3rd International Conference on Automation, Control, Engineering and Computer Science (ACECS'16)
Proceedings of Engineering & Technology (PET)
pp. 239-244

Control of DC-DC Boost Converter using sliding mode and synergetic theory

Ettouil Radhia
National School of Engineering of Gabes
Gabes University
Rue Omar Ibn El Khattab, Gabes 6029, Tunisia
Email: radhiaettouil@gmail.com

Chabir Karim and Abdelkrim Mohamed Naceur
National School of Engineering of Gabes
Gabes University, Tunisia
Email: karim.chabir@yahoo.fr
Email: Naceur.Abdelkrim@enig.rnu.tn

Essounbouli Najib
University Institute Of Technology Troyes
Troyes, France
Email: najib.essounbouli@univ-reims.fr

***Abstract*—The theory of sliding mode control(SMC) and the synergetic control are introduced. The connections of synergetic control design and the methodology of sliding mode controller are established. The operating mode of DC-DC Boost Converter is presented.In this paper we applied the SMC and the synergetic theory to control of the boost converter The comparison between the two type of controller Converter is discussed. The limit of SMC is presented. The simulation results of both type of control are compared to validate effectiveness of synergetic approaches.**

I. INTRODUCTION

The control of the non-linear system is an interesting challenge. A boost converter is a switching power supply that converts DC voltages into another DC voltages of higher value. The converter operation can be divided into two distinct phases according to the state of the switch. The control of the power converter is very challenging. In fact this type of system is non-linear time-varying system which makes the worst condition for control design. Many types of controller are implemented for the power converter system such as classical PID controller [1],[2] and [3]. However, they failed to satisfy some performance constraints, as under large parameter variations and load disturbance [4].

Other approaches are designed to control the power converter using the intrinsic non linearity and time variation for the control purpose, the Siding Mode Control (SMC) is a significant example of these approaches [5],[6],[7],[8] and [9]. Furthermore, the synergetic control is also implemented. It tries to overcome the problem of controlling of power converter by using the internal dynamic characteristics of the system, the most important advantages of this approach are order reduction, decoupling design procedure, and insensitivity to parameter changes [10],[11].
In this paper a comparison between sliding mode control and synergetic control are presented. This paper is organized as follows: Section II presents the synergetic control and the SMC.Section III shows the control of DC-DC boost converter using sliding mode control first and then using the synergetic control law after. In section IV the simulation results are proved. Concluding remarks are drawn in section V.

II. CONTROL FOR NON-LINEAR SYSTEM

A. Sliding Mode Control

We consider a nonlinear system modeled by:

$$\dot{x}(t) = A(x) + B(x)u(t) \quad (1)$$

Where $x \in \mathbb{R}^n$ and $u \in \mathbb{R}^m$ are respectively system state and the control input vector The principal of variable structure control is to force the system trajectories to evaluate in a desired surface, so called sliding surface, and to maintain the system along this surface.
We develop next a general method to control and stabilize nonlinear systems based on sliding mode control approach. It is two steps approach that force the system to follow a specific trajectory.
The first step is the construction of the manifold such as:

$$s(x) = 0 \quad (2)$$

Where $s(x)$ is the manifold, it can be a linear or nonlinear function of states system according to the system constraints. Two conditions have to be satisfied in the sliding mode control:

$$s(x) = 0 \quad and \quad \dot{s}(x) = 0 \quad (3)$$

The second step is to determine the control law solving the following equation:

$$\dot{s}(x) = 0 \quad (4)$$

using (1)

$$\begin{aligned}\dot{s}(x) &= 0 \\ &= s_x(x)(A(x) + B(x)u_{eq})\end{aligned} \quad (5)$$

In literature, the variable structure sliding mode controller is described by

$$u = u_{eq} + u_s \quad (6)$$

According to (5)

$$u = -(s_x(x)B(x))^{-1}(s_x(x)A(x) + u_d) \quad (7)$$

u_s is a discontinuous component that guarantees that the system stays on the sliding surface.

ISSN: 2356-5608

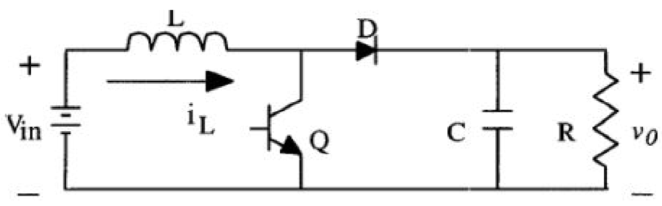

Fig. 1. Boost converter with a switching period of T and a duty cycle of u.

