Sliding Mode Control for a Buck Converter

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Abstract: - Chaotic behaviors of the buck converter were demonstrated by computer simulation studies. The paper implied theoretical considerations and simulations for this kind of converter using a sliding-mode control. The method tried to establish a periodic behavior from a chaotic one in converter behavior.

Key-Words: - buck converter, sliding-mode, control, bifurcation, periodic, chaotic

1 Introduction

These years, the possibility of controlling nonlinear chaotic systems has been the subject of research. The first mention that chaos could be important in a real physical system, was given by Lorenz, who discovered the extreme sensitivity to initial conditions in a simplified computer model of athmosferic conduction. Chaotic effects in electronic circuits were first noted by Van der Pool.

High efficiency solid state power conversion has become possible through the continuing development of high power semiconductor devices. The operation of these devices as switches, which is necessary for high efficiency, means that power electronic circuits are essentially nonlinear time varying dynamical systems. Many practical applications are becoming increasingly important in delivery and utilization of electrical energy [6-7,9].

It was proved that many unstable periodic orbits can transform in a periodic behavior using different control methods[1-5, 8].

2 Converter operation

The buck converter is one of the simple but most useful power converters, a chopper circuit that converts a dc inputs to a dc output at a lower voltage. The basic open loop buck converter is shown in Fig.1.

The functionality of the circuit can be described by the following dynamical system with variable structure:

$$\begin{cases} \dot{x}_1 = -\dfrac{1}{L}x_2 + \dfrac{(1-d)}{L}V_{in} \\ \dot{x}_2 = \dfrac{1}{C}x_1 - \dfrac{1}{RC}x_2 \end{cases} \quad (1)$$

where *d*=0 means the switch S is "on" and 1 means the switch is "off".

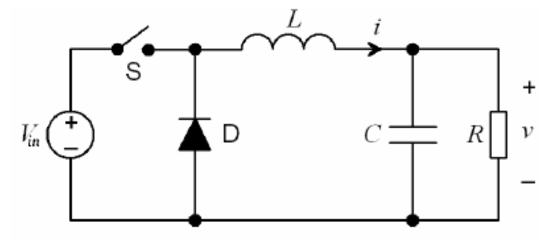


Fig. 1 Buck converter

The values for the circuit elements are R=15[Ω]; L=12[mH]; C=20[μF]; V_{in}=5[V][2].

The bifurcation diagram for this circuit is shown in Fig.2. It can be observed that the circuit exhibits a chaotic behavior[10].

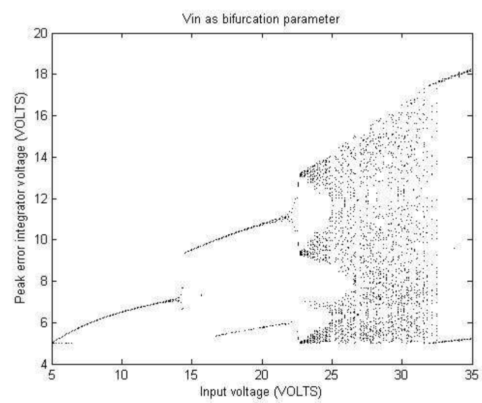


Fig. 2 The bifurcation diagram for the buck converter

The diagram shows the period doubling and after that, chaos. The first period doubling occurs at less than 15 V for the input voltage. The second period doubling occurs at about 23 V. After 25 V for input voltage we can observe that the system has a chaotic behavior, but at about 32 V the system becomes periodic again.

3 Theoretical background

Sliding mode control is a variable structure control, where the dynamics of a nonlinear system is altered via application of a high-frequency switching control. Sliding mode control proved to have good performance when dealing with nonlinear systems with time-varying parameters and uncertainties. The main goal of a sliding mode control is to drive the state trajectory of a nonlinear plant on a user-chosen hypersurface, called switching hypersurface, in the state space, and to maintain the plant's state trajectory on this surface for subsequent time. Given a nonlinear system described by:

$$\dot{x}(t) = f(x,t) + B(x,t)u(t) \quad (2)$$

where $x(t) \in R^n$, $B(x,t) \in R^{nxm}$, *f(x, t)* and *B(x, t)* are continuous and smooth enough.

