

CONTROL PERFORMANCES OF THE BI-BUCK INTERFACE USED FOR INVERTER CURRENT RIPPLE COMPENSATION

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Abstract- The control of the bi-buck structure used as active power interface between fuel cells stack and inverter system is further analysed in this paper. The objective of this analysis is to determine the control performances of the proposed bi-buck power interface [1] concerning the low frequency fuel cell current ripple compensation. Therefore two feedback control loops are used: a DC output voltage control for buck converter which operates as controlled DC voltage source, and a current ripple active compensation loop for buck converter operates controlled AC current source. The operation of the nonlinear loops gain is shown by simulation. Matlab-Simulink models and some designing aspects are presented, too.

Keywords: Nonlinear Control, Current Ripple, Active Power Interface, Fuel Cell, Buck Converter, Inverter System.

I. INTRODUCTION

The Fuel Cell with Proton Exchange Membrane (PEMFC) is a DC voltage generator, whose output voltage is depends on the load current. They have been considered as alternative DC power sources for vehicles, energy generation system (EGS), backup power sources, etc. In engineering applications, PEMFC stack are usually

arranged with auxiliary power sources, such as batteries and ultracapacitors, to form hybrid systems [2-7].

The Multi-port Power Converter (MPC) allows the charging of the ultracapacitors stack from regenerative load power flows and from other possible power flows marked by broken line (Figure 1).

Power interface has two control loops: one for adjusting the output voltage value imposed by the reference voltage, V_{DC} , and other for inverter current ripple compensation [8-13]. Both control loops and control surface variables are presented in Figure 2.

In this paper the analysis will be concentrate on designing of the current nonlinear controller. The remainder of the paper is organized as follows. Section II presents first results concerning the design of current control loop. The bang-bang control performances are shown and compared with two other well know control methods that use a switching command. The obtained results are compared and evaluated concerning the output current ripple and dynamic performances. The designing of the nonlinear control uses these results and the nonlinear control designing are briefly explains in section III. Section IV presents some selected simulation results for bi-buck interface using a pattern for input inverter current (DC current with AC ripple) which are modelled by a dynamic power load. Last section concludes the paper.

