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Comparison on Cell Balancing Methods for Energy Storage Applications

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Abstract

Background: Unbalanced cells in the battery caused by differences in cell compounds and initial charge capacities may reduce its capacity and exert on a bad influence on its safety and lifetime. Methods: This paper introduces comparisons on the different cell balancing methods for energy storage applications. This study first categorizes cell balancing circuits as passive or active cell balancing methods based on the usage of resistors. Then, this paper investigates the advantages and disadvantages of these passive and active cell balancing methods. The investigated passive cell balancing methodologies include a fixed shunting resistor circuit and a switching shunting resistor circuit. In addition, the studied active cell balancing methods in this paper include cell balancers using capacitor, inductor/transformer, or DC-DC converter. **Findings:** Based on the comparison results of this study, a passive cell balancer is easy to implement although it requires long balancing time and has low cell balancing energy efficiency because of a thermal loss from a resistor. This passive cell balancer is a suitable technique for portable tools and low-power systems. On the other hand, an active balancing method has higher energy transmission efficiency and shorter balancing time than a passive cell balancer although it requires complex control algorithms and high cost for fabricating the balancing circuit. **Applications:** By comparing the advantages and disadvantages of these cell balancing methods, this paper presents a guide for selecting a proper cell balancing method for energy storage applications.

Keywords: Active Cell Balancer, Cell Balancing Method Comparison, Energy Storage, Passive Cell Balancer

1. Introduction

Each cell in the battery pack usually has different cell compounds, initial charge capacities and external effects. In addition, series-connected cells in the battery pack are repeatedly charged and discharged in various energy storage devices. Hence, the differences of charge-discharge speed and lifetime may result in unequal state-of-charge in the battery cells[1]. The differences of charging and discharging speed in these unbalanced cells result in variations in the battery voltage and capacity of series-connected cells in the battery pack. These variations in the battery pack are the major source that is to reduce a cell capacity and to shorten the life of a battery. In order to resolve this imbalance of the cell energy, an auxiliary cell balancing circuit should be used in the battery management system.

As illustrated in Figure 1, various cell-balancing algorithms have been presented in the literature. Cell balancing methods are usually classified with a passive circuit and an active circuit. A passive cell-balancing methodology uses resistors to equalize the cell energy of a battery pack by consuming higher energy cell than others. Although this passive cell balancing circuit is easy to implement, its energy transmission efficiency is usually low due to energy losses generated by heat dissipation from the resistors. On the other hand, an active cell-balancing circuit transfers higher cell energy to lower cell energy using a power electronic interface. Although this active cell balancer has higher efficiency than a passive cell balancer, its control algorithm may be complex and its production cost is expensive because each cell should be connected with an additional power electronics interface[2-9].

The rest of this paper is organized as follows: Section 2 describes passive cell balancing methods using a fixed shunting resistor and a switching shunting resistor. Section 3 discusses various active cell balancing methods with a

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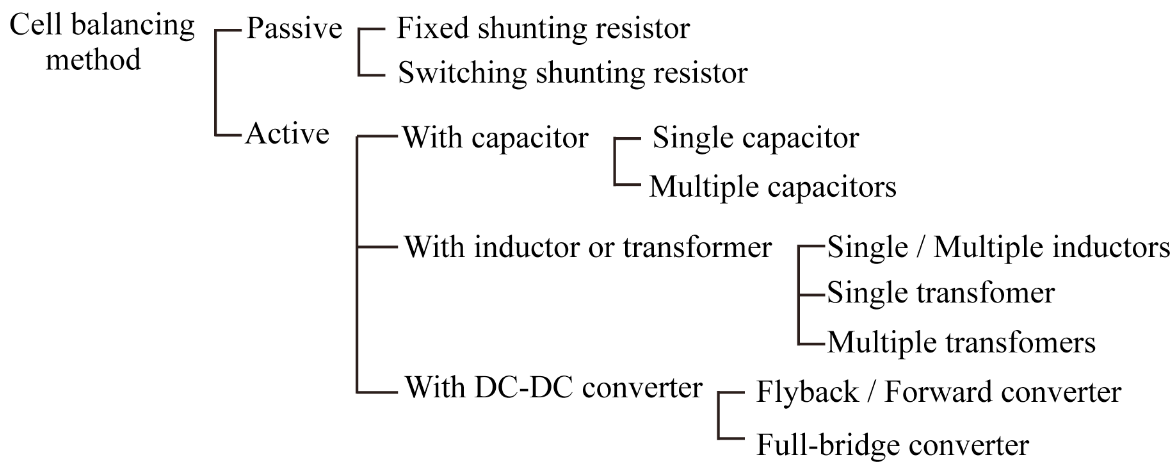

