Hinfinity Tracking Observer-Based Control of the Buck Power Converters

Abdelhamid Rabhi, N. Msirdi, M. Chadli

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Rabhi[1], M. Chadli[1] and N. K. M'Sirdi[2]

[1]University of Picardie Jules Verne, UPJV-MIS (EA 4290)

7, Rue du Moulin Neuf - 80000, Amiens – France.

[2]LSIS, CNRS UMR 6168. Dom. Univ. St Jérôme, Av. Escadrille,

Normandie– Niémen 13397, Marseille Cedex 20, France

abdelhamid.rabhi@u-picadrie.fr

Abstract-

In this paper, an H∞ robust observer based control is proposed for guaranteeing tracking performances of closed loop nonlinear systems. This approach is used to controlling DC-to-DC switched power converters of Buck type. The results are given in terms of linear matrix inequalities and they guarantee global asymptotic stability of the tracking error. The design conditions obtained using Lyapunov approach are given in terms of solvability as a set of Linear Matrix Inequities (LMIs) terms.

Index Terms - DC to DC converters, Observer, Controller, T-S models, LMI.

1 Introduction

DC to DC converters are electronic devices, used to regulate the output voltage. There are three main types of switched power converters respectively called Boost, Buck and Buck-Boost.

Switched mode DC-to-DC power converters have recently aroused and kept increasing deal of interest both in power electronics and in automatic control. This is due to their wide applicability domain that ranges from domestic equipments to sophisticated communication systems.

Recently, because of their intrinsic nonlinearity, these systems represent a challenging field for control algorithms.

Several control techniques have been used in this area. These control methods use the approaches of: frequency analysis in the classical control theory, time analysis in the modern control theory, both frequency analysis and time analysis domains in the post modern (digital and robust) control theory, and soft computing (fuzzy logic, neural networks and genetic algorithms) in the intelligent control theory [1, 2, 3, 4, 5].

This paper is organized as follows. In section 2, we present the converter nonlinear model and its representation by T-S fuzzy model. Section 3 presents the robust control objectives and design methodology of the controller based on a T-S converter. In section 4, simulation results are given to highlight the effectiveness of the controller design procedure and confirm the obtained good performance. Finally section 5 concludes this paper.

2 Buck Converter Modeling

The Buck converter has a highly non-linear characteristic, due to the incorporated switch. This converter accepts a source voltage, noted V_g and produces a lower output voltage, V_c with high efficiency.
There are several modeling techniques used to model the Buck converters [6,7].

Figure 1 shows an electrical circuit to describe a DC-DC buck converter. The circuit operates according to the so-called Pulse Width Modulation (PWM) principle. The switching period is T and the duty cycle is δ(t). When the switch is on position 1, the DC source supplies power to the circuit which results an output voltage across the resistor. When the switch changes its position to *0*, the energy stored in the inductor and capacitor will discharge through the resistor.

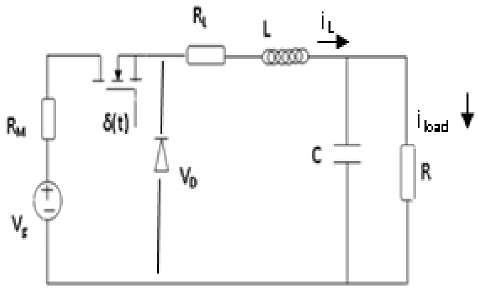

Fig. 1 DC-DC Buck Converter

Using the Kirchhoff's laws, the Buck converter differential equation is deduced and then its model can be represented in the state-space by the following nonlinear model :

$$\dot{x}(t) = Ax(t) + B(x)u(t) + B_w w(t) \quad (1)$$

where $x(t) = [i_L(t) \quad V_c]^T$ and

$$A = \begin{bmatrix} \frac{-R_L}{L} & \frac{-1}{L} \\ \frac{1}{C} & \frac{-1}{RC} \end{bmatrix}, B(x) = \begin{bmatrix} \frac{-(R_M x_1 - V_g - V_D)}{L} \\ 0 \end{bmatrix},$$

$$B_w(t) = \begin{bmatrix} 0 \\ -\frac{1}{C} \end{bmatrix}, w(t) = i_{load}(t)$$

x_1 and x_2 denote the inductor current (i_{load}) and the output capacitor voltage (V_c), respectively.
The control input for the above model is the duty cycle *δ(t)*, called duty ratio function.

Appropriately controlling the switching position can maintain the output voltage at a desired level lower than the source one.

