International Journal of Mechatronics, Electrical and Computer Technology

Vol. 4(13), Oct, 2014, pp. 1436-1451, **ISSN**: 2305-0543
Available online at: http://www.aeuso.org

Improve the Robustness and Performance of a Buck-Boost Type DC-DC Converter by Using Fuzzy Sliding Mode Controller

Majid Delshad*

Department of electrical engineering, Khorasgan Branch, Islamic Azad University, Isfahan, Iran

*Corresponding Author's E-mail: *delshad@khuisf.ac.ir*

Abstract

In this paper a Fuzzy sliding mode control scheme with the sliding surface as input is proposed in order to improve the robustness and performance of a buck-boost DC-DC converter. The simulation results show that the proposed controller overcomes the chattering problem and it is proved to be robust for the cases of the load and input voltage variations. However, the sliding mode controller here is of the PI loop does not suit all operating conditions. More accuracy can be achieved by modifying fuzzy rule base and membership functions. The introduced control system is simulated by MATLAB/SIMULINK.

Keywords: Switching mode power supplies, DC-DC converter, sliding mode control, robustness and fuzzy control.

1. Introduction

Switched mode DC-DC power converters are vastly used in electric power supply systems, such as cars, ships, aircraft and computers. They exhibit complex dynamic behavior because of their nonlinear nature, resulting from switching operation [11]-[19]. Traditionally, controllers for DC-DC converters are designed using classical control methods such as frequency response and root locus design methods which are based on small signal models of the DC-DC converters. The small signal models are only valid around an operating point and change due to changes in operating point for the reason that they are linear approximations. For a sepic converter's small signal model, the poles and a right-half plane zero, as well as the magnitude of the frequency response, are all dependent on the duty cycle D and the load resistance R. The controllers based on classical control methods are not able to respond to operating point variations and load disturbances adequately since they are designed using a fixed small signal model at one nominal operating point. Many nonlinear controllers are applied to dc-dc converters such as sliding mode controllers and fuzzy controllers to solve this problem. The system with sliding mode controller can be entirely independent of effects due to modeling uncertainties, parameter fluctuations and disturbances [9]. But, there are several disadvantages for sliding mode control. First, an assumption for sliding mode control is that the control can be switched from one value to another infinitely fast. In practice, it is impossible due to time delay for control computation and physical limitations of the switching devices. As a result, the duty cycle oscillates in steady state, which induces oscillation in the output voltage.

The second disadvantage is that the sliding mode controller will generate an ON-OFF control for the converter, and the switching frequency is not constant. The third disadvantage is when the sliding mode controller is implemented in discrete-time, the control action (in this case, ON or OFF of the switch) can only be activated at each sampling instant and the control effort is constant over each sampling period. Thus, the system is able to approach the sliding mode but not able to stay on it. These practical issues prevent sliding mode control from being extensively applied to DC-DC converters. Fuzzy controllers have been applied to control DC-DC converters [5]-[8]. In these controllers there is no need for an exact mathematical model in the system, and they are well suited to nonlinear time-variant systems. However, fuzzy controllers are usually designed based on expert knowledge of the converters, and extensive tuning is required based on trial and error method. The tuning can be quite time consuming. In addition, the response is not easy to predict.

In this paper, a single variable fuzzy sliding mode control technique is proposed for a DC/DC sepic converter. The proposed system's robustness is tested against input voltage and load variations and comparisons with typical sliding mode controller are introduced in [4].

2. Circuit Operation

Single-ended primary-inductor converter (SEPIC) is a type of DC-DC converter that allows output voltage to be greater than, less than, or equal to that at its input.

A SEPIC converter is similar to a traditional buck-boost converter, but has advantages including having non-inverted output, the isolation between its input and output which provided by a capacitor in series.

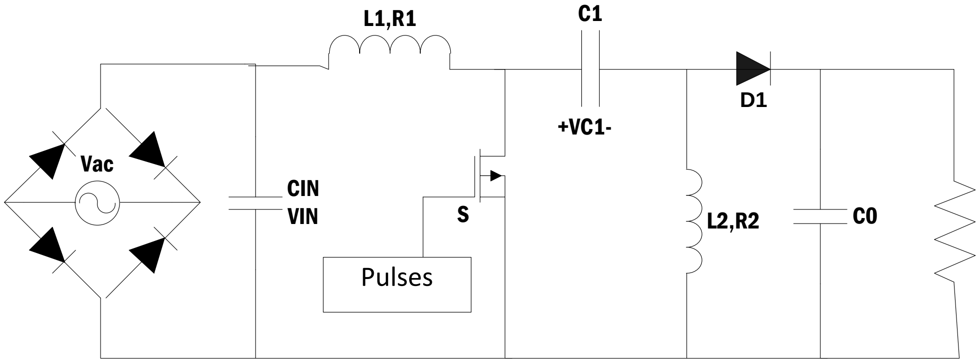

Figure 1: Schematic of buck-boost type (SEPIC) converter.

