FRACTIONAL ORDER SMC FOR DC-DC BUCK CONVERTER

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ABSTRACT
This paper proposed a fractional order sliding mode control for DC-DC buck converter. The traditionally P, PI and PID type linear controllers are used to control the voltages. The DC-DC buck converter is nonlinear and time variant in nature. To control such system variable structure control based sliding mode controller (SMC) is used. The fractional order sliding mode control method not only eliminates chattering problem of integer order SMC, it gives good transient response of the system. The simulation results shows fractional order SMC gives fast response compared to integer order SMC.

KEYWORDS: *DC-DC Converter, Buck Converter, Sliding Mode Control, Integer Order, Fractional Order.*

I. INTRODUCTION

The dc-dc buck converter is the simplest power converter circuit used for many power management and voltage regulator applications. Hence, the analysis and design of the control structure is done for the buck converter circuit. All the terms, designs, figures, equations and discussions in this report are most concerned with dc-dc buck converter circuit.

Many control methods are used for control of switch mode dc-dc converters and the simple and low cost controller structure is always in demand for most industrial and high performance applications. In **[1]**, The conventional PWM controlled power electronics circuits is proposed based on averaging technique but the system operates optimally only for a specific conditions stated in 1998. In **[2]**, presented linear controllers like P, PI, and PID but these controllers do not offer a good large-signal transient (i.e. large-signal operating conditions) for line and load variations in 2012. In **[3]**, the implementation of sliding mode control for dc-dc converters is first presented in 2008. In **[4]**, proposed a hysteresis modulation type of SM controller to achieve a generalized proportional integral (GPI) continuous control of a buck converter in 2003. In **[5]**, a comparative study on buck converter performance when controlled by PI, SM, and fuzzy-logic controllers is presented in 1997. In **[6-7]**, gives an analysis and experimental study of SM controlled buck converter with they also showed the implementation of the SM controller for buck-boost converter through control desk dSPACE in 2003. In **[8]**, gives idea about an adaptive hysteresis type of SM controller for buck converter in 1995. In **[9]**, they again proposed an indirect implementation of SM controllers in buck converter to achieve constant switching frequency operation in 1996. In **[10]**, a robust sliding mode controller is designed and analyzed for the control of dc-dc buck converter in 2011. In [2], they focuses the benefits of the nonlinear aspects by using non linear controller like sliding mode controller and hybrid type of controller for buck converter. This will also focus the benefits of non linear control in 2012.

On the other hand, in recent years it is remarkable the increasing number of studies related with the application of fractional controllers in many areas of science and engineering. This fact is due to a better understanding of the fractional calculus potentialities. In **[11]**, presented many applications of fractional order differentiation in engineering in 1999. In **[12]**, proposed the fractional order controllers which are the generalization of classical integer order controllers would lead to more precise and robust control performances for any system presented in 2003. In **[13]**, a fractional order control strategy has also been successfully applied in the control of a power electronic buck converter proposed in 2003. In **[14]**, the use of sliding mode approaches based on fractional order control is proposed in 2011. In **[15]**, proposes a direct Boolean control (BC) strategy based on fractional order surfaces. The application of BC has advantage of avoiding the use of PWM, in 2012. Therefore, nonlinear controllers come into picture for controlling dc-dc converters like SMC with fractional order. The advantages of these nonlinear controllers are their ability to react suddenly to a transient condition and fractional order for more precise and robust control performances with considering all these literature we have to compare the performance of buck converter with fractional order sliding mode control and integer order sliding mode control.

The paper is organised as follows: The study of DC-DC buck converter and Basic SMC concept, design of Integer order DC-DC buck converter and Fractional order DC-DC Buck converter have been discussed in Sections II, III and IV respectively, followed by Results and Discussions in Section V. Conclusions of the study are made in Section VI.

II. THE DC-DC BUCK CONVERTER

There are six possible basic configurations of DC–DC converters, namely, the buck, boost, buck-boost, ´Cuk, Sepic, and Zeta converters. However, since the buck, boost, and buck-boost converters are the simplest and most commonly used converters for power regulation, and that ´Cuk, Sepic, and Zeta converters can be constructed by combining these converters, we will limit our discussion to the buck converters. The operation of the buck converter is fairly simple, with an inductor and two switches (usually a transistor and a diode) that control the inductor. It alternates between connecting the inductor to source voltage to store energy in the inductor and discharging the inductor into the load. We should see how the switching frequency, the energy storage elements of the converter, the gain parameters, and the type of the controller would affect the control performance of a converter. 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. 1.1. It consists of a controlled switch, an uncontrolled switch (diode), an inductor, a capacitor, and a load resistance R.