Figure 1. Cell balancing method.

power electronics interface. Lastly, Section 4 describes reviews of the previous cell balancing studies and concludes this paper with the advantages and disadvantages of cell balancing circuits which have been investigated.

2. Passive Cell Balancing Method

A passive cell equalizing circuit usually uses resistors to balance cell energy by consuming higher cell energy relatively in a battery string. This balancing method is more reliable and uses less number of components than other cell equalizing circuits[8-11].

2.1 Fixed Shunting Resistor

As shown in Figure 2, a fixed shunting resistor circuit uses N number of resistors (i.e., $R_1 \sim R_N$) connected in each cell to prevent it from being overcharged[9]. Because of the resistors this passive balancing circuit is possible to control the limit value of each cell voltage and does not damage cells ($B_1 \sim B_N$). This fixed shunt resistor method is mainly used in the lead-acid and nickel battery applications. This fixed shunt resistor circuit requires low cost because its composition is simple. However, energy consumed by these resistors for balancing a battery may result in thermal losses in the battery management system. Therefore, this fixed shunting resistor method is an inefficient cell equalizing circuit.

2.2 Switching Shunting Resistor

As shown in Figure 3, a switching shunting resistor cell balancing circuit consists of N number of switches ($S_1 \sim S_N$) and resistors ($R_1 \sim R_N$) for each cell[8]. This cell balancing circuit is currently the most common method in the cell equalizing system. This method is divided into a continuous mode and a sensing mode. At the continuous mode, all switches are controlled to be turned on or turned off at the same time. When a resistor value is properly selected at this mode, it is effective to charge the entire battery[8].

In the sensing mode, this method requires a real-time voltage sensor for each cell. This cell balancing circuit

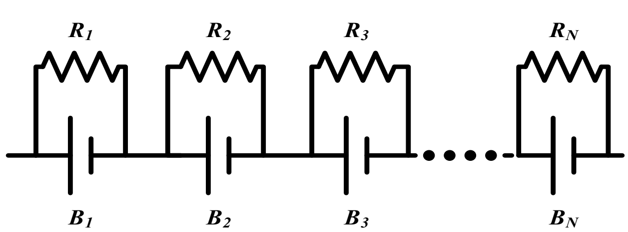

Figure 2. Cell balancing circuit with fixed shunting resistor[9].

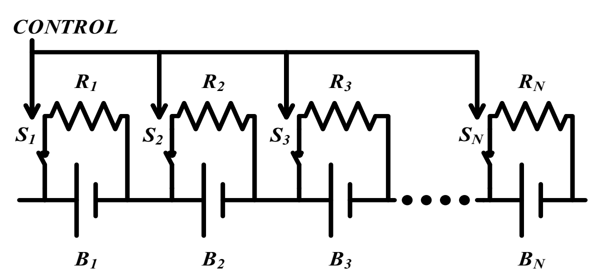

Figure 3. Cell balancing circuit with switching shunting resistors[8].

also consumes high energy through a balancing resistor. Because of this characteristic, thermal losses may result from high currents through balancing switches and resistors. Therefore, cell thermal management is also required to control the thermal losses. This cell balancing circuit is suitable for a battery system which requires a low current when it is charged or discharged[8].