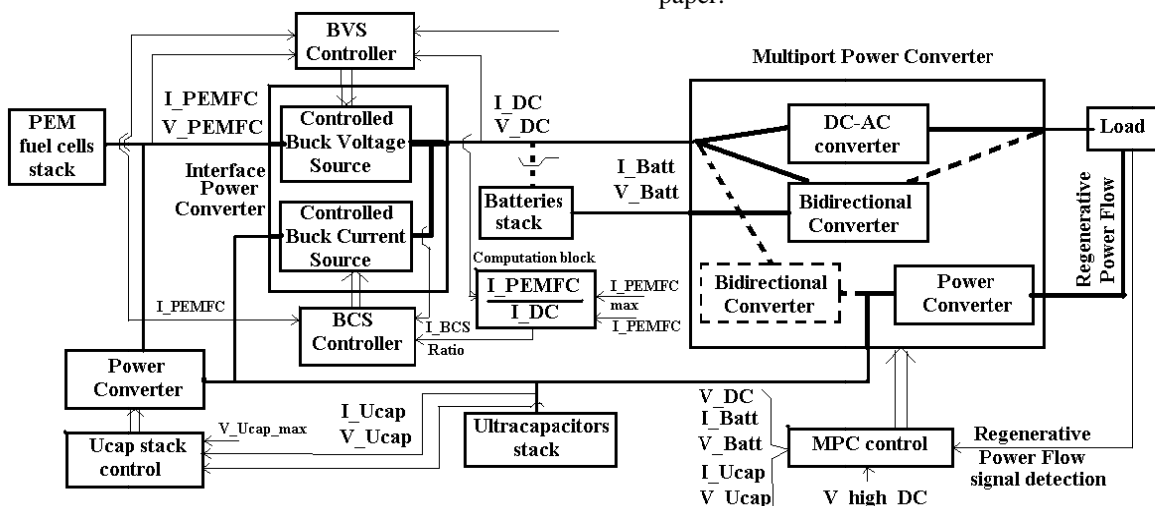


Figure 1. Bi-buck and multi-port power converter topology

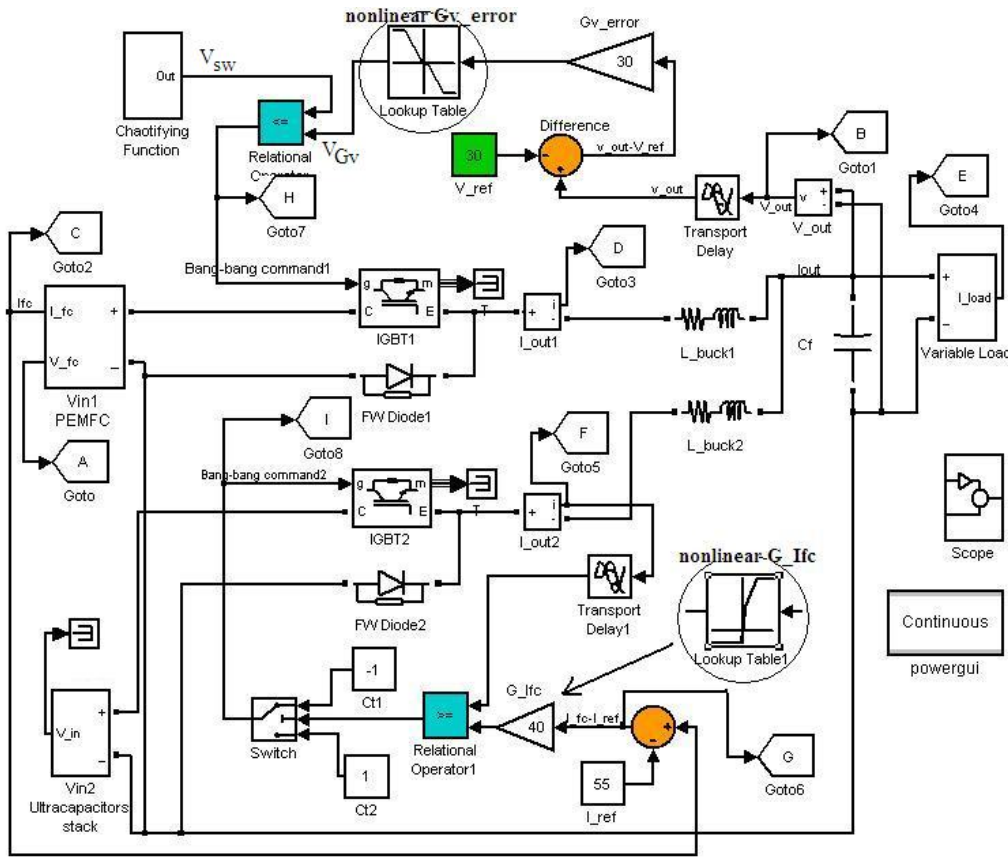


Figure 2. Bi-buck power interface using nonlinear current controller

II. CURRENT CONTROL LOOP DESIGNING

Obviously, the response time and fuel cell current ripple minimization is dependent by the bi-buck interface inductance ratio, L_{buck2}/L_{buck1} , and by controller type. In the following section simulations we considered $L_{buck2}=L_{buck1}=50\mu H$.

The Pulse Width Modulation (PWM) technique is the usually technique to control power converter, in particular the output current of the buck current source (Figure 3). An improved dynamic is obtained using a tuned proportional-integral (PI) regulator.

Simulation result for clocked Peak Current Control (PCC) technique is shown in Figure 4.

For simplicity of design, reliability or economic reasons, we choose the Bang-Bang Control (BBC) law for implementing the switching command for buck current source (Figure 2). Simulation result for BBC technique is shown in Figure 5.