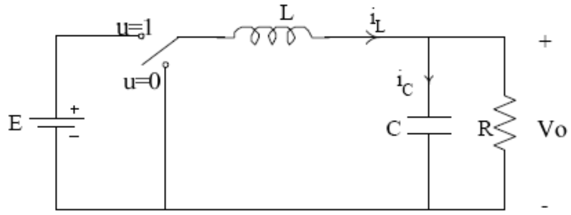

Figure 1. The buck converter

The buck converter is shown; when the switch is on position 1 the circuit is connected to the dc input source resulting an output voltage across the load resistor. If the switch changes its position to position 0, the capacitor voltage will discharge through the load. Controlling switch position the output voltage can be maintained at a desired level lower than the input source voltage. The buck converter shown in Figure 1 can be described by the following set of equations,

$$L\frac{di_L}{dt} = uE - V_O \qquad (1)$$

$$C\frac{dV_0}{dt} = i_{L-}\, i_o \qquad (2)$$

Where i_L is the inductor current, Vo is the output capacitor voltage, E is the constant external input voltage source, L is the inductance, C is the capacitance of the output filter and R is the output load resistance. u is the control input taking discrete values of 0 and 1 which represents the switch position.

u = 0 if switch is at position 0

u = 1 if switch is at position 1

It is assumed here that the inductor current will have a nonzero value due to load variations which is known as the continuous conduction mode (CCM). Rewriting Equations (1) and (2) in the form of state equations by taking the inductor current and output capacitor voltage as the states of the system, the following state equations are obtained.[10].

$$\frac{di_L}{dt} = u\frac{E}{L} - \frac{V_O}{L} \qquad (3)$$

$$\frac{dV_O}{dt} = \frac{i_L}{C} - \frac{V_0}{RC} \qquad (4)$$

where,

$$i_o = \frac{V_o}{R}$$

The buck converter is design by using state Equations (3) and (4).

III. SLIDING MODE CONTROL

Sliding mode controller provides a systematic approach to the problem maintaining stability and consistence performance. In SM controller, the controller employs a sliding surface to decide its input states to the system. For SM controller, the switching states which corresponds the turning on and off of the converter" switch is decided by sliding line. The sliding surface is described as a linear combination of the state variables. Thus the switching function is chosen as u.

The purpose of the switching control law is to drive the nonlinear plant's state trajectory onto a pre-specified (user chosen) surface in the state space and to maintain the plant's state trajectory for the subsequent time. This surface is called the switching surface.

3.1 Design of Integer Order SMC

Using the state equations given in Equations (1) and (2) and letting $x_1 = i_L$ and x_2 = V as the new states of the system, the new state equations become

$$\dot{X}1 = \left(\frac{E}{L}\right)u - \left(\frac{1}{L}\right)x_2 \qquad (5)$$

$$\dot{X}2 = \left(\frac{1}{C}\right)X1 - \left(\frac{1}{RC}\right)x_2 \qquad (6)$$

Generally, the control for dc-dc converters is to regulate the output voltage at desired level. Now the aim here is to obtain a desired constant output voltage Vd. The desired output is then x1 * = Vd/R. The task is to ensure the actual current x1 tracks the desired current. That is, in steady state the output voltage should be the desired voltage Vd. Thus,

$$X_2 = V_d$$

Sliding mode controller uses a sliding surface which ensures output voltage to go to desired value once the system gets onto the sliding surface. The state variables may be used to construct the sliding function [10]. From the general sliding mode control theory, the state variable error, defined by difference to the reference value, forms the sliding function which is given in equation 7 and corresponding control law for Integer order SM controller is designed in equation 9,

$$s = K_P \times e + K_i \times \int e\, dt + K_d \times \frac{de}{dt} \qquad (7)$$

$$c(s) = K_p + \frac{K_i}{S} + K_d S \qquad (8)$$

$$u = S - (K \times sgn(s)) \qquad (9)$$

Where,
K=1
Sgn(s) = 1, s>0
= 0, s=0
=-1, s<0

A) 1 if the corresponding element of s is greater than zero
B) 0 if the corresponding element of s equals zero
C) -1 if the corresponding element of s is less than zero