3. Active Cell Balancing Method

An active cell-balancing circuit usually uses energy transferring components such as capacitors, inductors, or transformers to balance cell energy in the battery pack. This active cell-balancing circuit has shorter cell balancing time and has higher efficiency than the passive cell balancing circuit. However, this cell equalizing circuit has high cost and requires complex system control algorithms for balancing cells.

3.1. Active Cell Balancing Circuit based on Capacitors

An active cell balancing circuit based on capacitors balances cells with capacitors by transferring unequal energy between multiple cells in the battery string. When a specific cell voltage is lower than a capacitor voltage, this cell is charged by the capacitor. In contrast, when a certain cell voltage is higher than a capacitor voltage, this cell is discharged to the capacitor. In other words, a charged capacitor by a higher energy cell than others discharges its energy to a relatively lower energy cell. Because energy is transferred from cells by capacitors, thermal losses of this cell balancing circuit are usually lower than those of a passive cell balancing method. However, this equalizing circuit requires a complex switch structure and a complicated control method for a switch[11-15].

3.1.1. *Single Capacitor*

As shown in Figure 4, an active cell balancing circuit with a single capacitor consists of N number of cells ($B_1 \sim B_N$), $N + 2$ number of switches ($S_1 \sim S_{N+2}$) and one capacitor (C) in the cell balancing circuit[11]. A capacitor in the battery string is charged or discharged in order to equalize each cell. This cell balancing circuit is simple because it uses a single capacitor regardless of the number of cells connected in the battery string. However, this cell balancer requires a large number of switches and intelligent control of the switches[11-13].

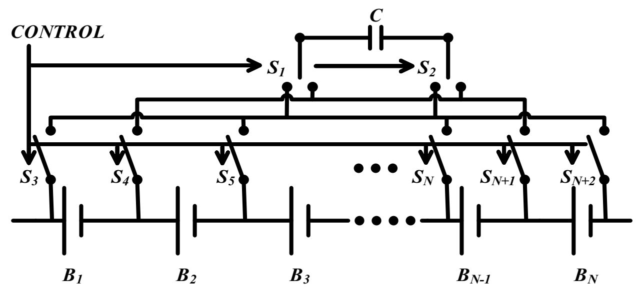

Figure 4. Cell balancing circuit with a single capacitor[11].

3.1.2. *Multiple Capacitors*

As shown in Figure 5, an active cell balancing circuit with multiple capacitors transfers unequal cell energy by multiple capacitors. This cell balancer is composed of N number of cells ($B_1 \sim B_N$), switches ($S_1 \sim S_N$) and N-1 number of capacitors ($C_1 \sim C_{N-1}$) in the cell balancing circuit[13]. In this circuit, capacitors for balancing unequal cell energy are connected to each battery. The advantage of this cell balancing circuit is that it is not required to use a voltage sensor or closed-loop control and that the stress of switches is low. However, its balancing speed is usually not satisfactory[14,15].

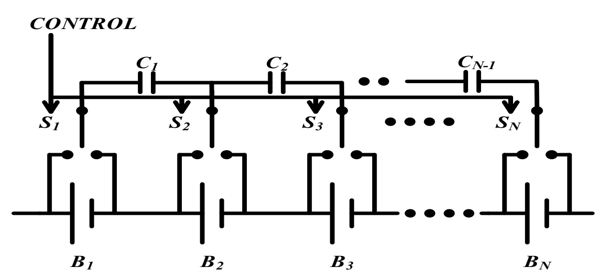

Figure 5. Cell balancing circuit with multiple capacitors[13].

3.2. Active Cell Balancing Circuit based on Inductors or Transformers

A cell balancing circuit described in this section equalizes battery cells with magnetic components, such as inductors or transformers, by transferring unequal energy between multiple cells. This cell balancer results in all cells to be equalized by transferring unequal cell energy from a higher energy cell to a lower energy cell in the battery pack through inductors or transformers. The balancing time of this cell balancing circuit can decrease by a high cell balancing current. However, this cell equalizing circuit requires high production cost, and a magnetic transformer loss should be considered during the design phase of this cell balancer. Because its switching frequency is usually high, each cell in the battery string should have a filtering capacitor[11,16-19,21].