If a proper L_{buck} value is chosen, the simulation results show that all these control methods have almost the same dynamic performances. This obvious if we consider that switching frequency (triangle signal frequency for the PWM control and clock signal frequency for PCC control) doesn't limit the buck converter dynamic. A buck inductance value up to $50\mu H$ gives big HF current ripple for the buck current source, and a bigger value reduce response time. The effect of the bi-buck interface inductance ratio on current ripple compensation will be shown in the simulation section.

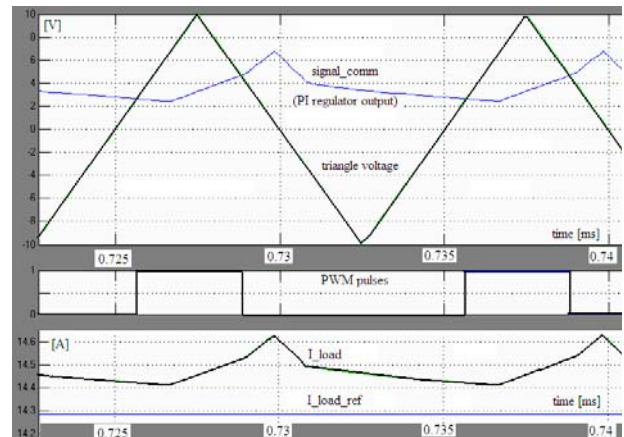


Figure 3. PWM command and load current ripple for $k_p=30$ and $k_i=300$ as PI regulator parameters

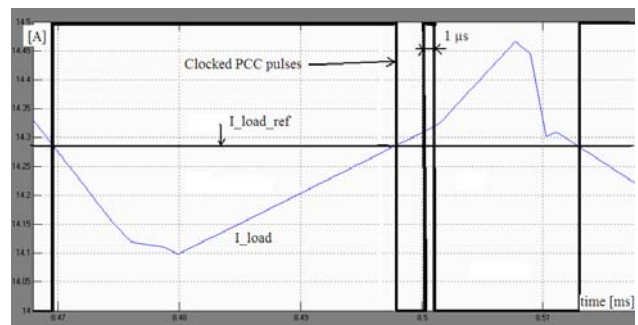


Figure 4. PCC command and load current ripple for 1μs clock



Figure 5. PCC command and load current ripple

III. NONLINEAR CURRENT CONTROL LOOP DESIGNING

Harmonics of the simulated inverter current [1] have the values shown in Table 1.

Table 1. The load current harmonics value for frequency f [Hz], $H_L f$

Value for	$H_L 100$	$H_L 200$	$H_L 300$	$H_L 400$	$H_L 500$
[A]	5,13	1,995	2,9925	4,275	7,8375

Obviously, the gain of the PEMFC current ripple, G_{Ifc} , plays a significant role in the active compensation of the low frequency inverter current harmonics with a buck current source that use a bang-bang current control. Table 2 shown the normal PEMFC current harmonics level (as ratio of the load current harmonics level), and these results are represented in Figure 6.

Table 2. First five harmonics of the normal PEMFC current

G_{Ifc}	The PEMFC current harmonics value normalized to the load current harmonics value is the normal PEMFC current harmonics for frequency f [Hz], H_f				
	H_{100}	H_{200}	H_{300}	H_{400}	H_{500}
1	2,500	0,500	0,200	0,700	0,250
20	0,410	0,120	0,200	0,210	0,350
40	0,220	0,070	0,140	0,150	0,200
60	0,160	0,050	0,100	0,110	0,185
80	0,115	0,045	0,075	0,090	0,150
100	0,095	0,038	0,065	0,075	0,130
120	0,085	0,035	0,055	0,068	0,115
200	0,055	0,020	0,040	0,049	0,088

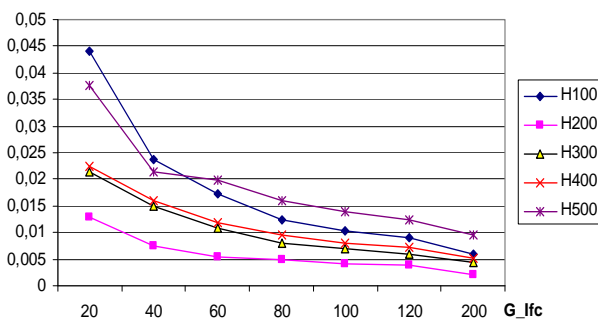


Figure 6. Normal PEMFC current harmonics values, H_f (100, 200, 300, 400 and 500 [Hz]), for different G_{Ifc} values

The active compensation start-up of the inverter current harmonics, I_{out} , by the buck current source, I_{out2} , is shown in Figure 7 for $G_{Ifc}=100$.

