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INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & RESEARCH TECHNOLOGY

# A Sliding Mode Controller for DC/DC Converters.

**Mohammad Sarvi[2], Iman Soltani[*1], NafisehNamazypour [3],Najmeh Rabbani[3]**

[*1,2,3]Faculty of Technical & Engineering, Imam Khomeini International University,Qazvin, Iran

i_soltani@ikiu.ac.ir

## Abstract

Modern electronic systems require high-quality, small, lightweight, reliable, and efficient power supplies. So the DC/DC converters are widely used in many industrial and electrical systems. As DC/DC converters are nonlinear and time-variant systems, the application of linear control techniques for the control of these converters are not suitable. In this paper, a new sliding mode controller is proposed as the indirect control method and compared to a simple direct control method in order to control a buck converter. The simulation results are presented for a step change in reference voltage and input voltage as well as step load variations. The simulations results of proposed method are compared with the conventional PID controller. The results show the good performance of the proposed sliding mode controller. The proposed method can be used for the other DC/DC converter.

**Keywords**: DC/DC Converter; Sliding Mode Control; PID Controller..

## Introduction

Modern electronic systems require high-quality, small, lightweight, reliable, and efficient power supplies. So the DC/DC converters are widely used in many industrial and electrical systems. The most familiar are switching power supplies, DC drives, photovoltaic systems and Fuel cell. Design of controller for these converters is a major concern in power converters design [1-3].

Different control techniques are applied to regulate the DC-DC Converters, especially buck converters, in order to obtain a robust output voltage [4-5].

As DC/DC converters are nonlinear and time-variant systems, the application of linear control techniques for the control of these converters are not suitable. In order to design of a linear control system using classical linear control techniques, the small signal model is derived by the linearization around a precise operating point from the state space average model [4]. The controllers based on these techniques are simple to implement however, it is difficult to account the variation of system parameters, because of the dependence of small signal model parameters on the converter operating point [6].

Sliding mode control is a well-known discontinuous feedback control technique which has been exhaustively explored in many books and journal articles. The technique is naturally suited for the regulation of switched controlled systems, such as power electronics devices, in general, and DC/DC power converters, in particular [2]. Many sliding mode controllers have been proposed and used for DC/DC converters [6-9]. These controllers are direct [6] or indirect control method [6-7]. The direct method is proposed in [6]. In [7] the output capacitor current of DC/DC converter is used to control the output voltage. The difference of the DC/DC output voltage and the reference voltage enter the proportional-Integrator (PI) type controller and then the output capacitor current of DC/DC converter is decreased from the output of controller [8]. The output voltage and inductor current are used to control of DC/DC converter in [9]. These references [6-9] have not completely investigated the load and line as well as reference regulations.

In this paper, a new sliding mode controller is introduced for DC/DC buck converter as the indirect control method. The proposed controller is compared with a simple direct control method as well as the conventional PID controller. The simulation results are presented for a step change in reference voltage and input voltage as well as for a step load variation. The main contributions of this paper are presentation of a new indirect sliding mode controller with good accuracy and performance against to load and line as well as reference regulations.

## Dc/Dc Converters

The dc-dc converters can be divided into two main types: 1- hard-switching pulse width modulated

(PWM) converters, and 2- resonant and soft-switching converters [1].
Advantages of PWM converters include low component count, high efficiency, constant frequency operation, relatively simple control and commercial availability of integrated circuit controllers, and ability to achieve high conversion ratios for both step-down and step-up applications.
The circuit diagram of the DC/DC buck converter is shown in Fig. 1. In this figure, the circuit schematic is depicted with the transistor-diode symbols.

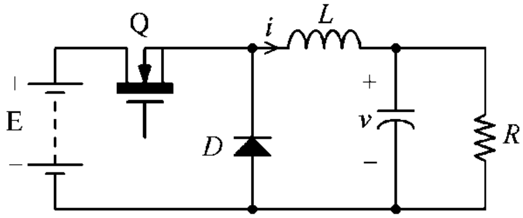


**Figure 1. Semiconductor realization of the DC/DC buck converter.**

By sensing of the DC output and controlling of the switch duty cycle in a negative-feedback loop, the DC output voltage could be regulated against input line and output load changes [3].

