A Power Control Scheme of a Fuel Cell Hybrid Power Source

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Abstract— **This paper describes a power control scheme to improve the performance of a fuel cell-battery hybrid power source for residential application. The proposed power control scheme includes a power control strategy to control the power flow of the fuel cell hybrid power system and a digital control technique for a front-end dc-dc converter of the fuel cell. The power control strategy enables the fuel cell to operate within the high efficiency region defined by the polarization curve and efficiency curve of the fuel cell. A dual boost converter with digital control is applied as a front-end dc-dc converter to control the fuel cell output power. The digital control technique of the converter employs a moving-average digital filter into its voltage feedback loop to cancel the low frequency harmonic current drawn from the fuel cell and then limits the fuel cell output current to a current limit using a predictive current limiter to keep the fuel cell operation within the high efficiency region as well as to minimize the fuel cell oxygen starvation.**

Keywords: fuel cell, hybrid power source, digital control, digital filter.

I. INTRODUCTION

This paper presents a new power control scheme for a fuel cell hybrid power source for residential application which includes a power control strategy to control the power flow between the power sources and the load and a digital control technique for the front-end dc-dc converter. By the proposed power control strategy, the fuel cell operation is maintained within the high efficiency region decided by the polarization curve and efficiency curve of the fuel cell. A dual boost converter with digital control is applied as a front-end dc-dc converter to control the fuel cell output current. The dc current drawn from the fuel cell includes a 120Hz harmonic current induced by the single phase ac load, which not only make it difficult to regulate the front-end dc-dc converter properly but also draw the current more than the fuel cell can output instantly with the fuel amount fed to the stack. The digital control technique of the converter adopts a moving-average digital filter and cancels the 120Hz harmonic current and then limits the fuel cell current to a current limit determined by the air amount fed to the fuel cell stack using a predictive current limiter to avoid the fuel cell oxygen starvation and improve the fuel cell durability.

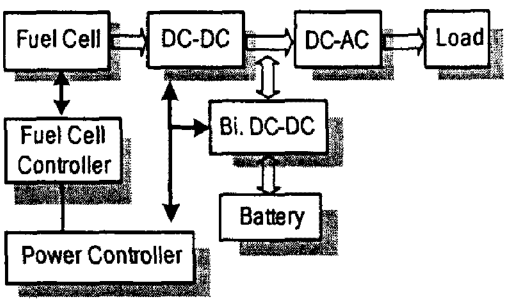
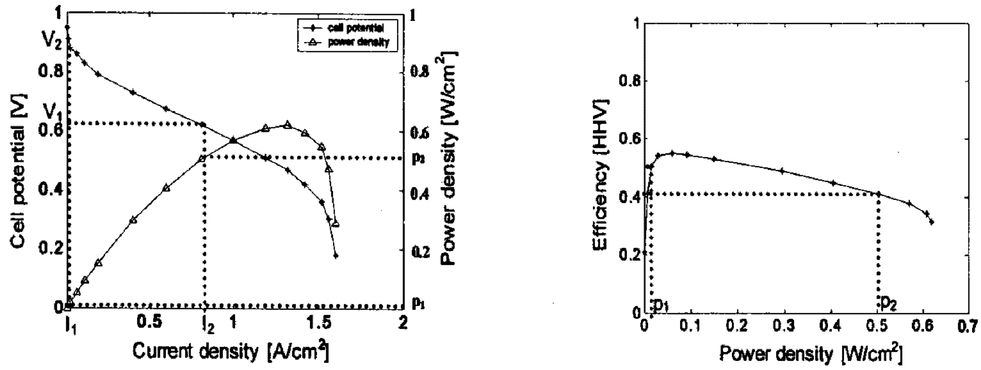