The first step in designing a sliding mode control for the nonlinear system described by (2), is to choose a so called switching function *σ(x)*. The equation *σ(x) = 0* identifies the switching surface.

$$\sigma(x) = [\sigma_1(x), \sigma_2(x), \ldots, \sigma_m(x)] \quad (3)$$

The second step consists of designing the control law (4) so that the system will reach the switching surface no matter what are the initial conditions, and once the switching surface was reached the system will stay on that surface.

$$u(x,t) = \begin{cases} u^+(x,t), & if\ \sigma(x) > 0 \\ u^-(x,t), & if\ \sigma(x) < 0 \end{cases} \quad (4)$$

In the control theory there have been proposed different methods to design the sliding mode control law, but we will stop just at one of these methods, the Lyapunov approach, which is described below.

Consider the following Lyapunov function:

$$V(\sigma(x)) = \frac{1}{2}\sigma^T(x)\sigma(x) \quad (5)$$

For the nonlinear system given by (2) and the switching surface defined by (3), a sufficient condition for the existence of sliding mode is:

$$\frac{dV(s)}{dt} = \sigma^T(x)\sigma(x) < 0 \quad (6)$$

in a neighborhood of *σ=0*. Thus from equation (5) one can compute the parameters of the sliding mode control (3).

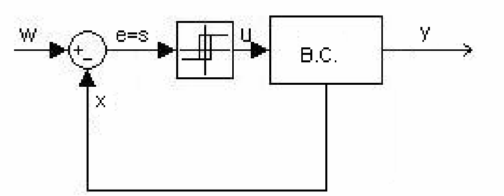
The most important advantages of the sliding mode control are: the ability to control higher order systems, and the fact that it does not require the system to be continuous. One of the main drawbacks of the sliding mode control is due to the fact that once the switching hypersurface was reached, the system should stay on that surface and slide along it, but in order to achieve this the system should switch infinitely fast, which is not possible in real life. Thus the sliding mode control introduces the so cold chattering effect.

In this paper we will use the following type of switching function:

$$s(t) = e(t) = w(t) - x(t) \quad (7)$$

In Fig.3 it is presented the block diagram of the controlled system, using a sliding mode controller:

Fig. 3 Block diagram for the sliding-mode controller



where w is the reference signal, x is the state of controlled system, e is the control error, u is the control signal (output of a hyteresis block), B.C. is the buck converter, and y is the output signal.

4 Results

We have performed the simulations with the controller presented above. The simulation was done basis on several plans. The first plan was the bifurcation diagram. In Fig.2 we obtained a bifurcation diagram for the buck converter. After we have applied the sliding-mode control the bifurcation diagram for the system is:

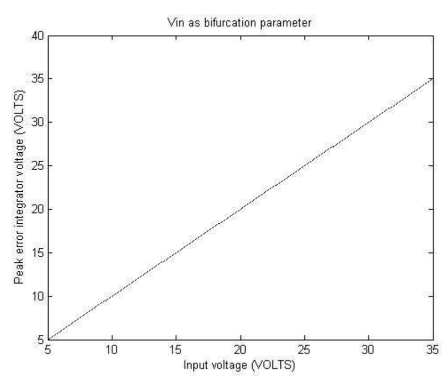


Fig. 4 Bifurcation diagram for the buck converter after sliding-mode control was applied

The second plan for our investigations was the states of the systems. In Fig.5 we present the dependence between the output voltage and the current amplitude for V_{in}=26.70 V. For these values it is obvious that the system exhibits chaotic behavior from the bifurcation diagram. Fig. 5 confirms this.

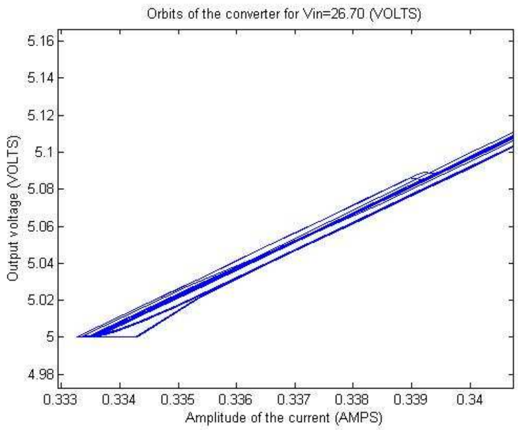


Fig. 5 The dependence between output voltage and amplitude of the current, for V_{in}=26.70 V before control

The control changes the orbits like in Fig.6, so the system becomes a periodic one.