## The State-Space Model of Buck Converter

To obtain the differential equations describing the buck converter, the ideal topology is used as shown in Fig. 2. The differential equations of describing the DC/DC buck converter dynamics are obtained through the direct application of Kirchoff's current and Kirchoff's voltage laws for each one of the possible circuit topologies arising from the assumed particular switch position function value. Thus, when the switch position function exhibits the value u = 1, we obtain the topology corresponding to the non-conducting mode for the diode is obtained. Alternatively, when the switch position exhibits the value u = 0, the second possible circuit topology corresponding to the conducting mode for the diode is obtained.

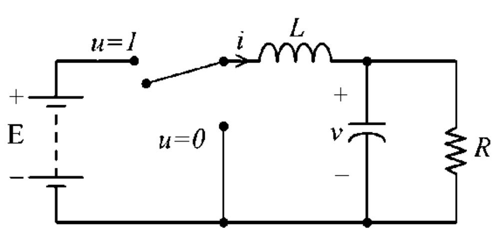


**Figure 2.Ideal switch representation of the DC/DC buck converter.**

The system dynamics are described by the following differential equations:

*For u=1:*

$$L\frac{di}{dt} = -v + E \quad (1)$$

$$C\frac{dv}{dt} = i - \frac{v}{R} \quad (2)$$

*For u=0:*

$$L\frac{di}{dt} = -v \quad (3)$$

$$C\frac{dv}{dt} = i - \frac{v}{R} \quad (4)$$

By comparing the obtained particular dynamic systems descriptions, the following unified dynamic system model can be obtained as:

$$L\frac{di}{dt} = -v + uE \quad (5)$$

$$C\frac{dv}{dt} = i - \frac{v}{R} \quad (6)$$

## Sliding Mode Controller Design

In these section two methods is presented in order to control the output voltage of a DC/DC Buck converter. These methods are direct and indirect sliding mode control.
Direct control based on the output voltage feedback, which the output voltage ($V_c$) is directly compared to the reference voltage ($V_r$).
Sliding surface:

S=$V_c - V_r$ (7)

Indirect control based on the inductor current control satisfying desired output voltage ($V_r$). In this method because of the possible load variation, at first the output impedance ($R_o$) is determined by dividing the output voltage by the output current and then the desired load current ($I_{Ld}$) is calculated by dividing the reference voltage by the output impedance ($R_o$). By adding a coefficient of capacitor current (k) to $I_{Ld}$, the desired inductor current ($I_{lr}$) is determined. So the sliding surface is defined by comparison between actual indirect current ($I_l$) and $I_{lr}$as the following:

Sliding surface:

S=$I_l - I_{lr}$ (8)

## Simulation of DC/DC Converter With Sliding Mode Control

In order to investigate the proposed controller performance and accuracy, MATLAB/SIMULINK and its facilities is used.
Simulations are performed on a typical buck converter with the following parameter values:

E= 10V, L=1mH, C=2200µF, R=25 Ω.

Figs. 3-4 show the SIMULINK block diagram of direct and indirect sliding mode control of the proposed buck converter, respectively.

