전기자동차 배터리 모듈용 직접 셀 전하 균등화 회로

팜반롱, 응웬킴헝, 간 압둘바싯, 최우진
숭실대학교전기공학부

A Direct Cell-to-Cell Charge Balancing Circuit for the EV Battery Module

Van-Long Pham, Kim-Hung Nguyen, Khan Abdul Basit, and Woojin Choi
Department of Electrical Engineering, Soongsil University

ABSTRACT

In this paper a direct cell-to-cell charge balancing circuit which can transfer the charge from any cell to any cell in the battery string is introduced. In the proposed topology the energy in the high voltage cell is transferred to the low voltage cell through the simple operation of a dc-dc converter to get fast equalization. Furthermore, the charge equalization can be performed regardless of the battery module operation whether it is being charged, discharged or relaxed. The monitoring circuit composed of a DSP and a battery monitoring IC is designed to monitor the cell voltage and protect the battery. In order to demonstrate the advantages of the proposed topology, a prototype circuit was designed and applied to 12 Lithium-Ion battery module. It has been verified with the experiments that the charge equalization time of the proposed method was shortest compared with those of other methods.

Index Terms–Battery management system (BMS), cell balancing, charge equalizer, direct cell-to-cell method

1. Introduction

Recently, the Lithium-Ion batteries have become more important for the Energy Storage Sytem (ESS) applications and the vehicular applications such as Hybrid Electric Vehicles (HEVs) or Plug-In Hybrid Vehicles (PHEVs). Typically, the battery is used as a module which is constructed by connecting multiple number of cells in series and parallel to meet the required power specification. For example, more than a hundred of cells are required for HEV or PHEV applications.

When there is a dispersion of the capacity among the cells in a module, the imbalance of cells tends to grow over time as the batteries of a string are charged or discharged many times. This reduces the capacity of the battery module and eventually results in early cell degradation and premature failure. Therefore, it is important to maintain the cell voltage at an equal charge/discharge level to enhance the lifecycle of the battery. Many kinds of the battery equalizing circuits have been proposed to overcome the forementioned problem. It can be divided into two types, passive cell balancing and active cell balancing. The passive cell balancing method utilizes resistors to discharge the over-charged cell. The advantages of the method are the easiness of implementation and low cost. However, it is disadvantageous that the energy is fully dissipated and converted into heat. In order to solve the problem, the active cell balancing is developed to transfer the energy from over-charged cells to under-charged cells by using converters.

There are several active charge balancing circuit topologies [1]. Each topology has its own advantages in terms of performance, cost, and complexity of the control. Active cell balacing can be classified into four methods: pack-to-cell balancing method, cell-to-pack balancing methods, cell-to-pack-to-cell balancing method which is a combination of two forementioned methods, and cell-to-cell method. The pack-to-cell balancing method is outstanding if one cell is less charged than the others, while the others are balanced. But if one cell have bigger voltage than the others, it takes quite long time because the module has to be discharged first and then all the other cell have to be charged again one by one. The cell-to-pack method has a similar problem. The cell-to-pack-to-cell method was developed to solve the problem by taking an advantage of each method however the method requires two DC/DC converters and the voltage stress of the MOSFET switch is quite large. In addition, the charge and discharge cannot be performed at the same time, thus it takes long time to balance the battery cells [2]. The cell-to-cell method has better performance over the other three methods but the equalization speed is not fast enough.

In order to overcome the abovementioned drawbacks with the conventional method, a cell-to-cell balancing circuit using a DC/DC converter to transfer the energy from any cell to any cell in the battery string directly (Fig. 1). It helps to reduce the balancing time significantly. The battery monitor IC is used to update the cell voltage and to protect the module. With this configuration, the charge equalization operation can be performed by a simple control algorithm.

