Multi-module Equalizer Circuit for Series-Connected Li-ion Batteries

Jong-Won Shin, Gab-Su Seo, Jong-Hoon Kim, and Bo-Hyung Cho

School of Electrical Engineering and Computer Science, Seoul National University
599 Gwanangno, Gwanak-gu, Seoul, 151-744, Korea

Abstract

In this paper, a multi-module selective battery equalizer for series-connected Li-ion battery pack is proposed. Selective Equalizer (SE) scheme achieves smaller volume and lighter weight than individual cell equalizer (ICE) by minimizing the part count of bulky circuit element. However, SE scheme shows slow balancing speed when the voltage imbalance simultaneously occurs in more than one cell. The proposed multi-module overcomes the problem by employing multiple power converters. Prototype hardware is implemented and experimented with 14Ah battery cells to validate the performance of the proposed equalizer.

1. Introduction

Generally, Li-ion battery pack in automotive application includes series connection of unit cells to meet the voltage and power demand. To prevent the voltage difference between cells which can cause the damage to battery, a balancing circuit or a voltage equalizer should be equipped to the battery pack.

Resistive balancing [1] is the simplest balancing method, but its low efficiency and limited current handling are the disadvantages of the method. Utilizing various kinds of DC/DC converter overcomes the problems of [1] while the equalizer circuit becomes complex. Individual Cell Equalizer (ICE) method provides power path to every cell to meet the voltage balance [2]. Selective Equalizer (SE) reduces minimizes the part count of bulky circuit elements such as magnetic components and electrolytic capacitors by introducing switch network or selective bus structure [3-4]. This paper proposes the extended version of SE scheme which can balance more than one unbalanced cells simultaneously. The proposed circuit provides flexible operation of cell voltage balancing and shorter balancing time than single module SE equalizer.

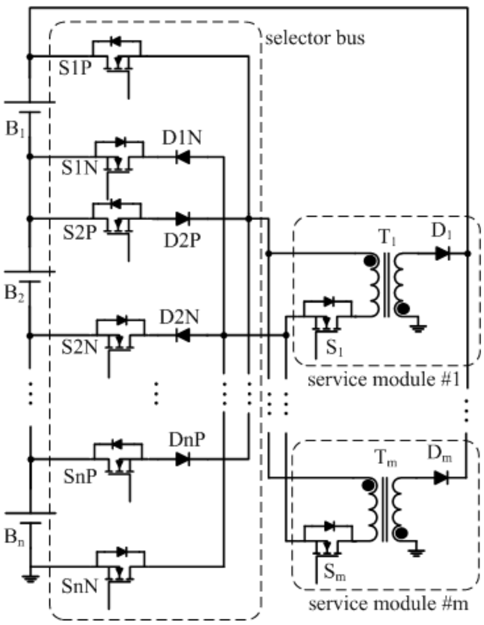


Fig. 1. Proposed multi-module battery equalizer with n-cell battery pack and m service modules.

2. Proposed Battery Equalizer

2.1. Circuit Structure

Fig. 1 shows the proposed equalizer circuit which consists of selector bus network and service modules.

The selector bus consists of MOSFETs and diodes to provide the power path for each cell. Series-connected MOSFET-diode pairs provide the unidirectional current paths. Diodes in selector bus are for the protection of short-circuit current when adjacent cell is in balancing and does not participate in the selecting operation [4]. If i-th cell should be balanced, a controller in Battery Management System (BMS) sends PWM signal to SiP and SiN to connect the cell to the service module.

A service module contains an isolated DC/DC converter to process the power between the unbalanced high voltage cell and overall battery pack. In this paper, flyback converter is used due to its simple structure and small size. The main switch of the flyback converter can be eliminated to avoid the redundancy with the switch in the selector bus when there is single service module [4]. Flyback switch in service module is synchronized with the PWM signal of SiP and SiN in selector bus. Output ports of the service modules are connected in parallel with the battery pack to recover the extracted charge from the unbalanced cells.

The number of service modules depends on the possibility of imbalance of unit cell. Because one module can control single cell, maximum number of unbalanced cells that can be balanced simultaneously is limited to the total number of service modules. Optimal number of service modules should be compromised between the circuit complexity and the balancing quality such as balancing speed and cell voltage deviation. If the pack is combined with many cells, many service modules will be needed. Severely fluctuating bulk current through battery pack which can induce

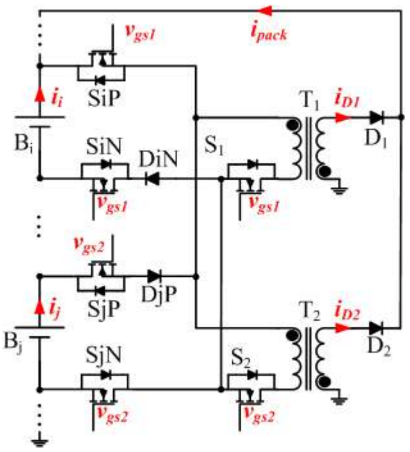


Fig. 2. Reference directions of key currents and distribution of gate signals.

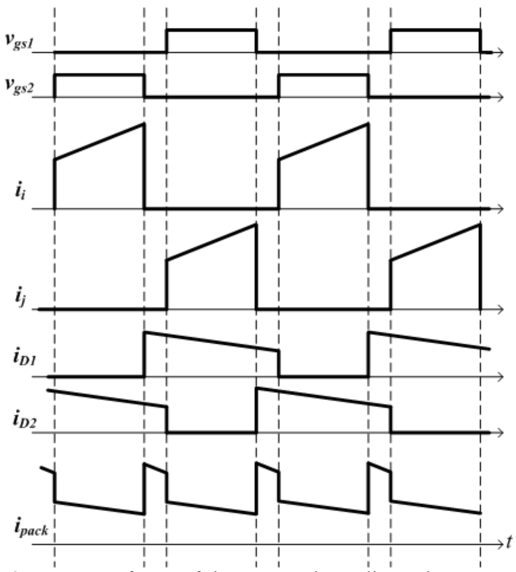


Fig. 3. Key waveforms of the proposed equalizer when two cells are in voltage imbalance simultaneously.

voltage imbalance is also the cause of the need of multiple service modules.

