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Adaptive pulse width modulation design for power converters based on affine switched systems

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HIGHLIGHTS

- A switched model is considered to better represent the actual power converter dynamics.
- A (reverse) mode-dependent dwell-time strategy takes into account limited switching frequency.
- We take into account deviations from the ideal state due to parasitic effects.
- Full switched parametric uncertainty is considered.

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ABSTRACT

In this work we propose a novel adaptive switching strategy for the design of pulse width modulation signals in power converters. Instead of an uncertain averaged model of the power converter, an uncertain switched model is considered, which can better represent the actual power converter dynamics. Uncertainties in the power converters parameters are handled via an adaptive control approach, and all circuit parameters of the switched model are assumed to be unknown (including the load and parasitic effects). After defining the pulse width modulation in terms of a reverse mode-dependent dwell time, an elementary-time-unit Lyapunov function is used to derive a set of linear matrix inequalities (LMIs) based on global uniformly ultimately boundedness of the switched system. The LMIs are solved in an adaptive fashion using an exploitation–exploration mechanism: exploitation is achieved by solving the LMIs based on the estimated switched model, while exploration is achieved by a persistently exciting input voltage source, which guarantees convergence of the estimated parameters to the true system parameters.

1. Introduction

Switching-mode devices are crucial in many applications in industrial and power electronics. The use of pulse width modulation (PWM) signals to drive the switching behavior is the key in the conversion between direct current voltages in DC-DC power converters. In such devices, the switching PWM signal has to be generated to regulate an output voltage, despite of changes in the load [1,2]. Different control designs to generate the PWM consider an averaged model for the converter [3]. This modeling approach averages the switching dynamics over the period of the pulse signal. The main advantage of averaged dynamics is their suitability for existing control designs, e.g. power converters with bilinear averaged dynamics have been

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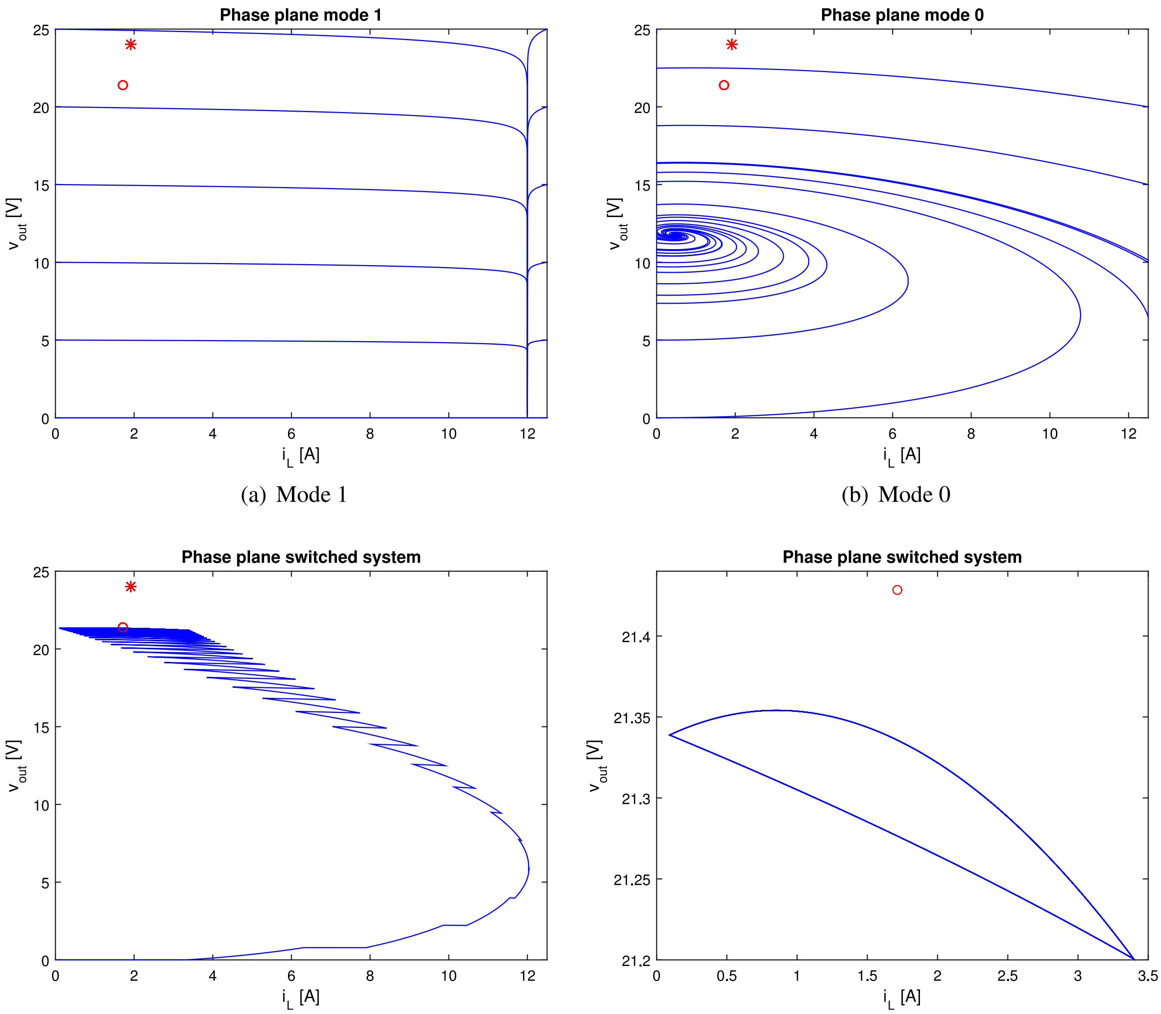

(a) Mode 1

(b) Mode 0

(c) Hybrid behavior

(d) Detail of the limit cycle

Fig. 1. Phase plane of the two stand-alone modes, and of the switched model with duty cycle $D = 0.5$ (the ideal state is indicated with a star, and the equilibrium of the averaged model with a circle).

analyzed by using Hamiltonian methods [4]. If the PWM signal is of sufficiently high frequency, the behavior of the averaged system will be close to the behavior of the original switching-mode converter. However, in case some of the assumptions for the averaged model do not hold, e.g. if the PWM is not of high frequency, a hybrid (switched) model for the converter is preferred and the development of a control design strategy for this switched model is of utmost importance [5].

As an example, let us focus on the boost converter, whose averaged and switched models are described in Appendix A with parameters as in Section 6. To explain the mechanism through which a desired voltage is achieved, we illustrate the behavior arising by switching from one mode to the other and compare it with the averaged model behavior. Fig. 1(a) and (b) show the phase plane of the two modes of the boost converter (mode 1 and 0, with closed and open switch respectively). Both modes have a stable equilibrium, with the first mode having two real eigenvalues, and the second mode having a pair of complex conjugate eigenvalues. When the two modes are combined via the duty cycle, the trajectories switch from the first to the second mode and *vice versa*. The resulting dynamics can be represented by the switched system

$$\dot{x}(t) = A_{\sigma(t)}x(t) + E_{\sigma(t)}v_s, \quad \sigma(t) \in \{1, 0\}, \tag{1}$$

where the signal $\sigma(t)$ is a time-dependent signal that determines at every time the switching between closed ($\sigma(t) = 1$) and open switch ($\sigma(t) = 0$); the matrices A_σ and E_σ contain the parameters of the boost converter operating in mode σ (cf. Appendix A); the state $x = [i_L \; v_{out}]'$ is a bidimensional vector composed of the inductor current i_L and output voltage v_{out}; and v_s is the (typically constant) input voltage.