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Ultra-Capacitors and Battery Management System for Electric Vehicles

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Abstract This paper presents a bidirectional converter system to manage power transfer between ultra-capacitors (UC) and batteries for electric vehicle applications. A bidirectional buck-boost converter is used as a key converter to control power flow of the system. A control method is introduced to increase life cycle of both batteries and UC. Ultimately, the proposed converter system is able to (i) manage power between DC-bus, batteries and UC, (ii) control the current to flow between batteries and UC, (iii) maintains battery operation within charging limits, (iv) maintain the voltage at UC as setting value, (v) control the recharging at the UC by using the energy feedback from the battery instead of the common DC-bus and (vi) manage UC and battery to be recharged by using regenerative braking system. The validation of the proposed system is verified with analysis and simulation results by using MATLAB/Simulink.

1. Introduction

In the first generation of hybrid vehicles, batteries are the only source of electrical supply. Few years later, UC has been applied to use as a secondary source of power in vehicles with the reason of high capability of fast energy absorb, fast power supply and energy storage. However, there are two important issues of UC that need to be improved in the power conversion system to increase efficiency and reliability in hybrid system. These issues are 1) the loss of feedback energy from the braking system and 2) the loss in driving system (between 20% - 50% of the energy consumed from the mains supply) [1]. To overcome the mentioned problems, buck-boost converter was used to manage power flow between two sides of the system, battery side and DC-bus. The converter is connected to the UC bank at the boost side and the main battery at the buck side [2]. However, the UC is directly connected to the converter which causes delaying of the first charge. The first charge UC is no stored energy, so as the converter starts, UC will absorb more energy based on its size before passing energy to DC-bus. Moreover, the buck-boost converter requires two inductors which generate more losses. Therefore, this paper will present a bidirectional converter and its control to manage energy between battery and UC.

2. System Description

Fig. 1 shows a general hybrid vehicle system, which composes of two dc/dc converters, a battery pack and a UC bank. Excessive energy charged to battery will cause shorter life cycle or damage of batteries. Therefore, an energy management system between batteries and UC is important in order to prolong the life cycle of storage system. In Fig.1, the dc/dc converters are to control charging and discharging battery and UC. The discharge mode was specified as the process of extracting energy from the battery bank and using it to supplement the DC-bus. This was accomplished by boosting the battery bank voltage to the necessary level to meet the demand of

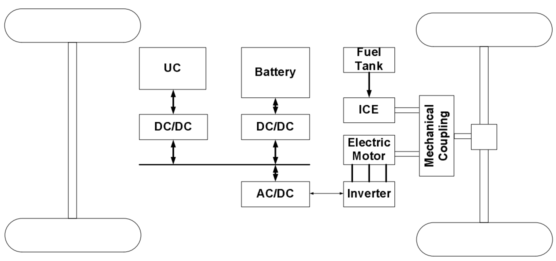


Fig. 1 A system block diagram of a Hybrid vehicle [3]

DC-bus. The charge mode was specified as the process of extracting energy from DC-bus back to UC unit to absorb all the power with high energy and fast charge and then transfer power to charge batter by buck converter. Even though, this system is practical, it uses two bidirectional converters which introduce more complexity.

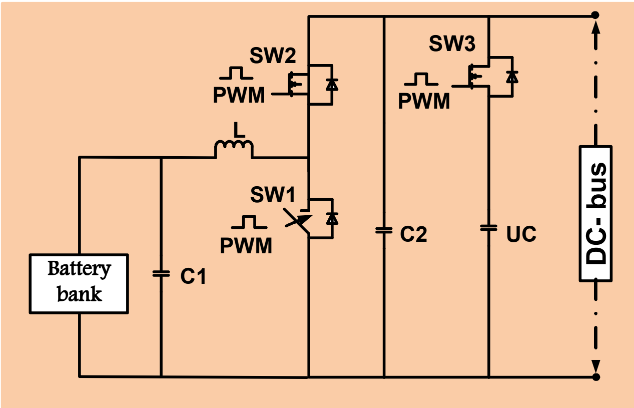


Fig.2 Shows a proposed bidirectional converter system using only a buck-boost converter to manage energy between batteries, DC-bus and UC of electric vehicle systems.

