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Nonlinear Control and Observation of a Boost Converter Associated with a Fuel-Cell Source in Presence of Model Uncertainty

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Abstract: This study deals with the problem of controlling DC-to-DC switched power converter of boost type associated with a fuel cell generator. The system is modelled using the PWM technique. The aim is to tightly regulate the output voltage of the converter to a desired reference. The voltage-current characteristic is subject to parameter uncertainty. The system load is in turn time-varying. A nonlinear adaptive controller is designed using the Lyapunov approach, based on the nonlinear model of the system. The controller is formally shown to meet its control objectives.
Keywords: Fuel cell, boost converter, adaptive control, nonlinear observer, Lyapunov approach

1. INTRODUCTION

A combination of high prices of fossil fuels and the increased awareness of their negative environmental impact has influenced the development of new cleaner energy sources. Among various viable technologies, fuel cells have emerged as one of the most promising sources for both portable and stationary applications.

Fuel cell stacks produce DC voltage with a variation in output voltage with load conditions. Hence, to increase the utilization efficiency a power conditioner consisting of DC-DC converters is required for load interface. In this paper, the design and analysis for the control of a Boost converter (BC) is presented in detail.

Design of controllers for boost power converter used in FC generation system presents interesting challenges. There is an increasing need for a good controller design to perform tight regulation under load variation due to the most of power electronic application operated with parameter variation, non linearity, load disturbance, etc.

Much effort has been spent to define small-signal linear approximation of power converter and fuel cell characteristic so that classical control theory could be applied to the design (Chen et al., 2006, Phatiphat and Davat, 2010, Thounthong et al., 2008, Rajashekara, 2005).

The point is that, both the boost converter and the fuel cell exhibit highly nonlinear behaviour making linear controllers only effective within around specific operation points.

In (Spinetti et al., 2009) a Lyapunov based control is used to design a controller that regulates the output voltage to v_e involving a nominal load value R_0. However the voltage regulation performances fail when the boost converter feeds an unknown load R. In (El Fadil 2007) a backstepping design approach is used in orde,to estimate the load resistance, and to regulate the output voltage.) A Lyapunov based control principle in a hybrid energy storage system associating a FC and a supercapacitor is dealt with in (El Fadil *et al.* 2012. In (El Fadil *et al* 2011) adaptive output feedback control of interleaved parallel boost converters is used based on Lyapunov stability tools.

All the above studies consider that FC voltage is known or measured. In (Sira-Ramirez et al 1995) and in (Sira-Ramirez et al 1996) the adaptive backstepping is used to update all the parameters of the boost converter (BC), among of this, the unknown constant voltage source.

In this paper, the problem of controlling fuel cell boost converter (FCBC) system is dealt with based on a more accurate model that really accounts for the system nonlinearities and varying FC voltage. Doing so, the model turns out to be well representative of both the boost converter large-signal dynamic behaviour and the fuel-cell nonlinear characteristics.

The uncertainty and the control are “matched” if they appear in the same equation (Kristic et al 1995), in this case one can apply the Lyapunov approach to adaptive nonlinear control. Consequently, according to the system plant (1), a Lyapunov based control is used to achieve two objectives: (i) asymptotic

stability of the closed loop system and (ii) tight output DC link voltage regulation, in spite of bus impedance changes and fuel cell characteristics uncertainties. Accordingly, the controller involves online estimation of the FC characteristic. It is formally shown, using theoretical analysis and simulations, that the developed adaptive controller actually meets its control objectives.
The paper is organized as follows. Section 2 is devoted to presentation and modelling the boost converter while section 3 is devoted to determine the FC voltage estimator and current controller. The error convergence analysis will be shown in section 4. Section 5 is devoted to the simulation results. A conclusion and list of references end the paper

2. PRESENTATION AND MODELLING OF FUEL CELL BOOST CONVERTER SYSTEM

The boost converter is a circuit that is constituted of power electronics components connected as shown in figure 1. The circuit operating mode is the so-called Pulse Width Modulation (PWM).

