ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 5, May 2015

Non-linear Control Techniques for DC-DC Buck Converter

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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. There are mainly two methods of controlling the DC-DC converters. One is the traditional method that is linear control. With the help of linear control satisfactory result can be obtain until a certain limit. Due to huge load variation and source voltage variation linear control may not give satisfactory result. PID controller is a very popular linear controller. The other method is non-linear control technique. Two popular and cost effective non-linear technique is Sliding mode control and Hysteresis control. Both have wide application in power converter section. The control method that gives the best performances under any conditions is always in demand.

KEYWORDS: Hysteresis Control, Sliding mode control, Non-linear Controller, DC-DC buck converter, 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 method is linear control. 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). The more advance control method is Hysteresis control method. It gives more stable output with a very minimal settling time.

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]. 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 [2]-[4] 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[5].Buck converter when operated in continuous conduction mode CCM, gives a continuous output current, with smaller current ripple and low switching noise. CCM operation is usually preferred for large current applications, because it can deliver more current than the converter operating in discontinuous conduction mode DCM. However, a DCM converter has a much faster transient response and a loop gain that is easier to compensate than a CCM converter. Hence, for fulfil of both the requirements, a new converter that combines the advantage of both CCM and DCM converters is developed. Converters operate in a new operation mode-the pseudo CCM. This new switching converter that is operating in pseudo-continuous-conduction-mode (PCCM) with freewheel switching control is proposed by Dongsheng Ma and Wing-Hung Ki [6]-[7].

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III.SLIDING MODE CONTROL FOR BUCK CONVERTER

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

$$x1 = Vref - \beta V0 \ldots\ldots 1$$

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

$$x2 = \dot{x}1 = -\beta \frac{dV_0}{dt} = -\beta \frac{i_c}{c} \ldots\ldots 2$$

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

$$\dot{x}2 = \frac{\beta C d(iR - iL)}{dt} \ldots\ldots 3$$

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

$$iL = \int \frac{uV_i - V_0}{L} Ldt \ldots\ldots 4$$

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

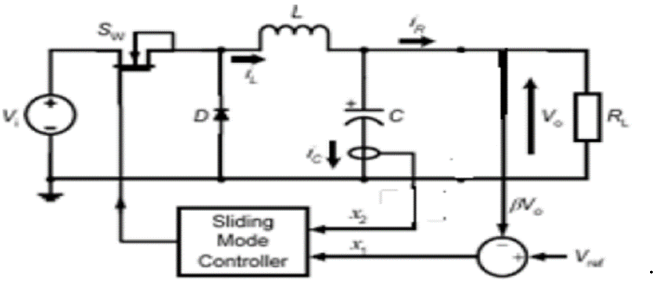

Figure 1: Schematic Diagram Of A Sliding Mode Control For Buck Converter

$$\dot{x}_2 = \frac{\beta}{R_L C} \frac{dV_0}{dt} + \frac{\beta}{C}\left(\frac{V0 - uVi}{L}\right) \ldots\ldots 5$$

$$= -\frac{x_2}{R_L C} + \frac{Vref}{LC} - \frac{x_1}{LC} - u\frac{\beta Vi}{LC} \ldots\ldots 6$$

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

$$\begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ \frac{-1}{LC} & \frac{-1}{R_L C} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + \begin{bmatrix} 0 \\ \frac{-\beta V_i}{LC} \end{bmatrix} u + \begin{bmatrix} 0 \\ \frac{V_{ref}}{LC} \end{bmatrix} \ldots\ldots 7$$

The proposed model for buck converter is as follows:

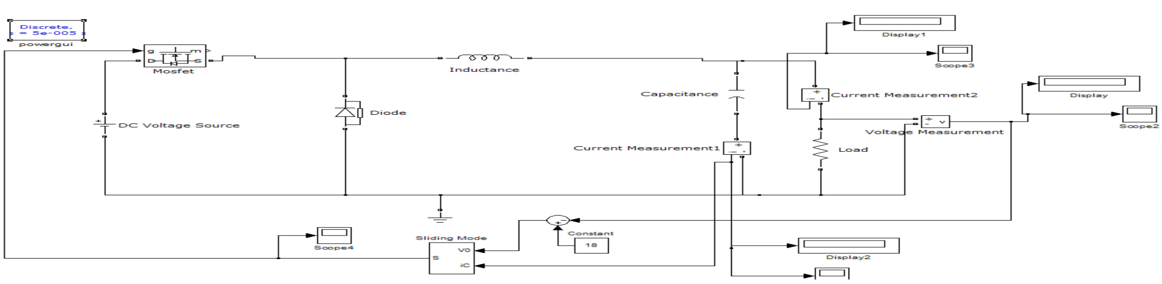

Figure 2: Simulink Model Of The Sliding Mode Control For Buck Converter

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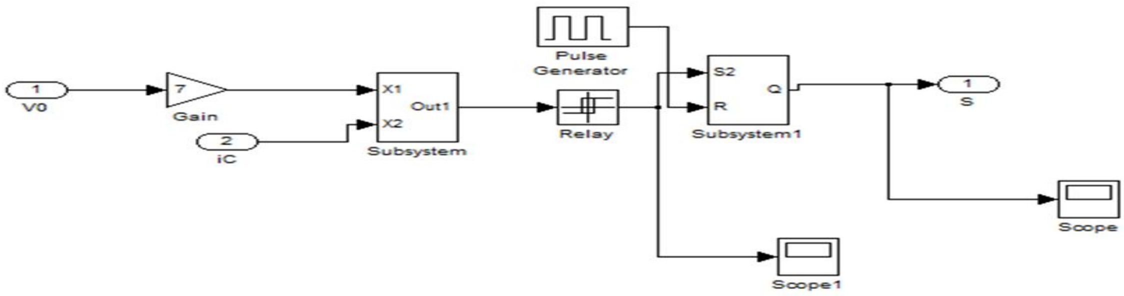

Figure 3: Sliding Surface Block Diagram

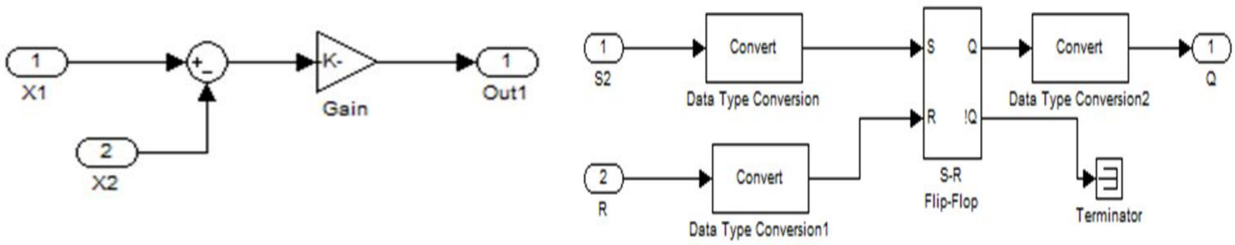

Figure 4: Sliding Line Block Diagram and SR Latch Block Diagram

IV. RESULT AND DISCUSSION

The model is verified in MATLAB/ Simulink environment. The input voltage of the buck converter is Vin 20 volt DC load is 10Ω. The reference signal of the system is Vref 5 volt DC. The output voltage Vout 5.083 volt. The rise time of the system is 0.045 sec and no overshoot in the output voltage.

The output current waveform is in the next figure. The value of output current is 0.5083 amp. The settling time is 0.04 second.

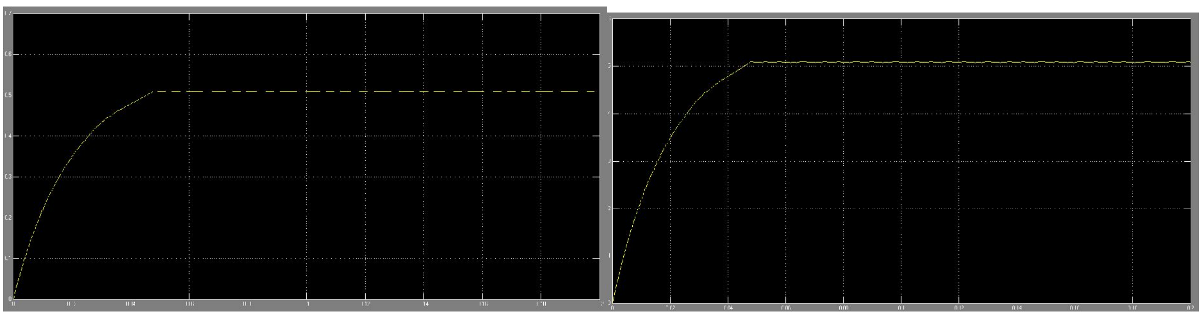

Figure 5: SM Mode Output (a) Current Waveform and (b) Voltage Waveform

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 Vin=20V, desired output

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ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

