DC/DC converters for fuel cell powered hybrid electric vehicle

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DC/DC Converters for Fuel Cell Powered Hybrid Electric Vehicle

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Abstract—**Many automotive companies are working in developing fuel cell powered Hybrid Electric Vehicles (HEV) because they offer a reduced emission and improves the fuel economy. The key technology for such development of fuel cell for propulsion is the power electronics. This paper reports different DC/DC converter topologies used to interface the fuel cell to the motor controllers in HEVs. The aim is to present a simple and practical boost converter topology with a coordinated control that can regulate both the output voltage and the input current simultaneously. The performance of the proposed power conditioning system is evaluated is simulation results under different dynamics.**

I. Introduction

A considerable amount of research is in progress to develop fuel cells as energy conversion devices. Fuel cells are especially attractive because it is the only current technology capable of reducing vehicle emissions and fuel consumption by a large amount in a short period of time [1]. Fuel cells are presently being considered for use in automotive systems to replace the internal combustion engines in buses, vans, and ultimately passenger cars [2].

Fig. 1 portrays the electrical components required for fuel cell powered Hybrid Electric Vehicle (HEV). The DC voltage required for the three-phase inverter to control the AC motor is in the range of 200 to 500 volts, while the voltage of the fuel cell is in the order of 60V (for the commercially available 10 KW module). The fuel cell is the main power source, however its power density is low. A storage unit such as battery or ultra-capacitor banks must be integrated with this system, which is not shown for simplicity, to supply the peak power demand during transient conditions, since the dynamic response characteristics of fuel cells is much slower than that required for traction [3]. The DC/DC converter boosts the fuel cell voltage to the required voltage of the motor controller. The major challenge in designing automotive fuel cell power systems is converting the electrical output from the fuel cell into a usable power [4]. In addition, the DC/DC converter must be implemented cost effectively with suitable weight and volume.

Many DC/DC converter topologies with their control strategies are proposed in the literature [5]. A push pull derived half bridge or full bridge type DC/DC converter with transformer isolation is suitable for the application, because of the higher power rating and the significant boost required in the DC voltage [6], [7]. Despite the simplicity of the control techniques for the isolated types of DC/DC converter, their main drawbacks are the additional weight of the transformer and their packaging volume. Resonant DC/DC converter is proposed to interface the fuel cell to the power train in [8], [9]. This type of converters has the privilege of reduced switching losses due to the soft witching. However, the large number of electrical components utilized to build the resonant converters beside that there is no direct method to control the input current are the disadvantageous of this converter topology.

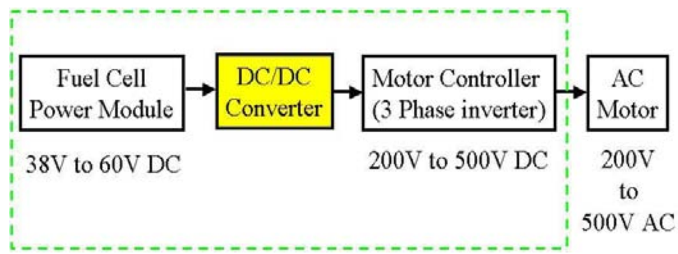

Fig. 1. block diagram of the fuel cell interface system.

The objective of this paper is to present a simple DC/DC converter, shown in Fig. 2, with a robust controller for the fuel cell powered HEV. As a result, reducing the volume and weight of the converter will enable significant improvements in power density. The proposed controller can provide a programmable and regulated high voltage to the motor controller as well as controlling the input current of the fuel cell. It can handle the load dynamics and the variation of the input voltage of the fuel cell.

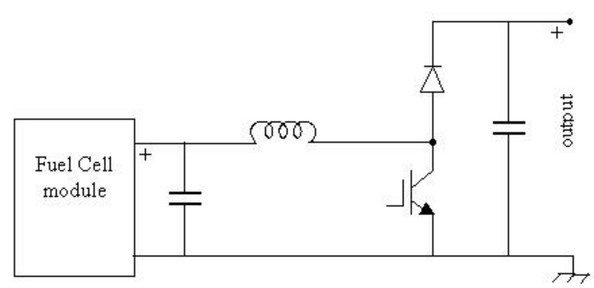

Fig. 2. block diagram of the fuel cell interface system.