Fig.1 Fuel cell-battery hybrid power source

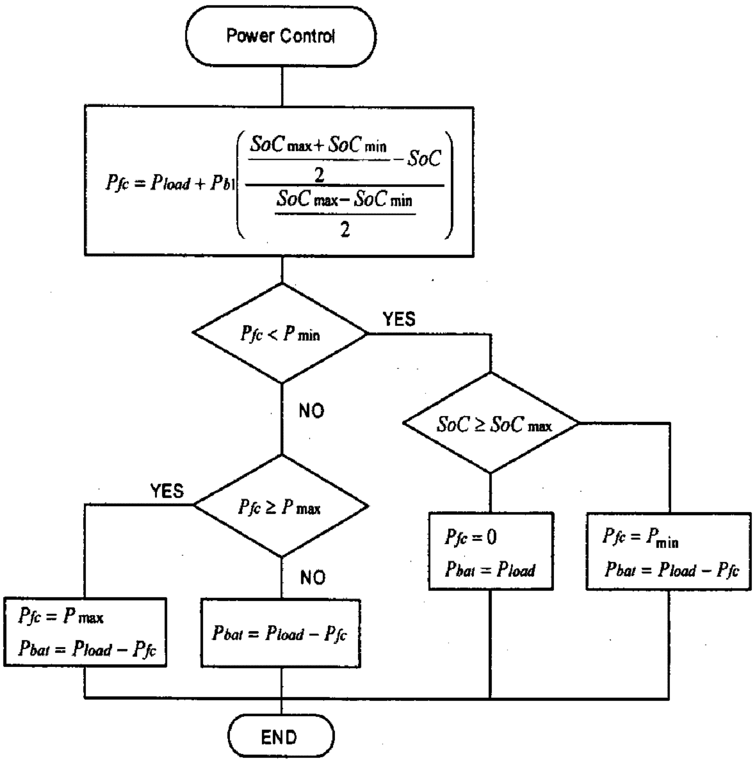
II. POWER CONTROL STRATEGY

The goal of the power control scheme is to operate the fuel cell hybrid power source with high efficiency while maintaining the required performance for residential application. This is achieved by the proposed power control strategy running in the power controller (Fig.1), which controls the fuel cell to operate within its high efficiency region.



(a) Polarization curve and power density curve (b) Efficiency curve

Fig.2 A typical polarization curve, power density curve and efficiency curve of a PEM fuel cell



* P_{b1}: Available power from the battery when SOC is 1.

Fig.3 Flow chart of power control strategy

The proposed power control strategy calculates the fuel cell power P_{fc} based on the SOC of battery and the power demand P_{load} and regulates the power flow so that the fuel cell operation can be maintained with high efficiency between the minimum power P_{min} and the maximum power P_{max} which are corresponding to the minimum power density p_1 and the maximum power density p_2 respectively in Fig. 2(b), while maintains the battery SOC at the proper level. The fuel cell is turned off and the battery supplies the power to the load when the calculated fuel cell power is lower than the minimum power P_{min} for the efficiency (Fig. 3). The calculated fuel cell power P_{fc} and the battery power P_{bat} are sent to the fuel cell controller and the bidirectional dc-dc converter respectively, and the power generated by the fuel cell is controlled by regulating the air amount fed to the stack based on the fuel cell power P_{fc}. As a result, the fuel cell operation is always maintained within the high efficiency region defined by the currents, I_{min} and I_{max} and the voltages, V_{min} and V_{max}, which are corresponding to I_1, I_2, V_1 and V_2 in Fig. 2(a).

III. DIGITAL CONTROL TECHNIQUE FOR DUAL BOOST CONVERTER

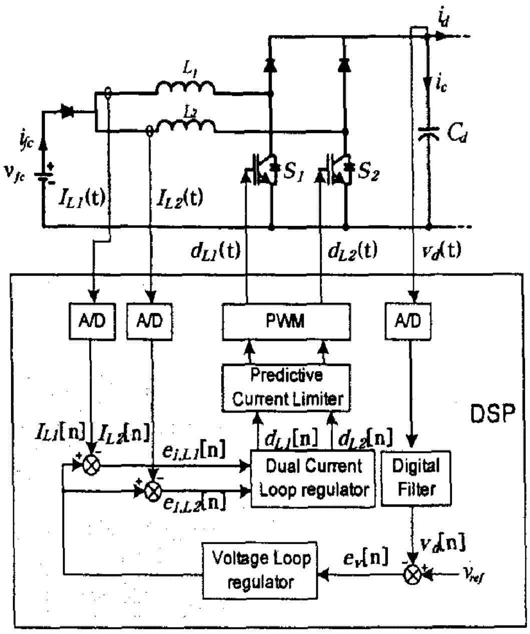


Fig.4 A digital control scheme for the dual boost converter

A. Cancellation of 120Hz Harmonic Curren

The steady state voltage error calculated in the voltage control loop of dual boost converter is presented as

