리튬이온 배터리 모듈을 위한 단일셀간 고속 밸런싱 회로

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A Cell-to-Cell Fast Balancing Circuit for Lithium-Ion Battery Module

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ABSTRACT

In this paper a cell-to-cell fast charge balancing circuit for the Lithium-Ion battery module is proposed. In the proposed topology the energy in a high voltage cell is transferred directly to a low voltage cell through the operation of the dc-dc converter. Furthermore, the charge balancing can be performed regardless of the battery 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 detect the inferior cell thereby protecting the battery module from failure. In order to demonstrate the performance 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 shorter compared with those of other methods.

*Index Terms–A*ctive cell balancing, cell-to-cell balancing circuit, charge equalizer, battery management system (BMS).

1. Introduction

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

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. 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 cells 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 [1]. The conventional 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 directly transfer the energy from any cell to any cell in the battery string is proposed in this research (Fig. 1). The balancing time can be significantly reduced with the proposed method. The battery monitor IC is used to update the cell voltage and to protect the battery module. With this configuration, the charge equalization operation can be performed by a simple control algorithm in a short period of time.

2. Proposed cell-to-cell balancing circuit

2.1 Circuit topology of the proposed charge balancing circuit

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 battery module; an isolated Cuk converter to transfer the energy between cell to cell and a switch network to select the cells.

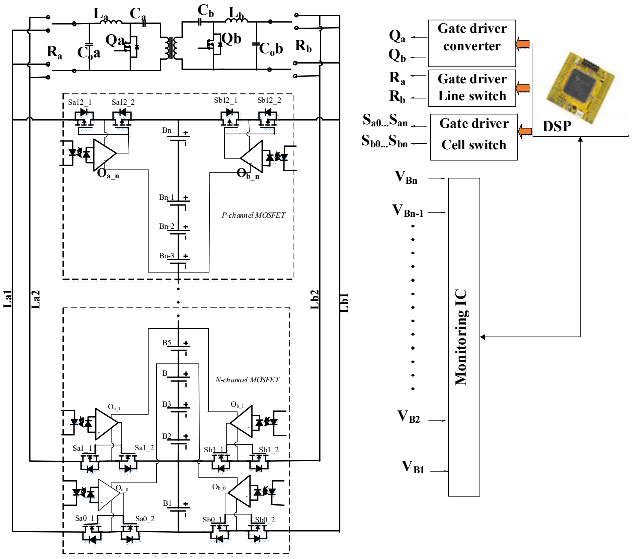

Fig.1. Proposed direct cell-to-cell balancing circuit

Due to the proposed cell switch network, only two bidirectional switches for each cell of the battery module are required and hence any two cells in a battery string can be connected to the DC/DC converter for the energy transfer. The cell switches are composed of two parts: S_a switches in the high voltage side and S_b switches in the low voltage side. S_{a0} to S_{an} switches are connected to the high voltage DC bus, L_{a_1} and L_{a_2}. S_{b0} to S_{bn} switches are connected to the low voltage DC bus, L_{b_1} and L_{b_2}. Each side of the converter has only one relay, R_a is in the high voltage side and R_b is in the low side to connect both terminals of the cell to those of the converter. N-channel

MOSFETs are used for the cell switches which are located at the lower side of the battery string and P-channel MOSFETs are used for the cell switches which are located at the upper side of the battery string to get the power for the gate driver from battery string (Fig.1).

2.2 Operation principle

Fig. 2 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.

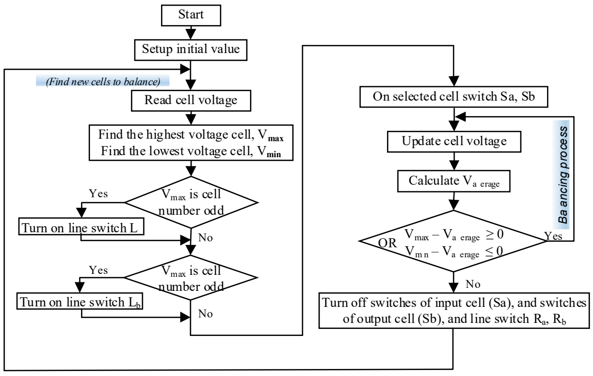

Fig.2. Flowchart of the proposed cell balancing algorithm

When two selected cells are balanced at the average voltage, the cell switches are disconnected and the controller finds another set of two cells to work. All the cells in a battery module can be balanced in sequence by the proposed algorithm.

3. Experimental results and discussion

In order to verify the superior performance and operation principle of the proposed topology, the prototype circuit has been implemented. In the switch network N-channel MOSFEF IRFZ44N and P-Channel MOSFET FQP17P10 are used to reduce the conduction loss during the cell balancing operation.