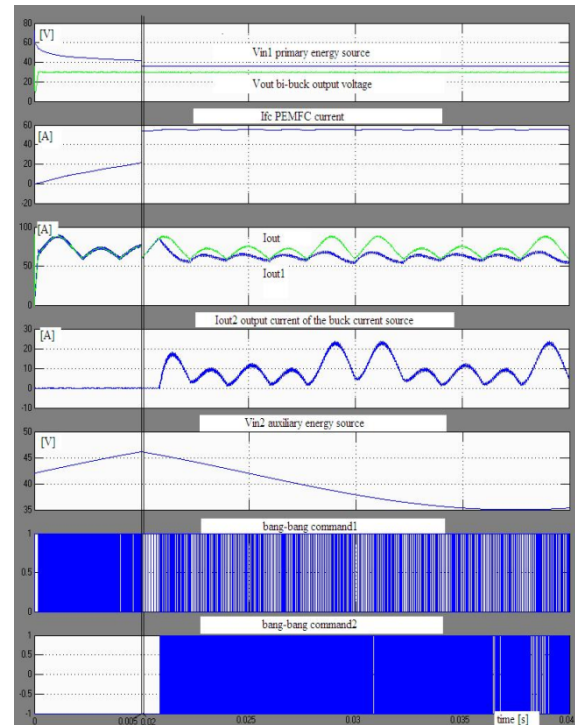


Figure 7.a. Bi-buck interface start-up: PEMFC (cells number=60; cell aria=100 cm²; time constant=20 ms), $I_{ref}=55$ A, $L_{buck1}=L_{buck2}=0.1$ mH and $G_{Ifc}=100$

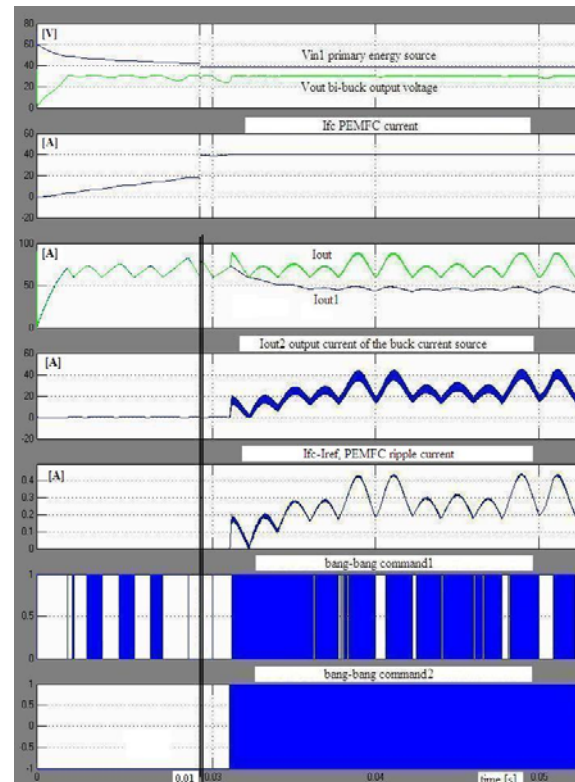


Figure 7.b. Bi-buck interface start-up: PEMFC (cells number=60; cell aria=100 cm²; time constant=20 ms), $I_{ref}=40$ A, $L_{buck1}=1$ mH, $L_{buck2}=0.01$ mH and $G_{Ifc}=100$

In Figure 7 are shown (from top to down) the following signals in time: PEMFC voltage, V_{in1} , and bi-buck output voltage in the first plot; the obtained PEMFC output current, I_{fc} , in the second plot; the simulated inverter current, I_{out} , and the bi-buck interface currents, I_{out1} and I_{out2} , and the fuel cell current ripple, $\Delta I_{fc} = I_{fc} - I_{ref}$, are presented in following three plots; the last two plots shown the bang-bang command signals.

