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MODELLING THE BI-BUCK INTERFACE FOR INVERTER CURRENT RIPPLE COMPENSATION

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Abstract- In this paper is proposed flexible power architecture for an energy generation system which uses a fuel cell stack as main DC energy source. The paper is an analysis of ways of solving the main problems that arise in such systems, insist on the role of passive and active filters in reducing the fuel cell current ripple. The bi-buck structure is used as active power interface between fuel cells stack and inverter system. The control performances of the proposed bi-buck power interface, concerning the fuel cell current ripple, are subject to the other authors' paper [1]. The bi-buck structure is implemented and simulated in MATLAB-SIMULINK using different inverter input current patterns. All other used models and some designing aspects are presented, too.

Keywords: Energy Generation System**,** Fuel Cell, Buck Converter, Inverter System, Current Ripple, Active Power Interface.

I. INTRODUCTION

Fuel cell current ripple must be limited by an adequate active control in order to increase control performances concerning inverter current ripple compensation. Inverter current ripple represents the main factor responsible for performance degradation of the Fuel Cell with Proton Exchange Membrane (PEMFC): PEMFC energy efficiency [2,3,4] and PEMFC life cycle [5,6,7]. The PEMFC low frequency (LF) current ripple affects in much measure the PEMFC life cycle, cause hysteretic losses and subsequently more fuel consumption. Therefore some restrictions of the fuel cell current ripple on frequencies bands are specified. Recent experimental results shown that LF inverter current ripple contributes with up to 10% reduction in the available output power [8,9].

Proposed state-of-the-art architectural and control solutions are: increasing of the passive filter rated capacity by adding more capacitors or adding external active filters [10,11,12]. Because the passive filtering solution for high PEMFC output current are bulky, expensive and inherently unreliable, active control remains an acceptable variant to reduce current ripple in the intermediate DC-link of the inverter system or using an intermediate power interface between fuel cell stack and inverter system. A mono-phase inverter system contains a single-phase DC-AC converter which produces a DC current with AC ripple having the spectral harmonics at even multiples of twice of the output frequency. If PEMFC stack is directly connected to the DC-AD converter, this high PEMFC LF current ripple reduces PEMFC performances.

As state-of-the-art control solution, the control technique for maximum power point (MPP) tracking of the PEMFC power is proposed using adaptive control with supervising neuronal network, MPP finding by genetic or chaotic algorithms etc. It is demonstrated that power ripple becomes lower and lower when the operation point gets closer to MPP [13]. As a state-of-the-art architectural solutions, the active filtering techniques are proposed [14,15,16,17]. An innovative converter topology as multi-port energy interface and appropriate control is proposed in [17,18], and a new converter topology without high DC bus is proposed in [19].

Mostly, mixed state-of-the-art architectural and control solutions are used in new energy generation system (EGS) topologies to increase the system performances at different power stages levels: in the DC-AC converter stage [20] and in the power interface stage (DC-DC converter) [21]. The proposed hardware solutions (active harmonics filters [22,23,24] or interleaved power structures [25]) can meet these requirements: for example, report a ripple factor up to 5% for a load power in the kW range. Anyway, all previously mention architectural and control methods eliminate the inverter current ripple going back to PEMFC stack by an innovative control and/or architectural design without auxiliary energy source involvement such as batteries and/or ultracapacitors stacks (usually available as energy storage devices in an EGS) [26,27].

II. POWER MANAGEMENT SOLUTIONS

Power management strategy is important in fuel cell hybrid system for energy storage devices (batteries and/or ultracapacitors stacks) sizing in achieving optimal fuel economy. The addition of a fast auxiliary storage device like a supercapacitor stack in fuel cell-based vehicles has a great potential because permits a significant reduction of the hydrogen consumption and an improvement of the vehicle efficiency [28,29,30].

In [17] is proposed a new state-of-the-art architectural and control solution for LF inverter current ripple reduction, using an ultracapacitors stack as secondary low energy source, combined with HF current inverter ripple spreading in the high frequencies (HF) band [31]. The secondary energy source, which assure the power flow for LF inverter current ripple compensation, can be charged from the primary energy source (PEMFC stack) or by recovered energy flow (for example in the HEV braking process).