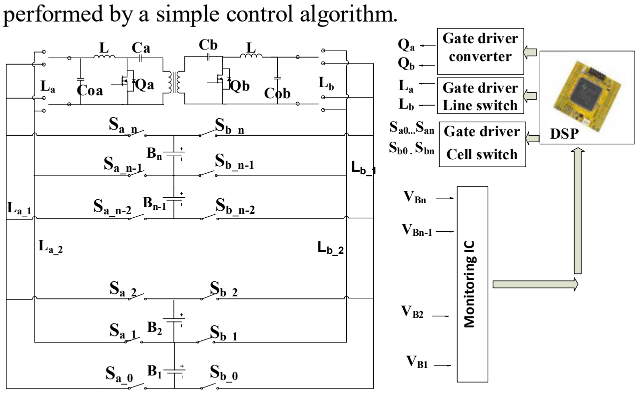


Fig. 1 Proposed direct cell-to-cell balancing circuit

2. Proposed direct cell-to-cell balancing circuit

2.1 Proposed topology of fast charge equalization

Fig. 1 shows the configuration of the proposed cell balancing circuit for a battery string, which includes four parts: a digital signal processor (DSP) to control the system; a monitoring circuit to update the cell voltage and protect the module; a DC/DC

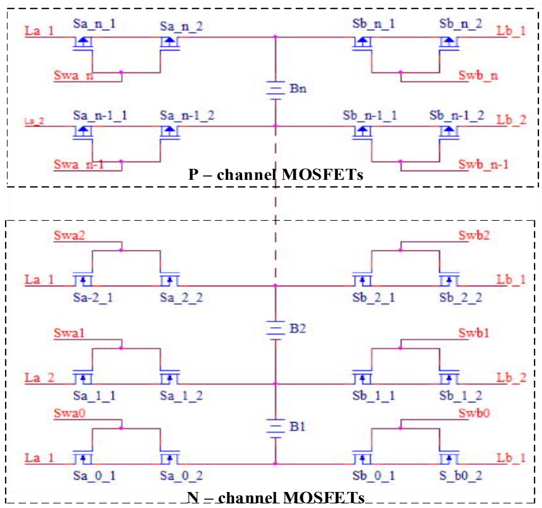


Fig. 2 Cell switch structure of the proposed method

converter based on an isolated Cuk converter; and a cell switch structure to select the cells. Due to the developed cell switch structure, the proposed topology only uses four switches for each cell of the battery module and it can select any two cells in a battery string. The cell switches are divided into two parts: S_a is in the high voltage side and S_b is in the low voltage side. S_{a_0} to S_{a_n} are connected to two line L_{a_1} and L_{a_2}; S_{b_0} to S_{b_n} are connected to two line L_{b_1} and L_{b_2}. Each side of converter has one relay, L_a is in the high voltage side and L_b is in the low side, to connect both terminals of the cell to those of the converter.

Fig. 2 shows structure of cell switch by using two types of MOSFETs. N-channel MOSFETs are used for the cells located at the bottom of the battery string and P-channel MOSFETs are used for the cell switches located at the top of the battery string to get the power for the gate driver.

2.2 Operation principle

Fig. 3 shows the flowchart of the balancing algorithm for the proposed topology. The monitoring IC reads the cell voltage and sends it to the controller. Based on the voltage of each cell, the controller selects the highest voltage cell and the lowest voltage cell to start the balancing directly. During the balancing operation, the monitoring IC keeps updating the cell voltage to protect the system.

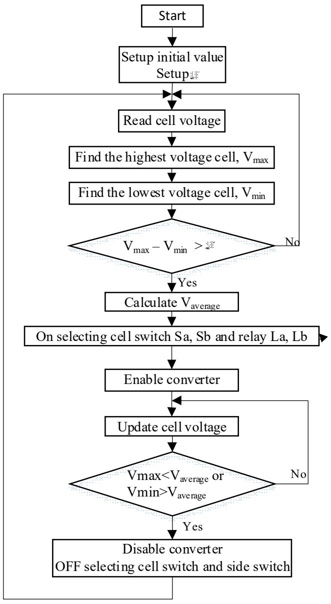


Fig. 3 Flowchart of the proposed cell balancing algorithm

3. Simulation and experimental results

3.1. Simulation results

To verify the validity of the proposed topology, PSIM simulation is performed. It is assumed that Vcell3 is 3.72V and Vcell7 is 3.5V, while all the other cells in the module is 3.6V. By using the proposed topology, any two cells in a string can be selected and balanced. Fig. 4 shows the simulation results during the relaxation. After a short time, two cells have been balanced at 3.6V.

