DEVELOPMENT OF A STATE FEEDBACK CONTROLLER FOR THE SYNCHRONOUS BUCK CONVERTER

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Abstract— **A digital control algorithm for a current-mode (CM) and a voltage-mode (VM) synchronous buck converter (SBC) is developed. In both cases, the design leads to a stable controller, even for a duty cycle larger than 50%. The desired output voltage and the transient response can be independently specified. Moreover, zero steady-state error in the output voltage can be obtained with the aid of additional dynamics. In both cases, the specification is done by pole placement using complete state feedback. A discrete-time model is used to design the feedback gains. Both the stability and the small-signal transient response are analyzed. In another paper (Oliva *et al.*, 2003) the control algorithms are experimentally validated with a DSP-controlled SBC.**

Keywords— **Switch-mode power supplies, digital control, buck converter.**

I. INTRODUCTION

Switch-mode power supplies (SMPS), like the buck converter, are frequently used in the current or the voltage modes of operation. Current-mode control is commonly used due to its intrinsic current limiting, providing a natural over-current protection. This characteristic allows to parallel modules to extend the current capability (Brown and Midlebrook, 1981).

Since CM SMPS show an instability (evident as a subharmonic oscillation) when the duty cycle is larger than 50%, the industry has adopted the *external ramp compensation* method to cancel out the oscillations. This method consists on adding an artificial ramp to the reference or to the current waveform (Unitrode, 1995; Brown and Midlebrook, 1981). It is a simple method, but it does not allow to arbitrarily place the closed-loop poles to achieve a desired dynamic response.

SMPS have traditionally been modeled with the averaged-state model, introduced by Cûk (Midlebrook and Cuk, 1976). However, this model does not explain the CM instability.

The origin of the CM instability is conveniently explained by another modeling technique, introduced by Packard (1976), known as *discrete modeling,* and by the *sampled-data model* from Brown (Brown and Midlebrook, 1981). These techniques are used in this work to obtain the discrete model of the switching converter, followed by a complete state feedback to adjust the closed-loop dynamics. The small-signal stability and transient response for this model are latter analyzed. The instability is completely eliminated from the CM converter, yielding a determined dynamic response. The regulator was analyzed using a discrete modeling technique, as in Fang and Abed (2001). For the VM converter, the desired output voltage and the type of transient response that the regulator would exhibit due to perturbations or a set-point variation can be separately specified (this is a main difference between this method and the traditional sawtooth-and-threshold method). Moreover, with the aid of additional dynamics, zero steady-state error can be achieved on the output voltage. Summarizing, an alternative control strategy is introduced for SMPS operating in VM and CM. The algorithms were experimentally tested on a SBC-based voltage regulator. The experimental results are shown in Oliva *et al.* (2003).

A DSP was used to implement the controller. This is not an issue when the target is a high-current converter, because the DSP is a small portion of the overall cost. The use of a DSP has additional advantages, such as monitoring of critical variables, communication with other devices and possible on-line tuning of the dynamic response.

II. STATE SPACE MODEL

A. Continuous-time model

Switching converters are, in general, non-linear and time-variant circuits. Nevertheless, different models have been developed to describe the small-signal behavior of the system with linear equations (Brown and Midlebrook, 1981). The boost and the Cûk converters exhibit a non-linear function between the control variable and the output voltage. On the other hand,