International Conference on Control, Engineering & Information Technology (CEIT'13)
Proceedings Engineering & Technology - Vol.2, pp. 191-195, 2013

Fuzzy Sliding Mode Control of a Parallel DC-DC Buck Converter

A. Sahbani, K. Ben Saad, M. Benrejeb
LA.R.A. Automatique
Ecole Nationale d'Ingénieurs de Tunis (ENIT), Université de Tunis El Manar,
BP 37, le Belvédère, 1002, Tunis, Tunisia
`abdellazizsahbani@yahoo.fr`

***Abstract*— Nowadays, parallel DC-DC switched converters are commonly used in many applications such as distributed power supply systems and embedded systems to extend battery life. As a single switched mode DC-DC converter topology, a parallel converter must provide a regulated output voltage. For such case the regulation of the voltage must be performed in a closed loop control mode. In this paper, a Fuzzy Sliding Mode Control (FSMC) is developed and applied to a parallel DC-DC converter. Fuzzy Sliding Mode Control is a robust control which combines the benefits of fuzzy logic control and sliding mode control. The efficiency and the robustness of the proposed controller are tested by simulation, with success, for different operating conditions.**

***Keywords*— Parallel DC-DC Buck converter, Fuzzy Sliding Mode Control, Robustness.**

I. INTRODUCTION

Parallel converters have an essential position in modern switched mode power conversion systems. It presents the advantage of allowing reduced switching loses and low load current ripple in comparison with conventional converters. In parallel converters the size and the losses of the filtering voltage are reduced [1-6].

A variety of industrial application of power supplies based on of parallel DC-DC converters like portable electronic devices, microprocessor alimentation and automotive application.

For the dual-voltage automotive application, the electronic power systems converters must provide a regulated output voltage with low ripple rate [5]. 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.

Several closed loop conventional techniques have been applied to parallel converters [5-8]. Among these techniques sliding Mode Control (SMC) was proposed [7]. SMC is a nonlinear control solution suitable for switched mode converters. It is considered to be a robust control strategy against parametric uncertainties [9]. It allows a good output voltage dynamical response. However, the major drawback of SMC is the chattering phenomena [10-11].

A high order SMC can be a solution to the chattering phenomena. However, such control can lead to a complex control law which can not be implemented in practice.

Another solution consists into extending the SMC to a Fuzzy Sliding Mode Control (FSMC). The FSMC provides more robustness and reduced chattering. It is known that Fuzzy Logic Control is suitable for nonlinear or complex systems characterized by parametric fluctuation or uncertainties.

In this paper, a FSMC is proposed for a three parallel DC-DC switching Buck converters. This paper is organized as follows. In section 2 the studied parallel DC-DC Buck converter is presented and modelled. The proposed FSMC is described in section 3. Finally, the simulated test results are given and discussed in section 4.

II. STUDIED PARALLEL DC-DC BUCK CONVERTER MODELING

The structure of the studied parallel DC-DC Buck converter is shown in figure 1.

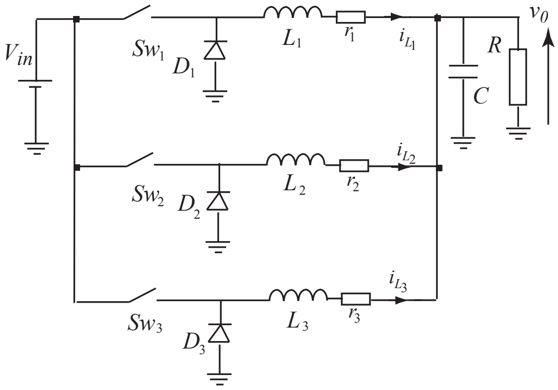

Fig.1. Structure of the studied parallel DC-DC Buck converter

It consists of a three controlled switches (Sw_1 , Sw_2 and Sw_3), a three diodes (D_1 , D_2 and D_3), a three inductors

(L_1 , L_2 and L_3) and their respective equivalent series resistors (r_1, r_2 and r_3), it uses a common DC voltage source delivering the input voltage (V_{in}), a common output filter capacitor (C)) and a load resistance (R).