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voltage Vout=5V, inductance L =100 mH, capacitance =150μF,load resistance R =10Ω. The sliding coefficients =0.167. The switching frequency is set to 150 kHz. The output is Vout = 5.083 volt Io = 0.5083 amp.

V.HYSTERESIS CONTROLLED BUCK CONVERTER

The use of hysteretic controllers for low voltage regulators used in computer and communication systems has been gaining interest due its various advantages. Advantages of this control approach includes fast response and robust with simple design and implementation. They do not require components for feedback loop compensation. This reduces the number of components and size of theoretical analysis for implementation and also reduces the design effort for calculating the circuit component values (like inductor, capacitor, and input voltage).

The operation of a hysteretic current-mode controller for tristate dc-dc buck converter is proposed and the schematic diagram of proposed controller is shown figure 9.

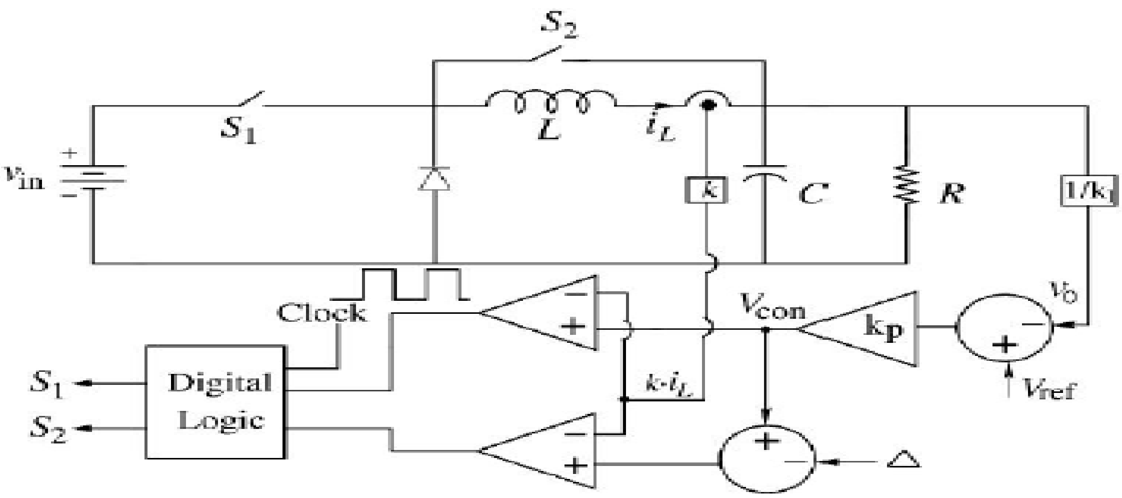

Figure 6: Schematic Diagram Of The Hysteretic Controller For Tristate Buck Converter

The digital logic blocks generates required switching pulses for controlling the switches $S_1$and S_2. This block consists of two SR flip-fops and some logic gates that can be shown in figure 10.

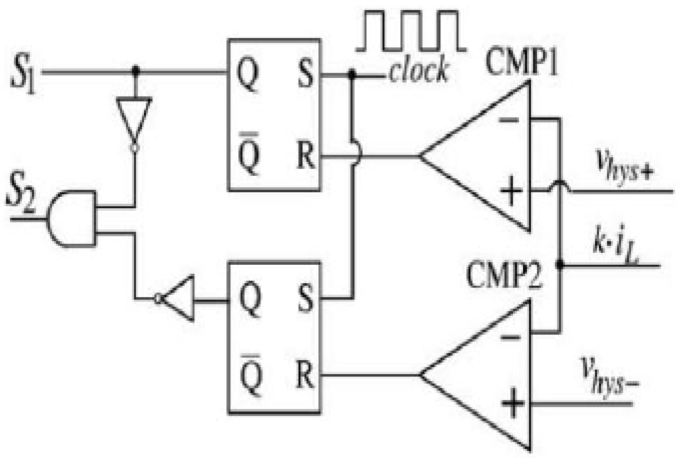

Figure 7: Schematic Diagram Of Pulse Generator Circuit

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The state-space description of the system in terms of the desired control variables (i.e. Voltage, current etc.) is developed. The proposed current controller employs both the output voltage error $x_1$and the inductor current $x_2$as the controlled state variables, which are expressed as

$$\begin{cases} x_1 = v_{ref} - v_{ref} \\ x_2 = i_L \end{cases} \ldots\ldots 8$$