3. Control Strategy

The design was specified to use the same hardware in two modes of operation to manage power from battery bank, UC, DC-bus and regenerative power. Fig.3 shows a system block diagram of bidirectional converter.

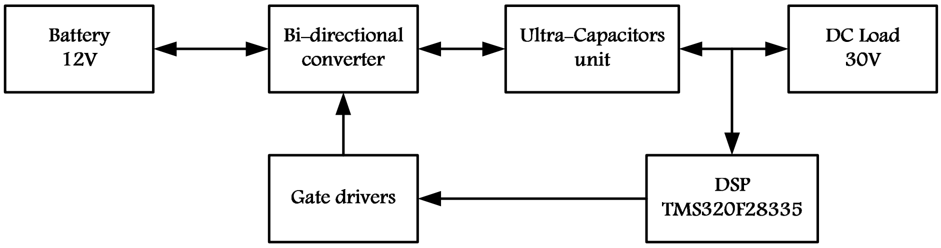


Fig.3 A system block diagram of the bidirectional converter system

3.1 Design of the DC-DC Converter

For a buck converter operating in the continuous region, the duty cycle is given by

$$D = \frac{V_{batt}}{V_{DC}} \tag{1}$$

The current at the continuous-discontinuous boundary is given by:

$$I_{LB} = \frac{DT_S}{2L}(V_{DC} - V_{BAT}) \tag{2}$$

The switching frequency is given as 25 kHz. The value of the inductance needed is approximately *19.2μH*. From this, the capacitance values can be calculated from:

$$f_C = \frac{1}{2\pi\sqrt{LC}} \tag{3}$$

3.2 Boost Mode (Discharge Mode)

In the discharge mode, the bidirectional buck-boost converter is used to boost the battery voltage to a higher level than the output of the battery, so that current will be allowed to flow from the batteries into the DC-bus as shown in Fig.4.

3.3 Buck Mode (Charge Mode or Regenerative Braking Mode)

In the charge mode, the bidirectional buck-boost converter is used to buck the DC-bus voltage to a lower level than the output of the DC-bus, so that current will be allowed to flow from the DC-bus into the batteries as shown in Fig.4.

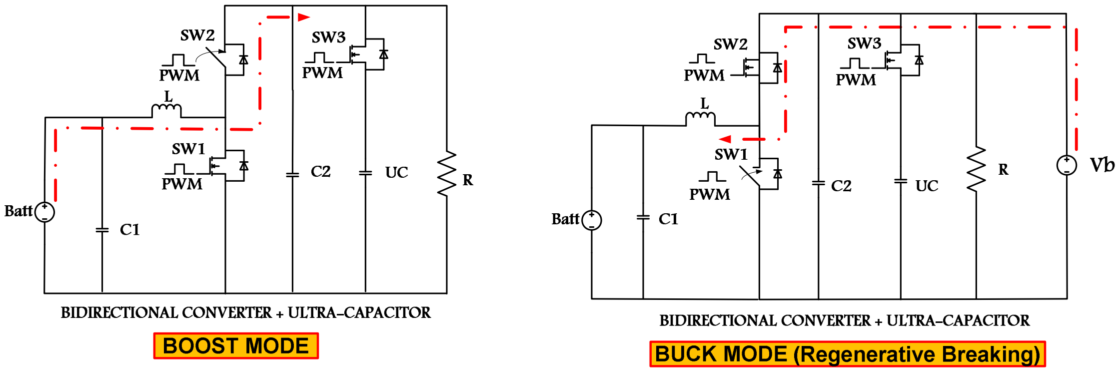
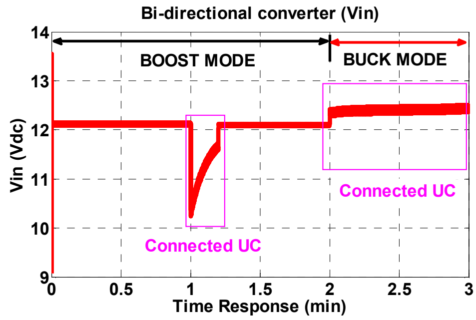


