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Sliding Mode Control of Buck Converter

Nagulapati Kiran
Anil Neerukonda Institute of Technology and Management
Sangivalasa, Visakhapatnam, Andhra Pradesh, India
email nkiran.ped@gmail.com

Abstract

DC-DC converters are used to convert DC voltage from one level to other. These converters are drastically used in industry as well as in research. One of the main limitations of these converters is unregulated supply of voltage and current. To overcome these problems there are various control techniques. This paper presents two such methods. This paper compares dynamic performance of buck Converter using PID controller and Sliding mode controller. Simulation of PI and Sliding mode control of Buck Converter is carried out in MATLAB SIMULINK.

Keywords: Buck Converter, PID Controller, Sliding Mode Controller

1. Introduction

DC-DC Converters play important role in field of power electronics. The main problem with operation of DC-DC converter is unregulated power supply, which leads to improper function of DC–DC converters as they contain non-linear components (capacitors, inductors, and resistors), the value of which changes non-linearly if the converter is disturbed or may change within a time.

Many control techniques are used to control the DC-DC converters and solve the problem mentioned above. Each control method has its own pros and cons due to which that particular control method appears most suitable method to control under specific conditions compared to other control methods. It is always demanded to obtain a control method that has the best performance under any conditions. Here two such methods are used.

Sliding Mode Control offers an alternative way to implement a control action which exploits the inherent variable structure nature of DC-DC converters. In practice the converter switches are driven as the function of the instantaneous values of the state variables in a way that forces the system trajectory to stay on a suitable selected surface in the state space called the sliding surface. The most remarkable feature of SMC is improving the transient response of the system. Here dynamic performance of Buck Converter using PI controller and Sliding mode controller is compared.

2. Buck Converter

Figure 1 shows the basic circuit diagram of buck converter.

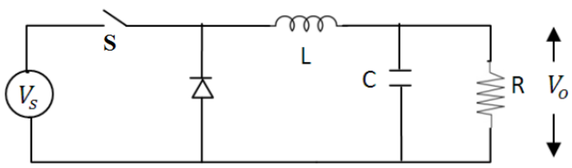

Fig. 1 Buck Converter

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Basic Operation of buck converter is depicted in its equivalent circuit during ON and OFF State.

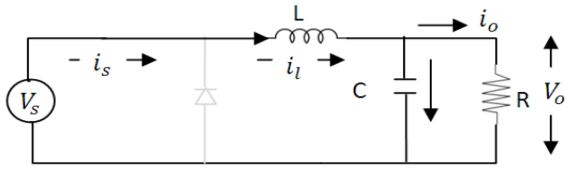

Figure 2. Equivalent circuit during turn ON

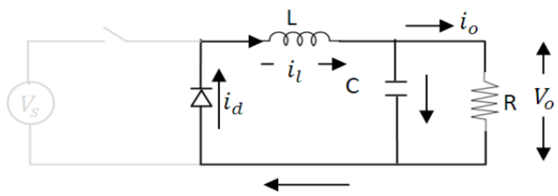

Figure 3. Equivalent circuit during turn OFF

For the buck converter:

$$(V_s - V_o)DT = -V_o(1-D)T$$

Where
Vs: Source Voltage
Vo: Load Voltage
T: Time Period
D: Duty Cycle

Hence the dc voltage transfer function can be defined as the ratio of the output voltage to the input voltage

$$D = \frac{V_o}{V_s}$$

3. PID Controller

PID controllers have been at the heart of control engineering practice for seven decades. A PID controller consists of the sum of three control actions, namely, a control action proportional to the control error, a control action proportional to the integral of the control error, and a control action proportional to the first derivative of the control error. By "tuning" the three constants in the PID controller algorithm the PID can provide control action designed for specific process requirements. The response of the controller can be described in terms of the responsiveness of the controller to an error, the degree to which the controller overshoots the set point and the degree of system oscillation.

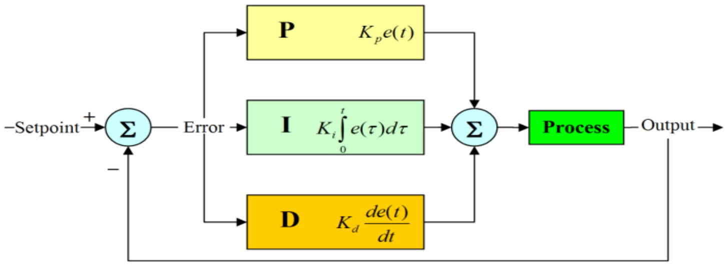

Figure 4. Block Diagram of PID Controller

The output of PID controller *u(t),* is equal to the sum of three signals: The signal obtained by multiplying the error signal by a constant proportional gain *KP*, plus the signal obtained by differentiating and multiplying the error signal by constant derivative gain *KD* and the signal obtained by integrating and multiplying the error signal by constant internal gain *KI*, . The output of PID controller is given by u(t), taking Laplace transform, and solving for transfer function , gives *ideal* PID transfer function given by U(s).

$$U(t) = K_P e(t) + K_D \frac{de(t)}{dt} + K_I \int e(t)dt$$

$$U(s) = E(s)\left[K_P + \frac{K_I}{s} + K_D s\right]$$

Advantages of PID controllers:

i. It is easy and simple to implement.
ii. Easy to understand.
iii. Reliable for linear systems.