The SEPIC is shown in Fig 1. This converter operates in continuous-conduction mode (CCM). In steady-state analysis operation, the average voltage across capacitor C_1 (V_{C1}) is equal to the input voltage (Vin).

By writing KVL in input loop:

$$V_{IN} = VL1 + V_{C1} + V_{L2} \quad (1)$$

Because the average voltage of V_{C1} is equal to V_{IN}, V_{L1} is equal to $-V_{L2}$. Also, since the voltages are the same in magnitude, the ripple currents from the two inductors will be equal in magnitude. By writing KCL as follows:

$$I_{D1} = I_{L1} - I_{L2} \qquad (2)$$

Mode1:When switch S1 is turned on this mode begins, current I_{L1} increases and the current I_{L2} decreases linearly. Since S_1 on, and the instantaneous voltage V_{C1} is equal to V_{IN}, also the voltage V_{L2} is approximately $-V_{IN}$.

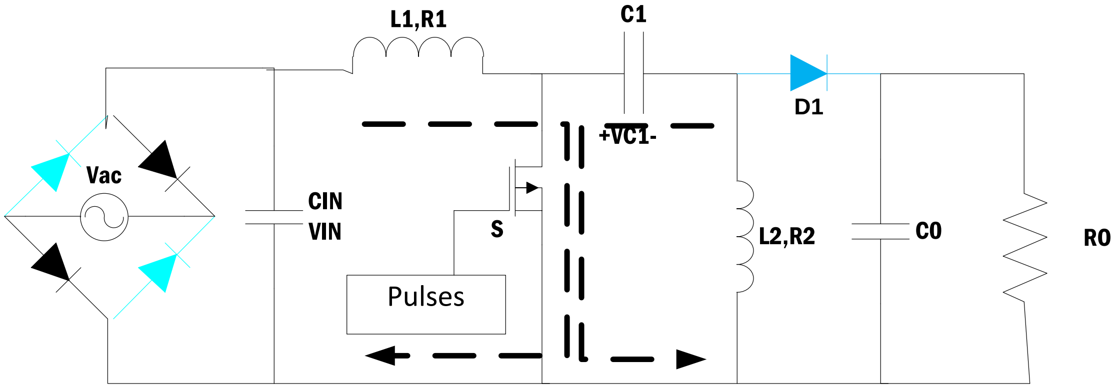

Figure 2: equivalent circuit in Mode 1

Mode2: mode 2 begins when switch S_1 is turned off and the current I_{C1} becomes the same as the current I_{L1}. The current I_{L2} will continue in the negative direction. When S_1 is off, power is delivered to the load from both L_2 and L_1. C_1, however is being charged by L_1 during this mode.

Vol. 4(13), Oct, 2014, pp. 1436-1451, **ISSN**: 2305-0543

Available online at: http://www.aeuso.org

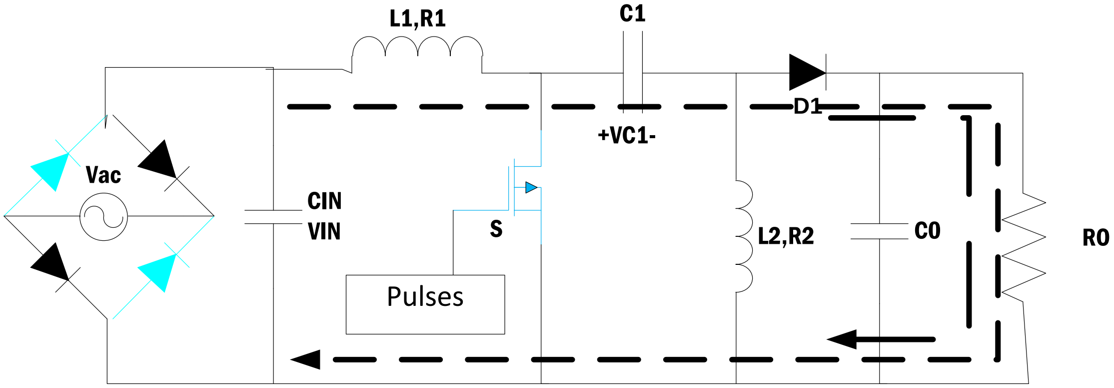

Figure 3: equivalent circuit in Mode2

Please do not write or print outside of the column parameters. Margins are 3.5 cm on the sides, 2.5 on the top, and 4.5 on the bottom, Gutter is 0 (zero) cm and multiple pages is normal.