3.2.1. Single/Multiple Inductors

As shown in Figure 6, this cell balancing method uses single or multiple inductor (L)[16,21]. The control algorithm of this cell balancing circuit with single or multiple inductors is that it detects each cell voltage and selects a cell to transfer energy. When MOSFETs (Q_N) are turned on and turned off, unequal cell energy is delivered to an inductor. In this circuit, unequal cell energy is transferred from a higher energy cell to a lower energy cell in the battery string through an inductor. A cell balancing circuit with a single inductor as shown Figure 6(a) has a small volume and low cost[15]. In addition, the cell balancing method with multiple inductors as shown Figure 6(b) has fast balancing speed and decent cell balancing efficiency. However this cell balancer requires accurate voltage sensors[16-18,21].

3.2.2. Single Transformer

Figure 7 shows an active cell balancing circuit based on a single transformer that consists of a MOSFET (Q), a transformer (T), a diode (D) and $N+2$ number of switches ($S_1 \sim S_{N+2}$) and N number of battery cells ($B_1 \sim B_N$)[11]. This cell balancing method with a single transformer has the following two topologies: the first one is a pack-to-cell topology, and the other one is a cell-to-pack topology. This cell balancer has a fast balancing speed with low magnetic losses. However, this cell equalizer requires accurate switch control[11,16,17,21].

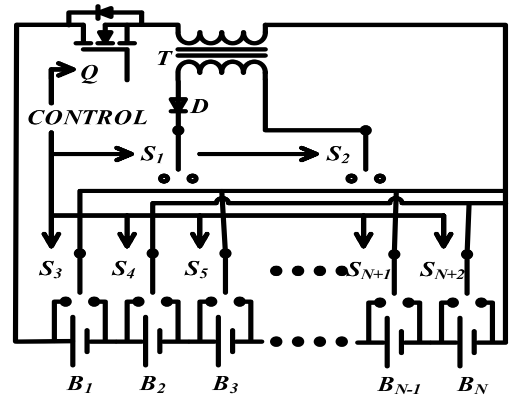

Figure 7. Cell balancing circuit with a single transformer[11].

3.2.3. Multiple Transformers

Figure 8 depicts an active cell balancing circuit with multiple transformers is composed of N number of cells ($B_1 \sim B_N$), transformers ($T_1 \sim T_N$), diodes ($D_1 \sim D_N$) and a single MOSFET (Q)[11]. The control method of this cell balancing circuit is simple because this circuit only uses a single switch. In addition, this cell balancer has a fast equalization speed. However, it requires high price and complicated circuit and should prevent transformer from being saturated[11,18,19,21].

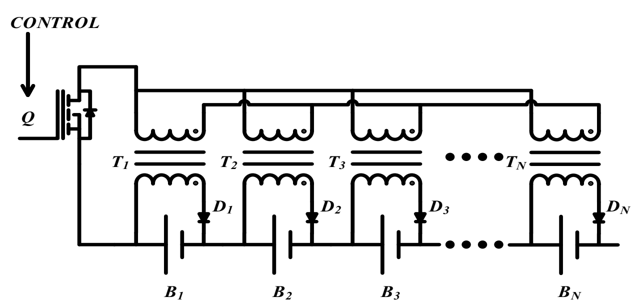

Figure 8. Cell balancing circuit with multiple transfomers[11].

