**Figure 12: Sliding Line Block Diagram and SR Latch Block Diagram**

## VI. RESULT AND DISCUSSION

The model is verified in MATLAB/ Simulink environment. The input voltage of the buck converter is $V_{in}$ 24 volt DC load is 10Ω. The reference signal of the system is $V_{ref}$ 18 volt DC. The output voltage $V_{out}$ 17.89 volt shown in fig 13 (a). The rise time of the system is 0.1 sec and no overshoot in the output voltage.

The output current waveform is in the next figure 13 (b). The value of output current is 1.764 amp. The settling time is 0.08 second.
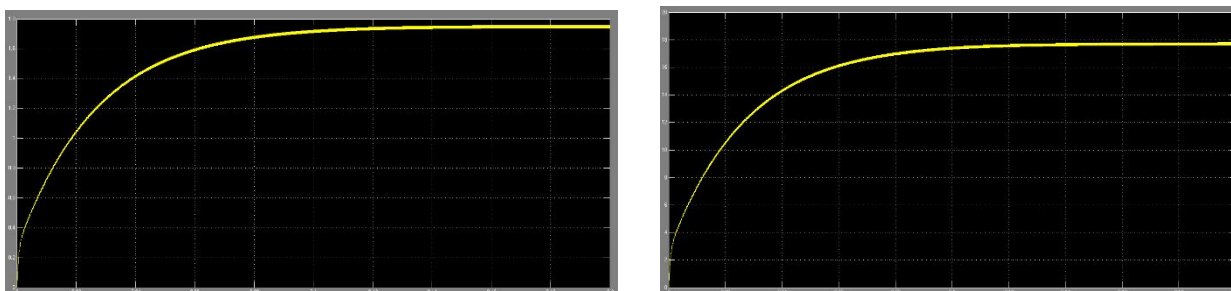


**Figure 13: SM Mode Output (a) Current Waveform and (b) Voltage Waveform**

The control methods have the same power circuit parameters and operate at the same input and output voltages. The design specifications and the circuit parameters, for simulation are chosen as: input voltage $V_{in}$ =24V, desired output voltage $V_{out}$ =18V, inductance L =100mH, capacitance =150μF, leakage inductance $R_L$= 0.08 Ω, leakage capacitance $R_C$ = 0.03Ω load resistance R =10Ω. The sliding coefficients =0.167. The switching frequency is set to 150 kHz. The output is $V_{out}$ = 17.97 volt $I_o$ = 1.764 amp.

## VII.CONCLUSION

In this section Sliding Mode control of buck converter is implemented and different output parameter is observed. The output voltage and current is stable and satisfactory. The output is better than the PID control buck converter. Output reaches stability quite fast and ripple is minimum. Load variation up to a certain range does not affect the output. The overall performance of nonlinear control is good as compared to the PID controller. PID controller reaches its final value faster but contains ripple. For different load and PID parameters there overshoot may be seen. But in SM control the output is smooth and no overshoot observed.

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## BIOGRAPHY

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