3. Modeling Converter

Most modeling concepts in power electronics intended to express the nonlinear time varying phenomena in a mathematical form in order to permit the incorporation of a suitable controller[1]-[3]. The state space averaging method which serves to bring out explicitly the static and dynamic characteristics of the system is used to build the control algorithm. The state matrix governing the operation of the SEPIC, with power switch on is:

$$\begin{bmatrix} di1/dt \\ di2/dt \\ dvc1/dt \\ dvo/dt \end{bmatrix} = \begin{bmatrix} -R1/L1 & 0 & 0 & 0 \\ 0 & -R2/L2 & -1/L2 & 0 \\ 0 & 1/C1 & 0 & 0 \\ 0 & 0 & 0 & -1/ROCO \end{bmatrix} \begin{bmatrix} i1 \\ i2 \\ vc1 \\ vo \end{bmatrix} + \begin{bmatrix} -1/L1 \\ 0 \\ 0 \\ 0 \end{bmatrix} vin \qquad (3)$$

With power switch off:

$$\begin{bmatrix} di1/dt \\ di2/dt \\ dvc1/dt \\ dvo/dt \end{bmatrix} = \begin{bmatrix} -R1/L1 & 0 & -1/L1 & -1/L1 \\ 0 & -R2/L2 & 0 & 1/L2 \\ 1/C1 & 0 & 0 & 0 \\ 1/C0 & -1/CO & 0 & -1/ROCO \end{bmatrix} \begin{bmatrix} i1 \\ i2 \\ vc1 \\ vo \end{bmatrix} + \begin{bmatrix} -1/L1 \\ 0 \\ 0 \\ 0 \end{bmatrix} vin \qquad (4)$$

Using state space averaging technique the final state matrix reduces to theform:

$$A = DA1 + \acute{D}A2 = DA1 + (1 - D)A2 \qquad (5)$$

$$B = DB1 + \acute{D}B2 = DB1 + (1 - D)B2 \qquad (6)$$

$$\begin{bmatrix} di1/dt \\ di2/dt \\ dvc1/dt \\ dvo/dt \end{bmatrix} = \begin{bmatrix} -R1/L1 & 0 & -(1-D)/L1 & -(1-D)/L1 \\ 0 & -R2/L2 & -D/L2 & (1-D)/L2 \\ (1-D)/C1 & D/C1 & 0 & 0 \\ (1-D)/C0 & -(1-D)/CO & 0 & -1/ROCO \end{bmatrix} \begin{bmatrix} i1 \\ i2 \\ vc1 \\ vo \end{bmatrix} +$$

$$\begin{bmatrix} -1/L1 \\ 0 \\ 0 \\ 0 \end{bmatrix} vin \qquad (7)$$

4. DESIGNING OF FUZZY SLIDING MODE CONTROLLER

Through the design of a switching surface which was predicted from the switching pattern the desired idea is inserted into the controller. The converter switches across this fuzzy sliding surface through the construction of a switching control law, which satisfies a set of necessary conditions for the operation of the sliding mode. The switching function is chosen as follows:

$$\sigma = [g_1 \quad g_2 \quad g_3 \quad g_4] \begin{bmatrix} e_{i1} \\ e_{i2} \\ e_{vc1} \\ e_{vo} \end{bmatrix} = g_t E \qquad (8)$$

where g_1 to g_2 are constant gains and e_{i1} is error in the input inductor current:

$$e_{i1} = i_{1ref} - i_1; \qquad (9)$$

ei2 is error in the current of inductor L2 :

$$e_{i2} = i_{2ref} - i_2; \tag{10}$$

evc1 is error in the coupling capacitor voltage:

$$e_{vc1} = v_{c1ref} - v_{c1}; \tag{11}$$

evo is error in the output voltage:

$$e_{vo} = v_{oref} - v_o; \tag{12}$$

The input current and output voltage are measured and controlled directly.

This is equivalent to setting gains g_2 and g_3 to zero.Fuzzy logic when combined with sliding mode control contributes significantly to the improvement of performance of nonlinear systems.

