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Sliding Mode Control and Fuzzy Sliding Mode Control for DC-DC Converters

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1. Introduction

Switched mode DC-DC converters are electronic circuits which convert a voltage from one level to a higher or lower one. They are considered to be the most advantageous supply tools for feeding some electronic systems in comparison with linear power supplies which are simple and have a low cost. However, they are inefficient as they convert the dropped voltage into heat dissipation. The switched-mode DC-DC converters are more and more used in some electronic devices such as DC-drive systems, electric traction, electric vehicles, machine tools, distributed power supply systems and embedded systems to extend battery life by minimizing power consumption (Rashid, 2001).

There are several topologies of DC-DC converters which can be classified into non-isolated and isolated topologies. The principle non-isolated structures of the DC-DC converters are the Buck, the Buck Boost, the Boost and the Cuk converters. The isolated topologies are used in applications where isolation is necessary between the input and the load. The isolation is insured by the use of an isolating transformer.

The DC-DC converters are designed to work in open-loop mode. However, these kinds of converters are nonlinear. This nonlinearity is due to the switch and the converter component characteristics.

For some applications, the DC-DC converters must provide a regulated output voltage with low ripple rate. In addition, the converter must be robust against load or input voltage variations and converter parametric uncertainties. Thus, for such case the regulation of the output voltage must be performed in a closed loop control mode. Proportional Integral and hysteretic control are the most used closed loop control solutions of DC-DC converters. This can be explained by the fact that these control techniques are not complicated and can be easily implemented on electronic circuit devises.

Nowadays, the control systems such as microcontrollers and programmable logic devises are sophisticated and allow the implementation of complex and time consuming control techniques.

The control theory provides several control solutions which can be classified into conventional and non-conventional controls. Many conventional controls, such as the PID control, were applied to DC-DC converters. The design of the linear controller is based on the linearized converter model around an equilibrium point near which the controller gives

good results. However, for some cases this control approach is not so efficient (Tse & Adams, 1992; Ahmed et al, 2003).

Sliding Mode Control (SMC) is a nonlinear control technique derived from variable structure control system theory and developed by Vladim UTKIN. Such control solution has several advantages such as simple implementation, robustness and good dynamical response. Moreover, such control complies with the nonlinear characteristic of the switch mode power supplies (Nguyen & Lee, 1996; Tan et al, 2005). Although, the drawback of SMC is the chattering phenomena. To overcome the chattering problem one solution consists into extending SMC to a Fuzzy Sliding Mode Control (FSMC), (Alouani, 1995).

Fuzzy Logic Control is a non-conventional and robust control law. It is suitable for nonlinear or complex systems characterized by parametric fluctuation or uncertainties (Kandel & Gideon, 1993; Passino, 1998). The advantage of the FSMC is that it is not directly related to a mathematical model of the controlled systems as the SMC.

This chapter aims to compare SMC and FSMC of DC-DC converters. The average models of Buck, Boost and Buck Boost converters are presented in section 2. Then in section 3, some classical sliding mode controls are presented and tested by simulations for the case of Buck and Buck Boost converters. In order to improve the DC-DC converters robustness against load and input voltage variations and to overcome the chattering problem, two approaches of FSMC are presented in section 4.

2. DC-DC converters modelling

The switching DC-DC converters are hybrid dynamical systems characterized by both continuous and discrete dynamic behaviour.

In the following, we present only a general modelling approach of DC-DC converters by application of the state space averaging technique of the Buck, Boost and Buck-Boost converters for the case of a continuous conduction mode.

Let us consider a switching converter which has two working topologies during a period T. When the switches are closed, the converter model is linear. The state-space equations of the circuit can be written and noted as follows (Middlebrook & Cuk, 1976):

$$\begin{cases} \dot{x} = A_1 x + B_1 u \\ y = C_1 x + E_1 u \end{cases} \tag{1}$$

When the switches are opened, the converter can be modelled by another linear state-space representation written and noted as follows:

$$\begin{cases} \dot{x} = A_2 x + B_2 u \\ y = C_2 x + E_2 u \end{cases} \tag{2}$$

From the equation (1) and (2) we can determine the averaged model given by equation (3) for an entire switching cycle T.

$$\begin{cases} \dot{\tilde{x}} = A(d)\tilde{x} + B(d)\tilde{u} \\ \tilde{y} = C(d)\tilde{x} + E(d)\tilde{u} \end{cases} \tag{3}$$

where the matrices $A(d)$, $B(d)$, $C(d)$ and $E(d)$ are defined as follows:

$$\begin{cases} A(d) = dA_1 + (1-d)A_2 \\ B(d) = dB_1 + (1-d)B_2 \\ C(d) = C_1 + (1-d)C_2 \\ E(d) = dE_1 + (1-d)E_2 \end{cases} \tag{4}$$

and $\tilde{x}$, $\tilde{y}$ and $\tilde{u}$ are respectively the average of x, y and u during the switching period T.
Let us consider the Buck, Boost and Buck-Boost converters presented by Fig. 1, Fig. 2 and Fig. 3 respectively. The state space representation can be expressed for these converters as follows :

$$\begin{cases} \dot{\tilde{x}} = A(d)\tilde{x} + B(d)\tilde{u} \\ \tilde{v}_o = C(d)\tilde{x} \end{cases} \tag{5}$$

where

$$\tilde{x} = \begin{pmatrix} \tilde{i}_L \\ \tilde{v}_o \end{pmatrix}$$

$$C(d) = (0 \quad 1)$$

$$\tilde{u} = V_{in}$$

$d = 1$ (Switch ON)

$d = 0$ (Switch OFF)

However the matrix $A(d)$ and $B(d)$ depend on the kind of converter. Table 1 gives the expression of these matrixes for the considered converters.

Buck converter	Boost converter	Buck Boost converter
$A(d) = \begin{pmatrix} 0 & -\dfrac{1}{L} \\ \dfrac{1}{C} & -\dfrac{1}{RC} \end{pmatrix}$	$A(d) = \begin{pmatrix} 0 & -\dfrac{1-d}{L} \\ \dfrac{1-d}{C} & -\dfrac{1}{RC} \end{pmatrix}$	$A(d) = \begin{pmatrix} 0 & \dfrac{1-d}{L} \\ -\dfrac{1-d}{C} & -\dfrac{1}{RC} \end{pmatrix}$
$B(d) = \begin{pmatrix} \dfrac{d}{L} \\ 0 \end{pmatrix}$	$B(d) = \begin{pmatrix} \dfrac{1}{L} \\ 0 \end{pmatrix}$	$B(d) = \begin{pmatrix} \dfrac{d}{L} \\ 0 \end{pmatrix}$

Table 1. Matrix $A(d)$ and $B(d)$ expression for the Buck, Boost and Buck Boost converters
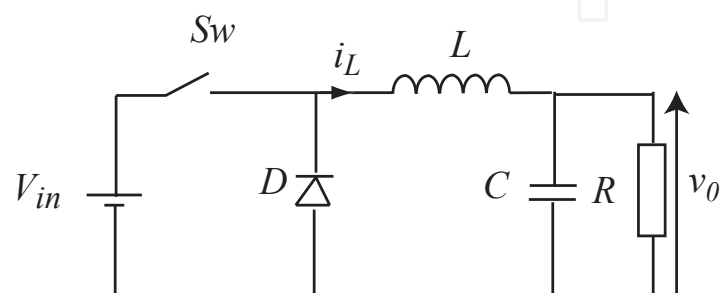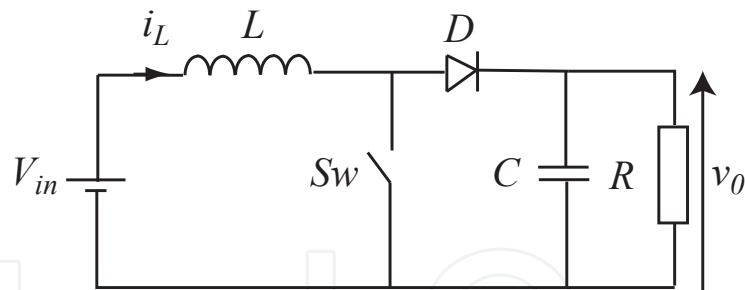

