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Active Cell Balancing of Series Connected Lithium Ion Battery Cells with Flyback Converter

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***Abstract*— Lithium-ion battery packs used in electric vehicles often suffer from cell voltage imbalance due to manufacturing inconsistencies, temperature variations and unequal aging characteristics. Cell imbalance reduces the available capacity, decreases battery life and may lead to overcharging or over-discharging of individual cells. Active cell balancing techniques provide an efficient solution by redistributing energy among cells instead of dissipating excess energy as heat. Among various active balancing methods, the flyback converter-based topology has attracted considerable attention because of its galvanic isolation, high efficiency, bidirectional energy transfer capability and modular structure. This paper presents active cell balancing using a flyback converter for lithium-ion battery packs. The operating principle, control strategy, converter design and balancing algorithm are discussed in detail. The proposed balancing system transfers energy from higher-voltage cells to lower-voltage cells through a flyback converter transformer, wherein the energy transfer takes place from cell to the pack. The MATLAB Simulation results are presented and performance evaluation is done on the basis of balancing time and state of charge equalization.**

***Index Terms*— Active Cell Balancing, Lithium Ion Battery, SoC, flyback converter.**

I. INTRODUCTION

The increasing demand for electric vehicles, hybrid electric vehicles, renewable energy storage systems, and portable electronic devices has accelerated the development of lithium-ion battery technology. Lithium-ion batteries are preferred because of their high energy density, long cycle life, low self-discharge rate and lightweight structure [1]. However, battery packs consist of multiple cells connected in series and parallel combinations to meet voltage and power requirements. Due to manufacturing tolerances, unequal internal resistance, temperature variations and aging effects, individual cells in the battery pack exhibit different charging and discharging characteristics. These differences create imbalance among cells, leading to reduced usable capacity and decreased battery lifespan [2]. In a series-connected battery pack, the weakest cell determines the overall performance of the system. During charging, some cells may reach the maximum allowable voltage earlier than others, causing overcharging, while during discharging weaker cells may become deeply discharged. Such conditions accelerate battery degradation and may create thermal runaway and safety hazards [3]. Therefore, cell balancing becomes an essential function of the Battery Management System (BMS).

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Cell balancing techniques are broadly classified into passive (dissipative) balancing and active (non-dissipative) balancing methods [4]. Passive balancing dissipates excess energy through resistors and is simple to implement, but it suffers from poor efficiency and thermal losses. Passive systems are noted to be effective for low-current applications but require robust thermal management to dissipate the heat generated during the balancing process [5]. Active balancing techniques redistribute energy among cells using capacitors, inductors, transformers, or DC–DC converters, thereby improving energy utilization and balancing efficiency [6]. Capacitor-based topologies, like the switched-capacitor design, are relatively simple but often suffer from slower equalization speeds in large strings because the energy must hop sequentially between adjacent cells. Inductive and transformer-based methods offer much faster balancing by allowing energy to be moved more directly across the pack, though they involve increased component bulk and more complex control circuitry [7].

More advanced active balancing architectures employ DC-DC converter topologies, such as Buck-Boost, CUK or Flyback converters, to achieve high-precision energy management. These systems can facilitate various transfer modes, including cell-to-pack or cell-to-cell, providing the highest levels of efficiency and speed [8]. Despite these technical advantages, the adoption of active balancing is often limited to high-performance electric vehicles (EVs) and large-scale renewable energy storage systems due to the higher costs of components and the sophisticated control algorithms required to manage the switching frequencies [9].

Among active balancing methods, flyback converter-based balancing has become highly attractive because it provides electrical isolation, flexible energy transfer, reduced switching losses, and scalability for large battery packs [10]. The flyback converter operates as an isolated DC–DC converter in which energy is temporarily stored in the transformer magnetizing inductance and then transferred to target cells [11]. Multi winding flyback topologies enable energy transfer between any cells in the battery string with high efficiency. Recent research has focused on improving balancing speed, reducing converter size, optimizing switching strategies, and minimizing transformer losses [12]. Advanced control algorithms including fuzzy logic control, predictive control, and intelligent balancing strategies have also been incorporated to improve system performance [13].

This paper discusses the architecture, operation, control and performance evaluation of flyback converter-based active balancing systems for lithium-ion battery packs. The MATLAB simulation results are presented to demonstrate the cell balancing operation.