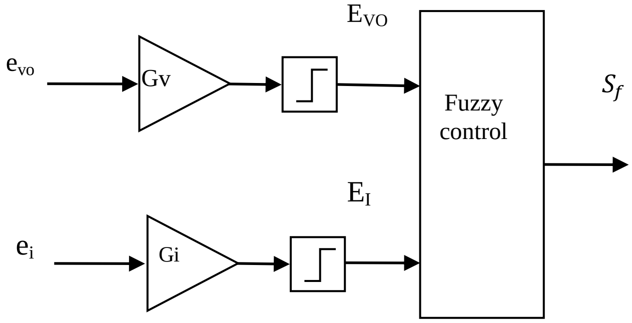

Figure 4: Fuzzy Sliding Mode Control Block in MATLAB / SIMULINK

Fig 5 and fig 6, Show two triangle membership functions which are designed for fuzzy block inputs. Also Ei and EVO are applied to fuzzy block according to figure 4. The fuzzy rules are given in Table I and the control signal Sf is produced by using this table. Triangle membership function of output is shown in figure 7.

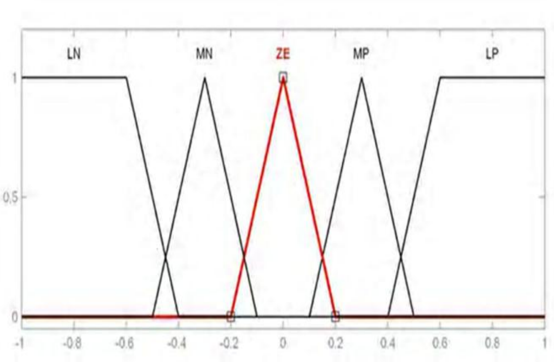

Figure 5: Membership function for E_{VO}

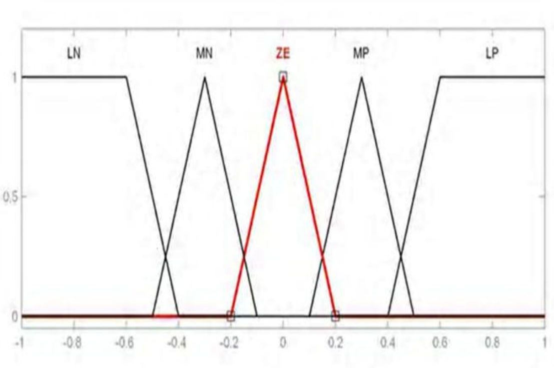

Figure 6: Membership function for E_I

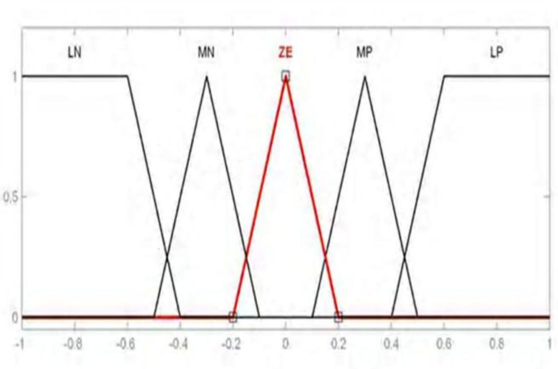

Figure 7: Membership function for output S_f

TABLE I: FUZZY RULE BASE

E_{VO} E_I	LN	MN	ZE	MP	LP
LN	LN	LN	MN	ZE	ZE
MN	LN	MN	MN	ZE	MP
ZE	MN	MN	ZE	MP	MP
MP	MN	ZE	MP	LP	LP
LP	ZE	MP	MP	LP	LP

In buck mode, if normalized error voltage is greater than constant point (Cr) which is obtained by using try and error method sliding mode control has better performance in comparison with Fuzzy sliding mode control. Otherwise, Fuzzy sliding mode control has the best performance.