II. THE PROPOSED CONTROL STRATEGY

Fig. 3 shows the proposed control for the DC/DC converter to regulate the voltage at the required value of V_o^* and to limit the current in the coil under its rated value. The outer controller, which is the voltage regulation loop, is realized by a simple PI controller to process the error between the reference value V_o^* and the actual output voltage V_o to get the required coil current signal I_L^* for voltage compensation.

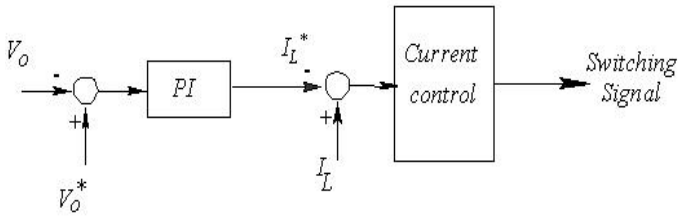

Fig. 3. Block diagram of the proposed control for the boost DC/DC converter.

The inner control loop is dictated to regulate the coil current at its estimated value I_L^* from the outer one. The I_L^* component is responsible for boosting the output voltage to the desired value. In addition, the objective of the current controller is to insure that the coil current is limited at its rated value to protect the coil. Various current controller strategies have been employed. A quick response, easy implementation, maximum current capability and insensitivity to parameters variation are among the important features of any current controller.

Hysteresis Current Control (HCC) offers a fast dynamics and high bandwidth among other current controllers. Adaptive HCC is utilized to force the actual current to its command values. The hysteresis band is adaptively adjusted according to the current command. The inner control loop, HCC, must be faster than the outer control loop, PI voltage regulator. Based on the ampere rating of the coil, limiters are designed for the current controller to prevent overloading the DC/DC converter.

III. RESULTS

Performance evaluation of the proposed strategy for boosting the output voltage of the fuel cell was carried out by conducting several test cases. The first case primarily examines the performance of the DC/DC converter against the fuel cell dynamics. The second case tests the dynamic response of the converter against load switching. Fig. 4 shows the system under study. EMTDC/PSCAD software is used to validate the accuracy of the proposed system. A simple, yet realistic, dynamic fuel cell model is programmed by using FORTRAN in the EMTDC environment to examine the performance of the proposed controller against input voltage variation. The fuel cell is connected to the boost converter through a diode to prevent reverse current from flowing into the cell. A dynamic load is connected to the output of the converter to emulate different action of the HEV. The execution time of the proposed controller was set at 0.1 msec., which is suitable for experimental implementation based on a low cost microcontroller chip.

