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Discrete-time modeling and control of a boost converter by means of a variational integrator and sliding modes

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Abstract

This work deals with the discrete-time modeling of a boost DC-to-DC power converter by means of a discrete Lagrangian formulation based on the midpoint rule integration method. Then in the basis of this model, a discrete-time sliding mode regulator is designed in order to force the boost circuit to track a DC-biased sinusoidal signal. Simulations and experimental tests are carried on where the great performance of the proposed methodology is verified.

1. Introduction

Switched mode DC-to-DC converters [37] are mainly used as constant current sources for LED, LED flashlights, industry lighting, mobile phones, among other commercial devices. Among the well known converter topologies as buck, boost, buck-boost and cúk converters, the last three mentioned topologies result to be non-minimum phase with respect to the output capacitor voltage variable [21]. Therefore, these topologies constitute a challenging area for the nonlinear control design point of view. So far, various control techniques either linear or nonlinear to regulate these converters have been proposed, such as I/O feedback linearization [7], linear designs [13], sliding mode control [30,10,20], current-mode-control [12,6,1], artificial neural networks [16], fuzzy logic control [32], passivity-based control [14,8], among others.

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With respect to DC-to-AC power conversion, a boost inverter was introduced in [4] as two individual boost converters. These converters produce a DC-biased sine wave output, so that each converter only produces a unipolar voltage. The modulation of each converter is 180° out of phase with the other which maximizes the voltage excursion over the load. The load is connected differentially across the converter. Thus, whereas a DC bias appears at each end of the load with respect to ground, the differential DC voltage over the load is zero. After the work by Cáceres and Barbi [4], several researchers were only interested in solving the tracking of a DC-biased sinusoidal signal problem for only one converter of the boost inverter. In [38], two solution approaches were proposed. The first one reduces the AC generation problem to the tracking of a Fourier series solution of an Abel type of differential equation. The second approach proposes a backstepping controller for the tracking task. In the work presented by Sira-Ramírez in [30], a sliding mode controller based on a boost circuit is proposed and the flatness property of the system is exploited. An indirect tracking approach of the capacitor voltage is used in order to avoid the underlying non-minimum phase internal stability problem, where the reference capacitor voltage signal is generated on the basis of a suitable inductor current reference signal determined in an iterative fashion. Moreover, the convergence of the capacitor voltage to its corresponding reference signal was not established. In the work presented in [28] a direct tracking sliding mode control for the boost power converter is developed based on a state transformation to the canonical form, where the reference signal for the internal state is generated by an equation of stable system center as a solution of the linearized internal dynamics. Meanwhile in [27] based on the same state transformation as in [28], a direct tracking sliding mode control for the boost power converter is addressed via dynamic sliding manifold where the existence of the sliding mode is locally provided. In both works the simulation studies are carried out for the transformed states where it would have been preferable to show the real behavior of the inductor current and output voltage capacitor. In [9] the obtaining of a uniform convergence sequence of Galerkin approximations of the inductor current reference, but two main handicaps appear. On the one hand, only the first Galerkin approximation is available in closed-form, and therefore, useful for dynamic compensation. On the other hand, the effectiveness of the control scheme depends on a number of hypotheses for which sufficient conditions are not provided. All of the above-mentioned works are characterized by cumbersome designs in the continuous-time setting.

On the other hand, the sliding mode control [33,3] is a popular technique among control engineer practitioners due to the fact that introduces robustness to unknown bounded perturbations that belong to the control sub-space. The residual dynamics under the sliding regime i.e., the sliding mode dynamics can easily be stabilized with a proper choice of the sliding surface. The chattering phenomenon (small oscillations of finite frequency at the output signal) can be caused by the deliberate use of classical sliding mode control technique. Electrical and electromechanical systems become vulnerable when the output tracking signals present the chattering problem. The chattering problem is harmful because it leads to low control accuracy; high wear of moving mechanical parts and high heat losses in power circuits. When fast dynamics are neglected in the mathematical model such a phenomenon can appear. Another situation responsible for chattering is due to implementation issues of the sliding mode control signal in digital devices operating with a finite sampling frequency, and then, the ideal infinite switching frequency of the control signal cannot be fully implemented [24].

This problem has motivated the last decades the work of various researchers, with the aim of improving the control performance by designing the controller directly on the basis of the digital model, see for instance [18,19]. If the digital model has been obtained, various important issues regarding the controller performance can be faced, such as parameter variations, observer design,