Figure 1 shows the new proposed EGS topology which includes the above mention power interface and the Multi-port Power Converter (MPC). The DC-DC power interface converter use a Buck Current Source (BCS) with a bang-bang control (BCS controller) as an active filter of low inverter current harmonics, and a Buck Voltage Source (BVS) controlled by the reference voltage as voltage source. For simplicity of design, reliability or economic reasons, the designer may choose the bang-bang control law for switching power converter or other controlled PWM switching commands [33]. Because the electrical stress of the electronics switches is too high, in future papers we will have in attention other ZVS/ZCS switching control techniques [34]. The Multi-port Power Converter (MPC) allows bidirectional and unidirectional power transfer between its input/output ports: for example, under MPC control the ultracapacitors stack may be charged from PEMFC and/or from regenerative load power flows. other possible MPC power flows are shown by broken line. The control loops and control surface variables are also presented.

In this paper the analysis will be concentrate on designing of the bi-buck power interface. The remainder of the paper is organized as follows. Section 3 presents the MATLAB-SIMULINK© models used in simulations. Because the current ripple control performances are shown extensively in [1], section 4 presents only the voltage control strategy. Last section concludes the paper.

III. BI-BUCK POWER INTERFACE MODELLING

The PEMFC power interface is the bi-buck topology shown in Figure 2 [17]. The DC Controlled Voltage Source is implemented by a Buck Voltage Source topology, and BVC is simple controlled by the reference voltage, V_{ref}, so average output voltage is $V_{out(AV)}=V_{ref}$. The bang-bang control is used in feedback current loop. A nonlinear control is used for voltage feedback loop in order to obtain low output voltage ripple. A choatification technique is used for power spectrum spreading in high frequencies band [32].

If the PEMFC reference current (I_{ref}) is estimate by the MPP control techniques for a nominal load current, I_{out}, then I_{out2} current is a estimation of the I_{out} current ripple, and $I_{out1(AV)} \approx I_{out(AV)}$. Usually, the load has high dynamic so an intelligent management of the EGS power flow, from energy sources to energy storage devices and load, must be implemented [28]. The BCS controller has many other EGS variables as inputs for control surface (see Figure 1) which can improve the EGS functioning.

The AC Controlled Current Source is implemented by a Buck Current Source (BCS), and is only controlled by the PEMF current ripple, I_{FC}-I_{ref}. So, the output current (I_{out2}) tries to follow the LF PEMF current ripple. The main power flow is supplied by PEMFC ($I_{out1(AV)} >> I_{out2(AV)}$), so $I_{out(AV)}$ $I_{out1(AV)}+ I_{out2(AV)} \approx I_{out1(AV)}$. The EGS variables used as inputs for BCS controller are shown in Figures 1 and 2. Obviously, the BCS response time and BCS output current ripple, I_{-load}, is high dependent by buck inductance value, L_{-buck2}, and by BCS controller control surface. In this paper a nonlinear control surface is proposed. The control surface shape is designed in order to obtain low LF output ripple.

In this paper a load current ripple shapes obtained by a superposition of the first three 100Hz inverter harmonics over nominal load current is used in simulations (Figure 3). The PEMFC as main energy source, V_{in1}, has in simulation the model parameters shown in Figure 4 and an appropriate dynamics [8,35].

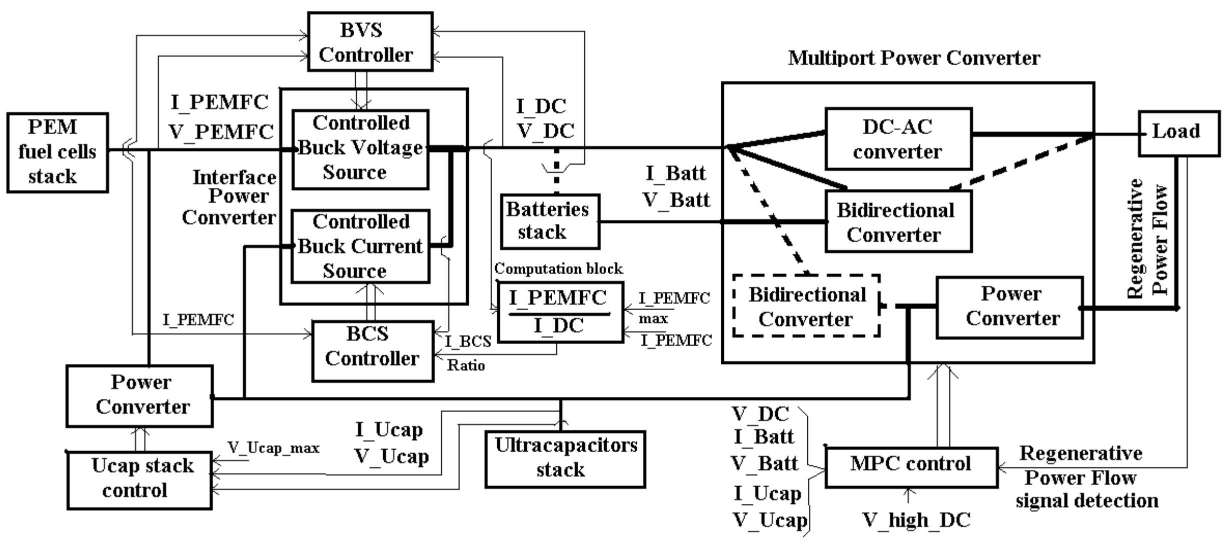

Figure 1. EGS topology

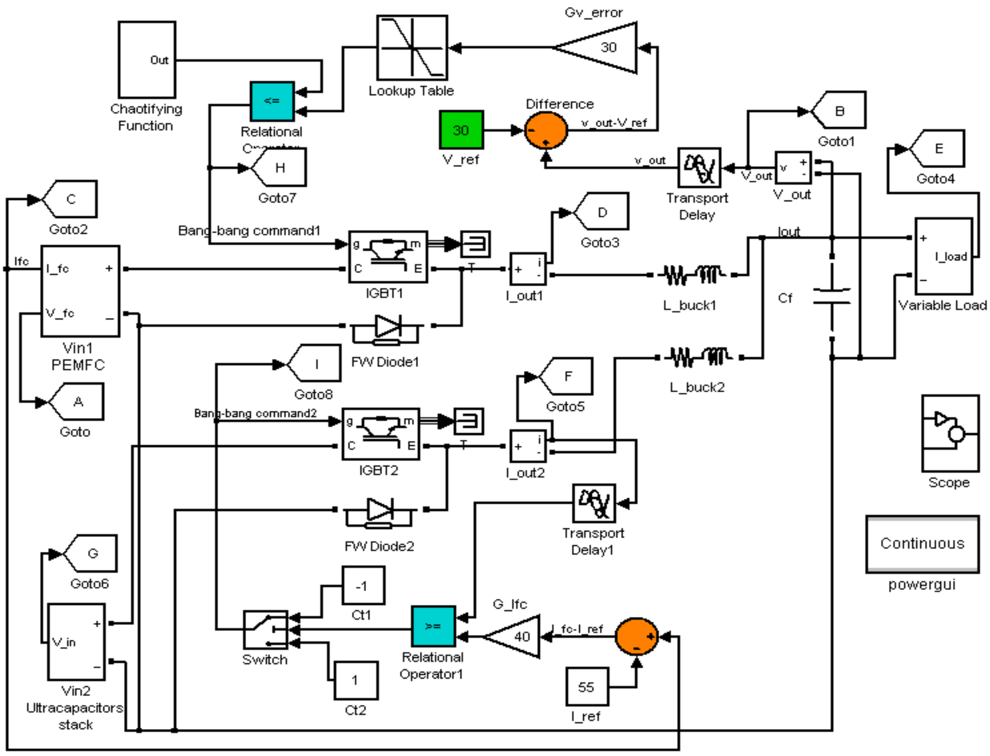

Figure 2. Bi-buck power interface using current superposition

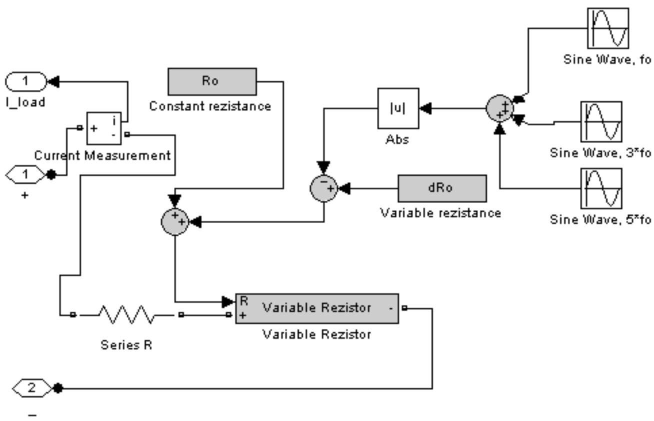

Figure 3. Variable load

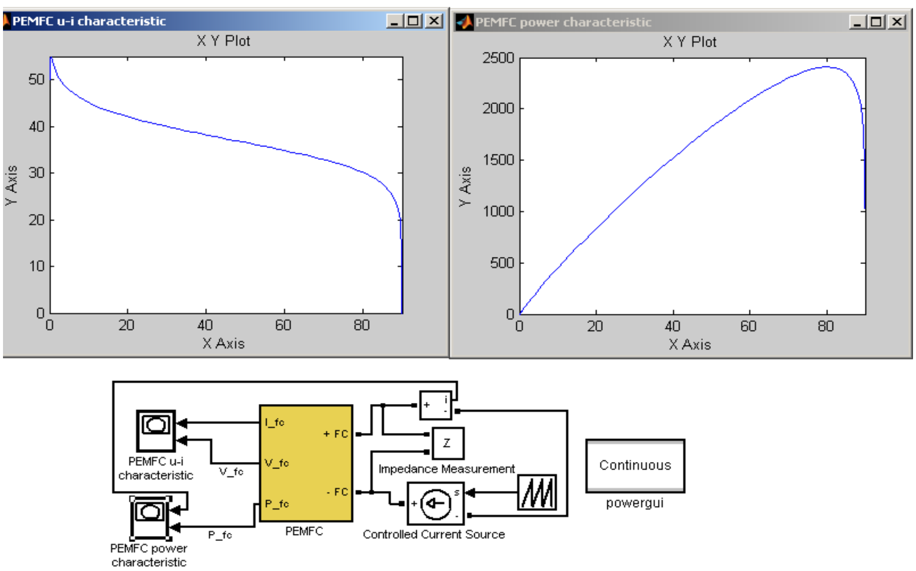

Figure 4. PEMFC model characteristics

The second energy sources, V_{in2}, assure the auxiliary power flow for LF inverter current ripple compensation, and can be an ultracapacitors stack (see Figure 1). To shown that current active control is independent by the Vin2 source level, a simple controlled voltage source is used in simulation (see Figure 2). This simulated inverter current ripple (see Figure 5) includes the LF harmonics (up to 500Hz) with different level of amplitudes and is simulated using the variable load from Figure 3.

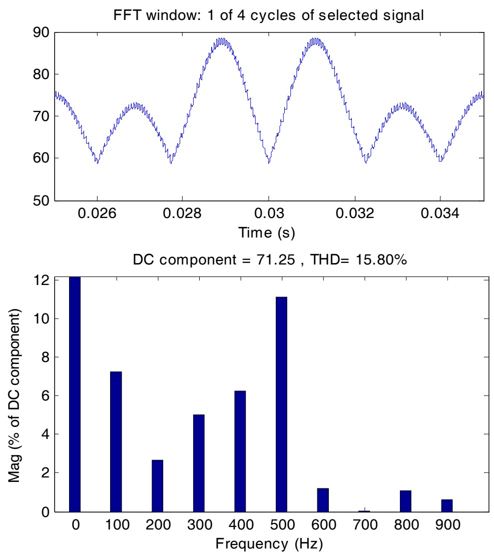

Figure 5. Harmonics of the simulated inverter current

IV. VOLTAGE CONTROL LOOP DESIGNING

A. Voltage Nonlinear Control Law

The nonlinear characteristic law of the voltage control loop is modelled by a look-up table, and is optimized for a small output voltage ripple:

$$\mathrm{v}_{\substack{\text{Look-up}\\ \text{table out}}}(\Delta \mathrm{v}_{og}) = \begin{cases} s_0 \cdot \Delta \mathrm{v}_{og} + \frac{1}{2} \cdot (s_1 - s_0) \cdot \\ \cdot \left(\left| \Delta \mathrm{v}_{og} + \Delta \mathrm{v}_{og(min)} \right| - \left| \Delta \mathrm{v}_{og} - \Delta \mathrm{v}_{go(min)} \right| \right), \\ for \quad \left| \Delta \mathrm{v}_{og} \right| < \Delta \mathrm{v}_{og(max)} \\ -\operatorname{sign}(\Delta \mathrm{v}_{og}) \cdot \mathrm{V}_{max}, \ \left| \Delta \mathrm{v}_{og} \right| \geq \Delta \mathrm{v}_{og(max)} \end{cases} \quad (1)$$

where $s_o = \frac{-1-1}{0.15-(-0.15)} = -\frac{20}{3}$ is the slope in the inner zone $\left|\Delta \mathrm{v}_{og}\right| < \Delta \mathrm{v}_{og(min)}$, $s_1 = \frac{1-10}{0.6-0.15} = -20$ is the slope in the intermediate zone $\Delta \mathrm{v}_{og(min)} < \left|\Delta \mathrm{v}_{og}\right| < \Delta \mathrm{v}_{og(max)}$, $\pm V_{max}$ are the voltage limits in the outer zone $\left|\Delta \mathrm{v}_{og}\right| \geq \Delta \mathrm{v}_{og(max)}$,

$$\left|\Delta \mathrm{v}_{og}\right| = G_{V\_error} \cdot \left|v_o - V_{ref}\right| \quad (2)$$

is the gained output voltage ripple (G_{V_error}=30), and $\pm \Delta \mathrm{v}_{o(min)}$, $\pm \Delta \mathrm{v}_{o(max)}$ denote the breakpoints ($\Delta \mathrm{v}_{o(min)}$ =150mV, $\Delta \mathrm{v}_{o(max)}$ =600mV).

B. Control Chaotification

The classical PWM feedback produces in stabilized regime a fixed switching frequency, f_{sw}, which is the frequency of the saw-tooth voltage, used to obtain the PWM command for the buck IGBT switch (Figure 6). The output voltage spectrum is concentrate at the switching frequency and its harmonics, generating high electromagnetic interference (EMI). Comparing the level of the v_{CD} feedback signal with the saw-tooth signal level (v_{sw}) it is clear the proposed control is of bang-bang type with programmable gain (Figure 7), and the saw-tooth signal represents a chaotification parameter.

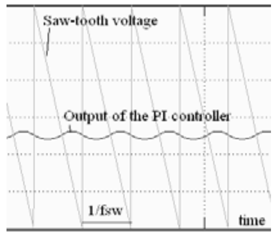

Figure 6. PWM principle

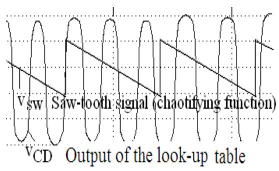

Figure 7.a. Saw-tooth signal (as chaotification function) and output of nonlinear controller (look-up table)

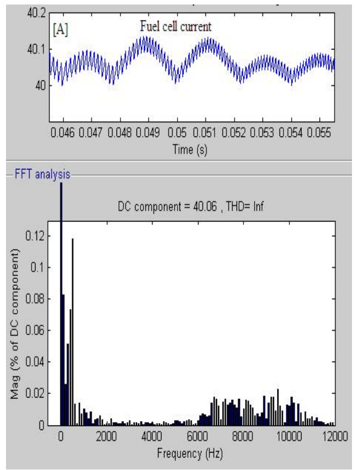

Figure 7.b. Fuel cell current and its power spectrum (spread by chaotification of PWM switching signal)

V. CONCLUSIONS

This paper presents EGS architecture wich minimize the inverter ripple effect on the PEMFC source by an active compensation of the low frequency current harmonics. Remaining power spectrum is spread by control chaotification of the buck voltage source. Simulation results are promising [1].

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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 university, in 1996. He is currently a Professor with the University of Pitesti, Romania. Previously, he was in hardware design with Dacia Renault SA, Romania.
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