Disadvantages of PID controllers:

iv. It does not reliable and satisfactorily in case of non-linear systems.
v. It shows longer rise time when overshoot in output voltage decreases.
vi. It suffers from dynamic response and produces overshoot affecting the output voltage regulation of converter.
vii. The dynamic performance is limited because a PI voltage control cannot react to disturbance until the effects have appeared in the converter output.

4. Sliding Mode Control

The Sliding Mode (SM) controller was introduced for controlling variable structure systems (VSS) [1]–[5].Sliding Mode Controller, a widely used Non-Linear Controller remains vibrant in overcoming the issues of the linear controllers. Sliding mode controller is a variable structure system which operates based on the switching strategy apart from the feedback controllers [6]. They are less sensitive to disturbance and parameter variations due to its binary nature adapting to the modern power switches [7]. This seems more naturally so since the design of conventional pulse width modulation (PWM) controllers in power electronics is small signal based and they often perform unsatisfactorily under large-signal operating condition [8]–[10]. Sliding mode controllers are well known for their robustness and stability. Use of SM controllers can maintain a good regulation for a wider operating range. This has aroused a lot of interests in the use of SM controllers for DC–DC converters [11]–[52]. Most of the previously proposed SM controllers for switching power converters are hysteresis modulation (HM) (or delta-modulation) based [53]–[57]. Naturally, they inherit the typical disadvantages of having variable switching-frequency operation and being highly control sensitive to noise. Possible solutions are to incorporate constant timer circuits into the hysteretic SM controller to ensure constant switching frequency operation [58], or to use adaptive hysteresis band that varies with parameter changes to control and fixate the switching frequency [59]. However, these solutions require additional components and are unattractive for low cost voltage conversion applications.

An alternative solution to this is to change the modulation method of the SM controllers from HM to pulse-width modulation (PWM). This concept was first published in [60]. The idea is based on the assumption that at a high switching frequency, the control action of a sliding mode controller is equivalent to the duty cycle control action of a PWM controller. Hence, the migration of a sliding mode controller from being HM based to PWM based is made possible.

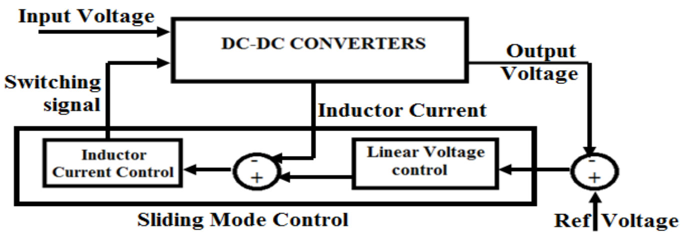

Figure 5. Block Diagram of Sliding Mode Control

The basic principle behind the SMC controlled system is to drive the converter to the steady surface called the sliding surface and maintain the stability of the system thus giving the regulated output voltage for any variations in the load or switching frequency.

Sliding Mode control principle is graphically represented in figure-4.

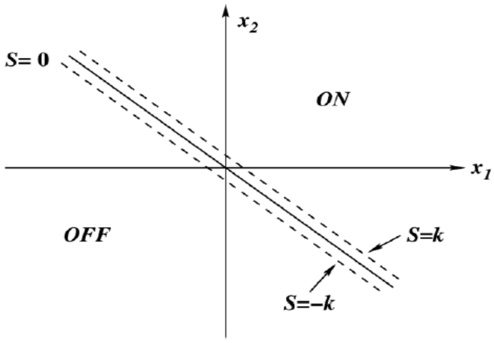

Figure 6. Sliding mode on x_1-x_2 phase plane

5. Simulation Results

Buck Converter using PI Controller and Sliding Mode Controller is simulated using MATLAB/SIMULINK. Dynamic performance of Buck Converter using PI Controller and Sliding mode Controller is compared.

