A SURVEY ON HYBRID MODELING AND CONTROL APPROACH OF DC-DC CONVERTERS

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DC-DC converters are essential parts of photovoltaic systems and would be providing maximum power output operation. Dealing with renewable energy resources has an impact on uncertainty and unpredictability. Hybrid Systems play a role in cost-efficient, stable and sustainable power supply all around the globe. The problem of hybrid modelling and control of a fixed frequency DC-DC converter, namely the Non-inverting Buck-Boost converter is surveyed and illustrated in in this paper in terms of accuracy and complexity for controller design.

Introduction

Over the past decades, an extensive demand for delivering electric power in different forms and with a requirement of high performance and reliability influenced a great impact on the field of power electronics. In this stream, various control strategies have been proposed to achieve the goal of high performance and consequently low cost power converters [1]. DC-DC converters are extensively used in different applications due to having multiple advantages such as, light weight, small size and high reliability. Due to the effect of non-linearity in the mathematical model of DC-DC converters, the controller design has been sought in various research areas. One of the challenges in controlling DC-DC converters stems from their hybrid characteristic. In fact, it has been noticed that external parameters can change discrete variables of converters between two or more discrete states. The system has a specific continuous dynamics in each state. Thus, these systems can be categorised as hybrid systems with controlled switching.[2].

I. An overview of controlling DC-DC converters

Considering the hybrid nature of the converters, Senesky et al. (2003) proposed a controller based on a hybrid automation model of the Boost converter. A non-linear model predictive control (NMPC) is used based on the non-linear average model of the converter in Lazar and Keyser [3]. In addition, another problem in designing DC-DC converters rises from introducing constraints in the design process. These constraints can be hard, such as constraints on duty cycle value or soft such as security constraints imposed on the inductor current. Model predictive control of hybrid systems has proved its power in controlling systems with hybrid nature and subject to various constraints [4]. MPC has been successfully tested on various DC-DC converters and mainly on Buck and Boost DC-DC converters [5]. The main negative aspect of this approach is how to overcome the optimisation problem in each step time. Bearing in mind that the high rate of sampling as well as the demand for low cost converters; then, such converters are not set as preferential converters. The idealistic approach to overcome this issue of online computational burden was to introduce an explicit hybrid control as stated by many researchers in this field [6]. Many conducted tests proved that to control DC-DC converters, then the first priority would be to start with the output voltage measurements, nevertheless, identifying the inductor current as well which can substantially improve the performance of the system. Hybrid control use inductor current in feedback loop which would increase the negative impact on hardware complexity and cost of the converter. Two methods that use computations based on input and output voltage measurements to estimate inductor current were proposed in recent literature. The validity and performance of the explicit method was proved by experimental results for Buck and Boost [7].

II. Physical set-up and hybrid automated model

Such converter can provide an output voltage below and above the source voltage. Its main advantage is that the provided output voltage has the same polarity of the source because of its specific topology utilising four switches as shown in figure 1.

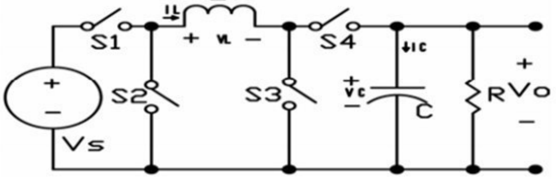

Рис. 1 – Physical set-up for the Non-inverting Buck-Boost

The switches are dependent and make two distinct topologies. Thus, the converter can be categorised as a mono-variable converter [8]. The main control objective here is to control the semiconductor switches (Figure 1) such that the DC component of the output voltage reaches a specific reference value. This must be done in the presence of changes of the source voltage and the load resistance.

The physical set-up of the converter is shown and hybrid automaton model of the system is can be obtained later.

In the set-up R, L and C denote load resistance, inductance and capacitance, respectively. r_L and r_C are parasitic elements of the inductor and capacitor and v_s is the input voltage. The converter including its switches has two distinct dynamical modes. The duty cycle which is a variable bounded between zero and one determines how long each of the dynamics is in charge. At the beginning of the first interval ($kT_s \leq t < (k + d(k))T_s$), the switches are in $u = 1$ position (Figure 2) which means S1 and S3 are ON and S2 and S4 are OFF as shown in figure 1.

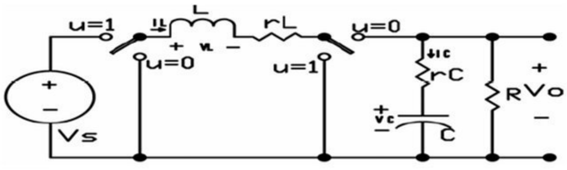

Рис. 2 – Schematic circuit of the converter with parasitic elements

At the end of the first interval, all the switches in Figure 1 toggle (switches in Figure 2 change to $u = 0$) and the dynamic of the system changes. In the second interval, the inequality $(k + d(k))T_s \leq t < (k + 1)T_s$ holds. By defining $x(t) = [i_l(t)v_c(t)]^T$ as the state vector, where $i_l(t)$ the inductor current and $v_C(t)$ is the capacitor voltage, the dynamics of the system can be defined by the following affine continuous time state space equations:

$$X(t) = \begin{cases} F1x + f1v_s, & kT_s \leq t < (k + d(k))T_s; \\ F2x + f2v_s, & (k + d(k))T_s \leq t < (k + 1)T_s \end{cases} \quad (1)$$

Where matrices Fi and fi can be found by applying Kirchhoffs laws and simple mathematical operations.

We need to understand that the first dynamic of the system is active at the beginning of each period. At the end of the first interval ($kT_s \leq t < (k + d(k))T_s$), a transition occurs and the second dynamic becomes active. As these parameters are taken into consideration the hybrid automaton model for the converter can be then easily found.

III. Conclusions

This article introduced a review to hybrid modeling systems as well as it addressed the already highlighted researches that have been done on Buck and Boost DC-DC converters as well it touch based Non-inverting converters. The main control objective of the converter is to derive DC component of the output voltage to its reference value as fast and with as little overshoot as possible. The control must be done in the presence of source voltage and load resistance changes. These are control objectives for the transient response of the controlled system. It was evident that the main control objective was to control the semiconductor switches in a sense the DC component of the output voltage reaches a specific reference value.

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