Fig. 1. Buck converter structure
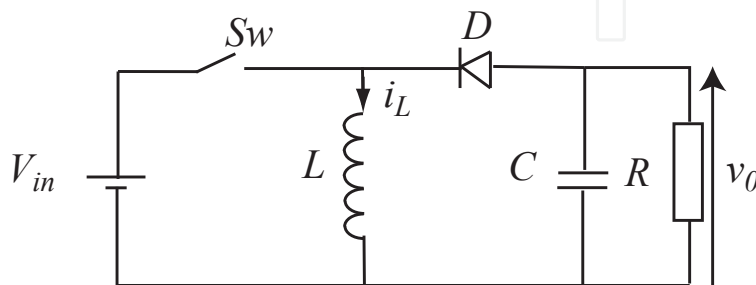
Fig. 2. Bosst converter structure

Fig. 3. Buck-Boost converter structure

The averaged modelling approach for the switching mode converter leads to an approximate non linear models. The linearization of this kind of models around the operating point allows the application of conventional control approach such as PID control and adaptive control. However, sliding mode control is considered to be the most adequate control solution because it complies with the nonlinear behaviour of the switching DC-DC converters and it is robust against all the modelling parametric uncertainties.

3. Sliding mode control for DC- DC converters

3.1 SMC general principle

SMC is a nonlinear control solution and a variable structure control (VSC) derived from the variable structure system theory. It was proposed by Vladim UTKIN in (Utkin, 1977).

SMC is known to be robust against modelling inaccuracies and system parameters fluctuations. It was successfully applied to electric motors, robot manipulators, power systems and power converters (Utkin, 1996). In this section, we will present the general principle of the SMC and the controller design principle.

Let us consider the nonlinear system represented by the following state equation:

$$\dot{x} = f(x,t) + g(x,t)u(t) \tag{6}$$

where x is n-dimensional column state vector, f and g are n dimensional continuous functions in x , u and t vector fields, u is the control input.

For the considered system the control input is composed by two components a discontinuous component u_n and a continuous one u_{eq} (Slotine & Li, 1991).

$$u = u_{eq} + u_n \tag{7}$$

The continuous component insures the motion of the system on the sliding surface whenever the system is on the surface. The equivalent control that maintains the sliding mode satisfies the condition

$$\dot{S} = 0 \tag{8}$$

Assuming that the matrix $\dfrac{\partial S}{\partial x} g(x,t)$ is non-singular, the equivalent control maybe calculated as:

$$u_{eq} = -\left(\frac{\partial S}{\partial x} g(x,t) \right)^{-1} \left(\frac{\partial S}{\partial t} + \frac{\partial S}{\partial x} f(x,t) \right) \tag{9}$$

The equivalent control is only effective when the state trajectory hits the sliding surface. The nonlinear control component brings the system states on to the sliding surface.
The nonlinear control component is discontinuous. It would be of the following general form (Slotine & Li, 1991; Bandyopadhyay & Janardhanan, 2005):

$$u_n = \begin{cases} u^+ \; with \; S > 0 \\ u^- \; with \; S < 0 \end{cases} \tag{10}$$

In the following SMC, will be applied to a buck and buck-boost converters.

3.2 SMC for Buck converter
3.2.1 Proposed SMC principle
For the Buck converter we consider the following sliding surface S :

$$S = ke + \dot{e} \tag{11}$$

where k is the sliding coefficient and e is the output voltage error defined as follows :

$$e = V_{ref} - v_0 \tag{12}$$

By considering the mathematical model of the Buck converter, the surface can be expressed by the following expression (Tan, et al, 2006; Ben Saad et al 2008):

$$S = -\frac{1}{C} i_L + \left(\frac{1}{RC} - k \right) v_o + K V_{ref} \tag{13}$$

and its derivative is given by :

$$\dot{S} = \left(\frac{1 - kRC}{RC^2} \right) i_L - \left(\frac{L - kRLC - R^2C}{R^2C^2L} \right) v_0 - \left(\frac{V_{in}}{LC} \right) u \tag{14}$$

The next step is to design the control input so that the state trajectories are driven and attracted toward the sliding surface and then remain sliding on it for all subsequent time.
The SMC signal u consists of two components a nonlinear component u_n and an equivalent component u_{eq} , (Ben Saad et al, 2008).

The equivalent control component constitutes a control input which, when exciting the system, produces the motion of the system on the sliding surface whenever the system is on the surface. The existence of the sliding mode implies that $\dot{S} = 0$. So the equivalent control may be calculates as:

$$u_{eq} = \alpha_1 i_L - \alpha_2 v_o \tag{15}$$

where

$$\alpha_1 = \frac{L - kLRC}{RCV_{in}}$$

and

$$\alpha_2 = \frac{L - kRLC - R^2C}{R^2CV_{in}}$$

Let us consider the positive definite Lyapunov function V defined as follows:

$$V = \frac{1}{2}S^2 \tag{16}$$

The time derivative $\dot{V}$ of V must be negative definite $\dot{V} < 0$ to insure the stability of the system and to make the surface S attractive. Such condition leads to the following inequality:

$$S\dot{S} = S\left(-\frac{V_{in}}{LC}u_n\right) < 0 \tag{17}$$

To satisfy such condition, the nonlinear control component can be defined as follows:

$$u_n = sign(S) \tag{18}$$

Fig. 4 presents the control diagram of the presented SMC.
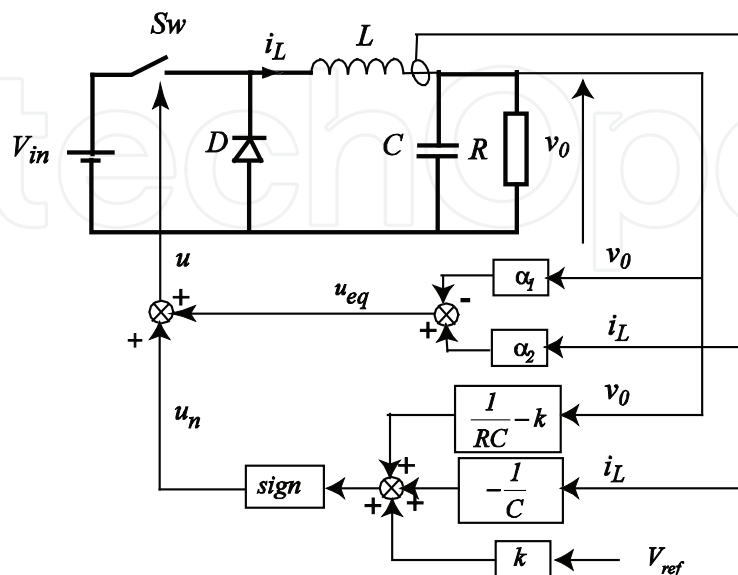
Fig. 4. SMC for Buck converter

3.2.2 Simulation and experimental results

The SMC is tested by simulation and experimentally using a dSAPCE control board. The test bench was built as shown in Fig. 10 and Fig. 11 around:
- a Buck converter,
- a computer equipped with a dSPACE DS1104 with its connector panel,
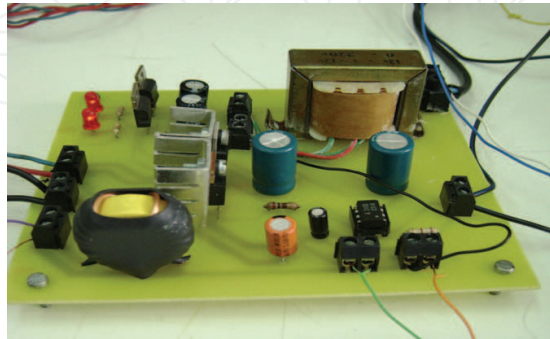- a DC voltage power supply,
- two load resistances.