The nonlinear characteristic law of the PEMFC current ripple control loop (nonlinear control block, $G_{I_{fc}}$, which is marked in a circle in Figure 2) is modelled by a look-up Table 3.

Table 3. The look-up table for nonlinear control block

Fuel cell current ripple, $\Delta I_{fc} = I_{fc} - I_{ref}$ [A]	<0	ΔI_{fc} (min)	ΔI_{fc} (max)	> ΔI_{fc} (max)
Gain, $G_{I_{fc}}$	$-I_{ref}$	100	200	200

The knee values, ΔI_{fc} (min) and ΔI_{fc} (max), are chosen to minimize the normal fuel cell current ripple (% of the DC fuel cell current) less than 5% (as reported in the references [14-17]). For $\Delta I_{fc}(\text{min})=0.15[\text{A}]$ and $\Delta I_{fc}(\text{max})=1[\text{A}]$ the fuel cell current ripple and its power spectrum are shown in Figure 8.

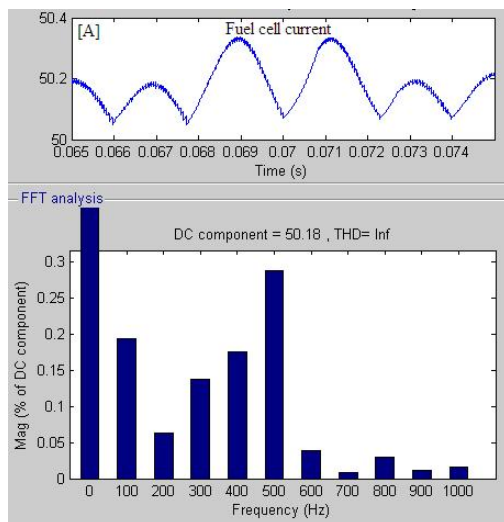


Figure 8. Harmonics of the fuel cell current

IV. SIMULATION RESULTS

The effect of the bi-buck interface inductance ratio on current ripple compensation is shown in Figure 9 for different values, L_{buck1} and L_{buck2} . Observe that a L_{buck1} value less than $50\mu\text{H}$ gives big HF current ripple for the buck current source (Figure 9.a). Good results concerning fuel cell current ripple minimization are obtained for $L_{buck1}=1\text{mH}$ and $L_{buck2}=0.1\text{mH}$ (Figure 9.b). A better filtering of the HF current ripple is obtained for a bigger value of the main inductance, L_{buck1} , but this is not a good option for large currents.

The DC output voltage ripple includes the inverter ripple and buck ripple, and this is spread in a large frequencies band by the proposed chaotifying technique [1,11]. For an approximately 2kW load (30V/71A) and a filtering capacitor, $C_f=47\mu\text{F}$, the output voltage ripple is less than 500mV (Figure 10).

