Model-free Control of a DC-DC Boost Converter Based on the Inductor Current Averaging

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In this work, a new model-free predictive control (MF-PC) technique is presented for controlling dc-dc converters based on calculating the slope of each switching instant. This technique has the simplicity required for converters operating at high frequencies. The simulation results show that the proposed method is robust against parameters and model changes compared to classical predictive controls.

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I Introduction

Model-free predictive control (MF-PC) theory has emerged as an alternative to conventional MPC (model predictive control) to address problems that can arise from poor model estimation or the loss of model accuracy, mainly caused by variations in the system's environmental conditions or operating point [1, 2, 3]. Besides the fact that it is not possible to know with certainty the model of the system to be controlled, either due to its high mathematical complexity or because, on some occasions, it has yet to be known a priori what will be connected to the system [1]. In any case, the MPC control will degrade, which will cause sub-optimal operation.

Although model predictive control (MPC) is widely used in power electronics, most of the applications reported in the literature have been focused on ac-dc and dc-ac converters [4, 5]. This is also the case with MF-PC applications, with a low number of works focused on dc-dc applications. However, the increase in the implementation of microgeneration systems, supported by the growth of dc-based renewable energies, such as PV systems and other dc-powered loads, promotes dc-based energy distribution on a residential scale. Being also supported by several studies that highlight the potential of dc microgrids and their involved dc-dc converters minimizing energy losses during its distribution [6, 7, 8]. Therefore, it is expected that having more efficient dc-dc converters, with lower costs, higher reliability, and low ripple in the output current, could drive the increased deployment of residential dc microgrids.

Additionally, dc-dc power converters have an important role in various energy applications, such as aircraft, electric vehicles, ship, dc homes, data center and microgrids [9]. This evidences the need to evaluate and study new approaches to the elements involved in this type of converter, as is the case of promising control strategies such as MF-PC.

Considering the above-mentioned, this paper proposes an MF-PC of the dc-dc boost converter shown in Fig. 1 to estimate the inductor's positive and negative current slopes with high accuracy and low computational cost.

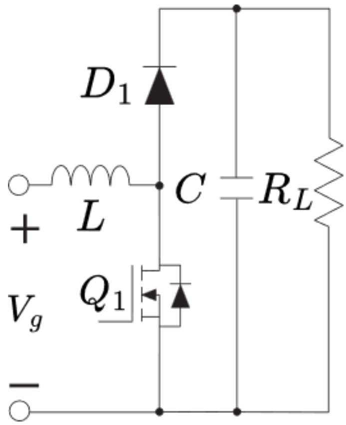

Figure 1: Boost converter.

II Control Description

The inductor current in classical second-order DC-DC power converters have a triangular waveform due to the semiconductors switching. Depending on the switching state, the slope of this current will be positive or negative. If the switching state is 1, meaning the switch is closed, the slope will always be positive, and vice versa. These two slopes can be calculated as follows in a discrete system with the proposed control topology:

$$m_k^1 = \begin{cases} 1000, & if\ k = 0 \\ m_{k-1}^1, & if\ Q_1 = 0\ or\ \frac{i_{Lk} - i_{Lk-1}}{Ts} <= 0 \\ \frac{i_{Lk} - i_{Lk-1}}{Ts}, & if\ Q_1 = 1\ and\ \frac{i_{Lk} - i_{Lk-1}}{Ts} > 0 \end{cases} \tag{1}$$

$$m_k^2 = \begin{cases} -1000, & if\ k = 0 \\ m_{k-1}^2, & if\ Q_1 = 0\ or\ \frac{i_{Lk} - i_{Lk-1}}{Ts} >= 0 \\ \frac{i_{Lk} - i_{Lk-1}}{Ts}, & if\ Q_1 = 1\ and\ \frac{i_{Lk} - i_{Lk-1}}{Ts} < 0 \end{cases} \tag{2}$$

whereas (1) is the positive slope calculation when the switching state is 1 and (2) is the negative slope calculation when the switching state is 0.