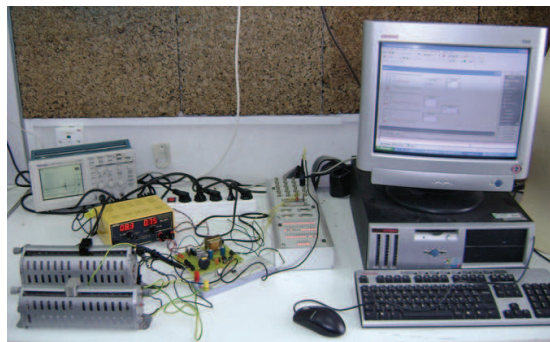Fig. 5. Photo of the studied Buck converter

Fig. 6. Photo of the test bench

The dSPACE DS1104 controller board is a prototyping system. It is a real time hardware platform. It can be programmed with MATLAB/SIMULINK software through a real time interface allowing the generation of a real time code. Two ADC input channels of the DS1104, characterized by a 16 bits resolution, are used to acquire the Buck converter output voltage and the inductance current. The control board generates a digital PWM signal which is used to control the switch of the Buck converter.

The proposed SMC was applied to a Buck converter characterized by the parameters given in the table 2.

Parameters	Values
V_{in}	15 V
C	22 μF
L	3 mH
R	10 Ω
Switching frequency	10 kHz

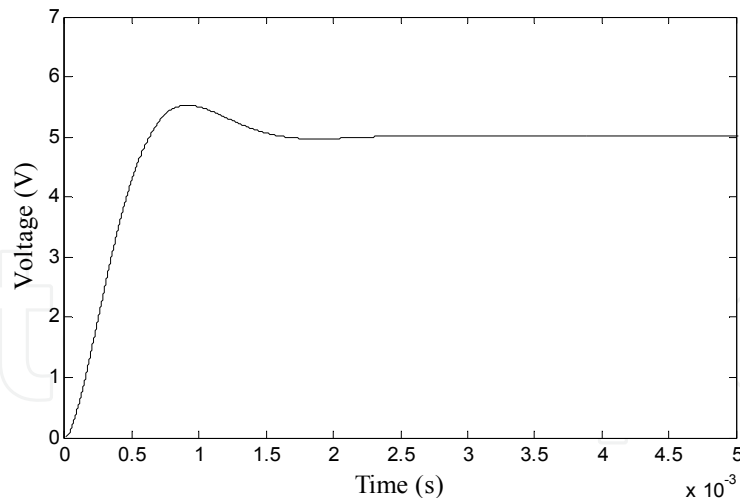Table 2. Studied buck converter parameters

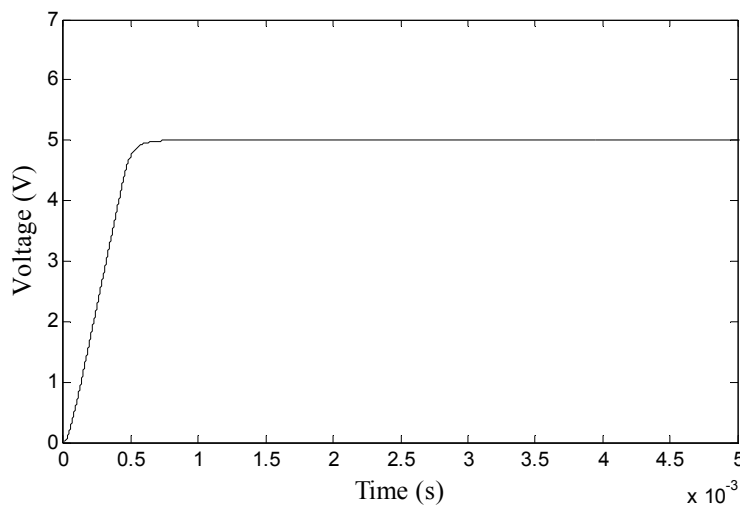Fig. 7. Open loop responses of the buck converter by application of 16% PWM control signal

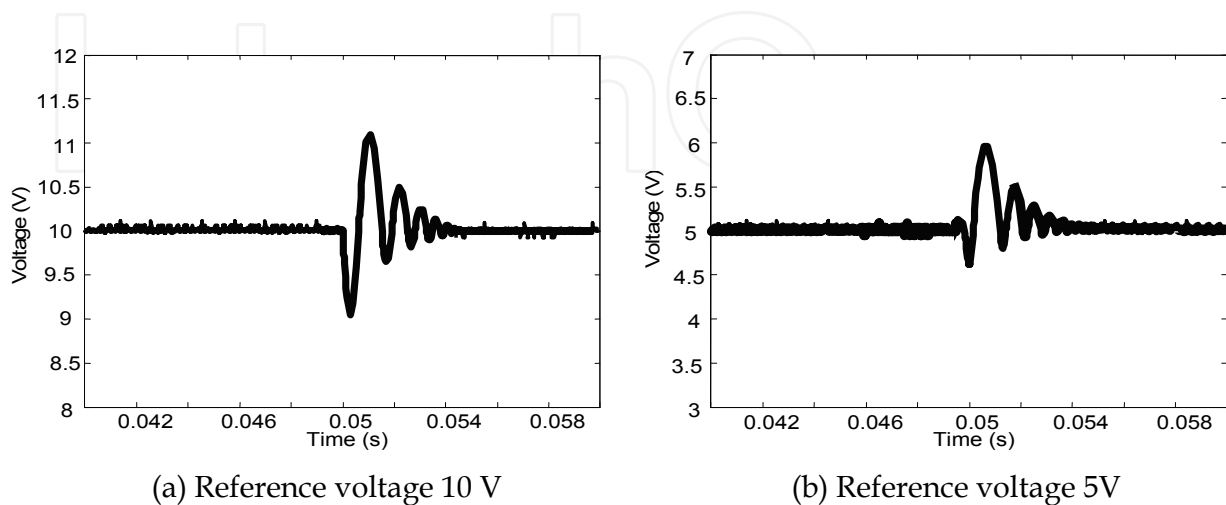Fig. 8. Application of the SMC to the studied Buck converter ($Vref = 5V$)

| (a) Reference voltage 10 V | (b) Reference voltage 5V |

Fig. 9. Experimental test robustness of the SMC for the variation of the load from 10 Ω to 15 Ω

Fig. 7 presents the simulated output voltage by application of a PWM control signal of 16% duty cycle. The voltage response corresponds to a second order damped system response with an overshoot. Fig. 8 presents the obtained result by application of the proposed SMC to the studied controller for a 5 V voltage reference. We can see clearly that the observed voltage overshoot obtained on the open-loop response disappeared by application of the SMC.