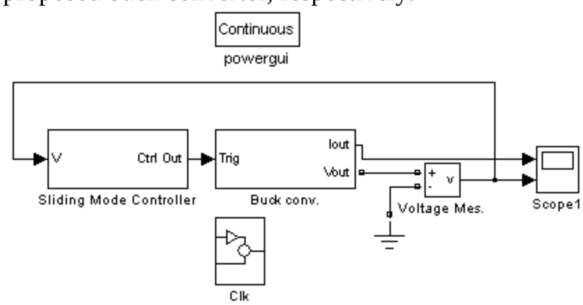


**Figure 3. SIMULINK block diagram of direct sliding mode control**

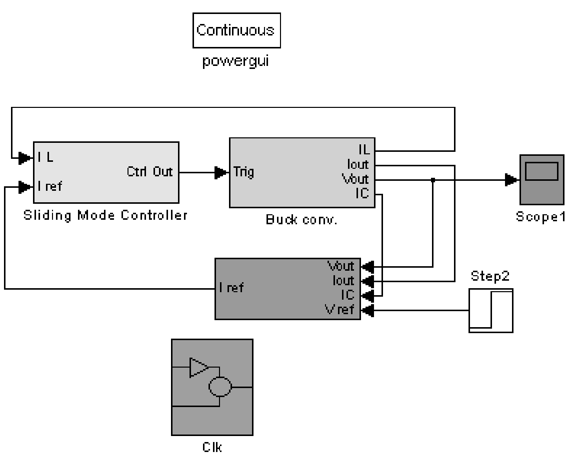


**Figure 4. SIMULINK block diagram of indirect sliding mode control**

## Results and Discussions

For the evaluation and validation of the proposed controller accuracy and performance, simulation results are presented in two subsections:
A. Analysis of the proposed sliding mode controller and determine the best sliding mode controller response.
B. Comparison of the proposed sliding mode controller with the conventional PID controller.

### *A. Simulation Results of the Proposed Sliding Mode Controller*

Figs. 5-6 show the output voltage during a change in reference voltage from V=5 to V=7 at t=0.05 sec in direct and indirect control method, respectively. Fig. 6 is plotted respect to different values of k, where k is capacitor current coefficient. Fig. 7 indicates a zoom window about the output voltage variation.

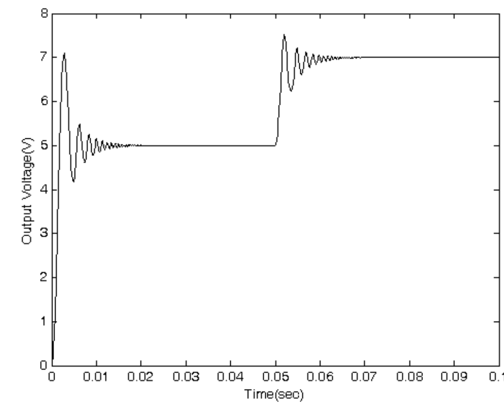


**Figure 5. The DC/DC output voltage for a step change in reference voltage in direct control method.**

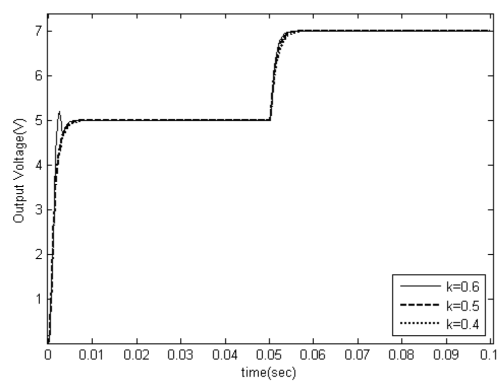


**Figure 6. The DC/DC output voltage for a step change in reference voltage respect to different values of k in indirect control method.**

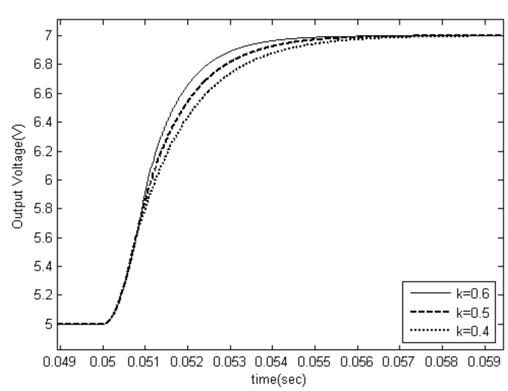


**Figure 7. The DC/DC output voltage variation about reference variation time**

 ISSN: 2277-9655

In order to evaluate the robustness of sliding mode control, the load is changed from 1 Ω to 0.5 Ω at t=0.05 sec. The results are indicated in Figs. 8-9 for direct and indirect control method, respectively. Fig. 9 is plotted respect to different values of k. Fig. 10 indicate a zoom window about the output voltage variation.

