# 낮은 출력 리플을 갖는 연료전지를 이용한 리튬폴리머 전지용 비절연형 승압 충전기의 설계

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# Design of the Non-Isolated Fuel Cell Boost Charger for the Lithium Polymer Battery with Low Output Ripple

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ABSTRACT

In the design of the fuel cell charger, it is important to find out the suitable topology and to design the converter to guarantee the performance of the fuel cell as well as the battery. Most of the chargers developed so far have used step-down converters. However, since the small fuel cell stack can only generate a low voltage, it is required to use the step-up converter to charge the battery. In this paper, a modified non-isolated boost charger topology for the Proton Exchange Membrane Fuel Cell (PEMFC) is proposed to meet the strict ripple requirements for the battery charge and its control method by using PI controller is detailed. The feasibility of the proposed topology and its control method is then verified by the experiments.

*Index Terms* – PEM fuel cell, Lithium-Polymer battery, non-isolated boost charger, PI controller

## 1. Introduction

Nowadays, portable electronics devices such as portable computers, media players and smart phones are going more and more developed and diversified. The energy density requirement for the power sources for these devices is ever on the increase. Small fuel cell is emerging as a promising solution for such power hungry devices to provide the sufficient run time and being developed and improved faster to catch up the development of the portable electronics sector. However, since the fuel cell requires the start-up power for its Balance-of-Plant (BOP) and takes some time to generate the power, it would be desirable to use it as the auxiliary power source for charging the battery. For the portable power system, it is essential to design it in light and compact form including power electronics[1]. In this paper, a modified non-isolated boost charger for the Lithium-Polymer battery is proposed and its design and control method are detailed.

## 2. Structure of the proposed PEM fuel cell charger for the Lithium-Polymer battery

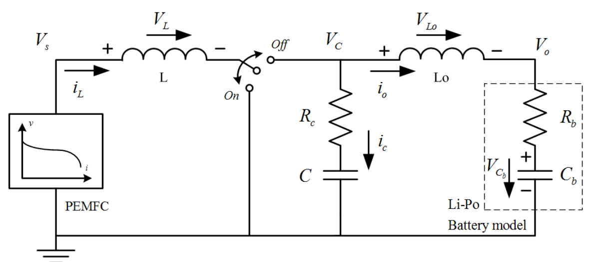


Fig. 1. Equivalent circuit of the proposed non-isolated boost converter with Li-Po battery impedance model

Fig. 1 shows the small proposed Proton Exchange Membrane Fuel Cell (PEMFC) charge system. In which the PEMFC stack is composed of 10 cells and its output voltage varies from 6[V] to 10[V] with maximum power of 180[W], and a Li-Po battery pack with its configuration is 3S3P meaning 3 cells are in series and 3 strings of these in parallel with 11.1[V] nominal voltage and 12[A] nominal current. The charger is required to charge the battery at a 6[A] (0.5[C]) charge current and a 12.6[V] charge voltage by using typical constant current/constant voltage (CC/CV) mode. The proposed boost converter has an additional output inductor with a Li-Po battery load modeled by an R-C circuit. Since the additional inductor ($L_o$) help to reduce the output current ripple, the size of the output capacitor can be smaller while meeting the output ripple requirements[2]. The output inductor has to be designed to meet the output current ripple limit 0.5[%] (0.005[C] in this case) and output voltage ripple limit 0.5[%], the design procedure will be detailed in the next section.

## 3. Derivation of the control-to-output transfer functions of the proposed boost converter

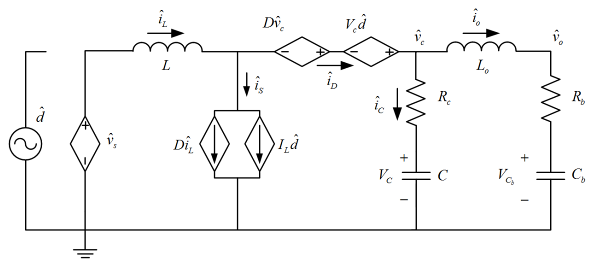

Fig. 2. Small-signal model circuit of the non-isolated proposed boost converter in continuous conduction mode

