The application of flyback DC/DC converter in Li-ion batteries active balancing

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***Abstract*—The two major classifications of active cell balancing methods are charge shuttling and energy converting [1]. In this paper, flyback transformer is used as storage element to move energy from one cell to another. A multi-output flyback transformer DC/DC converter prototype is built and tested. The test batteries used in this study were 8Ah manganese lithium battery pack. Through experiment, the advantages and disadvantages of this method are compared and the improvement is proposed.**

Keywords- flyback transformer; active balance; efficiency

I. INTRODUCTION

The capacity of a single cell is insufficient to support a hybrid or electric vehicle. The voltage and the current are both too low. To increase the current capability, cells may be connected in parallel. Higher voltages can be achieved by connecting cells in series. Because a Lithium battery cannot be overcharged, there is no natural mechanism for cell equalization. The lack of a natural equalization method will result in unbalanced cells. Series connected lithium cells may experience overvoltage or undervoltage which can damage or shorten battery life. With a balancing circuit, the voltage for the affected cells can be driven back into a safe area. The conventional method is dissipative techniques which find the high cells in the pack, and discharge excess energy through a resistor. But the discharge current is too small (about 100mA) because of thermal management requirements. It may take several hours to balance. For large capacity batteries like 40Ah $LiFePO_4$, this method is useless. Meanwhile it wastes all the energy. The active balancing method is using storage element to move energy between cells. In this paper, the storage element is a flyback transformer. The transformer has two different sides: The primary side is connected to the complete battery stack. Every cell is connected to a secondary winding. If Battery2 (B2, take for an example, show as Figure.1) is monitored as the lowest voltage cell, turn on the corresponding secondary switch S2. The energy is stored in transform from the stack while the primary switch T is on and shifted into selected Battery 2(B2) while closed. So the cell B2 can be charged to the average. Switch T is control by high speed frequency PWM (Pulse Width Modulation).

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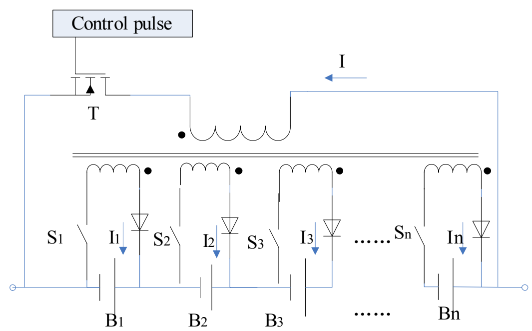

Figure 1. The structure of active balancing with multi-output flyback transformer

II. MULTI-OUTPUT FLYBACK CONVERTER

The equivalent circuit of flyback converter with RCD (resistor Rsn, capacitor Csn & diode Dsn) snubber is shown as Figure.3. Unlike mains transformers, a flyback transformer is designed not just to transfer energy, but also to store it for a significant fraction of the switching period. This is achieved by winding the coils on a ferrite core with an air gap. The air gap increases the reluctance of the magnetic circuit and therefore its capacity to store energy. When the main switch turns on, the energy is stored in the transformer as a flux form and is transferred to output during the main switch off-time. When the MOSFET turns off, a high-voltage spike occurs on the drain pin because of a resonance between the leakage inductor (L_{lk1}) of the main transformer and the output capacitor (C_{OSS}) of the MOSFET. The excessive voltage on the drain pin may lead to an avalanche breakdown and eventually damage the MOSFET. Therefore, it is necessary to add an additional circuit to clamp the voltage. Typical snubber and clamp circuits are shown in Figure.2.