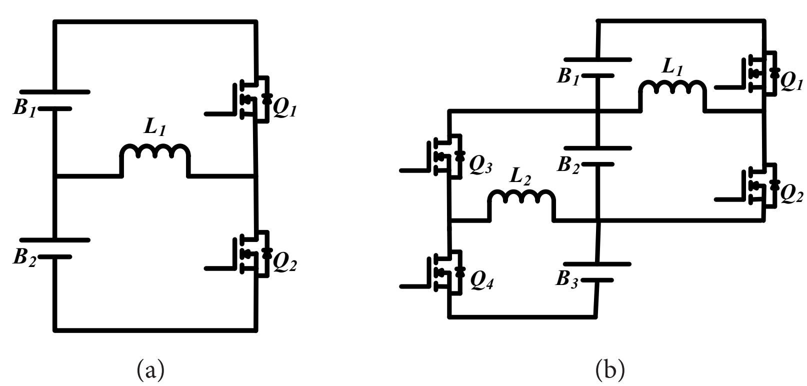

Figure 6. Cell balancing circuit with Single/Multiple inductor. (a) Single inductor[16]. (b) Multiple inductors[21].

3.3. Active Cell Balancing Circuti with a Power Electronics Interface

This active cell balancing circuit balances unequal cell energy in the battery string with a DC-DC converter such as flyback converter or forward converter. The structure of a balancer with a flyback converter topology has the primary and secondary side based on its transformer. This cell balancer charges or discharges unequal cell energy through a transformer which provides an insulated structure with safe energy transmission. However, a circuit designer should consider the design and magnetic hysteresis loss of a transformer for high energy transmission efficiency. This cell equalizer has higher energy transfer efficiency than a passive balancing circuit. This cell balancer can be bulky and may require a complex control algorithm because each cell should be connected with additional passive components and active switches[19-23].

3.3.1 Flyback /Forward Converter

As shown in Figure 9(a), a cell balancer with a flyback converter topology consists of *N* number of cells (B_1 ~ B_N), diodes (D_1 ~ D_N), a transformer (*T*), and a single MOSFET (*Q*)[20]. In this cell balancer, the energy of a high voltage cell is stored in the transformer. When the secondary side switch is turned on, this energy is transmitted to the lower voltage cells through the diodes (D_1 ~ D_N). This cell balancing method can be easily implemented in the large number of cells and is commonly used for EVs. However, there is a magnetic loss problem in the multi-winding transformer[9,11,20,21].

Figure 9(b) shows a cell equalizer with a forward converter that consists of *N* number of cells (B_1 ~ B_N), MOSFETs (Q_1 ~ Q_N), a transformer (*T*), and a single diode (*D*)[20]. This cell balancing circuit has high reliability. Although additional cells are also connected to this cell balancer, it does not require to change a transformer turns ratio. However this cell equalizer should require a reset circuit to prevent a transformer saturation problem[11,20].

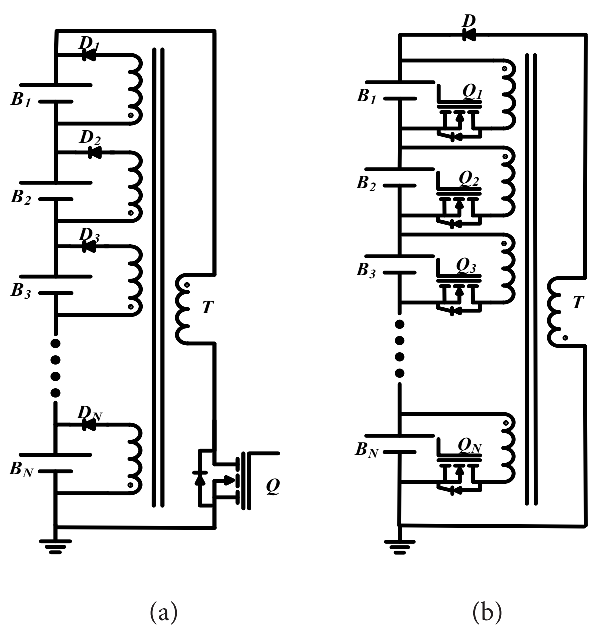

Figure 9. Cell balancing circuit with Flyback/Forward converter[20]. (a) Flyback converter. (b) Forward converter.