$$v_{err}(t) = V_d - v_d(t) = -\frac{V_{o.rms} I_{o.rms}}{2\omega_o C_d V_d}\sin(2\omega_o t - \phi) \quad (1)$$

, where $V_{o.rms}$ and $I_{o.rms}$ are rms values of the inverter outptut voltage and current, and the current command from the voltage loop is the voltage error multiplied by the voltage loop gain. Therefore, a large 120Hz harmonic current which is 180° phase shifted from the 120Hz ripple voltage of the dc bus is induced at the fuel cell output terminal.

The proposed digital control scheme for the dual boost converter emploies a moving-average digital filter into the voltage feedback loop to remove the 120Hz voltage ripple component included in the measured voltage, which cancels the 120Hz harmonic term of the current command (Fig.4). The moving-average digital filter is expressesd as follows;

$$f(n) = \frac{1}{N}\sum_{k=n+1-N}^{n} f(kT) \quad (2)$$

where N is a period corresponding to 1/120.

B. *Predictive Current Limiter*

After the 120Hz harmonic component of the fuel cell current is eliminated using the moving-average digital filter, the fuel cell current is limited by a predictive current limiter adjusted by the air amount fed to the fuel cell stack in order to avoid the oxygen starvation in the cathode channel (Fig.4). The current limit value calculated by the fuel cell controller is derived as following equations. The air amount for a fuel cell power P_{fc} is

$$Air = 3.57 \times 10^{-7} \times \frac{nP_{fc}}{V_{fc}} \ [kgs^{-1}] \quad (3)$$

$$P_{fc} = V_{fc} \times i_{fc} \quad (4)$$

Therefore, the current limit I_{limit} for the air amount fed to the stack is obtained as follows;

$$I_{limit} > \frac{Air}{n \times 3.57 \times 10^{-7}} \quad (5)$$

$$I_{limit} \le I_{max} \quad (6)$$

where n is the number of cells and I_{max} is the upper limit of fuel cell current of the high efficiency region .

The PI controller of the current control loop in Fig.4 regulates the current at every switching time and, but it can not limit the peak current to the current limit during the switching period effectively. In this paper, a predictive current limiter is proposed to limit the peak current to the current limit during switching cycle, where the maximum allowable duty ratio d_{max} for the next switching cycle is calculated based on the sampled inductor currents of the present cycle, the input voltage V_{fc} of the present and next step, the output voltage of the converter V_d and the duty ratio of the previous step.

The maximum allowable duty ratio of inductor current i_{L1} to be applied at the $(n+1)^{th}$ interval is derived as;

$$d_{L_1.max}[n] = \frac{L_1 f_s}{V_{fc}[n+1]}\left(\frac{I_{limit}}{2} - i_{L_1}[n]\right) - \frac{V_{fc}[n]}{V_{fc}[n+1]} + \frac{V_d[n]}{V_{fc}[n+1]}(1 - d_{L_1}[n-1]) \quad (7)$$

where f_s is the switching frequency and $V_{fc}[n+1]$can be estimated using the approximated V-I curve of the fuel cell stack.