The mathematical model of the studied converter is given by the following general differential equations system:

$$\begin{cases} \dfrac{di_{L1}}{dt} = -\dfrac{1}{L_1}(r_1 i_{L1} + v_0 - d_1 v_{in}) \\ \dfrac{di_{L2}}{dt} = -\dfrac{1}{L_2}(r_2 i_{L2} + v_0 - d_2 v_{in}) \\ \dfrac{di_{L3}}{dt} = -\dfrac{1}{L_3}(r_3 i_{L3} + v_0 - d_3 v_{in}) \\ \dfrac{dv_0}{dt} = \dfrac{1}{C}(i_{L1} + i_{L2} + i_{L3}) - \dfrac{1}{RC} v_0 \end{cases} \qquad (1)$$

d_1 , d_2 and d_3 take 1 for the on state of the switches and 0 for the off state.

The choice of the state vector $x = \begin{bmatrix} i_{L1} \\ i_{L2} \\ i_{L3} \\ v_0 \end{bmatrix}$ allows the establishment of the following nonlinear state space representation:

$$\begin{cases} \dot{x} = \begin{bmatrix} \dot{i}_{L1} \\ \dot{i}_{L2} \\ \dot{i}_{L3} \\ \dot{v}_0 \end{bmatrix} = A \begin{bmatrix} i_{L1} \\ i_{L2} \\ i_{L3} \\ v_0 \end{bmatrix} + BU \\ v_0 = Cx \end{cases} \qquad (2)$$

where:

$$A = \begin{bmatrix} -\dfrac{r_1}{L_1} & 0 & 0 & -\dfrac{1}{L_1} \\ 0 & -\dfrac{r_2}{L_2} & 0 & -\dfrac{1}{L_2} \\ 0 & 0 & -\dfrac{r_3}{L_3} & -\dfrac{1}{L_3} \\ \dfrac{1}{C} & \dfrac{1}{C} & \dfrac{1}{C} & -\dfrac{1}{RC} \end{bmatrix}; \qquad B = \begin{bmatrix} \dfrac{d_1}{L_1} \\ \dfrac{d_2}{L_2} \\ \dfrac{d_3}{L_3} \\ 0 \end{bmatrix};$$

$$C = [0 \quad 0 \quad 0 \quad 1] \; ; \qquad U = V_{in} \; ;$$

The electrical parameters of the studied buck converter are given in table 1.

TABLE 1

STUDIED PARALLEL DC-DC BUCK CONVERTER PARAMETERS

Parameters	**Values**
V_{in}	42V
C_{eq}	22.10^{-6}F
$L_1 = L_2 = L_3 = L$	1.10^{-3}H
$r_1 = r_2 = r_3 = r$	0.1 Ω
R	7 Ω
Switching frequency	30.0^{3}Hz

III. PROPOSED FSMC

For the three parallel Buck converters we consider the following sliding surface S_j for $j = 1,2,3$:

$$S_j = k_j e_{i_j} + \lambda e_v$$

where k and λ are the sliding coefficient, e_v is the output voltage error defined as follows : $e_v = V_{ref} - v_0$

V_{ref} is the reference voltage and v_0 the converter output voltage.

e_{i_j} is the inductors current error expressed as follows :

$$e_{i_j} = I_{ref} - i_{L_j}$$

So for the studied parallel converter the sliding surfaces are formulated as follows:

$$\begin{cases} S_1 = k_1 e_{i_1} + \lambda e_v = k_1(I_{ref} - i_{L_1}) + \lambda(V_{ref} - v_0) \\ S_2 = k_2 e_{i_2} + \lambda e_v = k_2(I_{ref} - i_{L_2}) + \lambda(V_{ref} - v_0) \\ S_3 = k_3 e_{i_3} + \lambda e_v = k_3(I_{ref} - i_{L_3}) + \lambda(V_{ref} - v_0) \end{cases} \qquad (3)$$

The proposed FSMC is composed by three synchronized fuzzy controllers. Each controller is applied to a converter and each one uses the surfaces S_j and its variation $\dot{S}_j$ as inputs to define the changes on the control signal.

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

$$V = \frac{1}{2} S_1^2 + \frac{1}{2} S_2^2 + \frac{1}{2} S_3^2 \qquad (4)$$

The time derivative $\dot{V}$ of V must be negative definitive $\dot{V} < 0$ to insure the stability of the system and to make the surface attractive.

Thus, the proposed Fuzzy Sliding Mode Control have to force the controlled system to satisfy the inequality $S_1\dot{S}_1 + S_2\dot{S}_2 + S_3\dot{S}_3 < 0$.

For example if $S_j < 0$ and $\dot{S}_j < 0$ the duty cycle of the PWM control signal must decrease and if $S_j > 0$ and $\dot{S}_j > 0$, the duty cycle must increase.

The output signal is the control increment $\Delta U_j(k)$ which is used to update the control law. Thus, the control signal is defined as follows:

$$U_j(k) = \Delta U_j(k) + U_j(k-1) \tag{5}$$

Trapezoidal and triangular membership functions, denoted by NB (Negative BIG), NM (Negative Middle), Z (Zero) and PM (Positive Middle) PB (Positive BIG), were used for both the surface and the surface change. They are respectively presented in figure 2 and figure 3 in the normalized domain $[-1 \;\; 1]$.

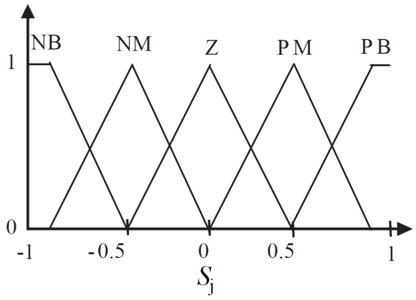

Fig.2. Surface S_j membership functions

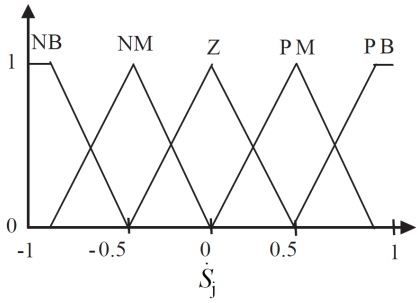

Fig.3. Surface change $\dot{S}_j$ membership functions

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_j

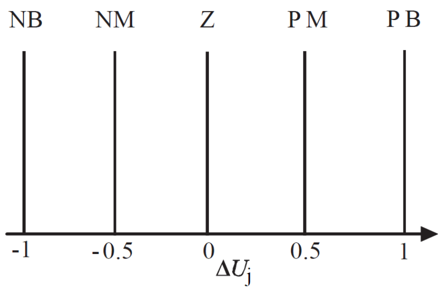

Fig.4. Output singletons

The normalized control surface of the proposed Fuzzy Sliding Mode Control, corresponding to the Rule Base given in table 2, is represented in figure 5. Such surface shows clearly the nonlinear characteristic of the proposed control law.

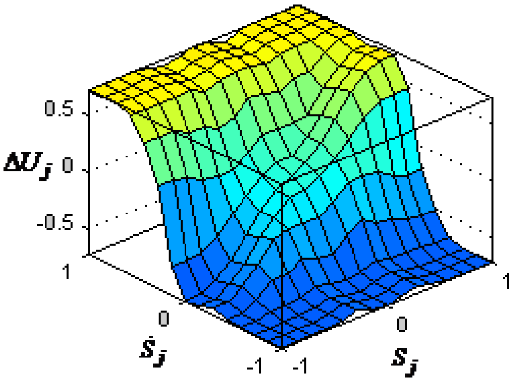

Fig.5. The FSMC surface

TABLE 2. RULE BASE OF THE PROPOSED FSMC

S_j

		PB	PM	Z	NM	NB
$\dot{S}_j$	NB	Z	PM	PB	PB	PB
	NM	NM	Z	PM	PB	PB
	Z	NB	NM	Z	PM	PB
	PM	NB	NB	NM	Z	PM
	PB	NB	NB	NB	NM	Z

The proposed control diagram is presented in figure 6 where k_1, k_2, k_3, k_4, k_5 and k_6 are the scaling factors.

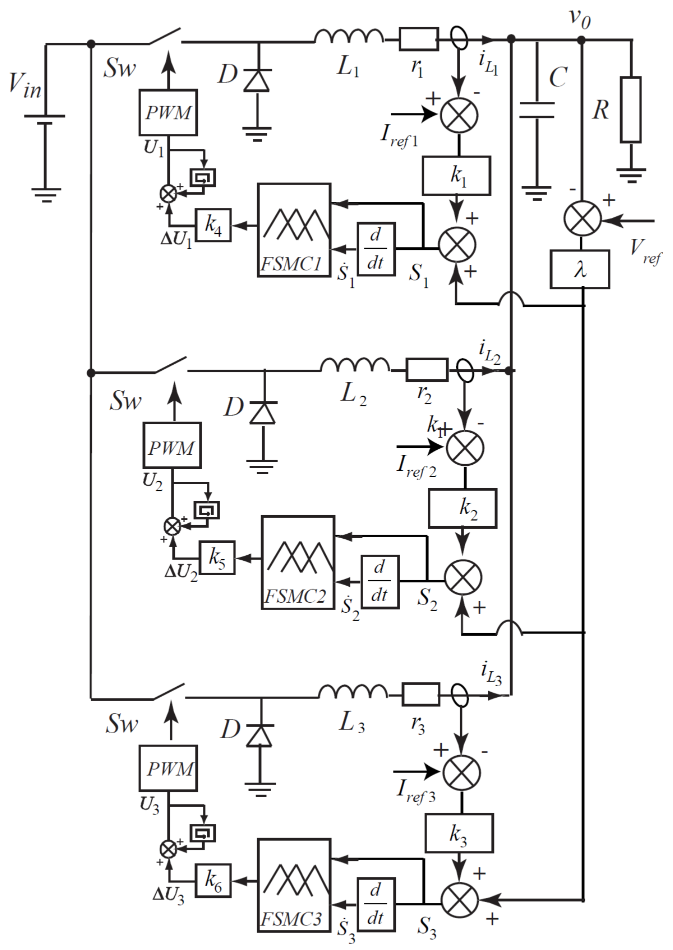

Fig.6. Block diagram of the proposed FSMC

IV. SIMULATIONS RESULTS

The proposed FSMC was tested by simulation. Figure 7 gives the simulated voltage step response of the studied parallel DC-DC Buck converter for 14V reference voltage.

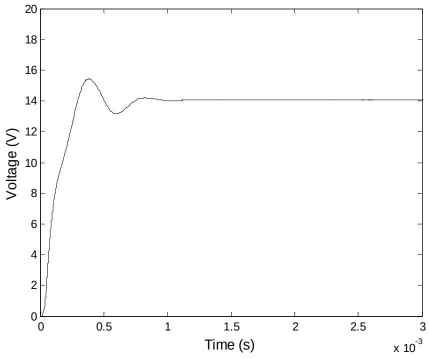

Fig.7. Output voltage evolution by application of the FSMC

Figure 8 presents the obtained load current evolution. From the obtained results, we can conclude that the dynamical behaviour of the transient state voltage response obtained by the FSMC is better than the one obtained by SMC.

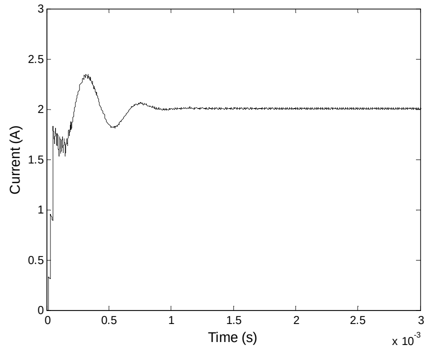

Fig.8. Load current evolution by application of the FSMC

Figure 9 presents the evolution of the output voltage for a change of the load resistance from 7Ω to 5Ω at 0.005s. We can notice that the FSMC rejects such perturbation. However, SMC allows a faster rejection of the perturbation than FSMC for the case of the studied parallel DC-DC Buck converter.

Figure 10 presents the output voltage evolution when the input voltage varies from 42V to 30V. We can notice that the FSMC rejects such perturbation.

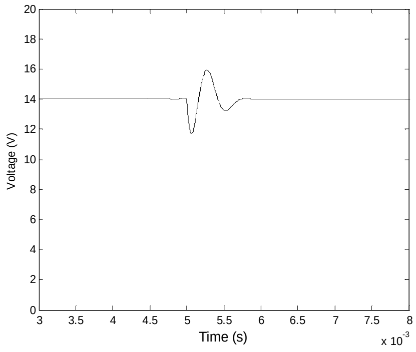

Fig.9. Output voltage evolution by application of the FSMC for the case of load variation from 7Ω to 5Ω

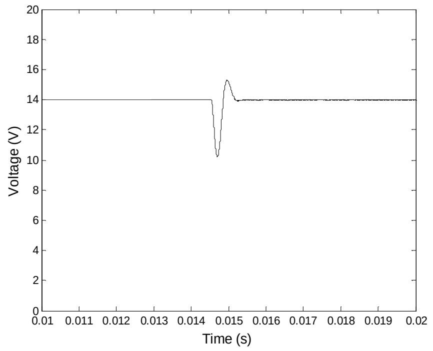

Fig.10. Output voltage obtained for the case of the input voltage variation from 42V to 30V

Figure 11 presents the obtained inductor current ripple for each converter and figure 12 presents the obtained load current ripple