IV. DESIGN OF FRACTIONAL ORDER SMC

The concept of fractional order controller means controllers can be described by fractional order differential equations. A commonly used definition of the fractional calculus is the Riemann-Liouville definition

$$aD_t^{\alpha} f(t) = \frac{1}{\Gamma(m-\alpha)}\left(\frac{d}{dt}\right)^m \left(\int_a^t \frac{f(t)}{(t-\tau)1-(m-\alpha)} d\tau\right) \qquad (10)$$

for m-1 < α <m , where $\Gamma(.)$ is the well-known Euler's gamma function. An alternative definition, based on the concept of fractional differentiation, is the Grunwald-Letnikov definition given by

$$aD_t^{\alpha} f(t) = \sum_{h\to 0} \frac{1}{\Gamma(\alpha)h^{\alpha}} \sum_{k\to 0}^{\frac{t-\alpha}{h}} \frac{\Gamma(\alpha+k)}{\Gamma(\alpha+1)} f(t-kh) \qquad (11)$$

By introducing notion of the fractional order operator aD_t^{α} the differentiator and integrator can be unified. Another useful tool is the Laplace transform. It is shown in [13] that the Laplace transform of an nth derivative ($n \in R+$) of a signal $x(t)$ relaxed at t =0 is given by

$$L\{D^n x(t)\} = \int_0^{\infty} e^{-st}\, oD_t^n\, x(t) = s^n X(s) - \sum_{k=0}^{m-1} s^k\, oD_t^{n-k-1} x(t) \qquad (12)$$

at t=0

for $m-1 < n < m$, where $X(s) = L[x(t)]$ is the normal Laplace transformation. So, a fractional order differential equation, provided both the signals $u(t)$ and $y(t)$ are relaxed at t =0 , can be expressed in the transfer function form

$$G(s) = \frac{a_1 s^{\alpha_1} + a_2 s^{\alpha_2} + \cdots + a_{m_A} s^{\alpha_{m_A}}}{b_1 s^{\beta_1} + b_2 s^{\beta_2} + \cdots + a_{m_B} s^{\beta_{m_B}}} \qquad (13)$$

where $(a_m, b_m) \in R^2$, $(\alpha_m, \beta_m) \in R_+^2, \forall(m \in N)$

The most common form of a fractional order SM controller involving an integrator of order λ and a differentiator of order μ where λ and μ can be any real numbers. The transfer function of such a controller with control law is given in equation 14 and 15[11],

$$C(S) = K_p + \frac{K_i}{s^{\lambda}} + K_d S^{\mu} \qquad (14)$$

$$u = S - (K \times sgn(s) \qquad (15)$$

Where,

μ= is order of derivative term.

λ = is order of integral term.

When the plant trajectory is above the surface a feedback path has one gain and a different gain if the trajectory drops below the surface. This surface defines the rule for proper switching. This surface is also called a sliding surface (sliding manifold). Ideally, once intercepted, the switched control maintains the plants state trajectory on the surface for all subsequent time and the plants state trajectory slides along this surface. By proper design of the sliding surface, using PID and discontinuous control (Relay) to attains conventional goals of control such as stabilization, tracking, regulation etc.

V. RESULTS AND DISCUSSIONS

The simulation model and results obtained for integer order sliding mode control and fractional order sliding mode control for DC-DC buck converter in terms of output voltage with considering converter parameters.

Table 1. Buck converter parameters.