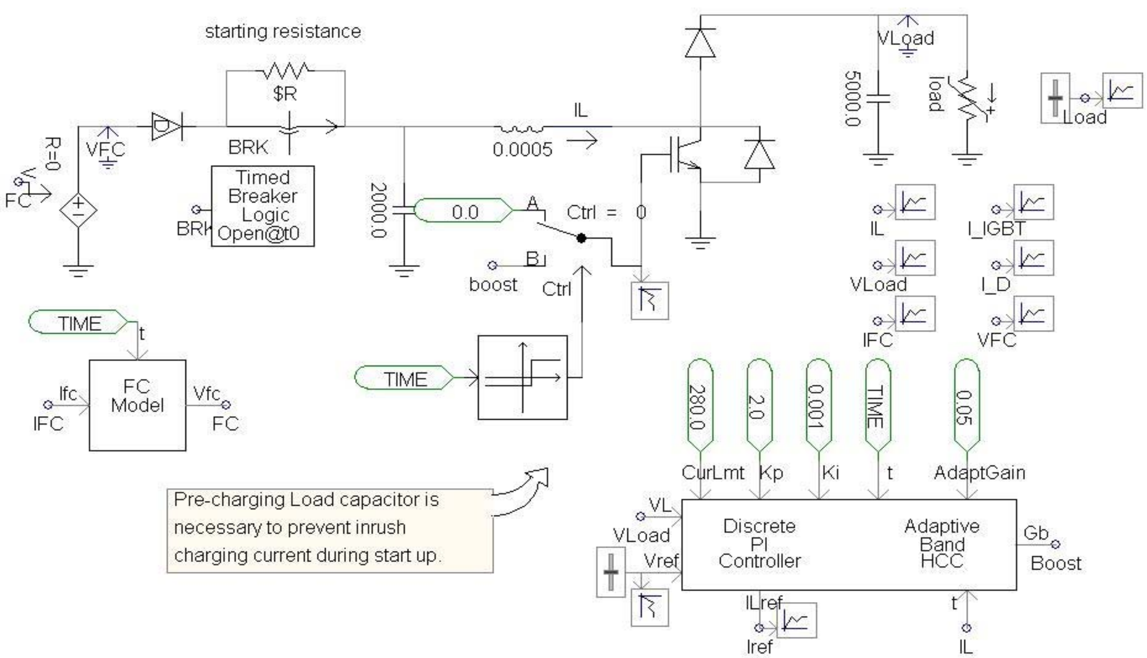

Fig. 4. System under study.

A. Case 1: FC dynamics

The first task of the simulation in this study is to evaluate the performance of the proposed control algorithm, presented in the previous section, for boosting the fuel cell voltage and regulating both the load voltage and the coil current.

The first track of Fig. 5 portrays the Fuel cell voltage at the input terminal of the DC/DC converter. The fuel cell voltage is programmed to decay from 60V to 36V in 0.5 sec. The output voltage at the load terminals is shown in the second trace of Fig. 5. Since the DC/DC converter succeeds in regulating the voltage at the desired value of 200V and compensating for the voltage drop at its input, the proposed control system is robust. The last trace of Fig. 5 shows the smooth transition of the coil current during the variation of the input voltage.

To investigate the internal performance of the DC/DC converter, the top trace of Fig. 6 shows the coil current limited by the lower and upper bands of the HCC. The middle trace portrays the output voltage. One can notice the ripple in the output voltage is limited to 0.25%. The bottom trace of Fig. 6 shows the firing signal of the converter switch. It can be noticed that the switching frequency is around 4KHz.

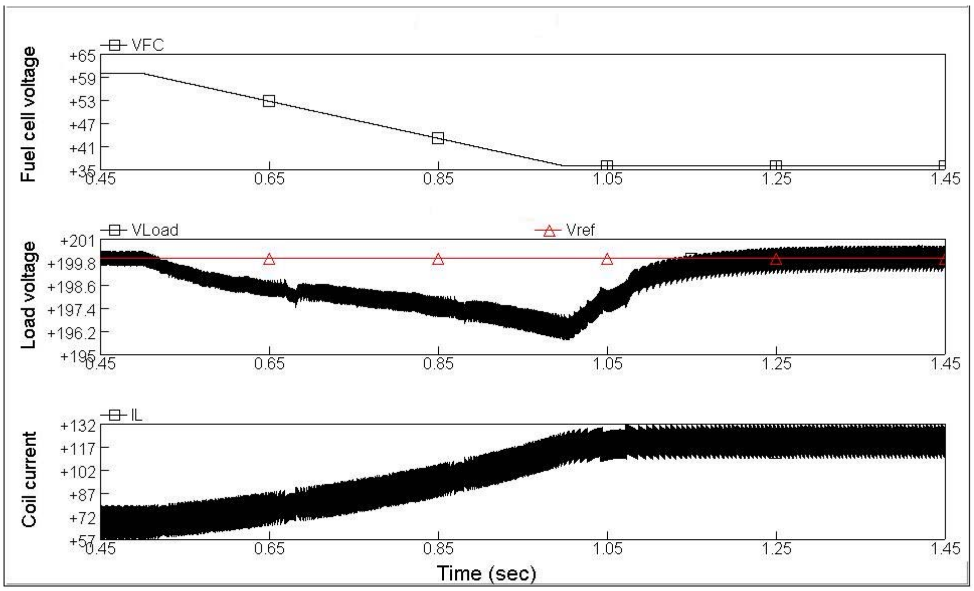

Fig. 5. Performance of the proposed DC/DC converter under FC dynamics.

