Digital control Strategy Based on Operate a Power Conditioner System for Hybrid Fuel Cell/ Supercapacitor Power Source

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Abstract

This paper proposes a digital control scheme to operate a Proton Exchange Membrane Fuel Cell (PEMFC) module a 1.2kW and a Supercapacitor (SC) throught DC/DC hybrid converter. A FC has been proposed as a primary source of energy and a SC has been proposed as an auxiliary source of energy. A control scheme for this system is proposed. An experimental validation of the system implemented in the laboratory is provided. Several tests have been performed to verify that the system achieves an excellent output voltage (V_o) regulation and SC Voltage (V_{SC}) control, under disturbances from FC voltage, load voltage and other perturbations described in results analysis.

I. INTRODUCTION

Fuel cells (FCs) can become an important future power source [1]. The interest in FCs has increased during the last years due to the fact that the use of fossil fuels for power has resulted in many negative consequences [2]. Some of these include severe pollution, climate changes, melting of ice caps, rising sea levels, acid rains, ozone layer depletion, oil spills, forest and agricultural land damage etc [3]. FCs are now closer to commercialization than ever, and they have the ability to fulfill all of the global power needs while meeting the efficacy and environmental expectations [5]. PEMFCs are the most popular type of FC, and traditionally use hydrogen as the fuel [6]. PEMFCs also have many other fuel options, which range from hydrogen to ethanol to biomass-derived materials. These fuels can either be directly fed into the FC, or sent to a reformer to extract pure hydrogen, which is then directly fed to the FC [7]. One FC problem is its relative slow dynamics caused by the time constant of the hydrogen and gas supply systems that can be in the range of several seconds [8]. In the mean time the FC may be starved of fuel which is not good for the electrocatalyst shortening its life [9]. Therefore, the FC should be operated under controlled dynamic regimes, ensuring an optimum performance and durability [10]. In this sense SCs respond faster than FC for a fast step increase or decrease in power demand [11]. Thus using SCs together with FCs performance and FC life can be improved by absorbing faster load changes and preventing fuel starvation of the FC [12]. Adding SCs will enable the hybrid system to follow fast changing loads while allowing the FC to respond at a slower rate [13].

Therefore, it becomes necessary to study structures of power conditioners with their respective control systems that can mitigate the disadvantages mentioned of the FC itself [14]. Several researches have studied the different topologies with their respective control proposals to operate FC and SC. Thoungthon et al. [15] studied the control of FC/Battery hybrid source for electric vehicle applications. His proposed control algorithm, managed energy exchanges between the DC bus, the main source and store device. The control strategy is cascade control structure composed of three loops, the outer loop is a battery state of charge, the middle loop of the battery current loop and the battery current control loop in the end. Sánchez-Squell et al. [16] studied energy management in electrical system fed by multiple sources. They proposed a topology that is used in some electrics cars. To ensure energy exchange, the interconnection of the storage and load devices is performed by using power converters. Thoungthon et al. [17] studied control strategy of FC/SC hybrid power source for electric vehicle. It

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presented a control principle for utilizing FC as main power source which operate with boost converter and SC as auxiliary power source which operate bidirectional converter. The novel conception was that the hybrid system control proposed a regulation of the DC bus voltage through the power only delivery by the fast auxiliary source.

Cervantes Isle et al. [18] studied a hybrid control technique applied in FC/SC electric vehicle platform. The paper proposed a hybrid controller that guarantees stability in the selected operation region, meanwhile it achieves an excellent output voltage control under disturbances either from supply voltage, load voltage or other perturbations. Gebre T. et al. [19] studied the control of converters to operation of FC and SC. In this case the control was carried out by using an external DC-link state of charge control loop which takes the bus voltage set point as reference and produces a FC current reference. This outer control can be a simple proportional controller with gain set to a value which would draw maximum FC current when the DC link researches the maximum depth allowed. The control strategy for the SC is determined by the status of DC bus voltage.

The mentioned control algorithms where were implemented analogically . The main drawback of analog control in the operation of FC and SC is related to the cost, because it will be increased linearly by the number of controllers. Another drawback of analog system is related to flexibility. Digital components are more robust, reliable and small and have lower sensitivity to noise, while presenting good efficiency. In the proposed scheme, a boost converter is proposed as main interfacing system between FC and the load, while a SC is proposed as a bidirectional source for the SC. This paper is organized as follows: the Section II presents a proposed configuration. The Section III describes the control system proposed. The Section IV experimental validation and the Section V conclusion where evaluates the experimental results and performance of system control in the power conditioner of PEM FC application. Figure 1 also shows the proposed structure of control of the converter fuel cell whose function is the control the SC voltage (V_{SC}) and the FC current through Proportional Integral (PI) controllers that are connected in cascade $PI_{\_VSC}$ and $PI_{\_IFC}$. While the structure of control for two-quadrant chopper converter has the function of controlling the Vo, as well as the current of the SC (I_{SC}) through the cascaded PI controllers $PI_{\_Vo}$ and $PI_{\_Isc}$.

II. PROPOSED CONFIGURATION.

A. Analysis of hybrid converter proposed to FC and SC system

Figure 1 shows the proposed power conditioner and the control structure. This system consists of two power supplies: FCs and SCs, and therefore it requires two power converters. The main converter operates the FC which corresponds to a unidirectional boost converter called in this paper FC converter and the second converter operates the SC with a bidirectional converter. The last converter allows to operate the SC in its two modes of operation. The first in charge and the second in discharge. When the operation mode is on discharge, the boost converter acts delivering energy to the load and when the mode of operation is on charge, the buck converter acts delivering energy to SC. These two converters are connected in parallel to the DC bus in Output Voltage (Vo). Figure 1 also shows the proposed structure of control of the power conditioner whose function is to control the SC voltage (V_{SC}) and the FC current through Proportional Integral (PI) controllers connected in cascade, $PI_{\_VSC}$ and $PI_{\_IFC}$. The structure of control for the two-quadrant chopper converter has the function of controlling the Vo, as well as the current of the SC (I_{SC}) through the cascaded PI controllers $PI_{\_Vo}$ and $PI_{\_Isc}$.

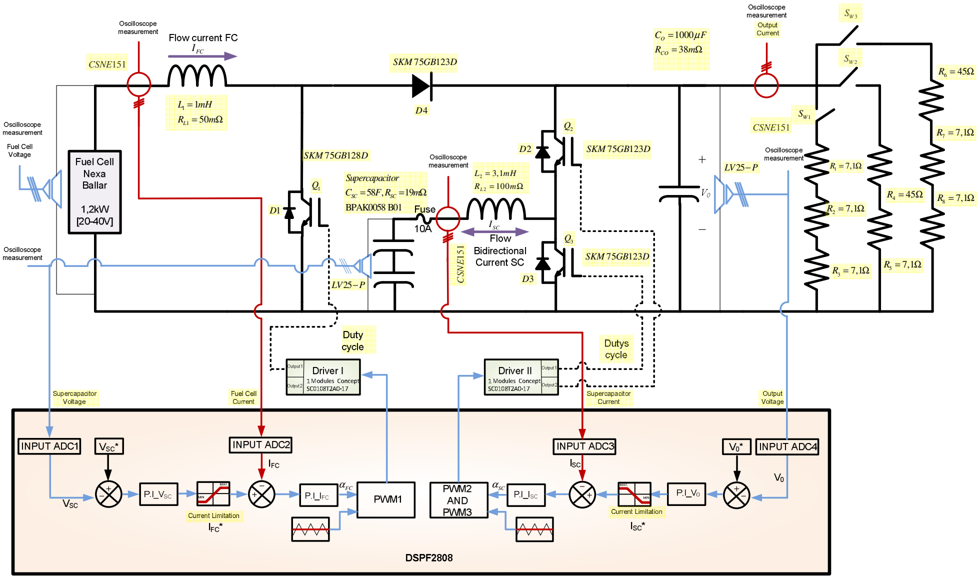


Fig. 1. Proposed digital controller with DSP2808 for the FC/SC hybrid power source.

III. CONTROL SYSTEM

A. Control description in close loop

Figure 2 shows the proposed control scheme to operate two converters of FC and SC respectively. The control for the fuel cell converter structure basically consists of two Proportional Integral (PI´s) controllers , one is located in the inner loop of current (PI_I_{FC}) which is connected in cascade with the external loop through (PI_V_{SC}). On the other hand, the control structure for the SC converter consists of two PI controllers. One is located in the inner loop current (PI_I_{SC}), which is connected in cascaded with the outer loop by the controller (PI_V_0).

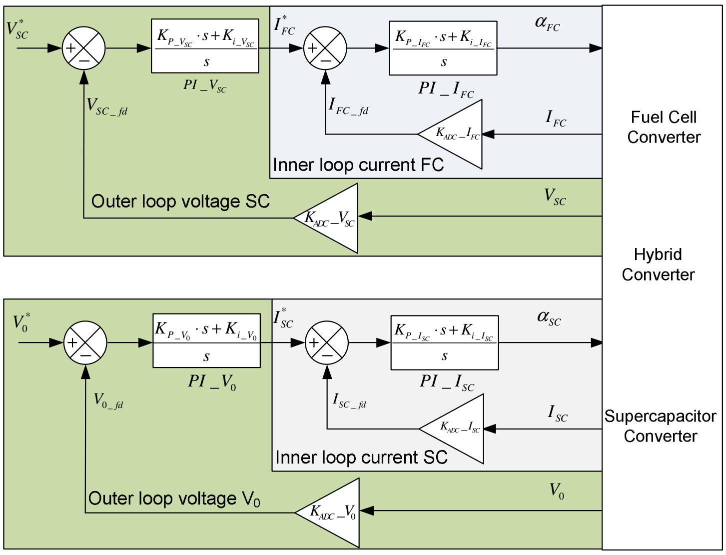


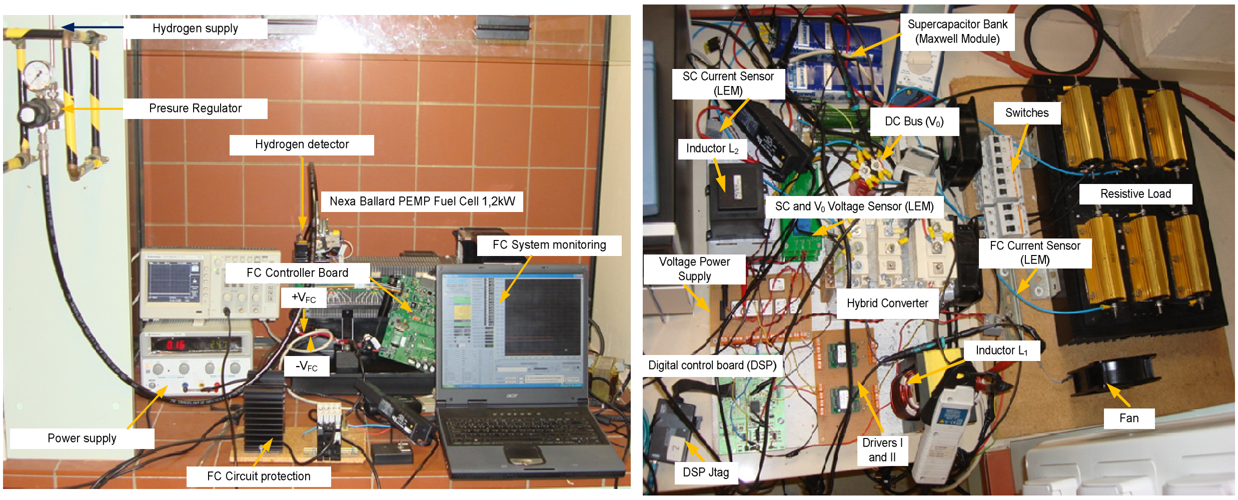
Fig. 2. Schematic Control system.

The general structure of control, has as the V_{SC}, I_{FC}, I_{SC} and V_0 as function controlling variables respectively. The microcontroller to be used to develop the algorithm from Figure 2 corresponds to the DSP2808 from Texas Instruments.

IV. EXPERIMENTAL VALIDATION

A. Test bench description

Figure 3a illustrates the basic installation of a Nexa ^{TM} power module in the lab and the mechanical, electrical and software interfaces necessary for operation. The Nexa ^{TM} PEMFC system (1.2kW, 46 A, 26 V) was developed and commercialized by the Ballard Power Systems Inc. The Nexa™ system is installed in a well-ventilated lab area equipped with hydrogen alarm sensors. The FC is provides a suitable supply of hydrogen connecting the fuel supply to the hydrogen connection as shown in Figure 3a.



(a) (b)

Fig. 3. Photographs a) PEMFC stack b) Hybrid converter.

FC requires an interface to communicate with the computer. A Labview software provided by the same manufacturer provides a graphical user interface to the Nexa™ module's operational status and performance. However, it provides basic data monitoring, logging and diagnostic features that can be very helpful when conducting a FC testing program in the Labview. FC needs a circuit protection, so therefore we will connect a blocking diode on the positive output terminal of the FC stack. To operate the FC it is necessary to connect a 24 VDC power-supply to the Nexa™ control board. The experimental set-up of the hybrid FC/SC power source uses a Nexa ™ BALLARD PEM FC stack as the main source. The auxiliary source is obtained with a Maxwell SC module associating two modules in series: Maxwell BPAK0058 E015. The power converter DC/DC is made with standard IGBT modules (SEMITRANS: SKM75GB128D and SKM75GB123D). A real-time Code Composer Estudio is used to programming the DSP 2808 of Texas Instruments to implement the energy management control strategy. The experimental environment is shown in Figure 3b.

B. Test bench parameters

The Nexa BALLARD PEM fuel cell stack has a nominal power 1200W related to a rated current of Inom=46 A and rate output voltage of Vnom= 26V. Two Maxwell modules in series (BPAK0058 E015) with the following characteristics: C=29F,V_{SCMAX}=30V,V_{SCMIN}=15V,$I_{SC\_PEAK\_MAX}$=1500 A, ESR_{SC}=38 mOhms are connected.

The specifications of the hybrid converter is shown in table I.

TABLE I
SPECIFICATION TO OPERATE FC AND SC CONVERTERS

Symbol	Description	Value
V_{FC}	Fuel Cell voltage	33-36 V
V_{SC}	Supercapacitor Voltage	25 V
V_0*	Consign output voltage	80 V
V_{SC}*	Consign SC voltage	25V
L_1	Fuel Cell Inductor	1mH
L_2	Supercapacitor Inductor	3.4 mH
ΔI_{L_1}	Ripple current in FC	0.8 A
ΔI_{L_2}	Ripple current in FC	0.2 A
f_S	Switching frequency	20 kHz

C. Experimental results

Three tests have been valued to operate the power conditioner. In this case the load values for different combination of demand power are 42.3W, 47.98W, 90W, 117.3W, 160,25W, 165.56W and 208.3W, which the hybrid converter shall submit in its operation in closed loop for the following proposed tests. Bellow we have listed the cases to analyze:

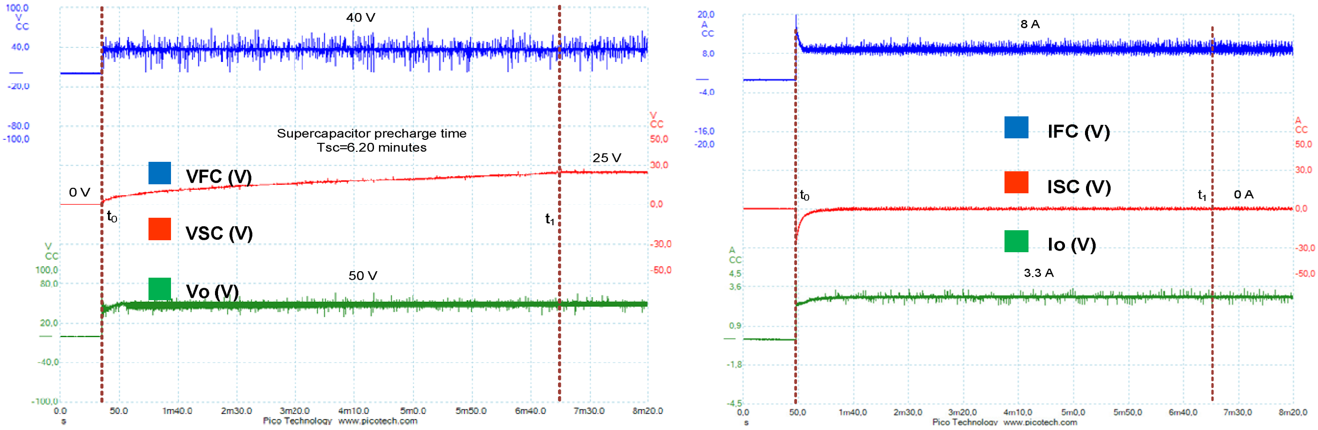
Case 1.- It consists in observing the preload of the SC. Initially, the SC is completely discharged. The load power used for this test corresponds to 165.56 W.

Case 2.- Consists in making a step changes in load based on load power of 42.3 W to 165 W and vice-versa.

Case 3.- Consists of making changes in the slogan V_0*, operating the system with a resistive load of 42.1 W.

C.1 Case 1

In Figure 4a, it can be observed that a preload of the voltage of the SC from t_0 to t_1 with a time of 6.20 minutes starting from 0 V to 25 V, where 25 V is the reference proposed for the SC $V^*_{SC.}$ Figure 4b also shows a negative current flowing in the SC for its preload. After t_1, the I_{SC} =0, as the SC is fully charged.

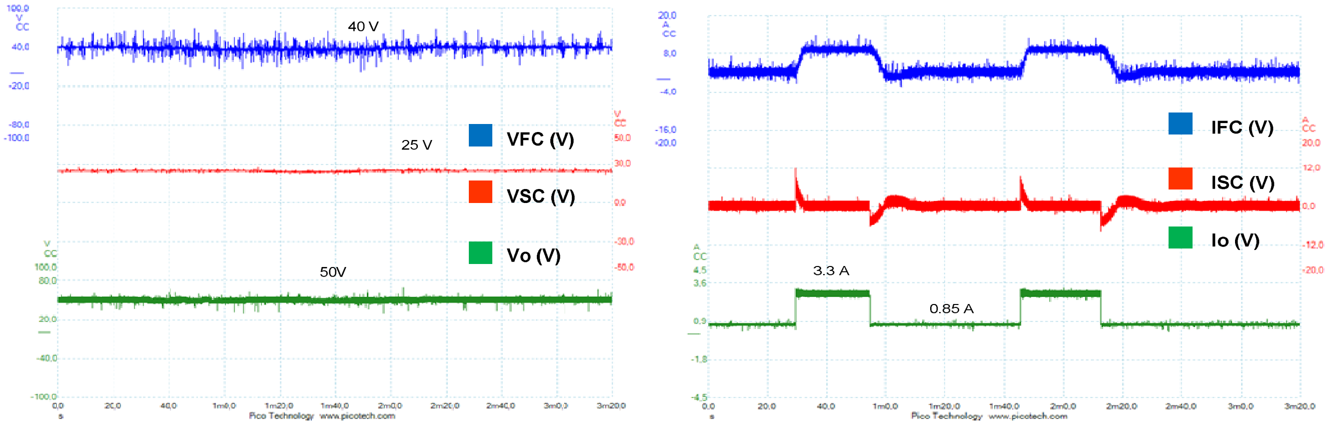


(a) (b)

Fig. 4. Waveforms a) Voltage and b) Current.

C.2. Case 2

Figure 5a shows a constant V_0 of 50 V and V_{SC} shows a voltage of 25 V to such changes.



(a) (b)

Fig. 5. Waveforms a) Voltage and b) Current.

Figure 5b also shows the response of I_{FC}, I_{SC} and I_O to the system flows. It is clear that to make the changes of load of 0.85 to a 3.3 A, I_{SC} helps often the changes demanded by the load.

C.3. Case 3

Figure 6 shows the regulation of V_0 subjected to changes of consign V_0*. In this case it can be seen that at the interval time t_0 to t_1 there is a change of 50 to 80 V.

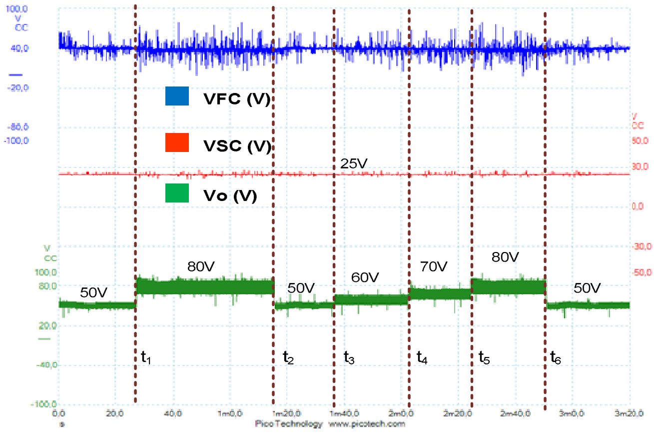


Fig. 6. Voltage waveforms.

V. CONCLUSION

In this article we have implemented a hybrid converter for the operation of a module of FC Nexa Ballard of 1.2kW and a SC, with the proposal of a control system which has been implemented digitally using the Texas Instruments DSP2808 microcontroller. The proposed control scheme contains four loops of closed control for the operation of the system, which allows to control the following variables: V_0, V_{SC}, I_{SC} and I_{FC}. The control is able to compensate for load changes as well as the backup power system responds quickly to slow start by the FC. The control of backup can also determine the charge and discharge of SC. The digital control allows to have greater flexibility and simplicity in the control of complex processes in form versus analogy. The programming and the good signal conditioning simplifies the process and reduce its cost.

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