The SMC is tested experimentally for the case of the load variation. Fig. 9 presents the obtained results for the case of the variation of the load resistance from 10 Ω to 15 Ω at 0.05s. It is clear that this perturbation is quickly rejected because the output voltage attends the reference voltage. The experimental test result for the case of the input voltage variation from 30 V to 20V, given in Fig. 10, shows the robustness of the applied SMC.
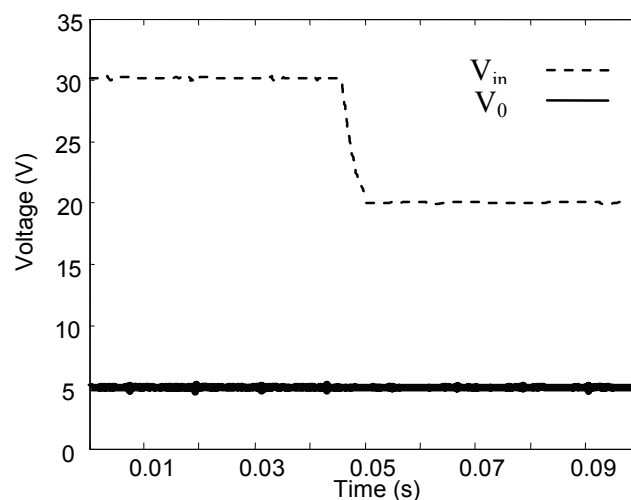

Fig. 10. Experimental output voltage evolution by application of the SMC for the variation of the input voltage from 30V to 20V

3.3 SMC for Buck-Boost converter
3.3.1 Proposed SMC principle

As for the Buck Converter, the Buck-Boost converter sliding surface and output voltage error are respectively defined by equations (8) and (9).

k can be chosen so that the outer voltage loop is enough to guarantee a good regulation of the output voltage with a near zero steady-state error and low overshoot.

Without any high frequency, when the system is on the sliding surface, we have $S = 0$ and $\dot{S} = 0$ (Hu et al, 2005; El Fadil et al, 2008).

As the control signal applied to the switch is pulse width modulated, we have only to determine the equivalent control component.

By considering the mathematical model of the DC-DC Boost converter, at the study state the variation of the surface can be expressed as:

$$\dot{S} = k\dot{e} = -k\dot{v}_0 = -k(\frac{1 - u_{eq}}{C}i_L - \frac{v_0}{RC})$$ (19)

and then from equation (20) and by considering the condition $\dot{S} = 0$ we have:

$$kv̇_0 + \frac{v̇_0}{RC} = \frac{1 - u_{eq}}{C} i_L \qquad (20)$$

From the state representation (7) we can write the following relation:

$$v̇_0(\frac{1}{RC} - k) = \frac{1 - u_{eq}}{C}(\frac{u_{eq} - 1}{L} v_0 + \frac{v_{in}}{L}) \qquad (21)$$

Then equivalent control component expression:

$$u_{eq} = 1 - \frac{v_{in} + \sqrt{v_{in}^2 + \frac{4kL}{R}(CRk - L)(v_{ref} - v_0)}}{2v_0} \qquad (22)$$

3.3.2 Simulation results

The proposed SMC was applied by simulation to the studied Buck-Boost converter characterized by the parameters given in Table 3. Fig. 11 presents the studied converter open-loop voltage and current responses. In Fig. 12 the output voltages evolution obtained by application of the SMC are presented for a reference voltages $V_{ref} = -20V$. So the application of the SMC allowed the elimination of the overshoot observed for the open-loop response. Fig. 13 presents the control signal. We can notice that it is strongly hatched. This is a consequence of the chattering phenomenon.

PARAMETERS	VALUES
V_{in}	20 V
C	22 μF
L	3 mH
R	10 Ω
SWITCHING FREQUENCY	10 kHz

Table 3. Studied Buck Boost converter parameters

To test the robustness of the SMC, we consider now the variations of the load resistance and the input voltage. Fig. 14 presents the evolution of the output voltage and the current in the load for the case of a sudden change of the load resistance from 30Ω to 20Ω. So by the application of the SMC, this perturbation was rejected in 10.10^{-3}s and the output voltage attends the reference voltage after. Fig. 15 illustrates the sudden variation of the input voltage from 15V to 10V at 0.05s. For such case we notice that the output voltage, presented by Fig. 16, attends after the rejection of the perturbation the desired value $-20V$ and the converter work as boost one.
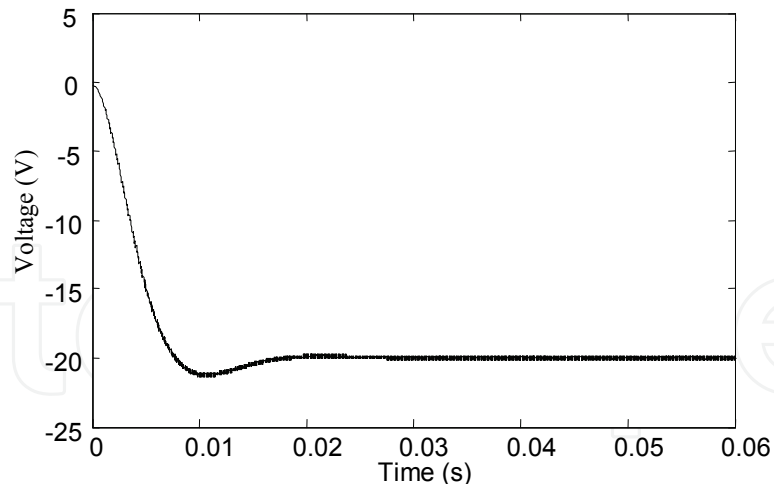
Fig. 11. Output voltage evolution of the Buck-Boost converter obtained by open-loop control.
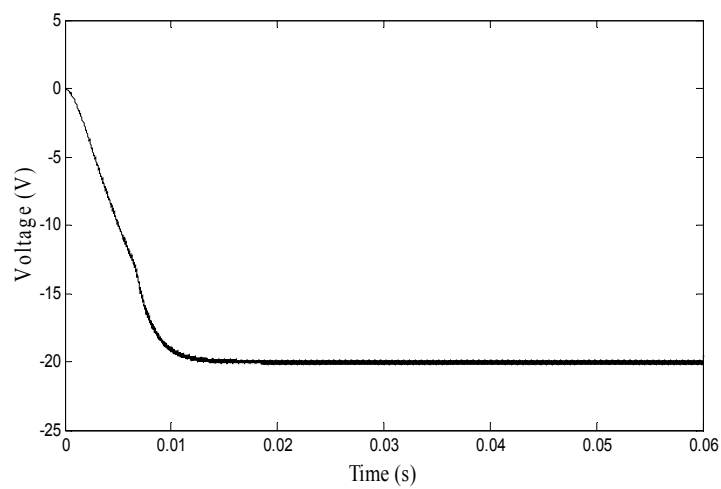