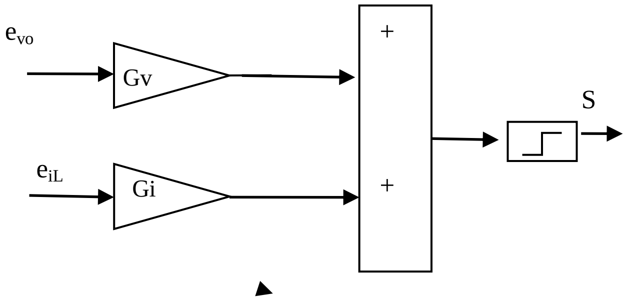

Figure 8: Fuzzy Sliding Mode Control Block in MATLAB / SIMULINK

Now a switching strategy should be designed to make the system reach sliding surface in finite time. After reaching the surface, the system achieves desired system dynamics and becomes globally asymptotic stable [10]. A positive definite Lyapunov function P may be defined as [6].

$$P = 1/2S^2 \tag{13}$$

Ensuring stability for the system in sliding mode requires derivative of P be negative definite i.e. $\dot{P} < 0$ and hence the following inequality should be fulfilled:

$$\dot{P} = S\dot{S} < 0 \qquad (14)$$

So, both reaching mode behavior and sliding mode

Stability is ensured by the following switching law:

$$u = \begin{cases} 0 & S_f \text{ or } S < 0 \\ 1 & S_f \text{ or } S > 0 \end{cases} \qquad (15)$$

5. SIMULATION RESULTS

A block diagram of the proposed system is shown in Fig. 10.

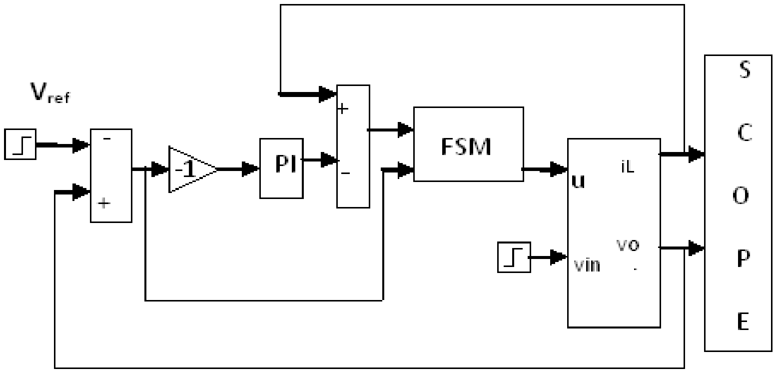

Figure 9: Block Diagram

The buck/boost converter parameters are chosen as R_1=□0.1Ω, L_1=200µH, R_2=0.2Ω, L_2=510µH, C_1=47µF, Co=200µF, $R_L = 100Ω$, switching frequency is 100kHz, Cr=0.04.Adc voltage of 200V obtained through a front end rectifier is applied to the buck/boost converter. The reference outputs are fixed at 150V for buck mode and 440 V for boost mode in sepic converter. Robustness is checked by testing the system in boost mode and buck mode response to step change in load power from 100Ω to 200Ω and input voltage Vin from 200 to 230 volts at 0.04 sec. Figures 10 and 13 show output voltage of converter with sliding mode control and fuzzy sliding mode control under load and input variations in .04S in boost and buck mode respectively. Figures 11 and 14 show input current with sliding mode control and fuzzy sliding mode control under load and input variations in .04S in boost and buck mode respectively. Also figures 12 and 15 shows the signal control of proposed controller under load and input variations in .04S in boost and buck mode respectively and these show robustness of proposed controller against perturbations.

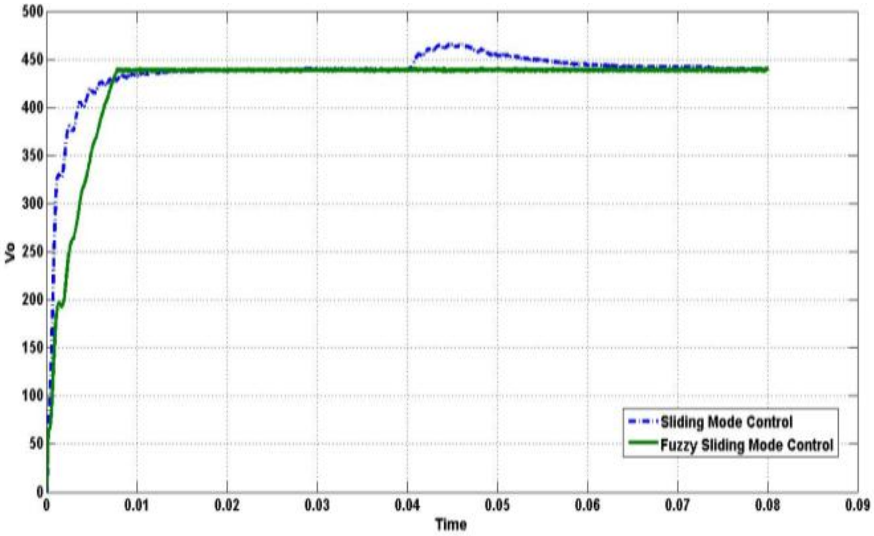

Figure 10: A comparison converter output voltage between slidnig mode control (dashed) and fuzzy sliding mode control under load and input variations in .04S in boost mode.