E(V)	L(mH)	C(μF)	R(Ω)
24	40	4	40

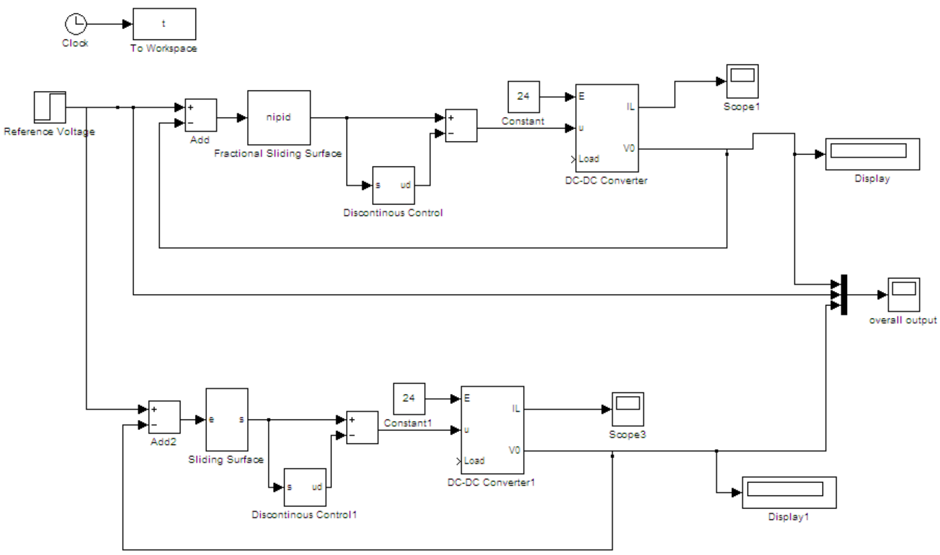

Figure 2. Simulation model of Fractional SMC DC-DC buck Converter.

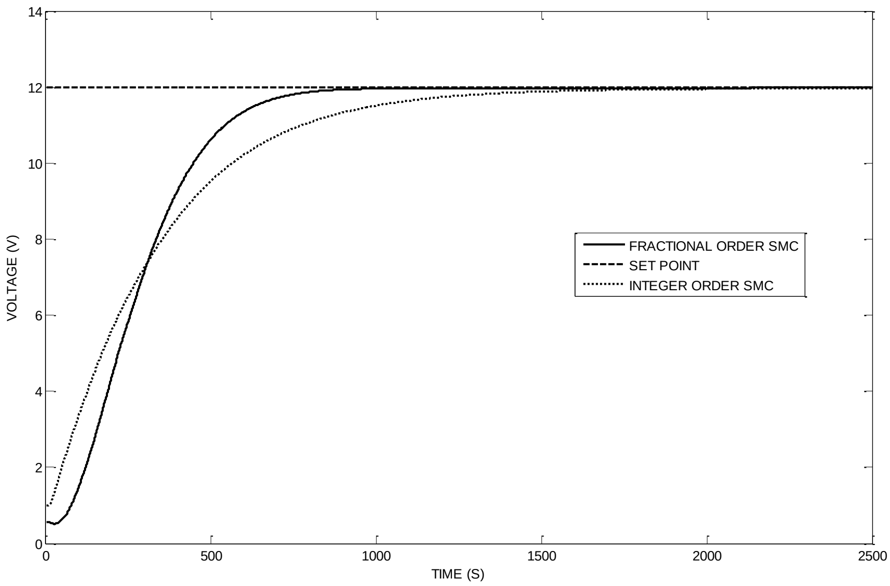

Figure 3. Amplitude response of fractional SMC and Integer order SMC for DC-DC Buck converter

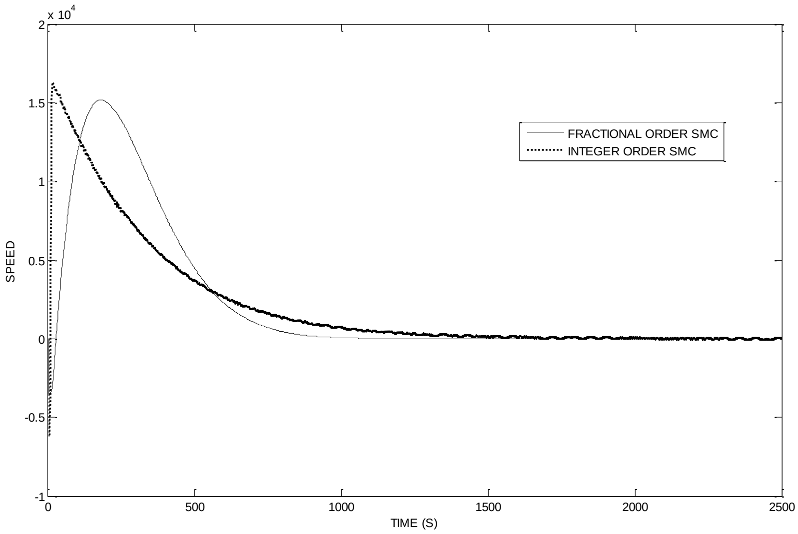

Figure 4. Speed response of fractional SMC and Integer order SMC for DC-DC Buck converter