Where $i_L$represent the inductor current, $v_0$and v_{ref}represent the output voltage and reference voltage respectively. Here the switching state of the switch is either 1 or 0. Then by taking the derivative of (7) with respect to time,

$$\dot{x_1} = \frac{dv_0}{d_t} \ldots\ldots 9$$

$$\dot{x_2} = \frac{di_L}{d_t} \ldots\ldots 10$$

Considering the buck converter when the switch $S_1$is on, S_2off

$$L\frac{di_L}{d_t} = v_{in} - v_0 \ldots\ldots 11$$

$$i_L = C\frac{dv_c}{dt} + \frac{v_0}{R} \ldots\ldots 12$$

Substituting equation (5.8)

$$\dot{x_1} = -\frac{1}{RC}x_1 - \frac{1}{C}x_2 + \frac{v_{ref}}{RC} \ldots\ldots 13$$

$$\dot{x_2} = \frac{1}{L}x_1 - \frac{v_{ref}}{L} \ldots\ldots 14$$

The dynamics of the converter circuit in mode 3, when $S_2$is on, $S_1$is off, can be expressed as,

$$L\frac{di_l}{dt} = 0 \ldots\ldots 15$$

$$i_L = C\frac{dv_c}{dt} + \frac{v_0}{R} \ldots\ldots 16$$

Since in this mode of operation, inductor current stays at a constant value, so we get the derivative of a constant value is zero. By substituting equation (5.10) into equation (5.11) and (5.12) results in,

$$\dot{x_1} = -\frac{1}{RC}x_1 \ldots\ldots 17$$

$$\dot{x_2} = 0 \ldots\ldots 18$$

As studied from the previous discussion that the basic principles of a hysteresis control is based on the two hysteresis bands (upper and lower bands), whereby the controller turns the switch on when the output current falls below the lower band and turns the switch off when output is beyond the upper bound. The switching action can be determined in the following way,

1. If i_L< lower bound, u = 1 (ON)
2. If i_L> upper bound, u = 0 (OFF), where *u* is the control input.

The proposed model for buck converter is as follows:

The Hysteresis controlled buck converter is modelled with the help of simulink. The Hysteresis mode control of the buck converter is proposed in the model. The operating condition is ideal. All ideal resistance capacitance and Inductance is applied. The operation mode is discrete. Input voltage $V_{in}$is 20 volt DC. The reference signal V_{ref} is 5 volt constant supply. Load is resistive and is of 10 Ω.