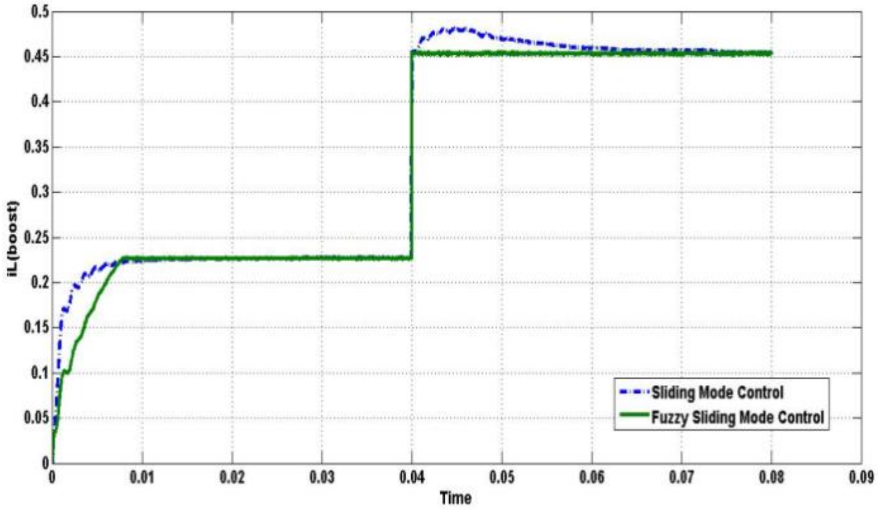

Figure 11: A comparison input current between slidnig mode control (dashed) and fuzzy sliding mode control under load and input variations in .04S in boost mode.

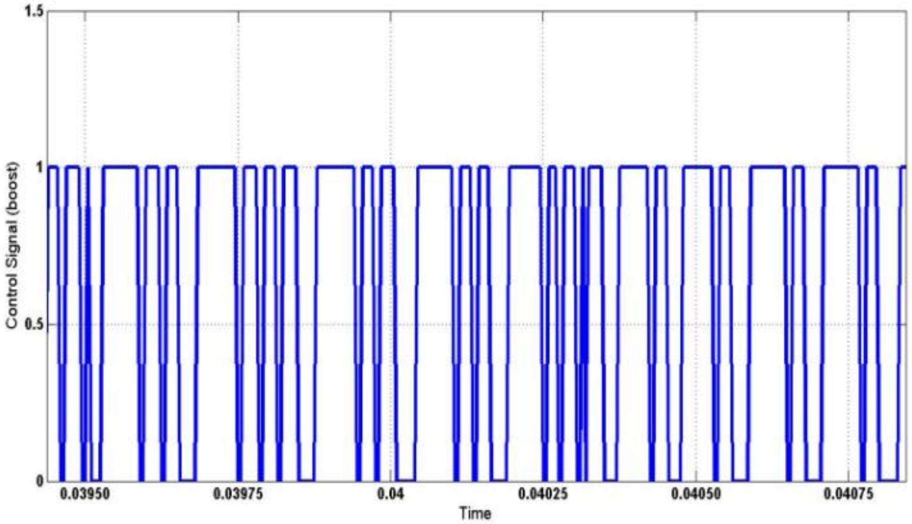

Figure 12:The signal control of proposed controller under load and input variations in .04S in boost mode.