3.3.2. Full-bridge Converter

Figure 10 shows a cell balancing circuit with a full-bridge converter that consists of eight MOSFETs (Q_1 ~ Q_8), *N+5* number of switches (S_1 ~ S_{N+5}), a transformer (*T*) and *N* number of cells (B_1 ~ B_N)[22]. This cell balancer with a full-bridge converter operates with the following two modes: "buck mode" and "boost mode". This method is widely used in relatively high-power systems such as plug-in hybrid electric vehicles (PHEV) and energy storage system (ESS). The cell balancing method has fast equalization speed and high efficiency. However, the price of this cell balancer is expensive, and its control scheme is complicated[22].

4. Conclusions

This paper analyzed the characteristics, advantages and disadvantages of cell balancing methods. Table 1 compared passive balancing methods and active balancing methods based on their advantages and disadvantages. A passive cell balancing method normally uses a low current. Therefore, its energy transmission efficiency is low

Table 1. Comparison of cell balancing method

Type	Advantages	Disadvantages	Applications
Passive balancer	Small size, Low cost	high energy losses, Poor thermal management	Portable device, Low-power system
Active balancer	High efficient, Fast balancing	High cost, Complicated control, Magnetic losses	UPS, ESS, EV/HEV

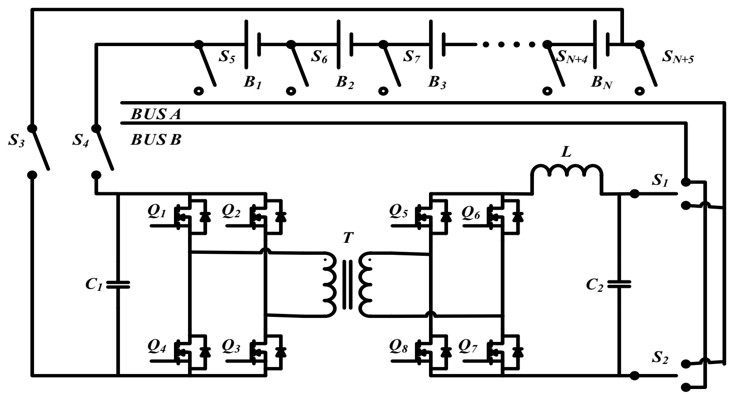

Figure 10. Cell balancing circuit with Full-Bridge Converter[22].

because of its low heat dissipation although it requires long balancing time. A passive method is a suitable technique for portable tools and low-power systems. An active balancing method has higher energy transmission efficiency and shorter balancing time than a passive cell balancer. Therefore, an active cell balancing method is a suitable technique for uninterruptible power supply (UPS), energy storage system (ESS) and electrical vehicle (EV).