2.2. Operational Analysis

In this section, operation of two modules when two cells are unbalanced in the same time is explained. Figs. 2 and 3 are the equivalent circuit and the key waveform when *i*-th and *j*-th cells ($i<j$) are unbalanced. Some diodes in selector bus are omitted for brevity in Fig. 2. Two flyback converters are operated in continuous conduction mode by 180˚ interleaved gate signals v_{gs1} and v_{gs2}. Cell currents i_i and i_j extracts the charge from high voltage cells. Each duty cycle is limited under 0.5 to avoid the gate overlap time. If the gate signals are overlapped, *j*-th cell cannot participate in the balancing operation because DjP will reverse biased. The pack recovery current, i_{pack}, is the sum of the output diode currents, i_{D1} + i_{D2}. During the operation, selected cell voltages are relieved and the extracted charge is recovered to battery pack.

In case *k* cells are unbalanced and *k* service modules are available, the operational principle remains same except that the duty cycles are limited to be smaller than *1/k* and interleaved each other by *360/k*˚.

3. Experimental Results

To verify the operation of the proposed equalizer, six 14Ah $LiFePO_4$ battery cells are connected in series. Two bottom cells B_5 and B_6 are scheduled to have higher voltage than others and to be balanced. Fig. 4(a) illustrates the experimental waveform of two-module operation of equalizer, which is similar with the waveforms in Fig. 3. Long-time measurement of cell voltages is shown in Fig. 4(b). The high voltages of B_5 and B_6 decrease and the other cell voltages increase due to the recovery current. Equalizer operation is programmed to stop when the difference between the average of two highest voltages and that of other cell voltages becomes smaller than 15mV. Voltage balance between cells is achieved in approximately 55 minutes after the equalizer operation starts.

4. Conclusion

Multi-module selective battery equalizer has been proposed and explained. The proposed circuit can handle multiple unbalanced cells simultaneously and provides flexible operation and fast balancing speed. Experimental results have verified the feasibility of the proposed battery equalizer.

Acknowledgment

This work is supported by Samsung Techwin Co. Ltd., Korea.

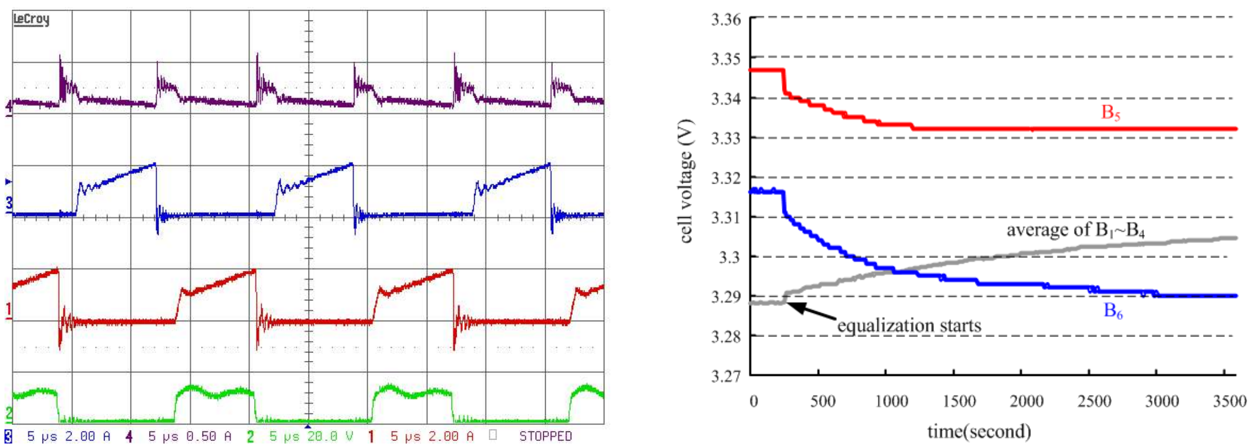
References

[1] S.W. Moore, and P. J. Schneider, "A Review of Cell Equalization Methods for Lithium Ion and Lithium Polymer Battery Systems," Society of Automotive Engineers, 2001.

[2] Y.-S. Lee and M.-W. Cheng, "Intelligent Control Battery Equalization for Series Connected Lithium-Ion Battery Strings," IEEE Trans. Ind. Electron., vol. 52, no. 5, pp. 1297-1307, Oct. 2005.

[3] M. Tang, and T. Stuart, "Selective Buck-Boost Equalizer for Series Battery Packs," IEEE Trans. Aerospace and Elec., vol. 36, no. 1, pp. 201-211, Jan. 2000.

[4] J.-W. Shin, G.-S. Seo, C.-Y. Chun, and B.-H. Cho, "Selective Flyback Balancing Circuit with Improved Balancing Speed for Series Connected Lithium-ion Batteries," Proceedings of International Power Electronics Conference – ECCE Asia, 2010.



(a) (b)

Fig. 4. (a) Experimental waveforms of the proposed battery equalizer. From top, i_{pack}, i_i, i_j, and v_{gs2} are shown. (b) Long-time measurement of cell voltages under balancing operation.