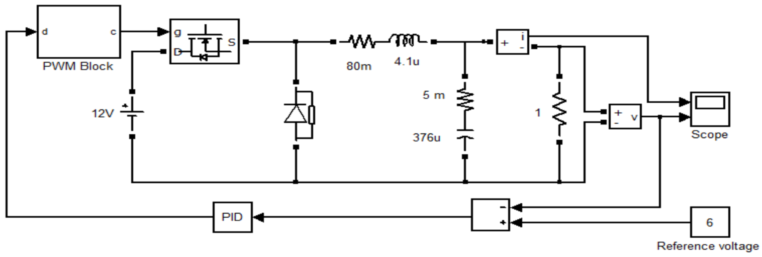

Figure 7. Simulink Model of Buck Converter using PI Controller

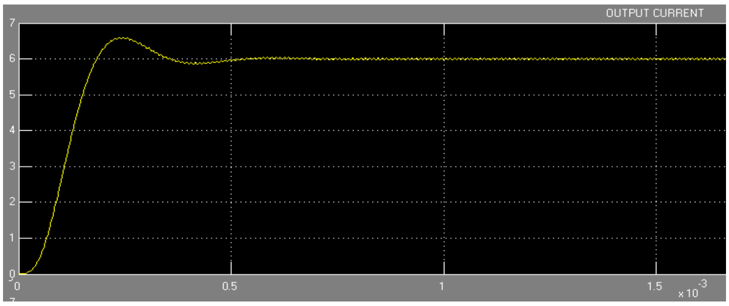

Figure 8. Output Current waveform of Buck Waveform using PI Controller

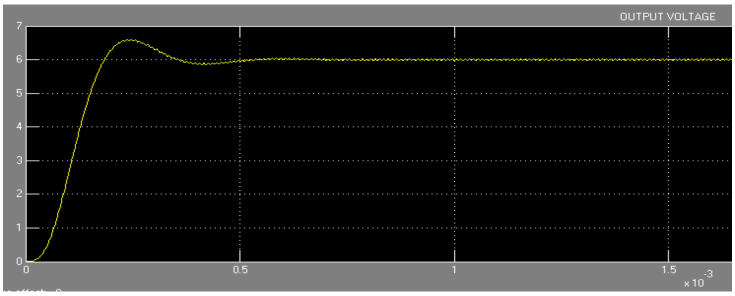

Figure 9. Output Voltage waveform of Buck Waveform using PI Controller

Figure 7 shows Simulink model of Buck Converter using PI Controller and Figures 8 and 9 shows the obtained waveforms for output current and output voltage respectively.

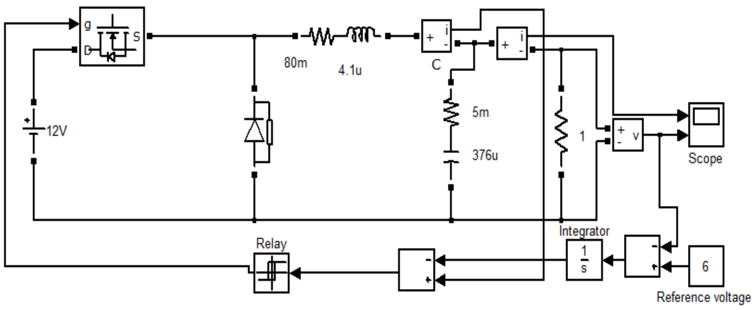

Figure 10. Simulink Model of Buck Converter using Sliding Mode Controller

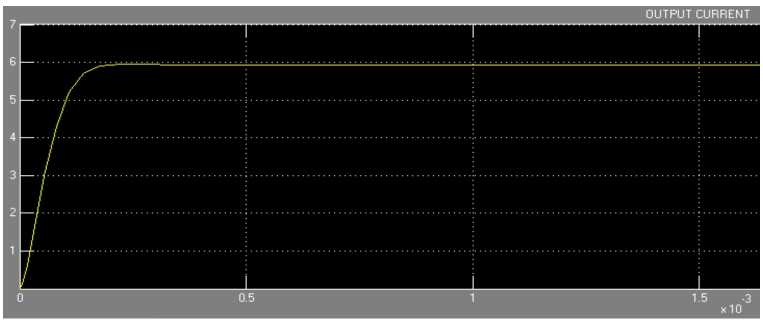

Figure 11. Output Current waveform of Buck Waveform using Sliding Mode Controller

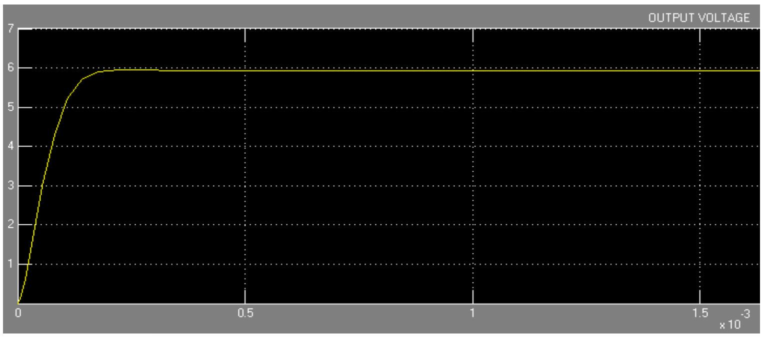

Figure 12. Output Voltage waveform of Buck Waveform using Sliding Mode Controller

Figure 10 shows Simulink model of Buck Converter using Sliding Mode Controller and Figures 11 and 12 shows the obtained waveforms for output current and output voltage respectively

6. Conclusion

In steady state region both the control methods give the same performance. In Transient region voltage and current overshoot are very low in SMC. In line variation SMC is insensitive to the input variations. For wide range of load variation SMC is more stable when compare to PI controller. SMC provides several advantages over other control methods: Robustness, stability for even very large line and load variations, good dynamic response and simple implementation. The advantage of using sliding mode controller is highlighted. It is shown that the sliding mode controllers generate more consistent transient responses for a wide operating range as compared to conventional PWM controllers.

Buck Configuration	%Mp	Settling Time
Closed Loop(PI)	60	0.55 msec
Closed Loop(Sliding Mode)	0	0.19 m sec

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