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References

1. Lee Y, Jeon S, Yun J, Bae S. Comparison of Battery Cell Balancing Methods. Vietnam: Proceedings of International Conference on Information and Convergence Technology for Smart Society (ICICTS '16). 2016; p. 125-26.
2. Krishna G, Prabhaharan S. Smart Battery Management System with Active Cell Balancing. Indian Journal of Science and Technology. 2015 August; 8(19):1-6.
3. Bui M, Bae S. Active Clamped Forward based Active Cell Balancing Converter. Indian Journal of Science and Technology. 2015 October; 8(26):1-6.
4. Jeon S, Yun J, Bae S. Comparative Study on the Battery State-of-Charge Estimation Method. Indian Journal of Science and Technology. 2015 October; 8(26):1-6.
5. Ashok J, Thirumopoorthy P. Design Considerations for Implementing an Optimal Battery Management System of a Wireless Sensor Node. Indian Journal of Science and Technology. 2014 September; 7(9):1-5.
6. Sidorov K, Golubchik T, Yutt V. Method for Calculating the Power Circuit Characteristics of the Isolated DC-DC Converters for Electric and Hybrid Vehicles. Indian Journal of Science and Technology. 2015 October; 8(27):1-8.
7. Davide A. Massachusetts: Artech House: Battery Management System for Large Lithium-Ion Battery Packs. 1st ed. 2010.
8. Cardar D, Petreus D, Pararau T. An Energy converter method for battery cell Balancing. Poland: Proceedings of IEEE 33rd International Spring Seminar on Electronics Technology (ISSE '10). 2010; p. 290-93.
9. Lindermark B. Individual Cell Voltage Equalizers (ICE) for Reliable Battery Performance. Japan: Proceedings of IEEE 13th International Telecommunications Energy Conference (INTELEC '91). 1991; 196-201.
10. Daowd M, Omar N, Van Den Bossche P, Van Mierlo J. Passive and Active Battery Balancing comparison based on MATLAB Simulation. USA: Proceedings of IEEE 7th Vehicle Power and Propulsion Conference (VPPC '11). 2011; p. 1-7.
11. Moore S, Schneider P. A Review of Cell Equalization Methods for Lithium Ion and Lithium Polymer Battery Systems. SAE Tech. 2001 March; p. 1-5.
12. Speltino C, Stefanopoulou A, Fiengo G. Cell Equlization in Battery Stacks Through State of Charge Estimation Polling. USA: Proceedings of American Control Conference (ACC '10). 2010; p. 5050-55.
13. Isaacson M, Hollandsworth M, Giampaoli P, Linkowsky F, Salim A, Teofilo V. Advanced lithium ion battery charger. USA: Proceedings of IEEE 15th Annual Battery Conference on Applications and Advances. 2000; 193-98.
14. Park H, Kim C, Park K, G. Moon G, Lee J. Design of a Charge Equalization Based on Battery Modularization. IEEE Trans. Vehicular Technology. 2009 September; 58(7):3216-23.

15. Pascual C, Krein P. Switched Capacitor System for Automatic Series Battery Equalization. USA: Proceedings of IEEE 12th Applied Power Electronics Conference and Exposition (APEC '97), 1997; 848-54.
16. Park S, Kim T, Park J, Moon G, Yoon M. A New Battery Equalizer Based on Buck-boost Topology. Korea: Proceedings of IEEE 7th International Conf. on Power Electronics (ICPE '07). 2007; 962-65.
17. Shin J, Seo G, Chun C, Cho B. Selective Flyback Balancing Circuit with Improved Balancing Speed for Series Connected Lithium-ion Batteries. Japan: Proceedings of International Power Electronics Conference (IPEC '10). 2010; 1180-84.
18. Moo C, Hsieh Y, Tsai I, Cheng K. Dynamic Charge Equalization for Series-Connected Batteries. Thailand: Proceedings of IEEE Electric Power Applications. 2003; p. 501-5.
19. Einhorn M, Roessler W, Fleig J. Improved Performance of Serially Connected Li-ion Batteries With Active Cell Balancing in Electric Vehicles. IEEE Trans. Vehicular Technologies. 2011 July; 60(6):2448-57.
20. Zhi K, Chun Z, Ren L, Kang C. Comparison and Evaluation of Charge Equalization Technique for Series Connected Batteries. Proceedings of 37th IEEE Power Electronics Specialists Conference (PESC '06). 2006 June; p. 1-6.
21. Imtiaz A, Khan F. Time Shared Flyback Converter Based Regenerative Cell Balancing Technique for Series Connected Li-ion Battery Strings. IEEE Trans. Power Electronics. 2013 December; 28(12):5960-75.
22. Guo Y, Lu R, Wu G, Zhu C. A High Efficiency Isolated Bidirectional Equalizer for Lithium-ion Battery String. Korea: Proceedings of IEEE Vehicle Power and Propulsion Conference (VPPC '*12*). 2012; p. 962-66.
23. Sukhi Y, Kirthiga S, Sujitha S. Implementation and Analysis of Low Stress PWM DC-DC Converter for Battery Charger. Indian Journal of Science and Technology. 2015 October; 8(28):1-6.