II. Flyback Converter for Active Cell Balancing

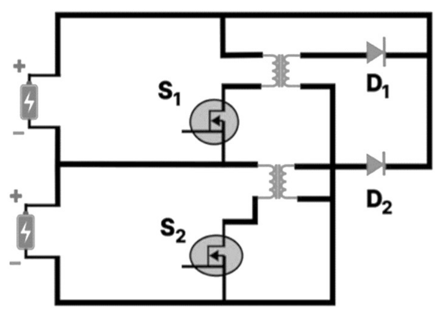

Figure 1: Flyback Converter topology for cell balancing

Flyback converters topologies that have gained prominence in battery management systems. These converters utilize transformer-based isolation to transfer energy between cells effectively [16]. The basic forward converter operates by storing energy in a transformer during the switch-on period and transferring this energy to the output during the same interval, distinguishing it from flyback converters that transfer energy during the off period. In battery balancing applications, flyback converters can be configured with multi-winding transformers where each cell connects to a primary winding [17]. This arrangement allows direct energy transfer from higher-voltage cells to lower-voltage cells through the transformer's magnetic coupling. The transformer's turn ratio plays a crucial role in determining the energy transfer rate and overall balancing efficiency. A carefully selected turn ratios can optimize balancing power and speed without compromising efficiency [18]. The circuit topology of flyback converter based active cell balancing is seen in figure 1. The primary side of a high frequency transformer is switched with a MOSFET and hence producing a pulsating signal which is transferred to the secondary winding through transformer action. The secondary side is connected to a rectifier diode which converts AC to DC. This DC voltage is connected to the entire battery pack. Thus the energy flows from a cell to the pack during cell balancing. The energy of higher charged cell is thus distributed to the lower charged cell.

III. SIMULATION AND RESULTS

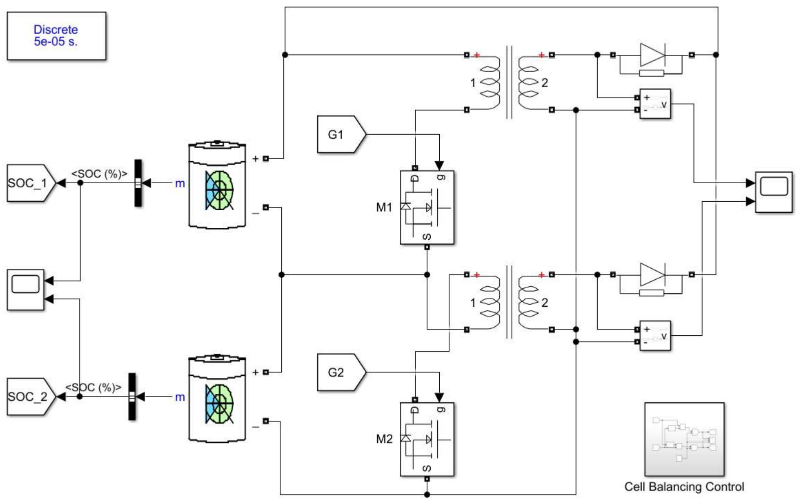

Figure 2: MATLAB Simulink Model of active cell balancing

The flyback converter based active cell balancing system is simulated with MATLAB Simulink. The system specifications are mentioned in table 1. The performance analysis of this is conducted in two cases by considering different initial SOC as ‘case a’ and ‘case b’ as mentioned in table 1. The performance of the cell balancing measured in terms of accurately balancing SOC in discharging mode and time taken for balancing. The SOC based balancing strategy is deployed with balancing algorithm as seen in flowchart of figure 4.

TABLE I: SYSTEM SPECIFICATION

Particulars	Value
Cell 1	3.7V, 5.4Ah
Cell 2	3.7V, 5.4Ah
DC-DC converter	Flyback converter
Transformer ratio	1: 3
Control strategy	SOC Based balancing algorithm
Case a: initial SOC	Cell 1: 80%, cell 2: 75%
Case b: initial SOC	Cell 1: 70%, Cell 2: 75%

The Simulink model is executed for a period of 350 seconds in two cases of initial SOC as mentioned in the table 1 and results are recorded for SOC and switching pulses of the MOSFETs of the Flyback converters.