According to Buck converter circuit, we denote that

$$i_{Lmin} \le i_L \le i_{Lmax}$$

Nonlinear model (1) can be then represented by two local LTI models. The overall T-S fuzzy model for the Buck Boost converter can be written as follows:

$$\begin{cases} \dot{x}(t) & = \sum_{i=1}^{n=2} \mu_{i}(z(t)) \left(A_i x(t) + B_i u(t) + B_w w(t) \right) \\ y(t) & = Cx(t) \end{cases} \quad (2)$$

Where

$$A_1 = A_2 = A = \begin{bmatrix} \frac{-R_L}{L} & \frac{-1}{L} \\ \frac{1}{C} & \frac{1}{RC} \end{bmatrix},$$

$$B_1 = \begin{bmatrix} \frac{-(R_M i_{Lmin} - V_g - V_D)}{L} \\ 0 \end{bmatrix}$$

$$B_2 = \begin{bmatrix} \frac{-(R_M i_{Lmax} - V_g - V_D)}{L} \\ 0 \end{bmatrix}$$

$C = [0 \quad 1]$ and the membership functions are given by:

$$\mu_1(x_1) = \frac{-x_1 + i_{Lmax}}{i_{Lmax} - i_{Lmin}},$$

$$\mu_2(x_1) = \frac{x_1 - i_{Lmin}}{i_{Lmax} - i_{Lmin}}$$

It is important to note that the model (2) represents exactly the nonlinear model (1) in the domain $i \in [i_{Lmin} \quad i_{Lmax}]$.

3 DC-DC Converters controller design

Our objective in this paper is to guarantee a convergence of V_{in} to V_{ref} while i_{load} varies. It is considered as a disturbance and then must be rejected.

Since the state variables are not fully measurable, we propose a fuzzy state observer for fuzzy model (3). The considered observer is represented as follows:

$$\dot{\hat{x}}(t) = \sum_{i=1}^{n=2} h_i(z)(A\hat{x}(t) + B_i u(t) + L_i(y(t) - \hat{y}(t))$$
$$\hat{y}(t) = C\hat{x}(t) \qquad (3)$$

While the considered TS fuzzy controller represented by:

$$u(t) = \sum_{i=1}^{2} h_i(z) K_i \hat{x}(t) \qquad (4)$$

where $\tilde{x}(t)$ is the state estimation, L_i and K_i are observer gains and controller gains respectively to be determined.

To design a controller based on observer with H_∞ performance, the following result is used [15][19].

Theorem: Given a prescribed scalar $\gamma > 0$, there exists an observer-based fuzzy control (4) law which makes the H_∞ norm of fuzzy system (2) less than γ if there exist symmetric matrices $X > 0$, $Y > 0$, $Q_i > 0$, P_i, matrices M_i and J_i, *i<j=1,2,…n*, such that the following LMI hold:

$$XA^T + AX + B_i M_i + M_i^T B_i^T + \gamma^{-2} B_w B_w^T < P_i \qquad (5a)$$

$$2XA^T + 2AX + B_i M_j + B_j M_i + M_i^T B_j^T + M_j^T B_i^T + 2\gamma^{-2} B_w B_w^T < P_{ij} + P_{ij}^T \qquad (5b)$$

$$AY + YA_i + C^T J_i^T + J_i C < Q_i \qquad (5c)$$

$$\begin{bmatrix} P_1 & \cdots P_{1n} & XC^T \\ \vdots & \ddots P_n & XC^T \\ P_{1n}^T & & \\ CX & CX & -I \end{bmatrix} < 0 \qquad (5d)$$

The controller gains K_i and the observer gains L_i are given by

$$K_i = M_i X^{-1}, \qquad (6)$$

$$L_i = Y^{-1} J_i, \qquad (7)$$

Proof: See for example [15]

4 Simulation results

The proposed T-S Model and controller are tested by simulation. The electrical parameters of the simulated Buck Boost converter are given in table I. These parameters allow a continuous conduction mode.

TABLE I: STUDIED BUCK CONVERTER PARAMETERS

Parameters	Values
R_M	*0,27 Ω*
L	*98,58 mH*
V_D	*0,82V*
R_L	*48,5 m Ω*

This section shows efficiency of designed control system and our design approach through computer simulations. The software package MATLAB/SIMULINK and LMI Control Toolbox is used for the simulations.
The simulation in Figure 1 shows the response of the buck converter. It is a comparison of estimated and measured states.