B. Synergetic Control

Both controller have the same principal to steer the system states to the manifold and then to force the trajectories to stay along the surface.
The discontinuous term of the control law can generates oscillations on the sliding function and can even leads to instability. In order to prevent this problem, we use the synergetic approach. The idea is that the controller approaches the manifold exponentially solving the first-order differential equation:

$$T\dot{s}(x) + s(x) = 0 \tag{7}$$

Where $T = T^T \succ 0$ is a design parameter matrix.
Solving (7) we synthesize the synergetic control law as following:

$$\begin{aligned} u_{syn} &= -(TS(x)B(x))^{-1}(TS(x)A(x)) - -(TS(x)B(x))^{-1}S(x) \\ &= u_{eq} + u_d \end{aligned} \tag{8}$$

The control law given by (8) does not include any discontinuous part, which proves that the synergetic control eliminates the chattering phenomenon. We can also conclude that u_d is a linear approximation to the switching component u_s.

III. Control Of Boost Converter

The boost converter is used throughout the paper as example to simulate the SMC and the synergetic control.A boost converter is a switching power supply that converts DC voltages into another DC voltage of higher value. The converter operation can be divided into two distinct phases according to the state of the switch.

The averaged model of the converter is:

$$\begin{aligned} \dot{x}_1(t) &= -\frac{x_2}{L}(1-u) + \frac{1}{L}V_{in} \\ \dot{x}_2(t) &= \frac{x_1}{C}(1-u) - \frac{x_2}{RC} \\ 0 &\leqslant u \leqslant 1 \end{aligned} \tag{9}$$

where $x1$ and $x2$ are respectively the inductor current, and the capacitor voltage This converter is controlled using sliding mode control and synergetic control. In both cases the control drives states trajectory of the system to the desired manifold. In designing of control for the two methods, u must satisfy the limitation on the duty cycle.

A. Sliding Mode Control

As presented in (9) the control u appears in both the current and voltages equations, which makes the control of the output voltage for the boost converter more difficult. Therefore, the voltage control using SMC is not acceptable because the zero dynamics with respect to the output voltage are unstable. So that for designing the proposed method, we need which called Cascade control for DC to DC Boost Converter [5]. In fact, two closed loop are required: PI controller as the voltage controller, and the second one is the sliding mode controller used to current control, it needs the output of the first loop as the current reference.
For designing the SMC, at the first we should choose the sliding surface which is, in our case, a linear function of the current:

$$\begin{aligned} s(x) &= x_1 - x_{1ref} \\ &= I - I_{ref} \end{aligned} \tag{10}$$

The reference current $x1ref$, as mentioned above, is the output of the PI control loop. This sliding surface must satisfy the convergence condition to guarantee that the state trajectory of system converges to the surface:

$$s\dot{s} < 0 \tag{11}$$

For this converter with the sliding mode the convergence condition is satisfied [9].
The sliding mode controller has two parts: an equivalent control law that forces the system states to the sliding surface, and switching control law that maintains it in this surface. In our case the sliding mode theory is applied to boost converter and equation of the control input can be written as:

$$\begin{aligned} u &= u_{eq} + u_s \\ &= 1 - \frac{V_{in}}{V_0} + \frac{1}{2}(1 - \mathrm{sgn}(s)) \end{aligned} \tag{12}$$

In the following section, we will present the synergetic approach.

B. Synergetic Control

The proposed control has the same objective as the sliding mode control, it will force the state trajectory to operate on the manifold $S = 0$. The manifold is selected according to system constraints. It can accord a new constraint on the states spaces domain and can also reduce the order of the system.In general the manifold is a linear function of the state variables.
The idea is that this controller approaches to the manifold exponentially as described by:

$$T\dot{s}(x) + s(x) = 0 \tag{13}$$

where T is the convergence parameter that specify the convergence speed of states system to the manifold. The control law u is synthesized from (13).
This procedure can be easily implemented as a computer program for automatic synthesis of the control law or can be performed by hand for simple systems, such as the boost converter used for this study, which has a small number of

state variables [10].
Now, let us applied the procedure described above to dc-dc boost converter.
Our goal for this system is to synthesize a control law u that drives trajectory states to get the reference output voltage $x2ref$, therefore the reference current $x1ref$.
First of all, we will choose the macro-variable, in this paper we will compare two approaches SMC and synergetic control, so that we have to use the same manifold as the previous section.

$$s(x) = x_1 - x_{1ref} \tag{14}$$

For the SMC a PI control loop is requires for output voltage control and also for getting reference current. While for synergetic control we use just one loop to regulate the current. Once the reference current is gotten, automatically the output voltage get her desired value. Substituting $s(x)$ in(13):

$$T\dot{x}_1 + (x_1 - x_{1ref}) = 0 \tag{15}$$

Replacing the derivative $\dot{x}_1$ by its expression and solving duty cycle u from (9), we obtain the following control law:

$$u = 1 - \frac{\frac{1}{L}V_{in} + \frac{x_1 - x_{1ref}}{T}}{\frac{x_2}{L}} \tag{16}$$

According to this control law, the state trajectory $x1$ operates on the manifold $s = 0$ with a convergence speed T. Thereafter, the output voltage $x2$ gets its reference and they will stay on this manifold at all times. The control law (16) will be used for the simulation, but in hardware experiments another equations are used [3].