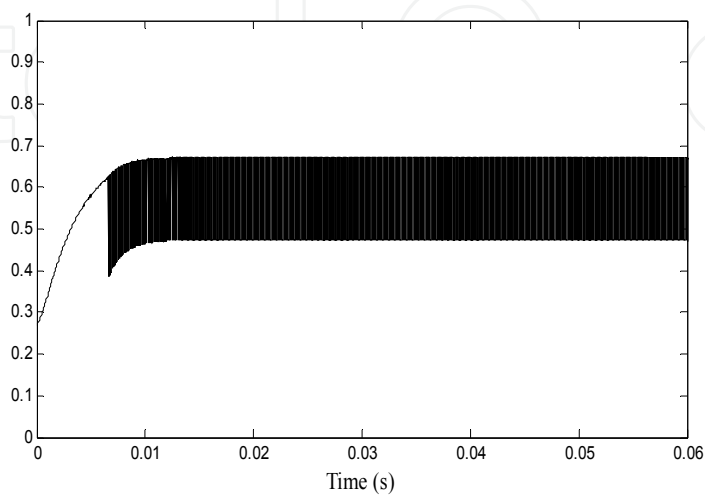Fig. 12. Output vvoltage evolution obtained by application of the SMC
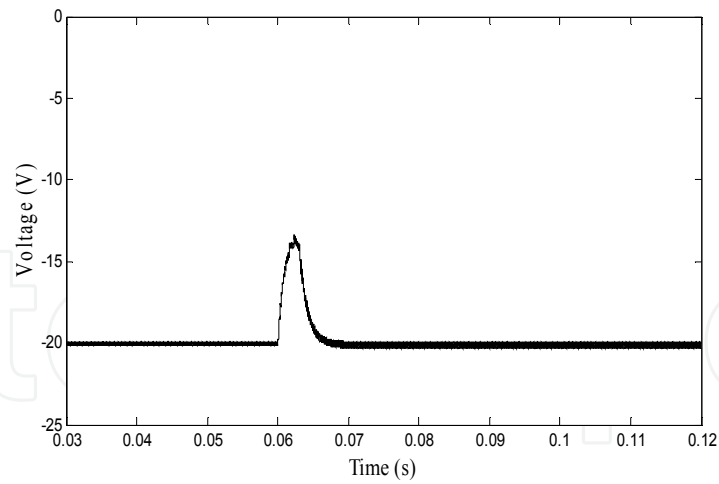

Fig. 13. Control signal evolution

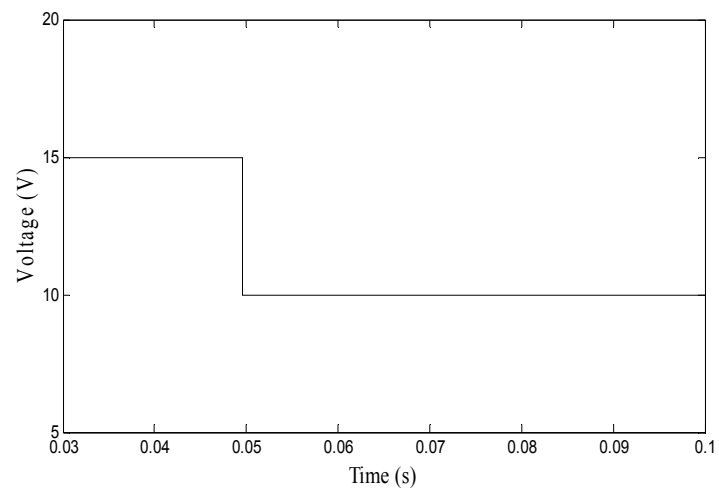Fig. 14. Output voltage evolution by application of the SMC for the case of load variation from 30Ω to 20Ω
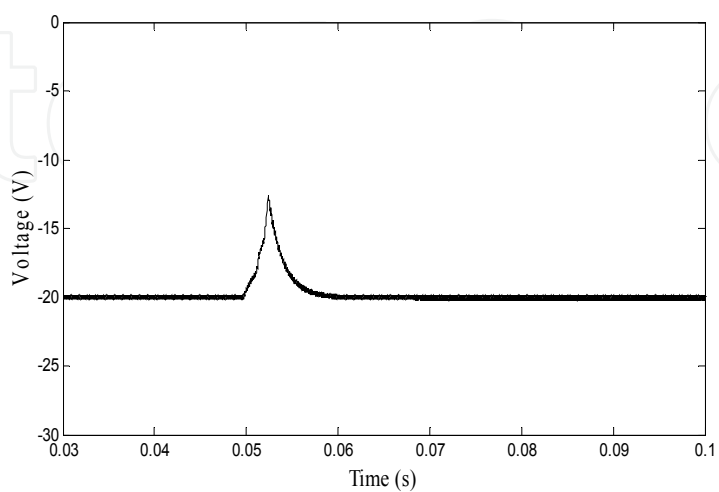

Fig. 15. Input voltage variation

Fig. 16. Output voltage evolution by application of the SMC for the case of input voltage variation from 15 V to 10V

In order to overcome the problem of the chattering phenomena, it is possible to apply a high order SMC. However, the obtained analytical expression of the control component can be so complicated.

In the following, we will propose to apply a FSMC to the studied converters in order to improve the robustness of the SMC and to overcome the chattering problem.

4. FSMC for DC- DC converters

As SMC, Fuzzy Logic Control (FLC) is known to be robust. Moreover, it is considered to be an alternative to the chattering problem. FLC is an intelligent control complying with complex or uncertain systems. Some researchers show that FLC is a general form of variable structure control. Thus, some attempts have been made in order to integrate the SMC and FLC to a Fuzzy Sliding Mode Control (FSMC). However, the design of a fuzzy sliding mode controller for nonlinear system is a difficult problem. There have been quite a lot of researches on the combination of sliding mode control with fuzzy logic control techniques for improving the robustness and the performances of nonlinear systems with uncertainty (Qiao et al, 03).

We can distinguish two classes of control algorithms for FSMC. The first class is the fuzzy boundary layer SMC where the signum function is replaced by a fuzzy map so that the control input switch in a smooth manner to the equivalent control component. As consequence chattering is reduced. As an example of this kind of control a FSMC proposed by PALM is adopted.

The second class consists of the set of fuzzy control algorithms which approximate the input-output map of traditional sliding mode control (Alouani, 1995).

4.1 Fuzzy boundary layer SMC

For the first class of FSMC we present in the following the method proposed by PALM in (Palm, 1992).
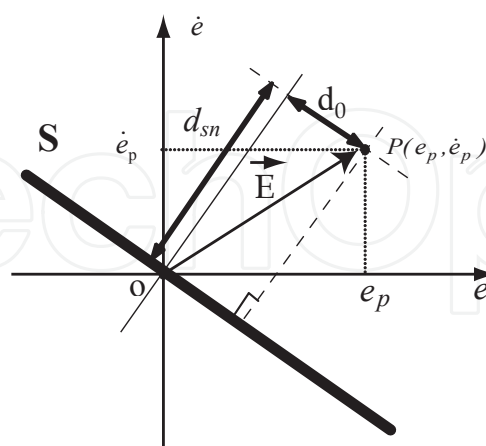

Fig. 17. Distances d_{sn} and d

Let us consider a second order system and as an example the sliding surface defined as follows (Sahbani et al, 2008):

$$S = EY^T \tag{23}$$

where $E = [e \; \dot{e}]$ and $Y = [k \; 1]$.

with k a constant gain and e the output system error.

The distance between the trajectory error and the sliding surface d_{sn} is defined as follows:

$$d_{sn} = \frac{\dot{e}_p + k e_p}{\sqrt{1 + k^2}} \tag{24}$$

d_{sn} is the normal distance between the point $P(e_p, \dot{e}_p)$ and the sliding surface. Such distance is illustrated graphically in Fig. 17 for an arbitrary point $P(e_p, \dot{e}_p)$.

Let $H(e_p, \dot{e}_p)$ be the intersection point of the switching line and its perpendicular passing through the point $P(e_p, \dot{e}_p)$.

d_o is defined as the distance between the point $H(e_p, \dot{e}_p)$ and the origin O.

The distance d_o is expressed as follows:

$$d_o = \sqrt{|E|^2 - d_{sn}^2} \tag{25}$$

The presented FSMC has as inputs the two distances d_{sn} and d_o. The output signal is the control increment $\Delta U(k)$ which is used to update the control signal defined as follows:

$$U(k) = \Delta U(k) + U(k-1) \tag{26}$$

The control law is equivalent to an integral action allowing a steady state error.

The presented FSMC is a Mamdani fuzzy inference system composed by a fuzzification block, a rule base bloc and a defuzzification block.