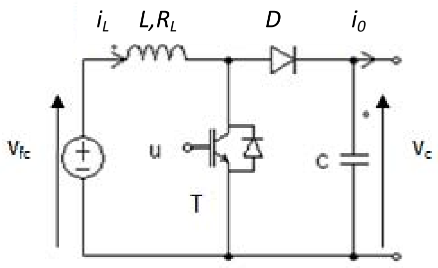

Fig.1: Fuel cell boost converter (FCBC)

A typical fuel-cell polarization curve is shown in Fig.2. This shows that the FC voltage v_{fc} is a decreasing nonlinear function of load current density i_L. For future analytical treatment, the polarization curve is given the following polynomial approximation (El Fadil et al., 2011):

$$v_{fc} = \sum_{k=0}^{n} b_k i_L^k \tag{1}$$

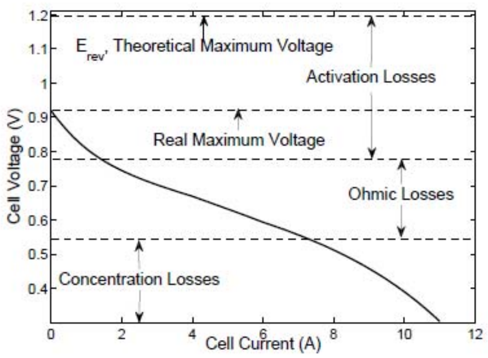

Fig.2: Fuel cell polarization zones

It is shown in many places that the averaged model of the power converter is the following (El Fadil et al., 2011, El Fadil et al., 2013)

$$\dot{x}_1 = \frac{-R_L}{L}x_1 - \frac{1-\mu}{L}x_2 + \frac{1}{L}\sum_{k=0}^{n} b_k x_1^k \tag{2a}$$

$$\dot{x}_2 = \frac{1-\mu}{C}x_1 - \frac{i_0}{C} \tag{2b}$$

Where x_1 and x_2 denote the average input current i_L and the average output capacitor voltage v_c respectively. The control input for the above model is the function μ, called duty ratio function.

3. CONTROLLER DESIGN

The V-I fuel cell characteristic is not unique as it depends on temperature, pressure and flow of hydrogen etc. In Fig3, two polarization curves are plotted in the case of two different pressure levels.

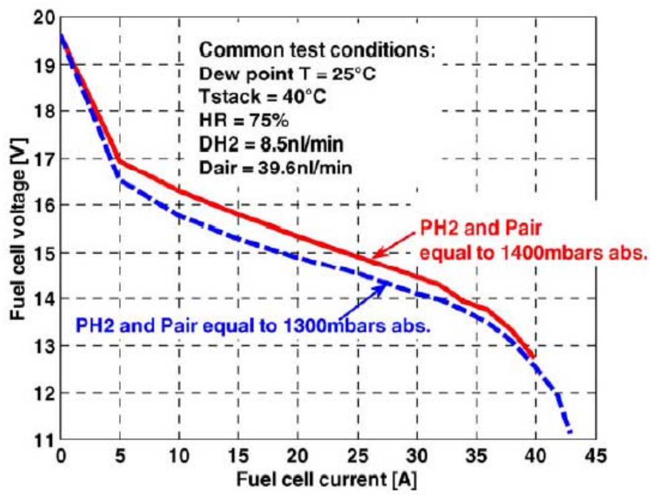

Fig.3: Polarisation curves recorded for two hydrogen and air pressures.

In this study, the coefficients b_k $(k = 0,..n)$ in (1) are let to be (what they are in practice i.e.) uncertain parameters. Also, the equivalent serial resistance, i.e. the parameter R_L in (2a), is let to be unknown. To cope with such model uncertainty the controller will be given a learning capacity. Specifically, the controller includes an on-line estimator of the unknown parameter vector:

$$\theta = \frac{1}{L}[b_0, b_1 - R_L, b_2 \cdots, b_n]^T \tag{3}$$

Accordingly, the model (2a-b) rewrites as follows: