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Non-smooth Dynamics in Ramp-controlled and Sine-controlled Buck Converters

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Abstract: The DC-DC Buck converter is a power converter system that converts high DC voltages to low DC voltages and is widely used in several applications. However, different non-smooth dynamics have been found especially in the ramp-controlled buck converter configuration that lead to undesired behaviors, due to the non-smooth nature of the ramp signal. As a consequence, we propose to change the ramp signal by a sine waveform as a smooth alternative to the non-smoothness of the ramp waveform, and thus try to avoid the non-smooth behaviors of the buck converter system. Nevertheless, we found that non-smooth dynamics remain present in the system even by using a smooth sine waveform instead of a non-smooth ramp waveform. In fact, a new variety of non-smooth bifurcations were found.

Keywords: buck converter, sine-control, ramp-control, non-smooth dynamics, bifurcations.

1. Introduction

DC-DC power converters have become a very relevant research area due to their applicability in a variety of electronic devices. Fig. 1(a) shows the Buck converter system under ramp- and sine-controlled schemes, and its ordinary differential equations are defined as in [2]. A_1 is an amplifier that has gain a, and V_{ref} is the reference voltage; therefore, the control voltage is given by Vco(t)=a(Vc(t)-Vref(t)). A_2 is a comparator that generates the control action u, and in this case, in order to compare the sine-control with the ramp–control scheme, the buck converter is studied using a ramp and a sine waveform as T–periodic signals. Hence, u commutes between 1 or 0 when Vco(t) < Vs(t) (or Vramp(t)) or Vco(t) > Vs(t) (or Vramp(t)) respectively. Vs and Vramp are the periodic sine and ramp waveforms (T = 400 μs), respectively, and are defined as follows:

$$v_s(t) = V_{LO} + \left(\frac{V_u - V_{LO}}{2}\right)\left(1+\sin\left(\frac{2\pi t}{T}\right)\right);\ V_{ramp}(t) = V_{LO} + (V_U - V_{LO})\frac{t}{T} \tag{1}$$

where V_{LO} and Vu are respectively the lower and upper voltages of the ramp or sine waveforms. The component values used are: L=20mH, R=22Ω, C=47μF, V_{ref} =12V, Vu=8.2V, V_{LO}=3.8V, T=400μs, a=8.4.

2. Results and Discussion

As can be seen in Figs. 1(b)-(c), both smooth and non-smooth bifurcations appear in the ramp-controlled system, as it has been investigated by other authors several years ago [1]-[3]. However, smooth

and non-smooth bifurcations also appear in the sine-controlled system under the same parameter variation (see Figs. 1(d)-(e)). Even though it was changed the non-smooth ramp signal by a smooth sine waveform, non-smooth bifurcations still remain. In fact, note from Fig. 1(e) that a cascade of border collision bifurcations appears, a phenomenon only seen in power inverter systems [4].

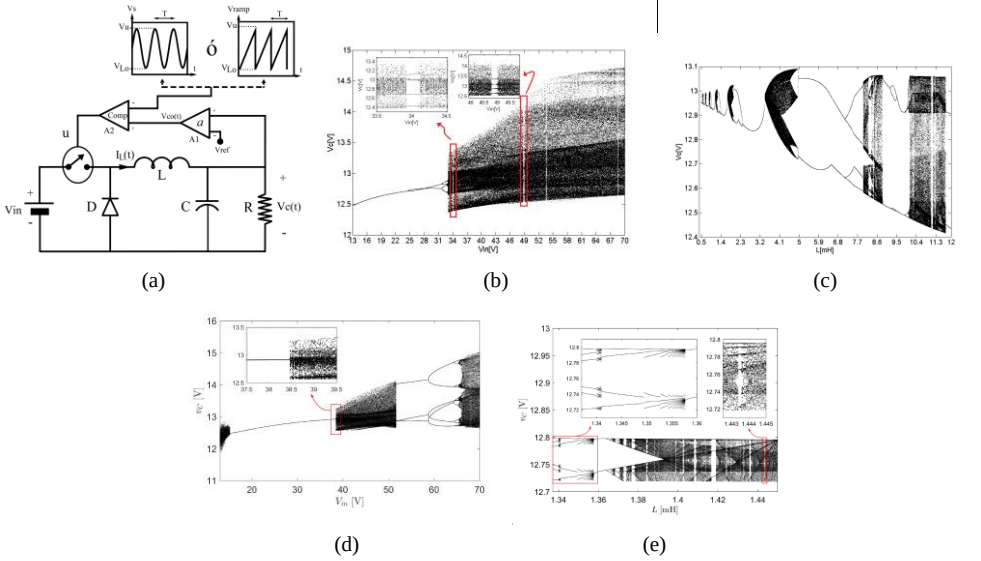

Fig. 1. (a) PWM–controlled DC-DC Buck converter using a sine or a ramp waveform. Bifurcation diagrams of V_C taking (b) Vin and (c) L as bifurcation parameters in the ramp-controlled system. Bifurcation diagrams of V_C taking (d) Vin and (e) L as bifurcation parameters in the sine-controlled system.

3. Concluding Remark

By changing the T–periodic signal changes radically the system dynamics. Nevertheless, it does not matter if the T-periodic signal is smooth (sine waveform) or non-smooth (ramp-waveform), complex behaviors are still present and non-smooth bifurcations cannot be avoided. In fact, by using a T–periodic sine waveform a cascade of border collision bifurcations was obtained, a phenomenon only seen in power electronic inverters [4]. Even though the T-periodic signal is smooth, tangent bifurcations occurs [3] and non-smooth behaviors appear. This suggests that no matter which type of T–periodic signal is used, non–smooth bifurcations of border collision or tangent type always become evident.

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