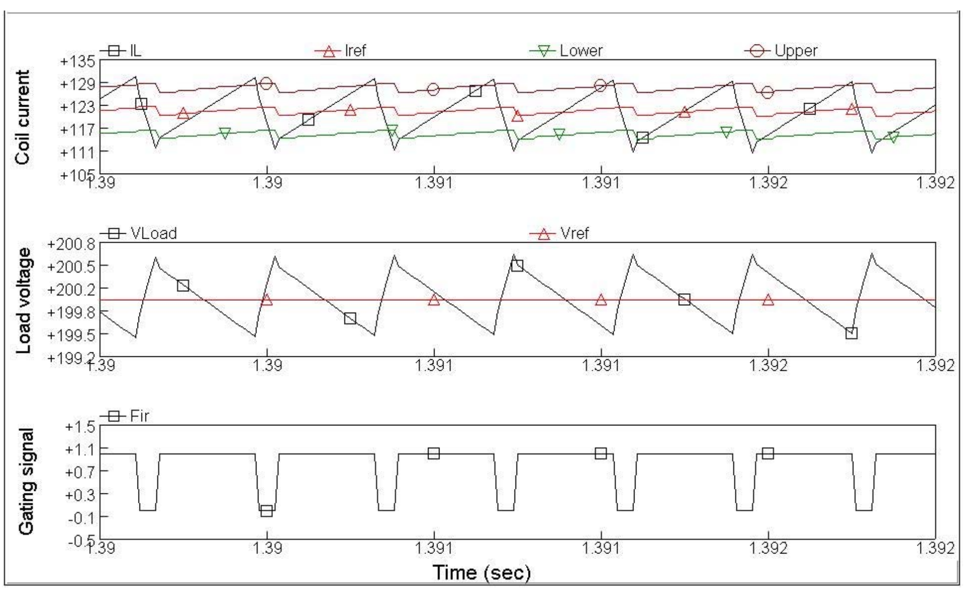

Fig. 6. Internal dynamics (zoom from Fig. 5)

B. Case 2: Load dynamics

In this case the load is dynamically changed to emulate acceleration and deceleration action of the Vehicle. Fig. 7 plots the dynamic response of the proposed system, when the load changes dynamically. The top trace of Fig. 5 reflects the dynamic coil current changing according to doubling the load. The bottom trace demonstrates that the proposed controller succeeds in regulating the PCC voltage at 200V, even when the load disturbance occurs at 0.55 sec and at 1.025 sec. The up and down dips in the load voltage occur at the changing instances of the load. This result examines the disturbance rejection capabilities of the proposed controller. A fast response and accurate tracking of the voltage setting is obvious.

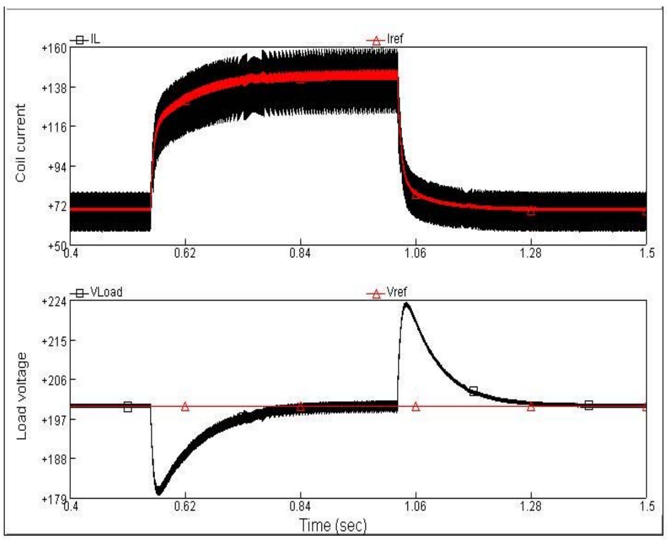

Fig. 7. Load disturbance rejection.

IV. CONCLUSIONS

This paper presents a multi-functional control for the DC/DC converters utilized in the Fuel cell powered electric vehicles. The controller of the DC/DC converter, which is comprised of two cascaded loops with a low computational complexity, is utilized to boost and regulate the output DC voltage and, at the same time, to protect the coil from overcurrent. The current controller method is insensitive to the parameter variation of the circuit, because it is adaptive in nature. This is an absolute necessity for systems such as electric vehicles, since many parametric values can be changed with the loading level and temperature. Also, the simulation results shows that the proposed control scheme offers a robust coordination between the different functions of the DC/DC converter.

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