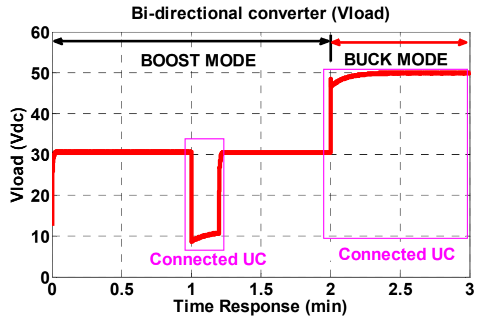
Fig. 4 Power flow in Boost and Buck Mode

4. Simulation Results

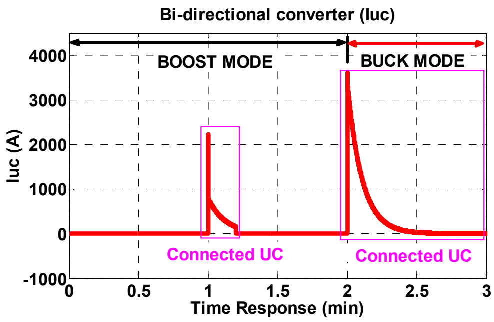
The bidirectional converter shown in Fig.4 is used for simulation to verify the concept of the proposed system. Moreover, the control strategy is shown in Fig 3 for bidirectional control mode. Parameters used in this simulation are as follows: Battery Voltage (Batt) = 12 [V], Filter Capacitance (C_1) = 1 [mF], Inductance (L) = 19.2 [µH], Filter Capacitance (C_2) = 2.4 [mF], Ultra capacitors (UC) = 50 [F] (12 Series, 2 Parallels), Resistive Load (R) = 10 [Ω], and Regenerative brake (V_b) = 50 [V].



(a.)



(b.)



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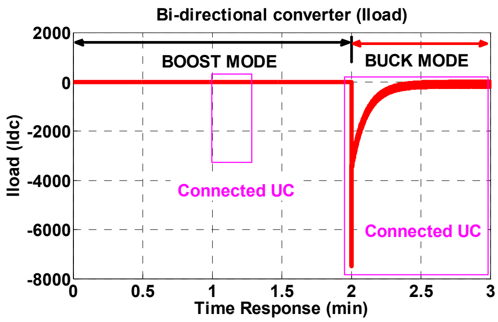
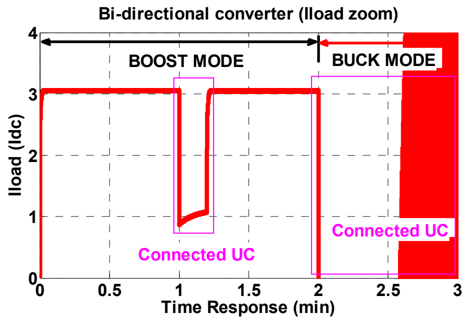


(d.)



(e.)

Fig.5 Simulation waveforms in boost and buck mode

(a) Battery's voltage
(b) Load's voltage
(c) UC's current
(d.) Load's current
(e.) Load's current (zoom)

Fig. 5 is simulation results of the bidirectional converter operating in 2 modes, boost and buck mode. The UC is connected twice in 3 minutes of starting time. In this boost mode, the UC absorbs energy at the first step. So, the DC-bus voltage and current reduces. During regenerative braking period, the UC will absorb energy from the load until its full and then bidirectional converter will work in buck mode for transferring power from UC to batteries. This concept is to prevent regenerative power transferring directly to batteries and to protect batteries from damage. Therefore, the purposed system can be perfectly used in the electric vehicle systems.

5. Summary

This paper has presented application of bidirectional converter to manage power between batteries and UC connected to DC-bus. The control method of bidirectional converter was introduced by 2 steps. First, the UC is controlled through the converter to operate at the same time of regenerative braking for absorbing energy. Second, if the UC are charged to reach the designed level, the converter will transfer the power from the UCs to charge batteries.

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