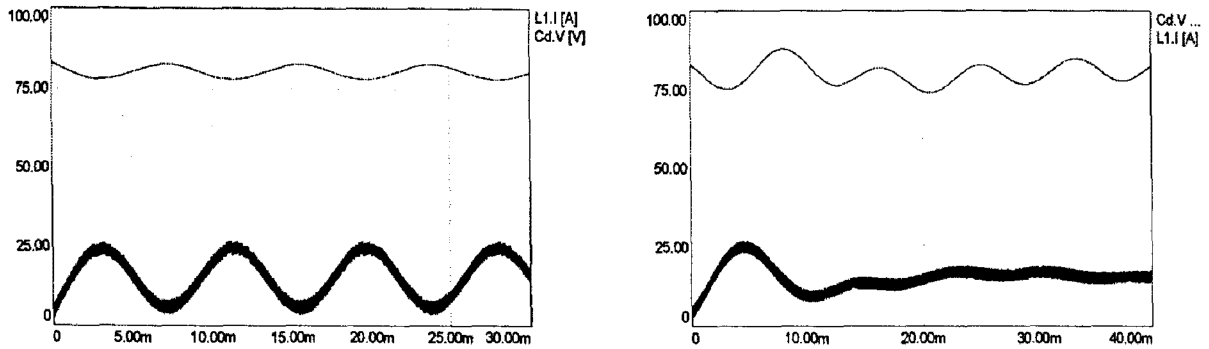
The calculated maximum duty ratio $d_{L1.max}[n]$ of i_{L1} limits the peak current $I_p[n+1]$ to $I_{limit}/2$ at the $(n+1)^{th}$ interval so that the fuel cell system can avoid the oxygen starvation at the cathode channel.

IV. SIMULATION RESULTS

To verify the feasibility of the proposed power control scheme for the fuel cell hybrid power source, a prototype converter design and simulation are carried out with the design parameters as follows:

Output power P: 1.5kW, Output voltage V_d: 84V, Input voltage V_{fc}: 40V ~ 60V
Inductor L_1, L_2: 60uH, Output capacitor C_d: 5600uF
Switching frequency f_s: 20kHz

The moving-average filter is employed to reduce the 120Hz ripple current induced from the fuel cell in this paper. Fig.6 shows the result waveforms of inductor current when there is 5% peak to peak voltage ripple at the dc bus. The inductor current ripple is reduced from 23A to 3.8A at t=30msec by using the moving-average filter while the output voltage ripple is increased from 6V to 8.3V. The 120Hz ripple of the inductor current becomes negligible as it goes to the steady state.



(a) without a moving-average filter (b) with a moving-average filter

* Cd.V: V_d, L1.I: I_{L1}

Fig.6 Inductor current with a moving-average filter

After the 120Hz ripple current is eliminated, the inductor current is limited to the current limit, $I_{limit1}=I_{limit}/2$, by the predictive current limiter so that the oxygen starvation of the fuel cell system can be avoided where the current limiter of I_{L1}, I_{limit1}, is 17A (Fig. 7).

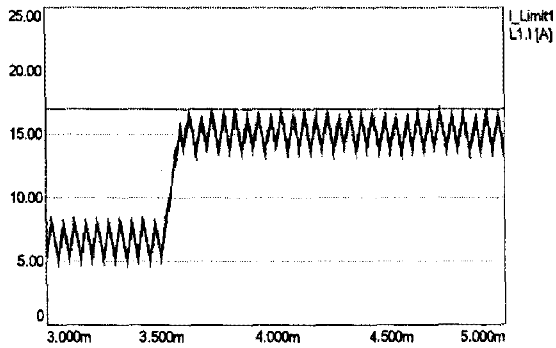


Fig.7 Inductor current with a predictive current limiter

The simulation results show that the proposed power control strategy controls the power flow between the power sources and the load properly and the digital control technique limits the fuel cell current to the current limit determined by the air amount fed to the fuel cell stack.

V. CONCLUSIONS

This paper has presented a new power control scheme for a fuel cell-battery hybrid power source for residential application which includes a power control strategy to control the power flow between the power sources and the load and a digital control technique for the dual boost converter. The proposed power control strategy enables the fuel cell to operate within the high efficiency region. The digital control technique of the dual boost converter adopts a moving-average digital filter and cancels the 120Hz harmonic current and then limits the fuel cell current to the current limit properly using a predictive current limiter to minimize the fuel cell oxygen starvation and improve the fuel cell durability.