Voltage Estimation of DC/DC Converters

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Abstract

This paper deals with the voltage estimation problem for the DC/DC converter. This problem is treated using the observability analysis and observer design concept for hybrid dynamical systems. Firstly, we study the observability, for a predetermined switching sequence, by using some geometrical tools. This study leads to a simple necessary and sufficient condition of the observability in term of subspaces. Secondly, we use a fundamental property, which is the gathering information property, to design a new observer state. This latter has two sub-observers; the first one is a partial observer, that gets the observable parts of the current mode in finite time while the second one is a gathering observer that accumulates the observable states provided from the previous modes of the switching sequence. Application of the obtained results to the three-cell dc-dc converter using a finite time sliding mode observer (as a partial one) and Pulse-Width Modulation strategy PWM (as a control) is given. Simulation results demonstrate the performances, efficiency and robustness of the proposed observer.

Keywords: DC/DC converter, observability analysis, finite time observer, piecewise affine systems, geometrical approach, PWM control

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1. Introduction

In the last years, industrial applications that require a high power level, security and efficiency have significantly increased. These requirements cannot be achieved by using the classical power converters. From this fact, new converter structures have appeared; one of them, the general DC/DC converter (also called multicellular converter) [1]. The basic idea is the serial connection of multiple cells, which enables us to reduce the voltage constraints among the passive and semiconductor components. In addition of this, lower conduction losses and improved output voltage waveform are experienced[1].

To gain from the above advantages, a particular distribution of the voltages in every cell of the converter is needed. This latter can be reached only for specific values of the capacitors voltages i.e. regular distribution. To ensure the regular distribution [2], a suitable control strategy of the switches must be designed. For this purpose, several control schemes have designed for the DC/DC converters such as hybrid control scheme for two cells converter [3-5], sliding mode control [6-7], control based on nonlinear theory [8], predictive control [9-10] and robust control for the two cells converter [11]. All these control strategies guarantee the objectives of control of the converter e.g. the suitable distribution of the voltage crossing each cell. However, the previous control strategies need the knowledge of states i.e. the knowledge of load current and capacitors voltages; this means that we need to use physical sensors to measure the whole states which increasing significantly the cost as well as the complexity of the system especially for a high number of cells. For these reasons, the estimation of the capacitors voltages using only the measurement of a small part of the vector states became a good solution. From point of view practical, the load current measurement and the knowledge of the switching control is the best way to overcome the considered problem.

Different works investigate the observation problem of the DC/DC converters in the last decades. For the observability, the authors in [12, 13] examined the observability of the DC/DC converter by using some geometrical tools i.e. using the subspaces concept, [14] applied the Z(TN) observability concept to the converter and they gave some interesting remarks about the observability of the converter, [15] treated the observability problem using nonlinear theory. For the state observer, one can find: nonlinear state observer [16], adaptive observer [17], classical sliding mode observer [18], second order sliding mode observer [14,16] and observers converges in finite time [19-20]. Even though the above-cited works provided some significant results on the estimation problem of the DC/DC converter, they need some complicated calculation in term of exponential matrix to deal with the observability problem and some conditions for the observer state such as the constraint of dwell time.

This work presents a deep study of voltage estimation problem for the DC/DC converters based on the load current measurement and the knowledge of the switching signal using the hybrid systems theory. Firstly, we treat the observability through the geometrical approach; we give simple conditions for the observability for the predetermined switching sequence. These conditions are based only on the switches states i.e. the instant times and the discrete modes order do not affect the observability. Then, we introduce a new observer state for a predetermined switching sequence using some dynamical properties of the converter as well as the finding results of the observability. The suggested observer has two sub-observers: partial and gathered observers; it ensures the finite time convergence, and it does not require any