Trapezoidal and triangular membership functions, denoted by N (Negative), Z (Zero) and P (Positive), are used for d_{sn}. The same shape of membership functions denoted by Z (Zero), PS (Positive small) and PB (Positive Big) are used for d_o. d_{sn} and d_o membership functions are presented respectively in Fig. 18 and Fig. 19 in the normalized domain $[-1 \; 1]$ for d_{sn} and $[0 \; 1]$ for d_o.
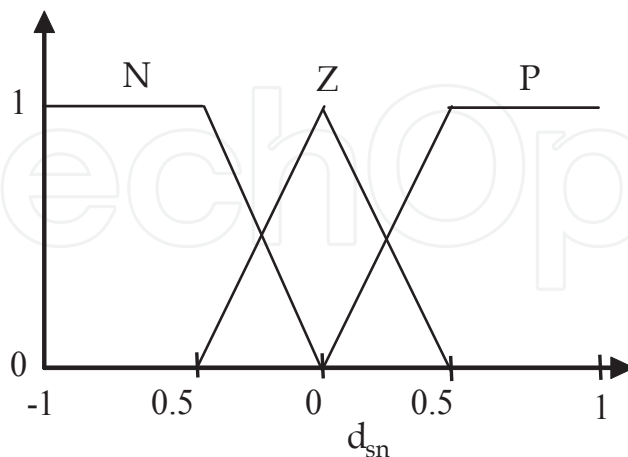

Fig. 18. d_{sn} membership functions

For the output signal of the proposed FSMC, fives triangular membership functions, denoted by NB (Negative Big), NM (Negative Middle), Z (Zero), PM (Positive Middle), PB (Positive Big) are used for the output signal Δd, Fig. 20. The rule base is given by table 4.
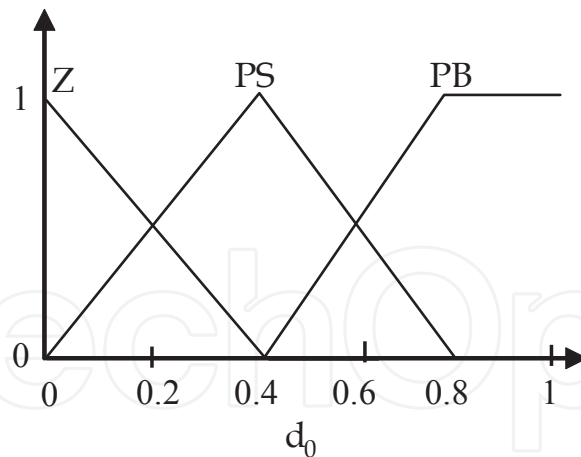
Fig. 19. d_o membership functions

		d_{sn}		
		N	Z	P
d_o	Z	PS	Z	NS
	PS	PB	PS	NB
	PB	PB	NS	NB

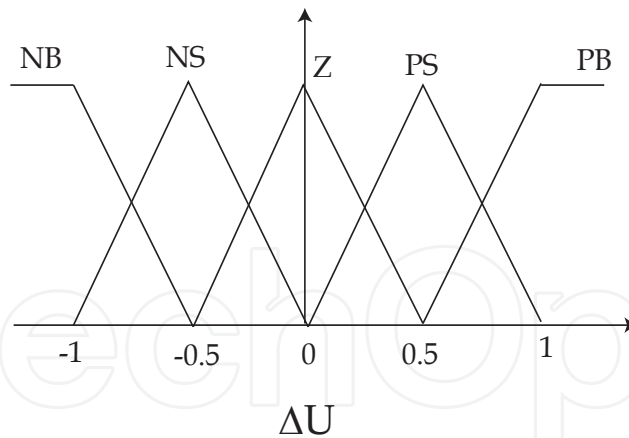Table 4. Rule base of the proposed FSMC.

Fig. 20. ΔU membership functions

4.2 Fuzzy Lyapunov function SMC

The second class of FSMC uses the surface S and its variation $\dot{S}$ to define the changes on the control signal. The aim of this kind of FSMC is to insure the Lyapunov stability condition $S\dot{S} < 0$.

Let us consider the sliding surface S. The proposed fuzzy sliding mode controller forces the derivative of the Lyapunov function to be negative definite. So, the rule base table is established to satisfy the inequality (17).

Intuitively, suppose that $S > 0$ and $\dot{S} > 0$, the duty cycle must increase. Also, if $S < 0$ and $\dot{S} < 0$ the duty cycle must decrease. Thus, the surface S and its variation $\dot{S}$ are the inputs of the proposed controller. The output signal is the control increment $\Delta U(k)$ which is used to update the control law. As for the Fuzzy boundary layer SMC the control signal is defined by equation (26). The proposed Fuzzy Sliding Mode Controller is a Sugeno fuzzy controller which is a special case of Mamdani fuzzy inference system. Only the antecedent part of the Sugeno controller has the "fuzzyness", the consequent part is a crisp function. In the Sugeno fuzzy controller, the output is obtained through weighted average of consequents.

As the proposed approach have to be implemented in practice, such choice can be motivated by the fact that Sugeno fuzzy controller is less time consuming than the Mamdani one

Trapezoidal and triangular membership functions, denoted by N (Negative), Z (Zero) and P (Positive), were used for both the surface and the surface change. They are respectively presented in Fig. 21 and Fig. 22 in the normalized domain $\begin{bmatrix} -1 & 1 \end{bmatrix}$.

For the output signals, fives normalized singletons denoted by NB (Negative Big), NM (Negative Middle), Z (Zero), PM (Positive Middle), PB (Positive Big) are used for the output signal ΔU, Fig. 23.

The normalized control surface of the proposed FSMC, corresponding to the Rule Base given in table 5, is presented in Fig. 24. Such surface shows clearly the nonlinear characteristic of the proposed fuzzy control law.
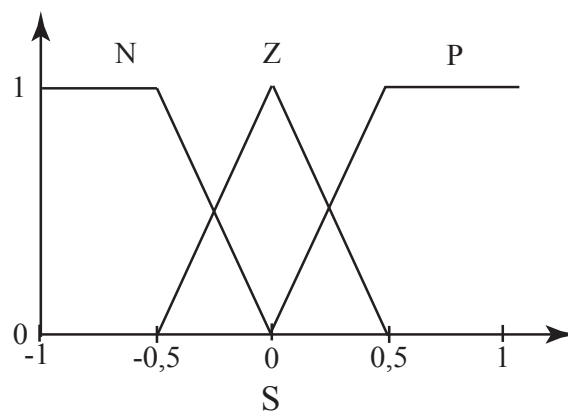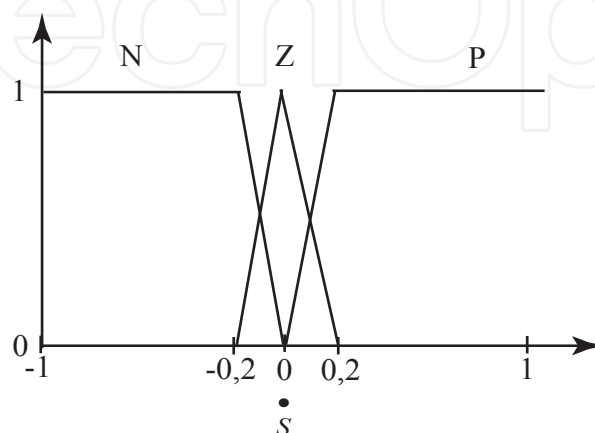

