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Boundary control of dual-output boost converter using state-energy plane

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Abstract: A boundary control scheme for dual-output boost converter (DBC) with enhanced performance using second-order switching surface is presented in this study. The derivation of the switching surface is performed in state-energy plane rather than the state-plane to obtain a general geometrical representation that provides a good dynamic response during start-up and sudden load changes, achieving steady state in two switching actions. To illustrate the control characteristic and performance, a detailed mathematical analysis is fully developed and compared with other control methods for the DBC. The proposed control was simulated, implemented in a digital signal processor TMS320F2812, and tested using prototype hardware. The results obtained for the DBC show good performance in terms of fast transient response under 50% load change and respectable output DC-bus balancing.

1 Introduction

To supply voltage, current and frequency needed for the load, and to guarantee the desired dynamics response, DC–DC power converters have to be suitably controlled. Conventionally, classical linear control techniques have been used for the control of these power converters [1, 2]. For the sake of simplicity, many existing control schemes for power electronic circuits are confined to develop small-signal models defined around the nominal operating point [3]. These methods are used to determine the dynamic behaviour of the system using classical linear system theories [4, 5]. If the injected perturbation has small magnitude, the system behaves as predicted by the small-signal model, and the transients converge to the quiescent operating point [5]. However, controllers failed to satisfactorily perform constrained specifications under large parameter variations and load disturbances [6]. Therefore the steady-state response may diverge from the desired quiescent point. In addition, the control performances may not be optimal. Hence, small-signal modelling is insufficient for the complete analysis of power switching converters [5, 6].

An alternative approach is to use the large-signal state-space geometric analysis which provides a more complete picture of the stability and performance for power electronic systems [7]. Switching boundary control (SBC) is a geometric approach where it was firstly introduced to power electronic systems by Burns and Wilson in 1976 [8]. In boundary control, a state-plane is introduced to analyse the switching boundary of a power electronic system. A switching boundary denoted by σ is used to divide the state-plane into disjointed regions. These regions allow us to visualise what goes on in non-linear system analytically. Detailed investigations into the modelling, design and analysis of these boundaries will lead to achieve desired transient response and insure stability [9].

Among the well-known theories using SBC are sliding mode control and hysteresis control. These controls use the theory of boundary control with first-order switching surface δ^1. In general, δ^1 derived boundary controllers offer good large-signal response and stability to the converter system, but the transient dynamics is still non-optimal for that many research works propose adaptive solution, such as the adaptive hysteresis control to enhance the dynamics performance of the system. However, an unstable combination or limit cycle may emerge. Moreover, the hysteresis band causes undesirable output steady-state error [10, 11]. The concept of the second-order switching surface δ^2 is proposed in [12–14]. It is derived by estimating the state trajectory movement after a switching action, resulting in a high-state trajectory velocity along the switching surface. This phenomenon accelerates the trajectory moving towards the target operating point. Converters with δ^2 exhibit better dynamic characteristics than the ones with δ^1. Instead of directing the state trajectory movement, as in δ^1, the proposed surface is derived from the natural movement of the state trajectory after a switching action. The goal is to make the converter revert to the steady state in two switching actions under large-signal disturbances [14, 15]. In [16], a new approach was presented by modifying the state-plane by energy-plane based on the theory of energy conservation. The proposed method is applied to boost converter and overcome the problems faced in developing SBC using state-plane. Results show good performance of the converter and can be applied also to other types such as buck–boost or inverters.