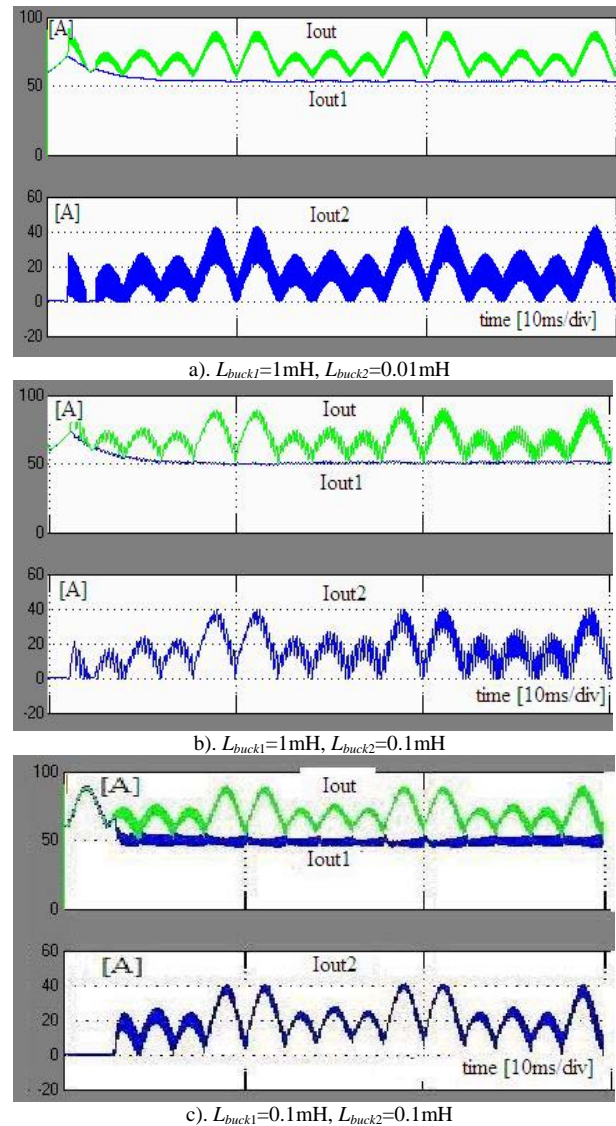


Figure 9. The effect of the bi-buck interface inductance values on current ripple compensation

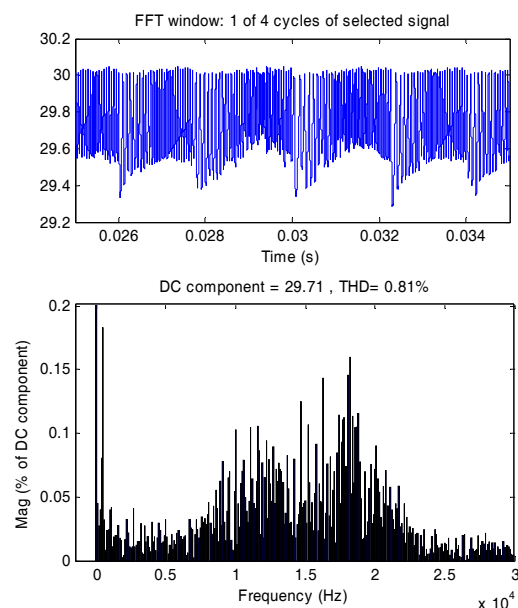


Figure 10. DC output voltage of bi-buck power interface (top) and associate frequencies spectrum (bottom)

V. CONCLUSIONS

It is obviously that PEMFC time constant gives only the moment when the active compensation start-up effectively, and doesn't affect the compensation performance. Therefore in simulation this was set to a value smaller than the real value (hundred of milliseconds), in order to speed up simulations

This paper presents a method to minimize the inverter ripple effect on the PEMFC source. The fuel cell current ripple is minimized by an active compensation of the low frequency current harmonics with a buck current source supplied by an auxiliary source. Remaining power spectrum is spread by chaotification of the buck voltage source behaviour. In both current and voltage loops is used a nonlinear controller, designed to obtain a small fuel cell current ripple and a small DC output voltage ripple, respectively. Simulation results using Matlab modelling are promising.

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BIOGRAPHIES



Nicu Bizon was born in Albesti Muscel, Romania, on February 14, 1961. He received a five-year degree in electronic engineering from the University "Polytechnic" of Bucharest, Romania, in 1986 and the Ph.D. degree in Automatic Systems and Control from the same

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He has authored of six books in Power Converter area, one in Theory and Control Systems, one in Fuzzy Control, one in Hardware topologies for PC and Devices, and one in Medical Electronics and Informatics (all in Romanian language). Also, he is co-authored of the book Fundamentals of Electromagnetic Compatibility, Theory and Practice (in English language) and of a book chapter - "Intelligent control of the Energy Generation System", in the book "Intelligent Information Systems and Knowledge Management for Energy: Applications for Decision Support, Usage and Environmental Protection". His current research interests include the broad area of

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