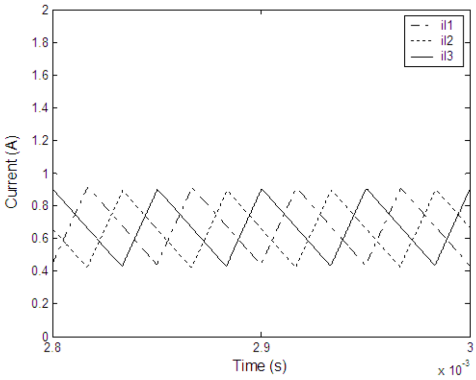

Fig.11 Three inductors current ripple

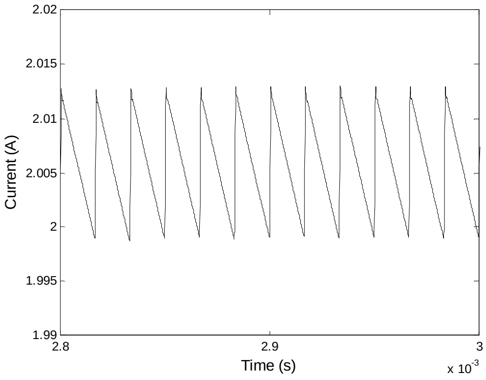

Fig.12. Load current ripple

V. CONCLUSION

In this paper, we propose FSMC applied to a three parallel DC-DC Buck converter. The major advantage of FSMC is that it is not based on the mathematical model of the controlled DC-DC parallel converter as SMC.

The proposed control is based on synchronized and identical fuzzy logic controllers. The input signals of each fuzzy controller are the surface and the surface variation of each one of the two converters. So, the proposed fuzzy sliding mode control defines the control signal to satisfy the stability and the attraction condition of the sliding surfaces.

The proposed control law was tested by simulation. The obtained results show the robustness of the proposed FSMC against variation of the input voltage and the load resistance.

REFERENCES

[1] B. Choi, Comparative Study on Paralleling Schemes of Converter Modules for Distributed Power Applications, IEEE Trans. Industrial Electronics, vol. 45, no. 2, pp. 194-199, April 1998.

[2] J. Liu, W. Xu, Y. Qiu, and J-H. Park, A comparative evaluation of current-sharing methods for paralleled power modules, Proceedings of the Virginia Power Electronics Center Seminar VPEC'01, Virginia, pp. 361–366, 2001.

[3] Y. Huang, et C-K. Tse, Circuit Theoretic Classification of Parallel Connected DC–DC Converters, IEEE trans. Circuits and Systems, vol. 54, no. 5, pp. 1099-1108, May 2007.

[4] C-H. Cheng, P-J. Cheng, M-J. Xie, Current sharing of paralleled DC–DC converters using GA-based PID controllers, Expert Systems with Applications, vol. 37, pp. 733–740, 2010.

[5] M-A. Shrud, A-H. Kharaz, A-S. Ashur, A-Faris and M. Benamar, Analysis and simulation of automotive interleaved Buck converter, Journal of the World Academy of Science Engineering and Technology, vol. 63, pp. 10-17, 2010.

[6] X. Liu, J. Deng, Y-F. Liu and P. Yang, Research and Simulation of Parallel Current-Mode Controlled Buck Converter, Proceedings of the 3rd IEEE Conference on Industrial Electronics and Applications ICIEA 2008, pp. 423-428, Singapore, 3-5 June 2008.

[7] M. López, and all, Current Distribution Control Design for Paralleled DC-DC Converters Using Sliding-Mode Control, IEEE Trans. Industrial Electronics, vol. 51, no. 2, pp. 419-428, 2004.

[8] R-J. Wai, et Y-C. Chen, Automatic Fuzzy Control Design for Parallel DC-DC Converters, Proceedings of the International MultiConference of Engineers and Computer Scientists, IMECS 2009, vol. 1, Hong Kong,March 2009.

[9] V.I. Utkin, Variable structure systems with sliding modes, IEEE Transactions on Automatic Control, vol. 22, no. 2, pp. 212-222, April 1977.

[10] A.Sahbani, K.Ben Saad and M.Benrejeb, Chattering phenomenon suppression of buck boost dc-dc converter with Fuzzy Sliding Modes control, International Journal of Electrical and Electronics Engineering (IJEEE), 4:1, pp.1-6, 2010.

[11] R. Palm, Sliding mode fuzzy control, proceedings of the IEEE international conference on fuzzy systems, pp. 519-526, March 1992.