트랜스포머 1차측 병렬 구조를 가진 직렬 연결 리튬이온 배터리 전하 균일 컨버터

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Charge Equalization Converter with Parallel Primary Winding for Series Connected Lithium-Ion Battery strings

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Abstract

A charge equalization converter with parallel-connected primary windings of transformers is proposed in digest. The proposed work effectively balance the voltage among Lithium-Ion battery cells despite each battery cell has low voltage gap compared with its SOC. The principle of the proposed work is that the equalizing energy from all battery strings moves to the lowest voltage battery through the isolated dc/dc converter controlled by the corresponding bi-directional switch. In this digest, a prototype of four Lithium-Ion battery cells is optimally designed and implemented, and experimental results show that the proposed method has excellent cell balancing performance.

1. Introduction

Battery lifetime is one of the major issues economically in hybrid electric vehicle (HEV), employed with series-connected battery strings as an alternative power source. To improve battery lifetime, an effective charge equalization method to avoid the voltage imbalance among battery strings is essential; this is because the voltage imbalance will decrease the total storage capacity and total life cycle of the battery [1].

In terms of Lithium-Ion battery application in HEV, a careful control and monitoring are considerably required to take precautions against a higher risk of the voltage limitation and cell damage when overcharging the cells [3].

Therefore, to enhance the battery lifetime and avoid the possible risks during charging time, the charge equalization for Lithium-Ion battery strings is significantly necessary in HEV.

Charge equalization methods for series-connected battery strings have been presented in [2-4]. One of them is an energy dissipative method such as charge shunting. This dissipative method is attractive to balance charge among battery cells because of simple and easy implementation. However, its method is not suitable for the HEV application using Lithium-Ion battery due to amount of energy loss.

To obtain more effective charge balancing, a non-dissipative method is presented in [3]. This work can achieve the excellent charge balancing, in which much more current can be flow automatically to the under-charged batteries by controlling the single MOSFET switch. However, this method can not be directly applied to Lithium-Ion battery equalization of HEV, since it is not easy to control both the leakage inductance of transformer and equalizing current at the low voltage gap between the over-charged and the under-charged cells in Lithium-Ion battery strings. Moreover, the implementation of one common core with multiple secondary winding is not easy for series-connected battery cells about fifty and over.

To improve these defects, this paper proposes a charge equalization converter with parallel-connected primary windings of transformers. The principle of the proposed work is that the equalizing energy from all battery strings moves to the lowest voltage battery through the isolated dc/dc converter controlled by the corresponding bi-directional switch.

In proposed circuit, by using the bi-directional switch, the efficiency of charge equalization is enhanced even at the low voltage gap between the over-charged and the under-charged cells in Lithium-Ion battery strings and total equalization time is reduced. Furthermore, the proposed circuit can be easily implemented with own magnetic core individually.

In this digest, a prototype of four Lithium-Ion battery cells employing the proposed method is optimally designed and implemented, and experimental results show that the proposed method has excellent cell balancing performance.

2. Operational principles

Fig.1 (a) shows the proposed charge equalization circuit, in which it is assumed that the batteries, B_1~ B_{N-1} are over-charged and only B_N is under-charged. Basically, the flyback DC/DC converter is parallel-connected to each battery in output stage and input stage of them are coupled together to be connected across the voltage of strings, where the solid state relays, S_1~ S_{N-1}, are placed in series with the primary sides as shown in Fig.1 (a). To show the operation of the proposed circuit, it is assumed that a battery management system (BMS) always monitors SOC of every battery in the strings. A MOSFET switch, Q, is controlled by the BMS with fixed duty, and S_1~ S_N are operated by On or OFF signal with respect to the state of charge (SOC).

As shown in Fig.1 (b) and Fig.2, mode 1 ($t_0 \sim t_1$) begins when Q is turned on, where S_1~ S_{N-1} are turned off and S_N is turned on. In this mode, the primary current of the Nth cell, I_{kgN}, builds up. Mode 2 ($t_1 \sim t_2$) starts when Q is turned off. In mode 2, the corresponding rectifier diodes, D_N, is turned on so that the magnetizing current flows into the B_N. It is similar to be operated individual flyback converter. With this process of a conventional flyback converter, equalizing currents from the over-charged cells can be transferred to the lowest voltage cell effectively although Lithium-Ion battery has a low voltage gap between over-charged cells and under-charged cells.

3. Experimental Results

In order to verify the operational principles and show the performance of the proposed charge equalization converter, a prototype of four 7Ah Lithium-ion cells is designed and implemented.

In this proposed circuit, to expect the equalization time, the equalizing current of conventional flyback converter, I_{in}, is designed. The relation between the equalizing current and equalization time can be estimated by following two simultaneous equations.