In order to implement the CC/CV mode charge with the proposed boost converter, it is required to derive the control-to-output current and control-to-output voltage transfer functions to regulate the charge current and voltage. Fig. 2 shows the small-signal model of the proposed boost charger including R-C equivalent circuit model of the battery in continuous conduction mode. By using KCL and KVL during the switch is on and off in state space average, the control-to-output voltage and output current can be found as in (1) and (2) respectively.

$$G_{vd}\Big|_{\hat{v}_s=0} = \frac{\hat{v}_o}{\hat{d}}\Big|_{\hat{v}_s=0} = \frac{V_o}{1-D}\times\frac{(1+\frac{s}{\omega_{ESR}})(1+\frac{s}{\omega_b})(1-\frac{s}{\omega_{RHPZ}})}{b_4s^4+b_3s^3+b_2s^2+b_1s+b_0} \quad (1)$$

where,

$$\omega_{RHPZ} = \frac{R_b}{L(1-\frac{V_{C_b}}{V_o})}(1-D)^2; \quad \omega_b = \frac{1}{R_bC_b}; \quad \omega_{ESR} = \frac{1}{R_cC}$$

$$b_o = 1; \quad b_1 = R_cC + R_bC_b; \quad b_2 = \frac{L(C+C_b)}{(1-D)^2} + R_bR_cCC_b + L_oC_b$$

$$b_3 = \frac{(R_b+R_c)LCC_b}{(1-D)^2} + R_cL_oCC_b; \quad b_4 = \frac{LL_oCC_b}{(1-D)^2}$$

$$G_{id}\Big|_{\hat{v}_s=0} = \frac{\hat{i}_o}{\hat{d}}\Big|_{\hat{v}_s=0} = \frac{V_{C_b}+I_oR_b}{R_b(1-D)}\times\frac{(1+\frac{s}{\omega_{ESR}})(1+\frac{s}{\omega_b})(1-\frac{s}{\omega_{RHPZ}})}{b_4s^4+b_3s^3+b_2s^2+b_1s+b_0} \quad (2)$$

where,

$$\omega_{RHPZ} = \frac{(V_{C_b}+I_oR_b)}{I_oL}(1-D)^2; \quad \omega_b = \frac{1}{R_bC_b}; \quad \omega_{ESR} = \frac{1}{R_cC}$$

## 4. Design of the controller of the proposed boost charger for CC/CV mode charge

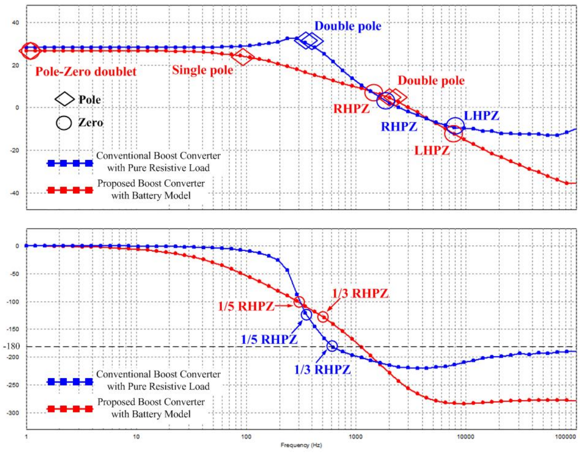


Fig. 3. Bode plot with pole-zero positions in the conventional boost converter and the proposed boost converter

In the proposed converter, a signal pole occurs at the low frequency (96Hz) due to the additional inductor at the output and causes the phase lag around its frequency. As shown in the gain plot, the resonance peak and the phase reversal are smoothed due to the smaller resistance value in the battery model compared to the pure resistive load. Similarly, the RHP zero moves towards the origin little bit according to (1). In results, due to the effects of the battery model and the output inductor, at one third of the RHP zero frequency the phase margin of the proposed boost charger is 60 degree, which is enough to make the closed system stable. In the case of the conventional boost converter, the phase margin is almost $0^o$ at one third of the RHP zero frequency. Thus, unlike the conventional boost converter which often uses Type 3 controller to boost the phase, the PI controller can be used to control the output current and out voltage. It is advantageous since the controller can be simply implemented by using commercially available PWM IC.