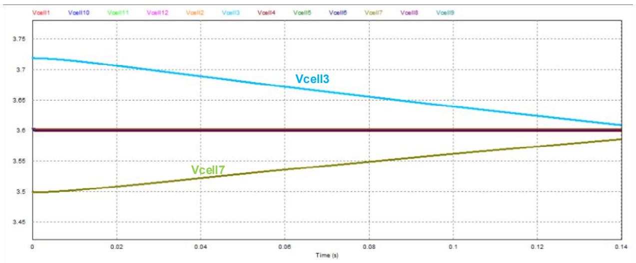
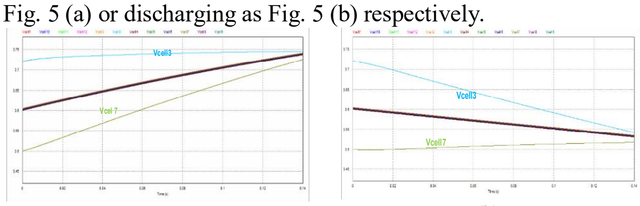


Fig. 4 Result of 2 cell balancing in 12 cell string

The system can balance cell voltage when battery is charging as Fig. 5 (a) or discharging as Fig. 5 (b) respectively.



(a) (b)

Fig. 5 Balancing operation (a) during charge (b) during discharge

3.2. Experiment results and comparison

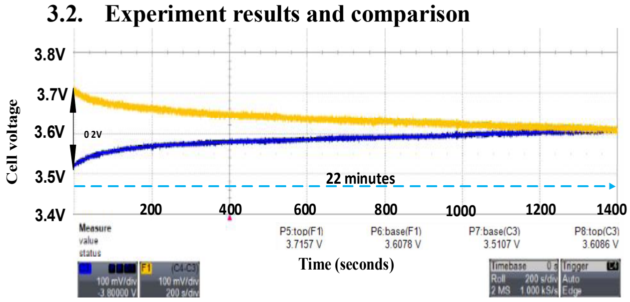


Fig. 6 Cell balancing operation of the proposed circuit

An experimental circuit is implemented for 12-cell lithium-ion battery string. Fig. 6 shows the voltage waveforms of the two cells being balanced. At the beginning, the voltage difference between two cells is 200 mV and two cells are balanced after 22 minutes operation.

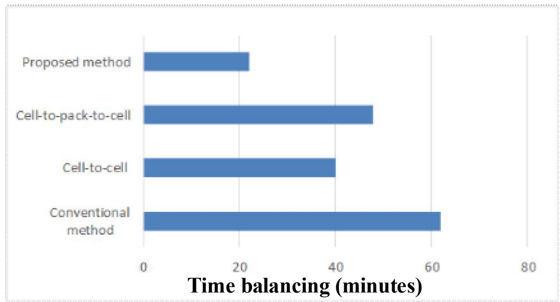


Fig. 7 Comparison of the cell balancing methods in terms of time

Fig. 7 shows the comparison of each method in terms of the time taken for the balancing with a same battery module. As shown in Fig. 7, the proposed method shows the outstanding performance in the charge equalization time.

4. Conclusion

In this paper a fast direct cell-to-cell charge balancing circuit has been introduced. In order to prove the validity of the proposed method, prototype circuit has been implemented. With the proposed topology, any cell in a battery string can be selected and balanced. The proposed method is fast in equalization time, lower in cost and simple in control, which makes it suitable for EV applications

References

[1] Moon-Young Kim, Student Member, IEEE, Jun-Ho Kim, Student Member, IEEE, and Gun-Woo Moon, Member, IEEE, “Center-Cell Concentration Structure of a Cell-to-Cell Balancing Circuit With a Reduced Number of Switches”, IEEE Transactions on Power Electronics, vol.29, no.10, pp.5285 -5297, Oct. 2014.

[2] Chol-Ho Kim, Student Member, IEEE, Moon-Young Kim, Student Member, IEEE, and Gun-Woo Moon, Member, IEEE, “A Modularized Charge Equalizer Using a Battery Monitoring IC for Series-Connected Li-Ion Battery Strings in Electric Vehicles”, IEEE Transactions on Power Electronics, vol.28, no.8, pp.3779 -3787, Aug. 2013.