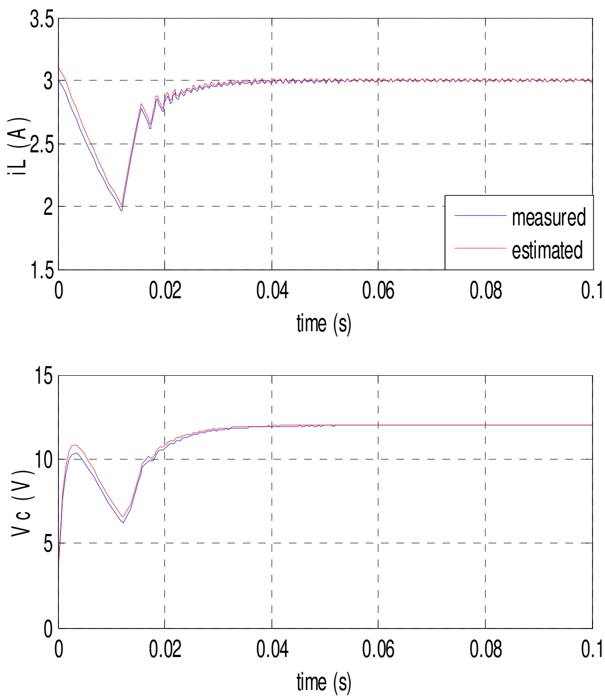

Figure 1: Comparison of estimated and measured states

It is clear that the different states of model coincide with measurements.

To verify the performance of our approach, we take a variable load and compare the developed controller with PI controller with $V_{in} = V_g = 30V$, $V_{ref} = 12V$.

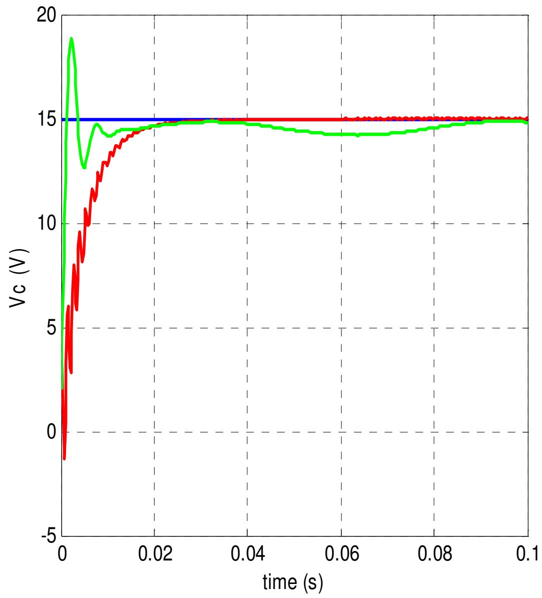

Figure 2: Comparative results of proposed controller (red line) and PI controller response output voltage.

We verify also the proposed algorithm when the reference value varies between two values below the input voltage.
Figure 3 shows the simulation results of the designed inverter when the reference value varies between two values. We note that the output converges to the reference and the controller provides good stability compared with PI controller.
Thus, it can be seen that the robustness of proposed controller is guaranteed even if both the load and the reference vary.

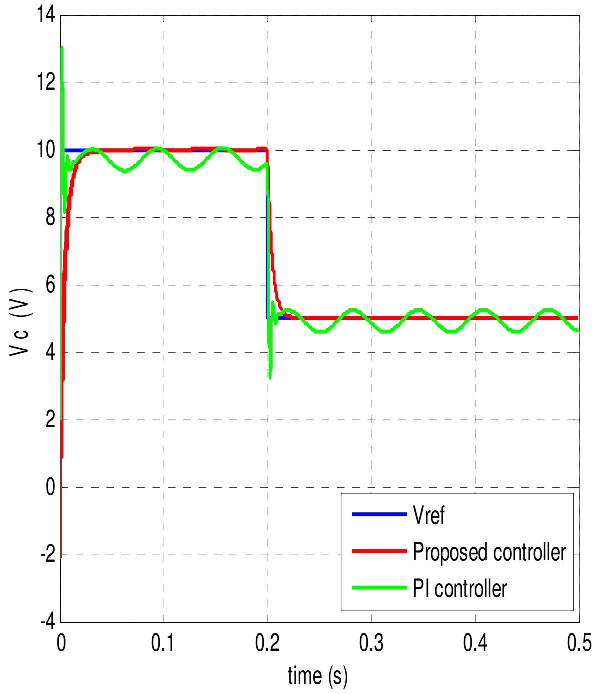

Figure 3: Comparative results when the reference value varies between two values

5 Conclusions

In this paper, T-S fuzzy model and a robust control scheme for parallel DC-DC buck converters is proposed. Then observer-based control is given using Lyapunov method. The design conditions are formulated in LMIs terms and guarantee H_∞ performance. Simulations show that the proposed controller guarantees asymptotic convergence of the state to a desired output voltage with load change.

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