Fig.3 shows the experimental results of the prototype with 12 cells in a battery module during the relaxation of the battery module. At the start, after reading all the cell voltages, the system finds that the cell number 3 shows the highest voltage (3.74V) and cell number 12 shows the lowest voltage (3.54V). Hence these 2 cells are balanced first. After 19 minutes, the cell number 12 reaches the average voltage of the module (3.62V). After then the system starts find another set of two cells to work. In the next step, the controller finds that the voltage of the cell number 10 is the highest and that of cell number 5 is the lowest. Then, these two cells are selected for balancing. In this way, the system can balance all the cells in a battery module quickly. In this experiment, all the cells are balanced at the average voltage after 47 minutes.

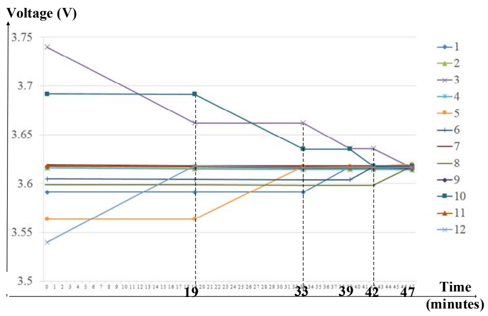

Fig.3. Balancing process for 12 cell in the battery module during the relaxation mode

In this test cell balancing is performed when the battery module is being charged with 2[A]. At the initial state, voltage difference of each cell is large as shown in Fig.4. By applying the proposed cell balancing algorithm, all the cells in the battery string are charged successfully to the voltage of 4.2V after 49 minutes.

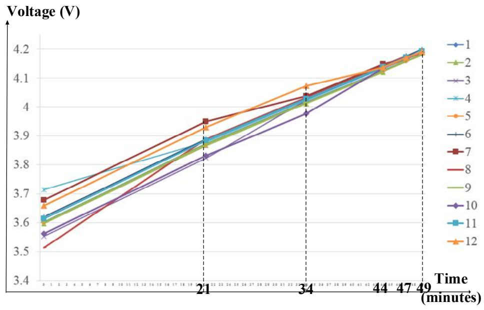

Fig.4. Balancing process for 12 cell in the battery module during the charge mode

Fig.5 shows the experimental result obtained during the battery module is being discharged with 1.5[A]. It also shows that all the cells are fully discharged equally up to the cut-off voltage (3.0V) after 58 minutes.

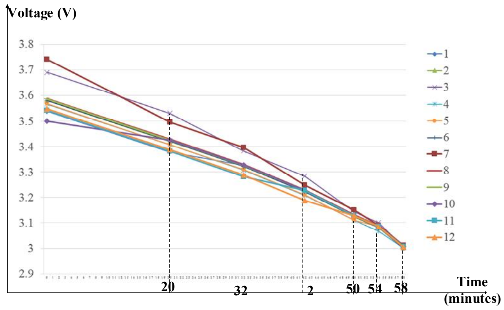

Fig.5. Balancing process for 12 cell in the battery module during discharging mode

Table I shows the comparison between proposed method and other active cell balancing methods in terms of the components, cost, balancing speed, efficiency, and complexity of the control. As shown in the Table I, the proposed method is advantageous in that the number of the component can be reduced, the control algorithm is simple and it is fast.

TABLE I. COMPARISON OF THE PROPOSED CELL BALANCING METHOD FOR N-CELL IN THE BATTERY STRING

	Pack-to-cell	Cell-to-pack	Cell-to-pack-to-cell method	Next-to-next cell method	Center cell-to-cell	Single switch capacitor	Proposed method
MOSFET	(2N+2+2m) double	m(N-2)	2(N+1) double	2(N+1)	N	(2N+2+m) double	2(N+1) double
Diode	m+1	m(N-2)	2m	0	N	0	0
Inductor	0	0	0	N	N+1	1	2
Transformer	m+*1 (m is number of module)*	m *(m is number of module)*	2 (high voltage stress)	0	0	0	1
Capacitor	m	0	2	0	0	1	2
Cost	High	High	Medium	Medium	**Low**	Medium	Medium
Balacing speed	Low	Low	Low	Low	Low	Low	**Fast**
Approx. efficiency	Low	Good	Good	**High**	Low	Low	Good
Balancing control	Medium	Complex	**Simple**	**Simple**	Complex	**Simple**	**Simple**

4. Conclusion

In this paper, a cell-to-cell fast charge balancing circuit has been proposed. In order to prove the validity of the proposed method, prototype circuit has been implemented. The experimental result shows fast charge balancing with good performance. The proposed method is fast in equalization time, lower in cost and simple in control, which makes it suitable for battery module applications such as ESS or EVs.

References

[1] 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.