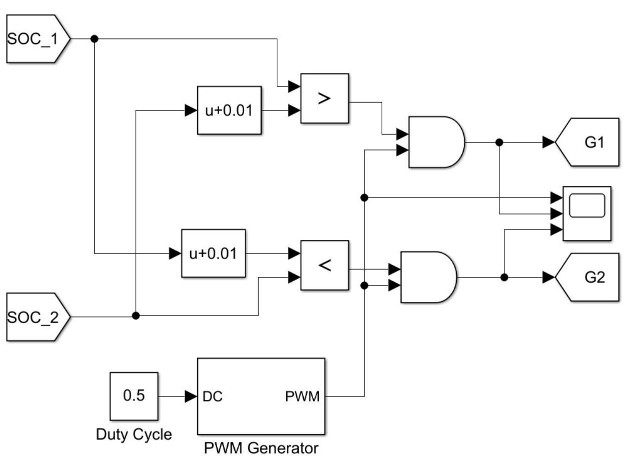

Figure 3: SOC Balancing Control Scheme

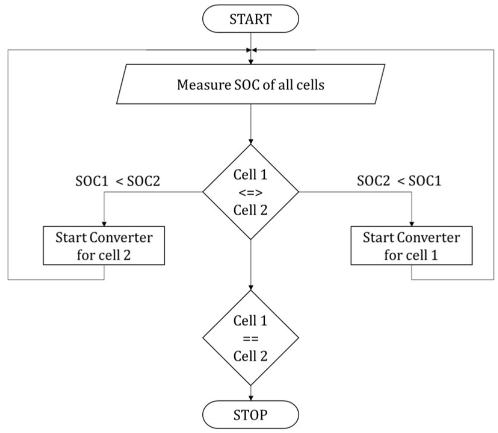

Figure 4: flowchart of SOC based cell balancing

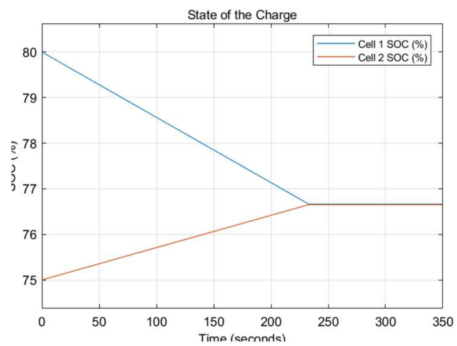

Figure 5: SOC of Cell 1 and Cell 2 during balancing operation (case a)

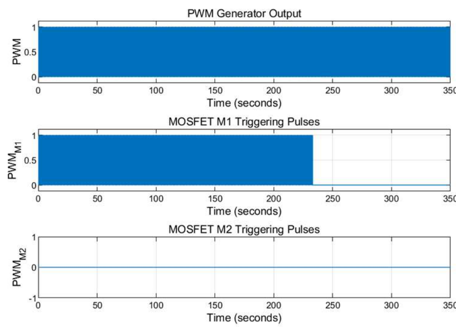

Figure 6: PWM Triggering pulses (Case a)

B. Case b: Cell 1 SOC = 70% and Cell 2 SOC = 75%

When the SOC of cell 2 is greater than the SOC of cell 1, the balancing algorithm takes the PWM pulses to the MOSFET M2 and MOSFET M1 is turned OFF. This forces the energy of cell 2 to drain through the transformer with pulsating DC in AC form is then transformed to the secondary windings. The secondary winding of the transformer is connected to a rectifier diode which converts this AC to DC and the energy is transferred back to the battery pack and enables the charging to the cell 1 at lower SOC level to rise. The graph of SOC during this operation is shown in figure 7. The PWM pulses used for triggering the flyback converter are shown in figure 8. The 5% SOC difference is balanced in 235 seconds which is same as that of the case a.

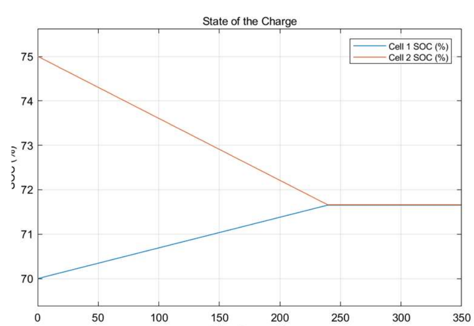

Figure 7: SOC of Cell 1 and Cell 2 during balancing operation (case a)

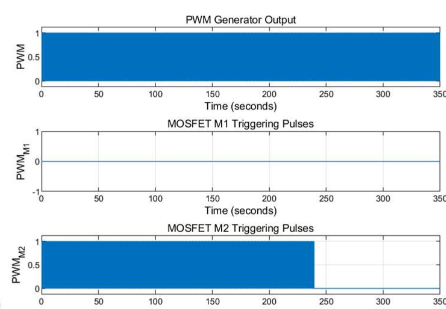

Figure 6: PWM Triggering pulses (Case a)

From the results of the cell balancing, it is seen that the time required for balancing the SOC of the cells depends upon the initial SOC values. In terms of the cell balancing speed, the speed of cell balancing is determined to be 47 seconds per percent of the SOC.

III. Conclusions

Flyback converter technology is a significant advancement in active cell balancing for battery management systems supporting cell to pack energy transfer and offers a flexible solutions for maintaining cell balance in series-connected battery packs. Key advantages include reduced component count, simplified control requirements and faster balancing compared to alternative methods. The cell balancing speed was found to be 47 seconds for every percentage of SOC imbalance. As battery technology becomes increasingly critical for electric vehicles, renewable energy storage and portable electronics, these balancing solutions will play an essential role in maximizing energy utilization and extending battery life while maintaining safety and reliability.

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