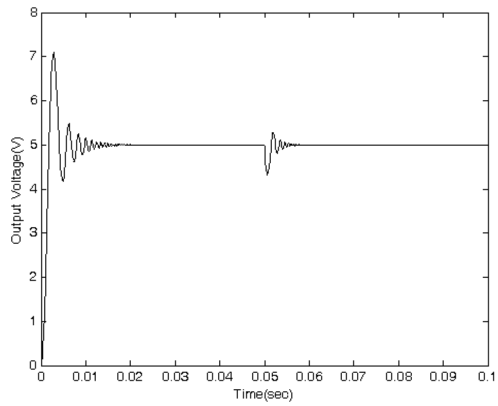


**Figure 8. The DC/DC output Voltage for step Load variation in direct control method.**

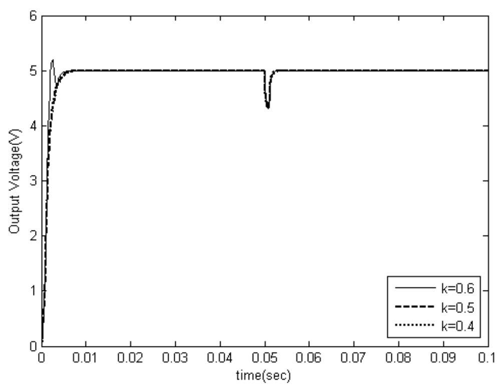


**Figure 9. The DC/DC output Voltage for step Load variation respect to different values of k in indirect control method.**

Figs. 11-12 show the input voltage regulation, which the line voltage changes from E=10 to E=20 in t=0.05 sec. Fig. 12 is plotted respect to different values of k. Fig. 13 indicates a zoom window about the output voltage variation.

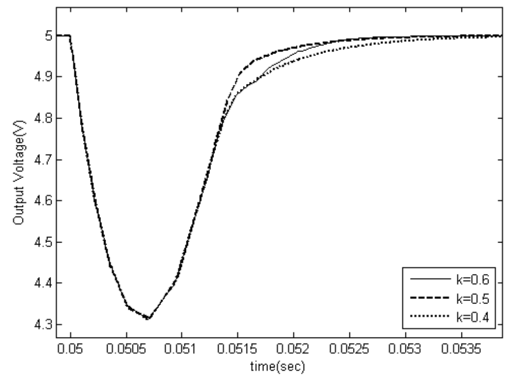


**Figure 10. The DC/DC output voltage variation about step Load variation time.**

These results (Figs. 5-11) show that the direct control method has not a good performance. In the other hand indirect control performance is good but it is related on the K value. By the selection of suitable value of K, the indirect method performance is very good. The results show that the best performance is obtained for k=0.5.

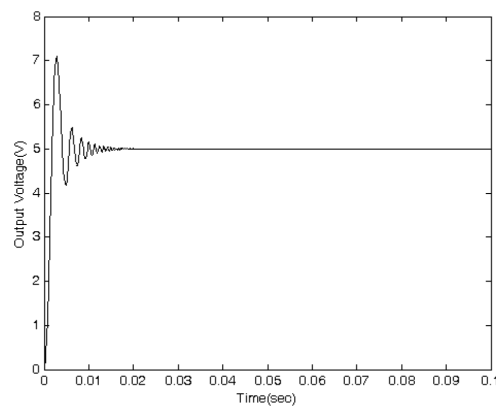


**Figure 11. The DC/DC output voltage variation for a step change in Line voltage.**

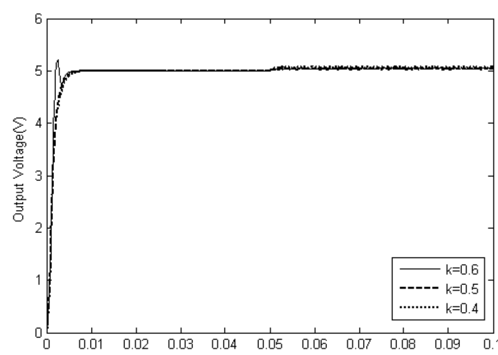


**Figure 12. The DC/DC output voltage variation for a**

**step change in Line voltage respect to different values of k in indirect control method.**

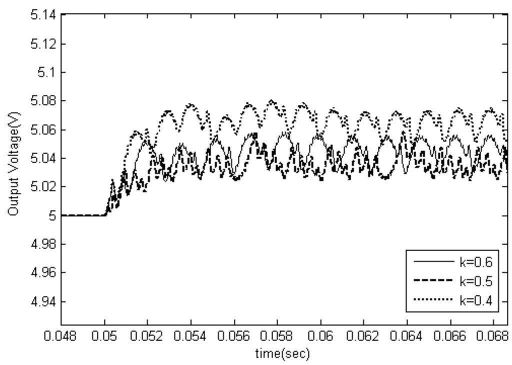


**Figure 13. The DC/DC output voltage variation about line variation time.**

### B. *Comparison of the Proposed Sliding mode and PID Controller*

For the validation of the proposed sliding mode controller, the best simulated result compares with conventional PID controller.