IV. Numerical Example

A Dc-Dc Boost converter with the parameters described in Table 1 was designed.

TABLE I
BOOST CHARACTERISTIC

Vin	L	C	R	F
14V	11.5H	77F	62.98	10KHz

In order to verify and compare the performance of the converter using the two proposed controllers: sliding mode controller and the synergetic controller simulation models have been developed using Simulink.
First for the sliding mode control two loops are used, PI control loop for voltage regulation and the output of which is the current reference and further sliding mode controller is proposed for current regulation.
The desired output voltage is set to Vout=80V.

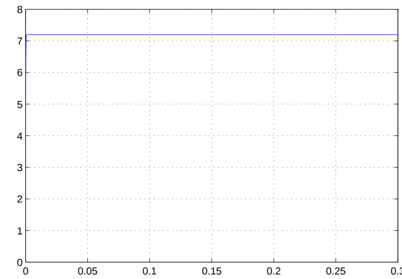

Fig. 2. Current evolution using synergetic control

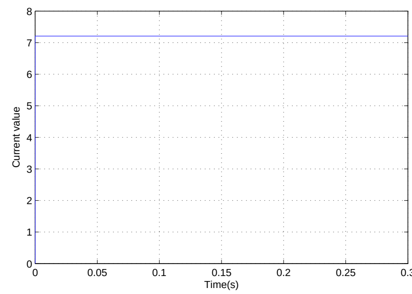

Fig. 3. Current evolution using sliding mode control

The simulation results of both controllers presented by Fig 2 and Fig 3: Current evolution with sliding mode control and synergetic control prove the efficiency of these control laws. Fig.4 and Fig.5 shows that the output voltage evolution of DC to DC boost converter using the sliding mode control and synergetic control with different value of T. As it showing With $T = 0.0001$ the synergetic controller has the same performance as SMC. As a comparison between the two proposed controls we remark that with synergetic control the tracking time is $Tt = 0.014s$, however, with SMC $Tt = 0.017s$. Therefore, as mentioned above, the last one need another cascade loops, PI loop to voltage regulation because the voltage control using SMC theory is not acceptable. This proves that synergetic control is simpler to implement, and the current regulation lead directly to a voltage regulation as it shows in Fig. 3.

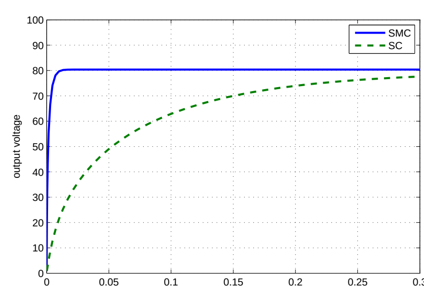

Fig. 4. output voltage with $T = 0.1$

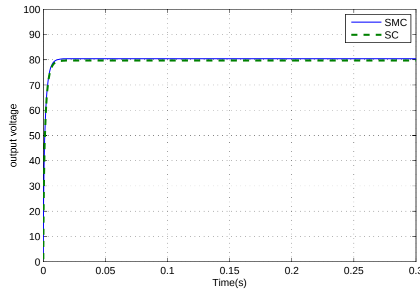

Fig. 5. output voltage with $T = 0.0001$

As it shown the output voltage for two type of controller have the same dynamic evolution. In addition, the synergetic control has always the advantage that it is didnt need another loop to voltage regulation unlike the SMC. Moreover, for the synergetic control, the tracking problem using a constant reference input could be reformulated in both terms: the voltage and current as it shown in [9]. As comparison between synergetic control and sliding mode control we conclude:

- Sliding mode control gives a variable switching frequency, whereas, the synergetic control gives a constant one.
- Synergetic control is suitable for digital implementation more than the other approach.
- The first one is more insensitive to high-frequency noise.

To improve the insensibility of the two type of control we will variate the input voltage at the first time and after we will variate the load value.

A. Simulation with input voltage variation

To simulate line disturbance, we change the value of the input voltage from the initial value 14 V to 16 V at the time 0.2 sec. Simulation results for both type of control, SMC and synergetic control are shown in Fig.6.