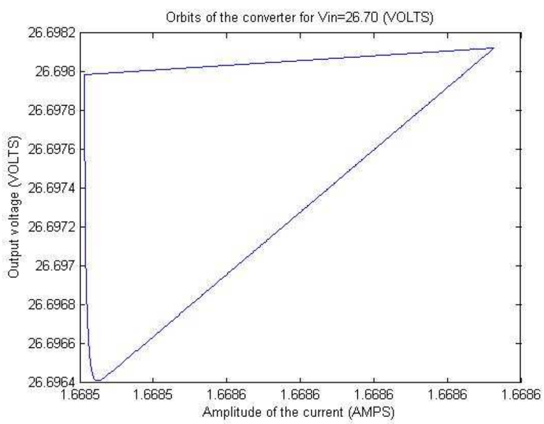


Fig. 6 The dependence between output voltage and amplitude of the current for V_{in}=26.70 V after control

These diagrams show that the chaotic behavior of the converter was transformed in a periodic one after the control was applied.

For the quality of the control we have used the waveforms for the current and voltage. In Fig.7 and Fig.8 are presented the output voltage and the output current for the same value for V_{in}. The control is quick and the system becomes stable. For the output voltage it could be observed that after 0.025 seconds the output voltage manifests a little instability. In Fig.9 we have zoomed in the zone between 0.04 and 0.05 seconds, and the chattering phenomenon can be observed. The difference between the voltage peaks is about 0.02 V. For the V_{in}=26.70 V this value could be neglected. This chattering phenomenon is characteristic for the sliding-mode control and could be attenuated with a PID structure added to the controller.

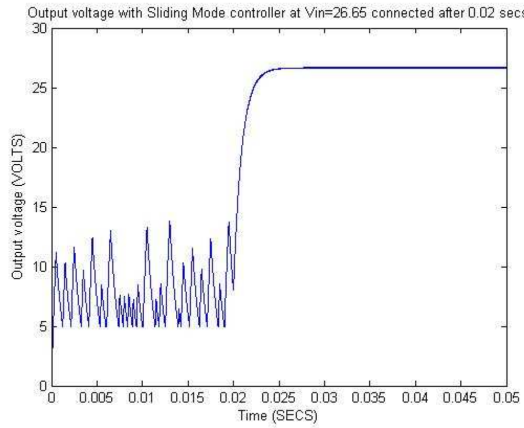


Fig. 7 Waveforms for the output voltage with the control applied after 0.02 seconds

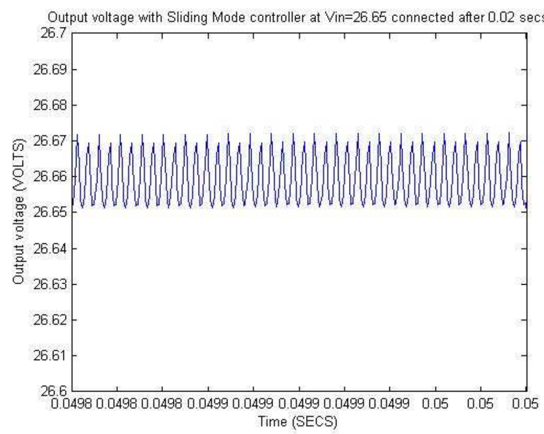


Fig. 8 Waveforms for the output current with the control applied after 0.02 seconds

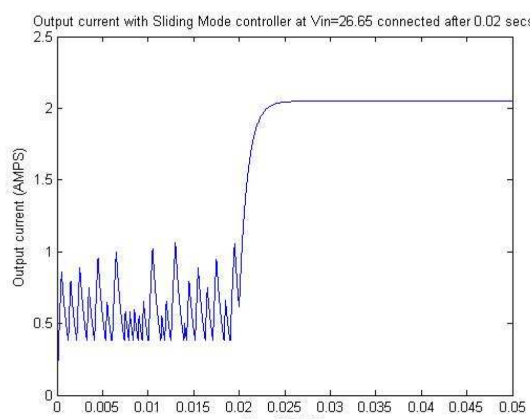


Fig. 9 The chattering phenomenon for the sliding-mode control

However, the system becomes a periodic one without the PID structure added to the controller.

5 Conclusion

A sliding-mode control strategy is proposed in order to avoid the unstable chaotic regimes of the behavior of a buck converter and to ensure the stable periodic operation required by application.

The proposed method solves the chaotic behavior with good time response and with neglected chattering effects. In practice the method has the advantage that is very easy to implement on a microchip board.

Switching surface control, with sliding-mode control and hysteresis control is a tool of variable structure system well suited to power electronic converters. The applications of these controllers in power electronics continue to expand.

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