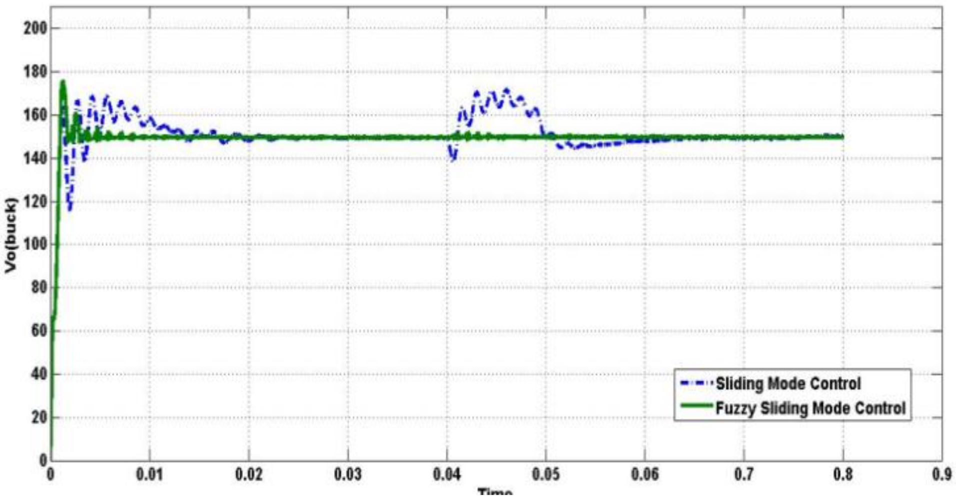

Figure 13: A comparison converter output voltage between slidnig mode control (dashed) and fuzzy sliding mode control under load and input variations in .04S in buck mode

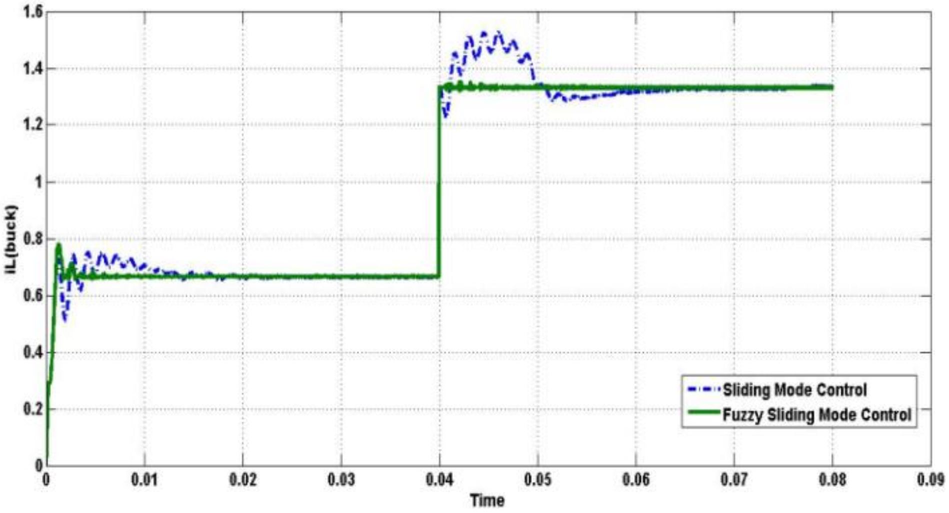

Figure 14: A comparison input current between sliding mode control (dashed) and fuzzy sliding mode control under load and input variations in .04S in buck mode.

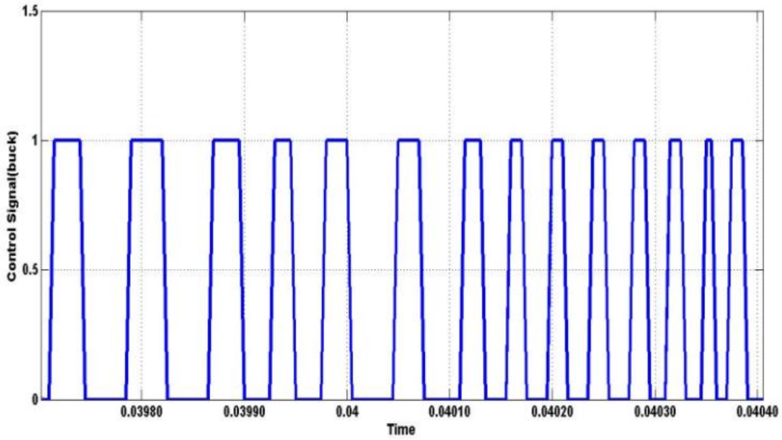

Figure 15: The signal control of proposed controller under load and input variations in .04S in buck mode.

Conclusion

This paper introduces a modified design of a fuzzy sliding mode controller for a dc-dc buck-boost type converter. Sliding mode controller guarantees robustness against all variations and fuzzy logic helps to reduce chattering phenomenon due to sliding controller, in that way efficiency increases and error, voltage and current ripples decreases. The proposed system is simulated by MATLAB / SIMULINK. This model is tested under variations of input and reference voltages and it was found that in comparison with conventional sliding mode controllers they perform better.