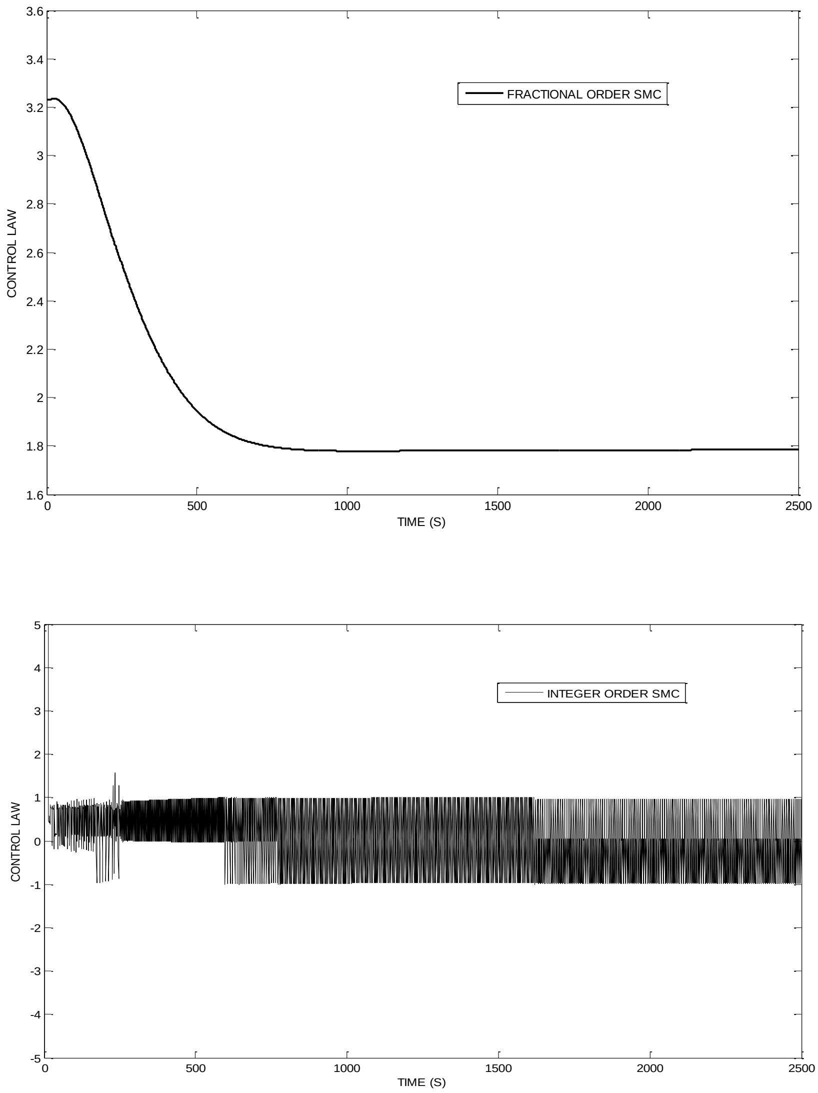

Figure 5. Control law (u) of fractional SMC and Integer order SMC for DC-DC Buck converter.

VI. CONCLUSION

A fractional order SMC and Integer order SMC controlled buck converter is designed and verified by simulation results in the MATLAB and as per simulation results Fractional order SMC has fast response with less settling time and chattering free response.

ACKNOWLEDGEMENTS

First of all, I would like to thanks my guide and P.G. Coordinator Prof. R. M. Nagarale, Department of Instrumentation, College Of Engineering Ambajogai, Maharashtra for guidance during my work and for reading and comments on the manuscript of this paper. Dean (P.G.) Dr. Veeresh G.K**.** for his valuable direction and guidance, Finally, I would like to thank my family for supporting me.

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