Fig. 21. Surface S membership functions

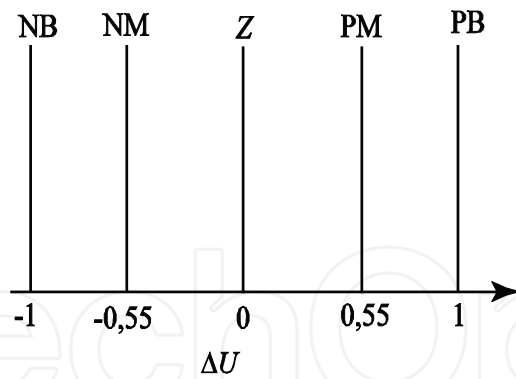Fig. 22. Surface change $\dot{S}$ membership functions

Fig. 23. Output singletons

		S		
		N	Z	P
$\dot{S}$	P	Z	PM	PB
	Z	NM	Z	PM
	N	NB	NM	Z

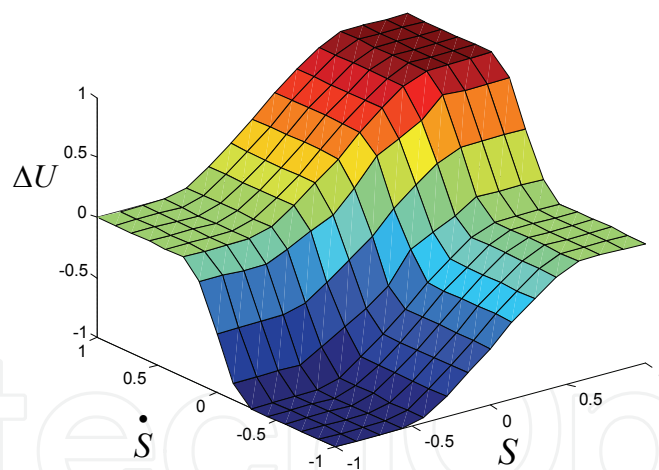Table 5. Rule base of the proposed FSMC

Fig. 24. FSMC control surface

In the following this second class of FSMC will be applied to the Buck and Buck Boost converters.

4.3 Application of the Fuzzy Lyapunov function SMC to Buck and Buck-Boost converters

The proposed Fuzzy Lyapunov function SMC is applied to the Buck and Buck-Boost converter to prove the efficiency of the proposed control law. The obtained results are compared to the classical SMC. As a fuzzy control, the main advantage of the FSMC is that it is not based on an analytical study.

4.3.1 Application of the Fuzzy Lyapunov function SMC to Buck

Fig. 25 presents the simulated output voltage and output current evolutions by application of the proposed FSMC for a reference voltage $V_{ref} = 5V$. The obtained result is similar to the one obtained by SMC.

As the SMC, the SMC is tested experimentally for the case of the load variation. Fig.26 presents the obtained results for the case of the variation of the load resistance from 10 Ω to 15 Ω at 0.05s. The perturbation is rejected and the output voltage attends the reference voltage. Moreover, the amplitudes of oscillations are smaller than those obtained by application of the SMC. As for the SMC, the experimental test result for the case of the input voltage variation from 30 V to 20V, given in Fig.27, shows the robustness of the applied FSMC for this kind of variation.

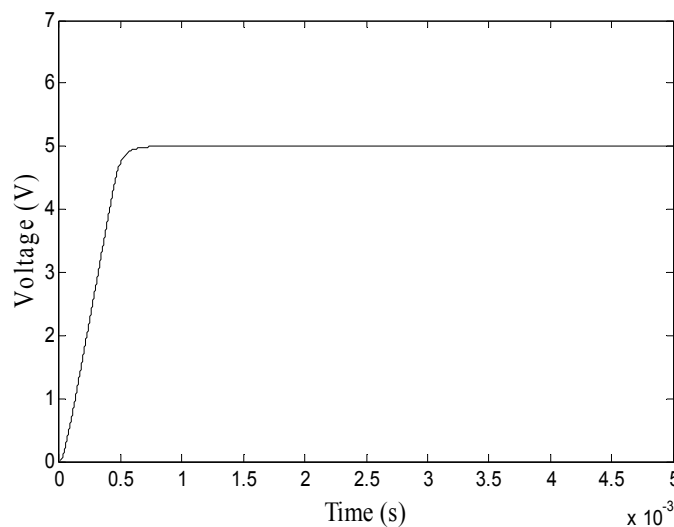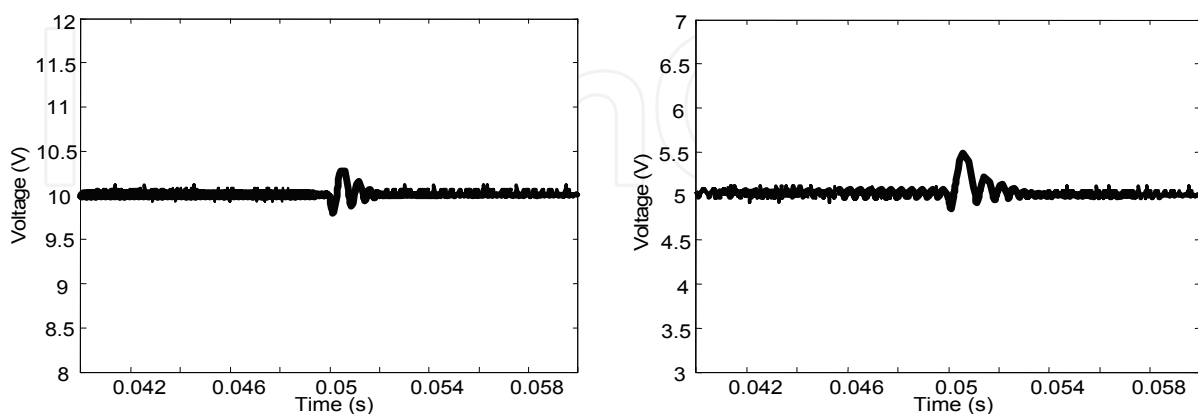Fig. 25. Output voltage evolution by application of the SMC to the studied Buck converter ($Vref = 5V$)

| (a) Reference voltage 10 V | (b) Reference voltage 5 V |

Fig. 26. Experimental test robustness of the FSMC for the variation of the load from 10 Ω to 15 Ω
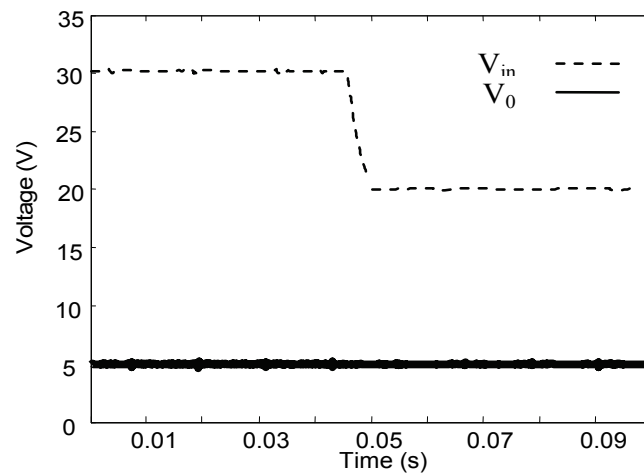
Fig. 27. Experimental output voltage evolution by application of the FSMC for the variation of the input voltage from 30V to 20V