References

[1]. R.B. Ridley: "A New Continuous-time Model for Current-mode Control", IEEE Transaction on Power Electronics, Vol. 6 , No 2, April 1991, pp. 271 – 280.

[2]. R. Tymerski, D. Li: "State-space Models for Current Programmed Pulse width Modulated Converters", IEEE Transaction on Power Electronics, Vol. 8, No. 3, July 1993, pp. 271 – 278.

[3]. R.D. Middlebrook: “Modeling Current-progr ammed Buck and Boost Regulators”, IEEE Transaction on Power Electronics, Vol. 4, No. 1, Jan. 1989, pp. 36 – 52.

[4]. Arivukkannu Ezhilarasi, Muthiah Ramaswamy: “A DSPIC Implementation of a Sliding Mode Strategy for a SEPIC Converter”SERBIAN JOURNAL OF ELEC TRICAL ENGINEERING Vol. 6, No. 2, November 2009, 215-225 UDK: 681.515:621.314.1

[5]. H.S. Ramírez and R. S.Ortigoza, “Control design techniques in power electronics devices”. (Power systems), London, U.K.: Springer-Verlag Limited, 2006.

[6]. J. J. Slotine and W. Li, Applied Nonlinear Control, New Jersey, U.S.A.: Prentice-Hall Inc., 1991

[7]. W. Perruquetti and J. P. Barbot, Sliding mode control in engineering, New York , U.S.A.: Marcel Dekker, Inc., 2002

[8]. P.T. Krein, Elements of Power Electronics, New York, U.S.A.: Oxford University Press, 1998.

[9]. M. K. Kazimierczuk, Pulse Width Modulated DC-DC Converters, 1st ed. West Sussex , U.K. : John Wiley & Sons, Ltd, 2008.

[10]. J. Y. Hung, W. Gao and J. C. Hung, “Variable Structure Control: A Survey,” IEEE Trans. Ind. Electron., vol. 40, no. 1, Feb. 1993.

[11]. C.K. Tse, M. di Bernado: Complex Behavior in Switching Power Converters, Proc. IEEE, Vol. 90, No. 5, May 2002, pp. 768 – 781.

[12]. J.M. Kwon, W.Y. Choi, J.J. Lee, E.H. Kim, B.H. Kwon: Continuous Conduction Mode SEPIC Converter with Low Reverse-recovery Loss for Power Factor Correction, IEE Proc. Electric Power Application, Vol. 153, No. 5, September 2006, pp. 673 – 681.

[13]. G. Spiazzi, P. Mattavelli: Design Criteria for Power Factor Pre Regulators Based on SEPIC and CUK Converters in Continuous Conduction Mode, IEEIAS, Denver, Oct.1994, pp. 1084 – 1089.

[14]. A. Hren, P. Slibar: Full Order Dynamic Model of SEPIC Converter, IEEE ISIE 2005, 20-23 June 2005, Vol. 2, pp.553 – 558.

[15]. W.M. Moussa: Modeling and Performance Evaluation of a DC/DC SEPIC Converter, Appl. Power Electronics Conf. and Expo. 1995, APEC ’95, Conf. Proc. 1995, 5-9 March 1995, Vol. 2, pp. 702 – 706.

[16]. R.D. Middlebrook: Modeling Current-programmed Buck and Boost Regulators, IEEE Transaction on Power Electronics, Vol. 4, No. 1, Jan. 1989, pp. 36 – 52.

[17]. O. Pop, G. Chindris, A. Grama, F. Hurgoi: Power Factor Correction Circuit with a New Modified SEPIC Converter, Electronics Technology: Concurrent Engineering in Electronic Packaging, 2001, 24th Int. Spring Seminar, 5-9 May 2001, pp. 117 – 120.

[18]. W. Gu: Small Signal Modeling for Current Mode Controlled CUK and SEPIC Converters, Appl. Power Electronics Conf. and Expo. 2005, APEC 2005, Twentieth Annual IEEE, 6-10 March 2005, Vol. 2, pp. 906 – 910.

[19]. M. Shamim-Ul-Alam, M. Quamruzzaman, ; K.M.Rahman "Fuzzy logic based sliding mode controlled dc-dc boost converter" ICECE 2010, pp.70-73.

Authors

Majid Delshad was born in Isfahan in 1979.He received MS.c and Phd degree from Isfahan University of Technology in Electrical Engineering. He is Assistant professor in Islamic Azad University Khorasgan Branch until 2010. His research field is Power electronics, Dc-Dc converters, Soft Switching Techniques.