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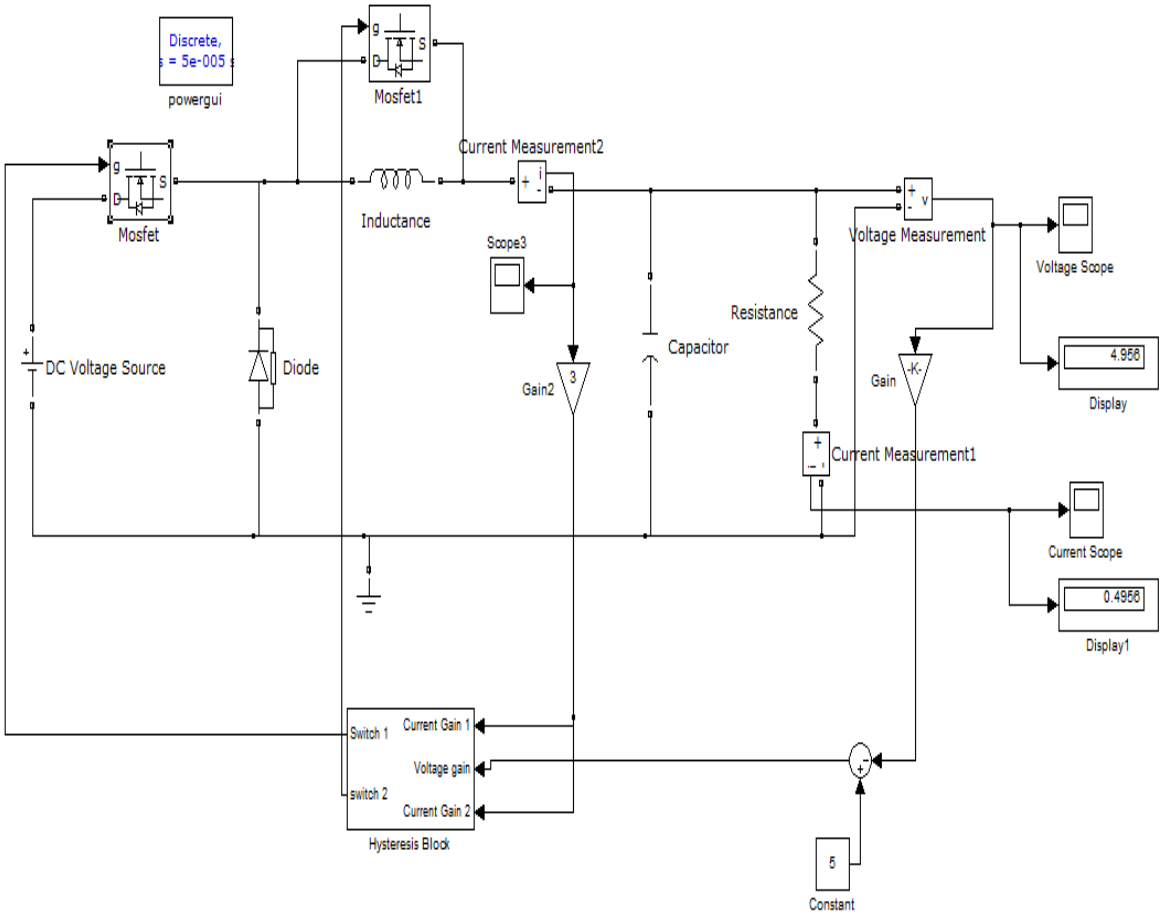