## 5. Design of the output voltage and output current controller of the proposed boost charger using PWM analog IC

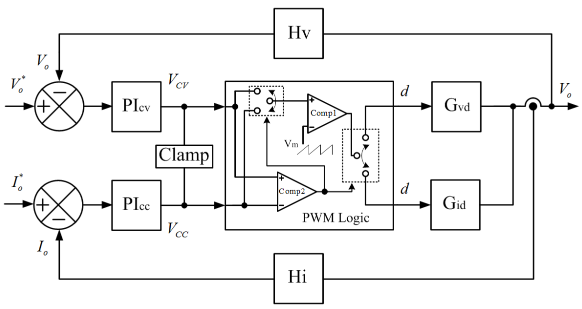


Fig. 4. Block diagram of the CC/CV charge control algorithm for the proposed boost charger by using PI controllers

Fig.4 shows the block diagram of the CC/CV charge control algorithm for the proposed boost charger with MAX745 PWM controller. Each loop works independently according to the state of charge of the battery. It should be noticed that unlike the conventional boost converter, the PI controller is used to control the current and voltage, respectively. In the charge process, the comparator (comp1) compares the saw-tooth waveform ($V_m$) to the output of the voltage controller ($V_{cv}$) or current controller ($V_{cc}$) to generate the PWM signal for gating the semiconductor switch. Another comparator (comp2) compares the output of the two controllers and the charge mode is selected depending on the magnitude of the output from the controller. When the output of the current controller is smaller than that of the voltage controller, then the system will work in the CC mode and vice versa. While the current is in regulation, the output voltage of $V_{cv}$ is clamped less than $V_{cc}$+80[mV] to prevent the battery voltage from overshooting when the charge mode is turned over to CV mode.

## 6. Experiment results

Fig. 5 shows the output voltage and the output current of the proposed boost charger. As shown in the figure, both of the charge voltage and charge current ripples are less than 0.5[%], which can satisfy the ripple requirements of the Li-Po battery recommended by the manufacturer. Fig. 6 (a) shows the CC/CV charge profile of the Li-Po battery. As shown in the figure, the output current and output voltage of the proposed boost charger are properly regulated at each charge mode. In order to verify the dynamic performance of the system, a 12A load is applied to the system during the CV mode charge. As shown in the Fig. 6 (b), the charger and battery supplies 6A each to the load. Since the output current of the charger is regulated at 6A, the battery discharges 6A to supply the load. Thus the PEM fuel cell stack is not overloaded and it can continue the normal operation.

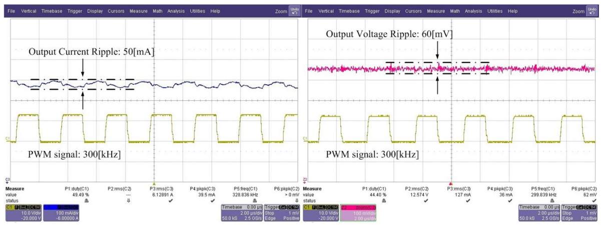


Fig. 5. Output voltage and output current ripples in the proposed boost charger

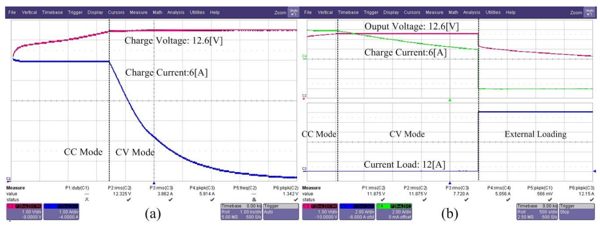


Fig. 6. (a) CC/CV charge profile of the Li-Po battery
(b) System response to the applied load (12A) during CV mode charge

## 7. Conclusion

In this paper, a non-isolated boost charger topology for the PEM fuel cell application has been proposed and its feasibility and validity have been verified through the experiments. Due to the additional inductor at the output the output current and voltage ripple can be successfully limited to meet the suggested ripple limits. Unlike the conventional non-isolated boost converter, the proposed boost charger can be controlled by the PI controller, which can be easily implemented by using commercial PWM IC such as MAX745.

## References


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[2] P. Rueda, S. Ghani, and P. Perol, "*A New Energy Transfer Principle to Achieve a Minimum Phase & Continuous Current Boost Converter*," Power Electronics Specialists Conference. 35th IEEE, Vol. 3, pp.2232-2236, 2004.