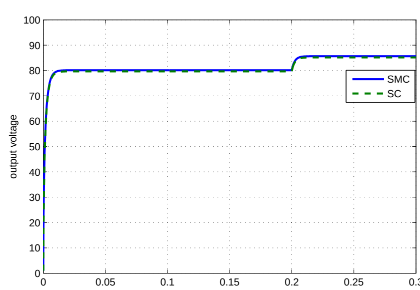

Fig. 6. SMC current controller and synergetic controller for DC to DC boost converter under line disturbance

B. Simulation with load variation

To simulate load disturbance, we variate the load value as follows :

- R=62.98 at the first
- R=70 at the time 0.1 sec
- R=80 at the time 0.18 sec
- R=90 at the time 0.24 sec

Simulation results for both type of control, SMC and synergetic control are shown in Fig.5.

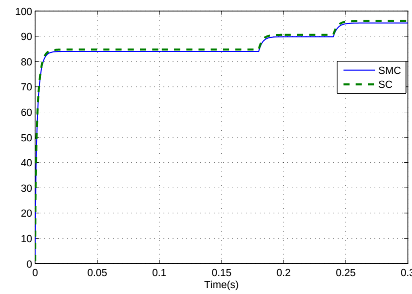

Fig. 7. SMC current controller and synergetic controller for DC to DC boost converter under load disturbance

Both Fig.5 and Fig.6 show that the SMC and the synergetic controller have the same dynamic performances. The dynamic performance as: Tracking time, Steady state error and Settling Time. Also, it shown that both synergetic control and sliding mode control are highly insensitive to parameter variation.

V. Conclusion

In this paper sliding mode control has been applied in closed loop control of DC to DC boost converter to current regulation using Cascade control technic. In fact, two closed loop are required: PI controller as the voltage controller and the second one is the sliding mode controller used to current control. The synergetic control has been also developed, it control at the same time the current and the voltage without using another loop cascade to voltage regulation. Both types of control have the same objective is to obliged the system to converge to a manifold, but each types have its own characteristics. That is why, the two approaches were compared. Also the load disturbance and the line disturbance improve that the synergetic control law is highly insensitive to parameter disturbance. After comparison its improved that last one is more suitable for the example of DC to DC boost converter.

References

[1] S. Arulselvi, G. Uma and M. Chidambaram, *Design of PID controller for boost converter with RHS zero*, 4th International Power Electronics and Motion Control Conference (IPEMC 2004), China: 14-16 august 2004.

[2] L. Guo, J.Y. Hung and R. M. Nelms, *Design and implemenation of a digital PID controller for a buck convert*, Proceedings of the 36th Intersociety Energy Conversion Engineering Conference, July/August 2001.

[3] H. Mingzhi and X. Jianping, *Nonlinear PID in Digital Controlled Buck Converters*, Applied power electronics conference APEC 2007. 1461-1465, USA: Anahein CA, 2007.

[4] V.S.C Racirah and P.C Sen, *Comparative Study Of Proportional- Integral Sliding Mode, and Fuzzy Logic Controllers for Power Converters*, IEEE Transactions On Industry Applications, vol. 33 no. 2, pp 518- 524,China: 14-16 august , 1997.

[5] A. Kumbhojkar and N. Patel, *A Sliding Mode Controller with Cascaded Control Technique for DC to DC Boost Converter*, International Conference on Circuit, Power and Computing Technologies [ICCPCT], 2014.

[6] J. Mahdavi, A. Emadi and H.A. Toliyat, *Application of State Space Averaging Method to Sliding Mode Control of PWM DC DC Converters*, IEEE Industry Applications Society, New Orleans, Louisiana, October 5-9, 1997.

[7] Viji Vijayakumar, Divya Rand Vivek A, *Sliding Mode Controlled Quadratic Boost Converter*, International Conference on Computation of Power, Energy, Information and Communication (ICCPEIC) , 2014.

[8] A.Singh and S.Purwar, *Sliding Mode Controller for PWM based Buck-Boost DC/DC Converter as State Space Averaging method in Continuous Conduction mode*, 2nd International Conference on Power, Control and Embedded Systems , 2012.

[9] H.Guldemir, *Sliding Mode Control of Dc-Dc Boost Converter*, Journal of Applied Sciences 5 (3): 588-592, 2005. ISSN 18125654., 2012.

[10] E.Santi, A.Monti, D.Li, K.Proddutu, and R.A.Dougal, *Synergetic Control for DCDC Boost Converter: Implementation Options*, Ieee Transactions on Industry Applications, vol. 39, no. 6, november/december 2003.

[11] A. Kolesnikov, G. Veselov, A. Monti, F. Ponci, E. Santi and R. Dougal, *Synergetic Synthesis Of Dc-Dc Boost Converter Controllers:Theory And Experimental Analysis*, IEEE, China: 14-16 august 2004.