Figure 8: Simulink Model Of Hysteresis Controlled Buck Converter

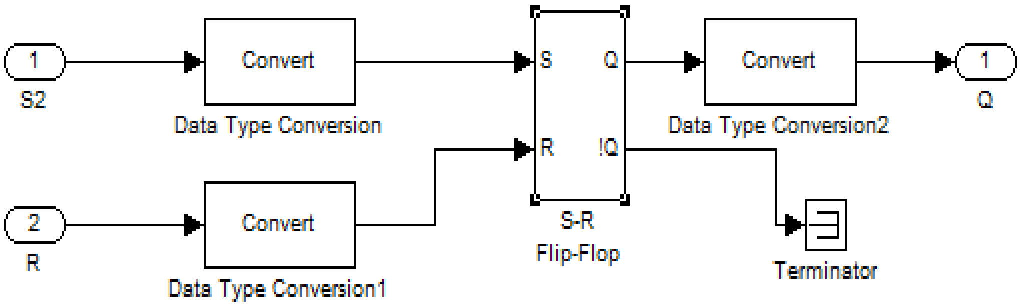

Figure 9: Simulink Model Of S R Block

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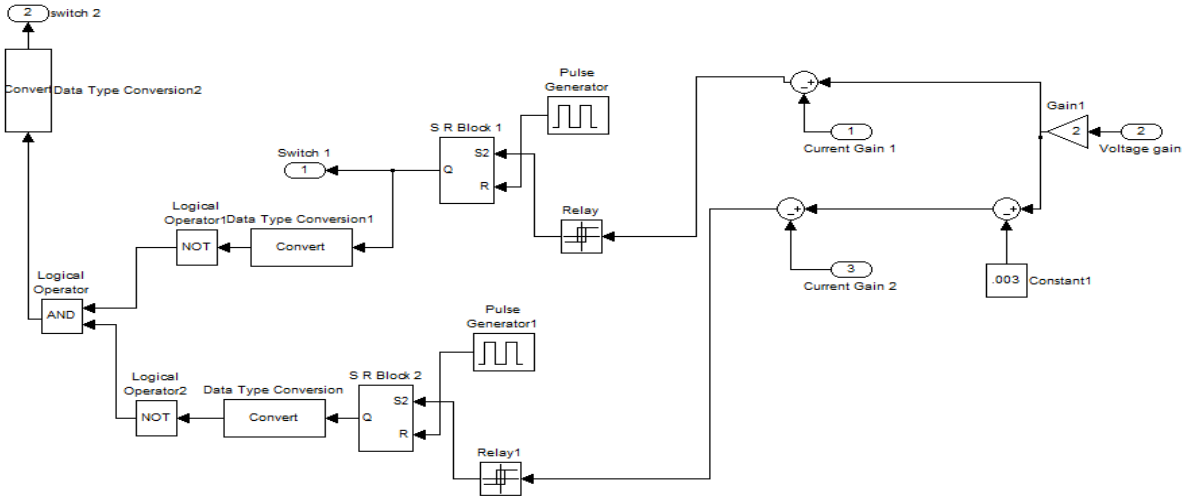

Figure 10: Simulink Model Of Hysteresis Block

In this subsection, based on the above proposed hysteretic current control method, the simulation studies have been performed on a dc-dc buck converter under steady-state and also under dynamic conditions of line and load variations. The buck converter parameters chosen for the simulation studies are input voltage V_{in} = 20V, desired output voltage V_0 = 5 V, inductance L = 3mH ,capacitance C = 3 mF ,minimum load resistance min R = 10Ω ,maximum load resistance max R = 15 Ω ,voltage reduction factor k_1 = 0.8,proportional gain k_p = 2 , delta Δ = 0.003 and current sensing gain k = 3 .The switching frequency $f_s$is set to 50 kHz. A simple proportional controller is considered here. The simulations are done using MATLAB/SIMULINK.

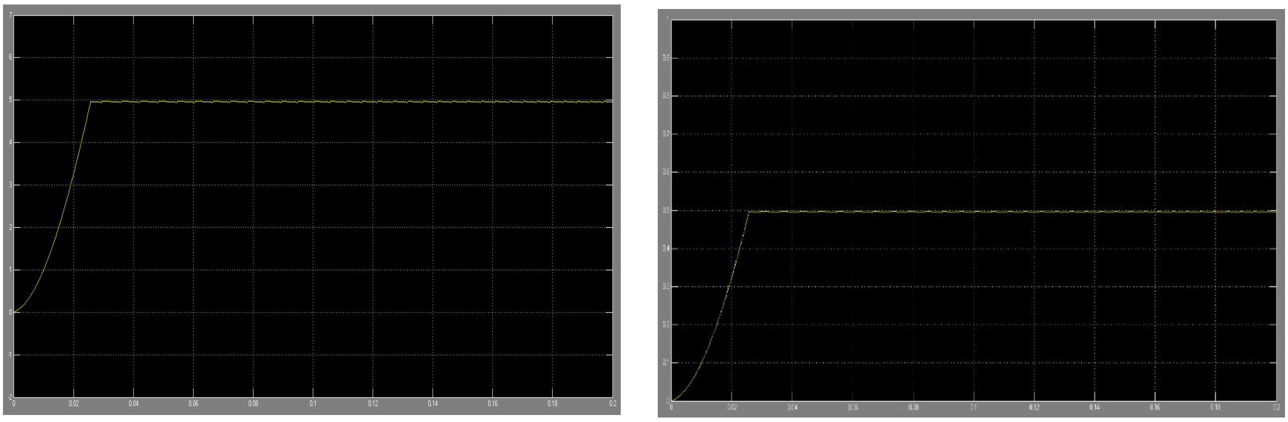

Figure11: Hysteresis Mode Output (a) Current Waveform and (b) Voltage Waveform

VI.CONCLUSION

In the two above section SM control of Buck converter and Hysteresis control of buck converter is represented with the help of SIMULINK tool of MATLAB. The electrical model of buck converter is ideal and same in both the cases. Only the control technique of the converter is changed. From the above experiment we can observe that in both the cases the output is satisfactory and reaches stability quite fast. But the Hysteresis control is much faster compare to the SM mode

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control. In Hysteresis control voltage and current ripple is lessas compared to the SM control. But on the other hand Hysteresis control is

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