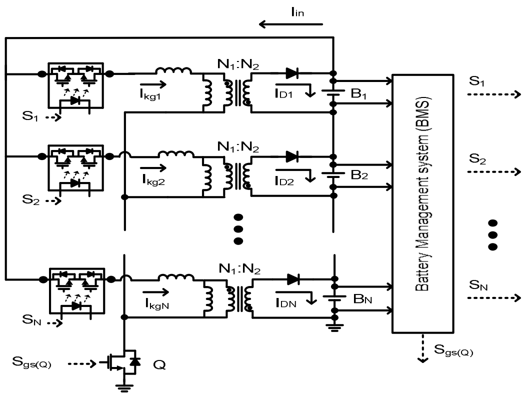
$$Q_{OC}(t) = Q_{UC}(t) \tag{1}$$

$$P_{out} = \eta \cdot P_{in} \tag{2}$$

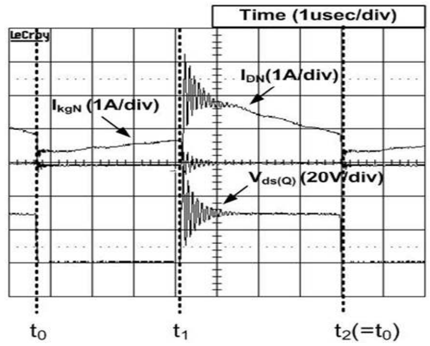
$Q_{OC}(t)$ and $Q_{UC}(t)$ are amount of charge remained in the over-charged cell and the under-charged cell at t. P_{in} and P_{out} are input and output power of the proposed charge equalization converter with efficiency of η, respectively. Fig. 3 (a) shows simulation results of input current versus equalization time. For the equalization test of this prototype system, 4W flyback converter, designed by simulation results, is utilized at unbalanced SOC gap 20%, where the voltage of over-charged cells is 3.92V at SOC 60% and the voltage of single under-charged cell is 3.80V at SOC 40%. Fig. 3 (b) shows the experimental results of the prototype system, where equalization test takes about 70 minutes to achieve cell balancing as expected.

4. Conclusions

In this paper, charge equalization converter with parallel-connected primary windings of transformers for the series-connected battery strings is proposed and optimally implemented. The proposed circuit has good equalization performance and easy implementation, thus it is useful for Lithium-Ion battery system in a HEV application.

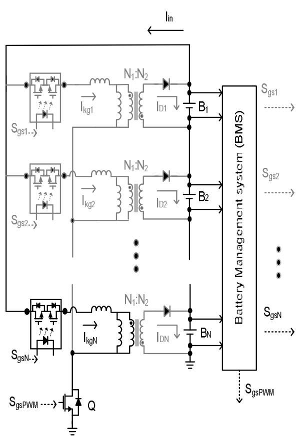


(a)



(b)

Fig. 1. Proposed charge equalization converter with parallel primary winding, (a) circuit diagram, (b) experimental key waveforms



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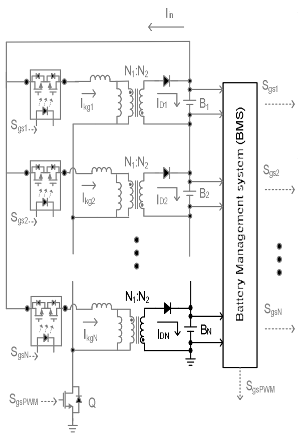
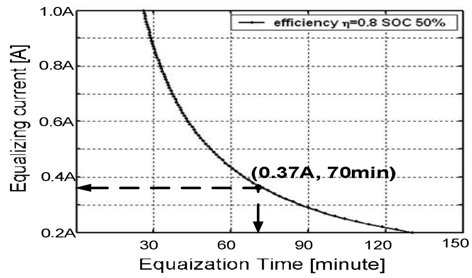
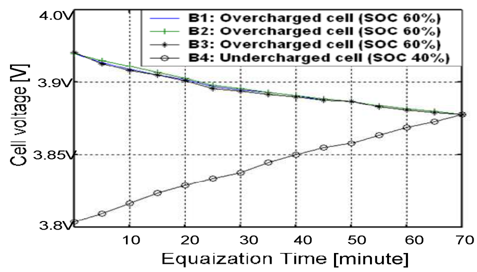


(b)

Fig 2. Operational modes of the proposed charge converter with parallel primary winding, (a) Mode 1, (b) Mode 2



(a)



(b)

Fig. 3. Simulation and experimental results, (a) simulation result (input current versus time), (b) equalization test

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