The best result is one the wave forms of indirect sliding mode control with capacitor current coefficient (k) equal to 0.5.

The non-interacting structure of PID controller is used. This describes by the following equation:

$$G_{PID} = k_p\left(1+\frac{1}{sT_i}+sT_d\right)$$

(9)

Where $k_p$ is proportional gain and $T_i, T_d$ are integrator and derivative time constants, respectively.

The simulation results of comparison between the proposed sliding mode controller and PID controller are indicated in Figs. 14-19.

Figs. 14-15 show the output voltage of buck converter with sliding mode and PID controller with a step change in reference voltage from 5V to 7V at t=0.05 sec. Fig. 15 indicates a zoom window about the output voltage variation.

Finally the load resistance is changed from 1 Ω to 0.5 Ω at t=0.05 sec. The output voltage variation is indicated in Fig.16. Fig. 17 indicates a zoom window about the output voltage variation.

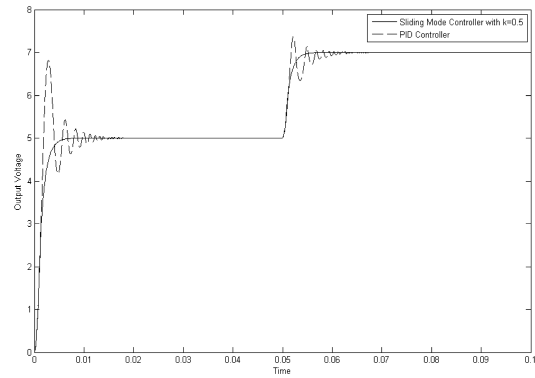


**Figure 14. The DC/DC output voltage variation with a step change in reference voltage.**

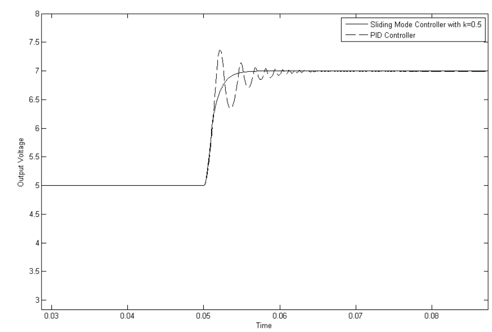


**Figure 15. The DC/DC output voltage variation about reference voltage variation time.**

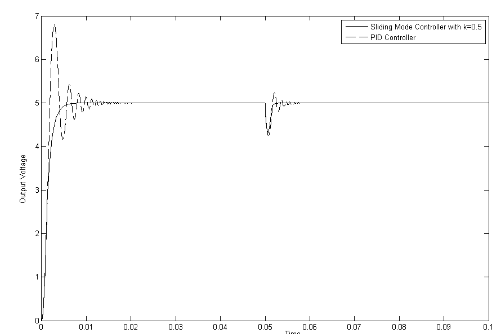


**Figure 16. The DC/DC output voltage variation with a step change in load**

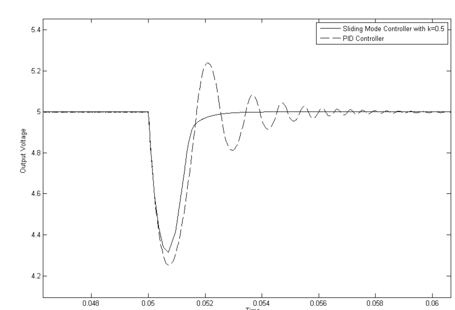


**Figure 17. The DC/DC output voltage variation about load variation time.**

## Conclusions

In this paper a new indirect sliding mode controller for DC/DC converters is presented. The results of analysis and simulation of proposed method is compared by direct sliding mode as well as conventional PID controller. The main conclusions are:

-The proposed indirect sliding mode controller has more good performance as compared with direct sliding mode as well as PID control.

-The performance of the proposed sliding mode controller is related on suitable selection of its parameter (k).

-The proposed controller is robust to load and line as well as reference variations.

-The propose controller can be used to every DC/DC converters.

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