With this slope's values, we can estimate the inductor current for both switching states as follows:

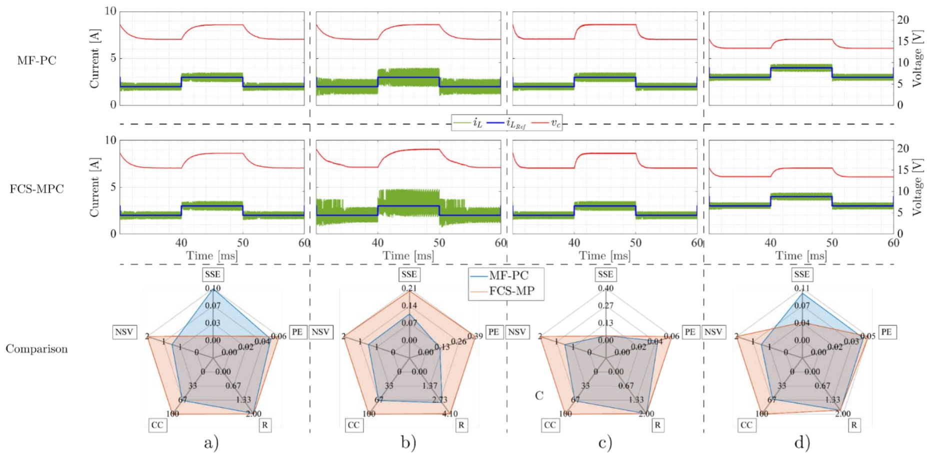

Figure 2: Simulation results for the boost converter: a) Converter operating at its nominal values ($v_i = 12\ V$, $R_L = 10\ \Omega$, $L = 94\ \mu H$ and $C = 250\ \mu F$) while the current reference changes between 2 A and 3 A, b) converter operating with a inductor of $L = 47\ \mu H$ (theoretical nominal value of $L = 94\ \mu H$), c) converter operating with a capacitor of $C = 100\ \mu F$ (theoretical nominal value of $C = 250\ \mu F$), d) converter operating with a resistor of $R_L = 5\ \Omega$ (theoretical nominal value of $R_L = 10\ \Omega$) while the current reference changes between 3 A and 4 A.

$$i_{L_{k+1}} = \begin{cases} i_{L_k} + m_K^1 T_s, & \text{if } Q_1 = 1 \\ i_{L_k} + m_K^2 T_s, & \text{if } Q_1 = 0 \end{cases} \tag{3}$$

where Ts is the sample time of the measured current. With this prediction, we can use an appropriate cost function and then choose the state that minimizes it the most. In this case, the cost function must be calculated for both current predictions, one with the positive slope and the other with the negative slope. We can also calculate the average of the slopes, which helps us to reduce prediction error in systems with more noise. The calculation can be seen in (4).

$$m_{mean}^1 = \sum_{n=1}^{N} m_n^1 \tag{4}$$

III Simulation results

Simulation results are summarized in Fig. 2. The proposed controller is compared with the classical FCS-MPC (finite control set-model predictive control) by means of a spider chart focusing on the following performance measures: steady-state error (SSE), prediction error (PE), ripple (R), computational cost (CC) in percentage (where the FCS-MPC is 100%), and number of sensed variables (NSV). In all the tests, the parameters R_L, L, and C are physically changed on the power converter, while the nominal values in the controller's code are maintained.

IV Conclusions

A model-free predictive control approach based on the inductor current averaging for the dc-dc boost converter has been presented. A comparison with the FCS-MPC approach was performed, evaluating the steady-state error, prediction error, current ripple, computational cost, and the number of sensed variables required by each control technique. The proposed MF-PC controller exhibits a superior dynamic characteristics to the FCS-MPC in all the cases.

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