4.3.2 Application of the Fuzzy Lyapunov function SMC to Buck-Boost converter

The proposed control is now applied to the studied Buck-Boost converter. Fig. 28 presents the simulated control signal obtained by application of the proposed FSMC. By comparison with the control signal obtained by application of the SMC and presented in Fig. 13, we notice that the control signal is smooth. So the chattering phenomenon obtained by application of the FSMC disappeared.
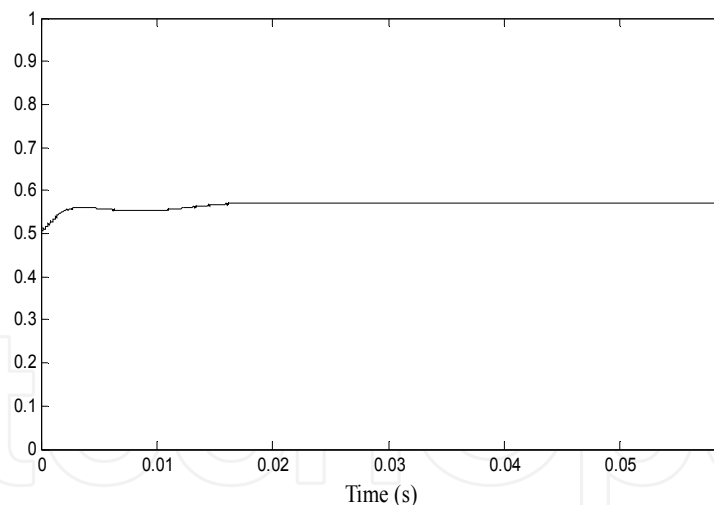

Fig. 28. Control signal by application of the FSMC

Fig. 29 presents the studied converter the output voltages evolution for $V_{ref} = -20V$. The obtained result is better than the one obtained by open-loop control. However, by comparing it with the output voltage presented by Fig. 12 we can notice a small oscillation.

Fig. 30 presents the evolution of the output voltage and the current in the load for a change of the load resistance from 30Ω to 20Ω. By application of the FSMC, this perturbation was rejected and the output voltage attends the reference voltage after $30 \cdot 10^{-3}$ s. For the case of a variation of the input voltage from 15V to 10V at 0.05s the output voltage, presented by Fig. 31, attends after the rejection of the perturbation the desired reference value −20V.
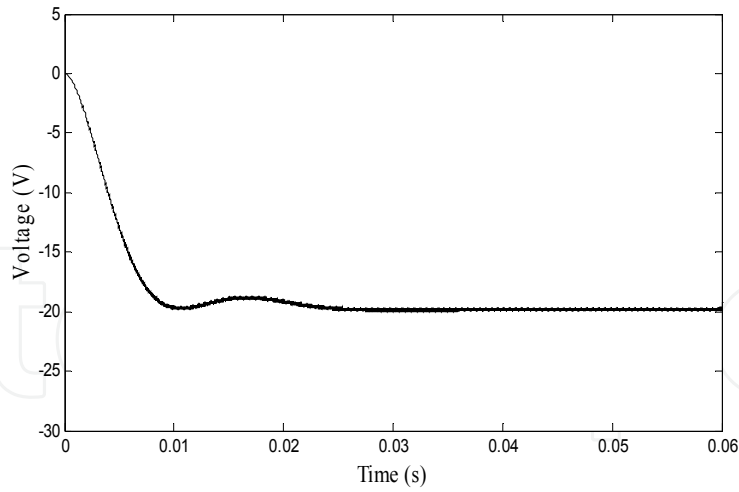
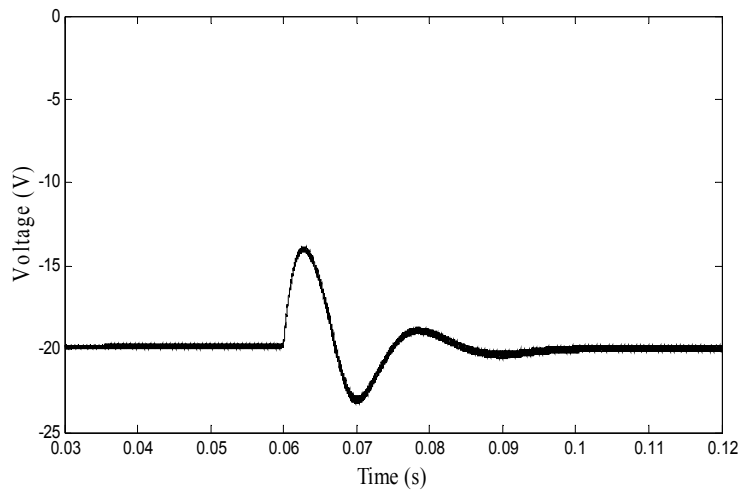Fig. 29. Output voltage evolution obtained by application of the FSMC

Fig. 30. Output voltage evolution by application of the SMC for the case of load variation from 30Ω to 20Ω
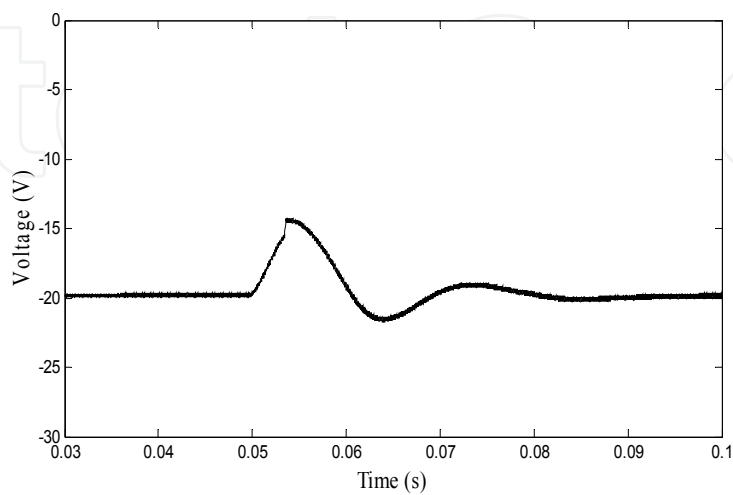

Fig. 31. Output voltage evolution by application of the SMC for the case of input voltage variation from 15 V to 10V

By comparing the robustness test results obtained by application of SMC with those obtained by FSMC we can notice that SMC allows a faster rejection of the perturbation than SMC for the case of the studied Buck-Boost converter.

5. Conclusion

In this chapter, Sliding Mode Control (SMC) and Fuzzy Sliding Mode Control (FSMC) for Buck, Boost and Buck-Boost converters are proposed, tested and compared. SMC is suitable for switched mode DC-DC converters. Moreover, such control approach leads to good results.
Two classical SMC are proposed respectively for Buck and Buck-Boost converters. The obtained simulation and practical results confirm the robustness of this control technique.
The extension of SMC into FSMC aims to improve the SMC robustness and to overcome the chattering problem. Two classes of FSMC are presented in this chapter. The first class of FSMC aimed to reduce chattering by changing the nonlinear component control by a fuzzy function. The second class of FSMC is based on a fuzzy control insuring the Lyapunov function stability. Then, a Fuzzy Lypunov based SMC is developed and applied to the Buck and Buck-Boost converters.
FSMC is not based on a rigorous analytical study as SMC. Thus, the same FSMC can be applied to Buck and Buck-Boost converters. In addition, FSMC allows the reduction of chattering for the case of the Buck-Boost converter thanks to the fuzzy control surface which allows a smooth and continuous control signal. However, the obtained results are nearly similar to those obtained by SMC.

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Sliding Mode Control

Edited by Prof. Andrzej Bartoszewicz

The main objective of this monograph is to present a broad range of well worked out, recent application studies as well as theoretical contributions in the field of sliding mode control system analysis and design. The contributions presented here include new theoretical developments as well as successful applications of variable structure controllers primarily in the field of power electronics, electric drives and motion steering systems. They enrich the current state of the art, and motivate and encourage new ideas and solutions in the sliding mode control area.

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