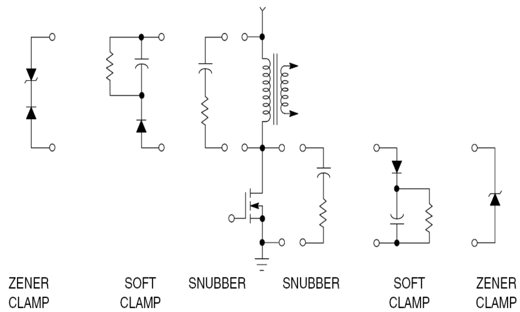

Figure 2. Common Methods for Controlling Voltage Spikes

The Soft clamp consists of a resistor, capacitor and diode. So it also called RCD snuber. This clamp circuit is low cost and widely used. The current in the leakage inductor can be RCD snubber circuit absorbed by turning on the snubber diode (Dsn) when Vds exceeds Vin+nVo.

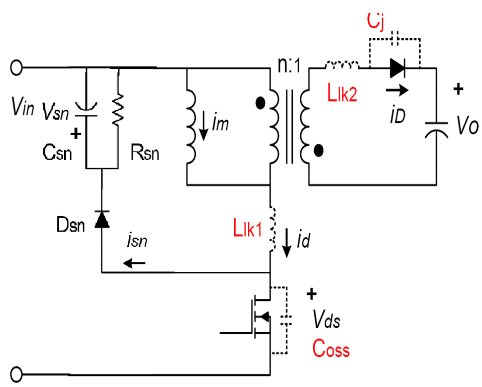

Figure 3. The equivalent circuit of single output flyback converter with RCD snubber

According to the analysis, an evaluation test board is designed shown as Figure.4. The prototype transformer has 12 outputs. Main parameters are:

- Switching frequency :55kHz
- Primary induction :45μH
- Transformer turns-ratio: 6
- Core type:EFD30

In order to facilitate testing, the main switch (MOSFET) is driven by the signal generator.

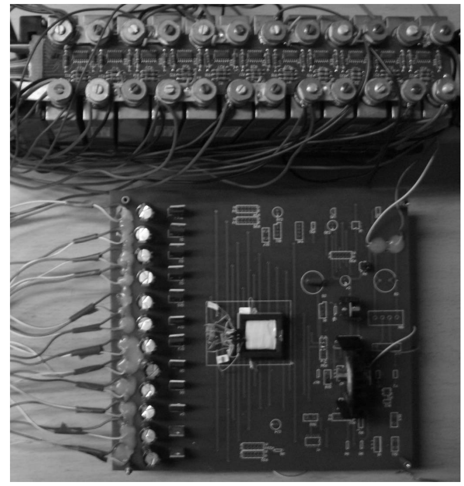

Figure 4. Evaluation test board and battery pack

III. EXPERIMENT

The test batteries used in this study were 8Ah manganese lithium battery pack (12 cells series). When the difference in voltage between any two cells exceeds the minimum cell differential for 10mV (defined by practical requirement), then cell balancing is activated. The minimum voltage cell is found and charged by 2 minutes using the converter. The average output current is as large as 1A. Then voltage of all the cells is checked again to find the cell differential and the lowest voltage cell. If the cell differential is still greater than the minimum cell differential, charge the lowest voltage cell. Repeat the above steps until the cell differential achieved the requirement.

Initially, the cell voltage differential of the batteries is 141mV. After 187 minutes balancing as the above balancing strategy, the cell differential was kept less than 10mV. Figure.4 shows the voltage changes of the 12 cells in balancing time.

Form the Figure.5, it is seen that the active balancing method can balance the differential cells in a relatively less time. For the balancing current 1A is as much as 10 times than passive resistor discharge method.

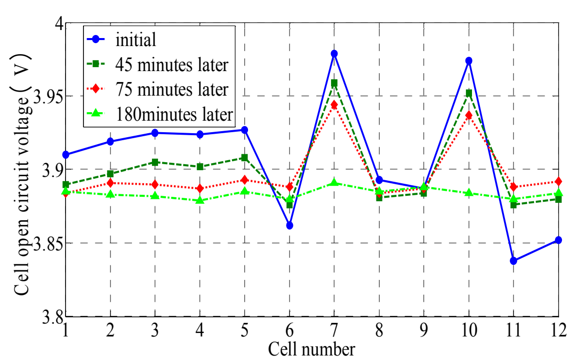

Figure 5. 12cells voltage after different balancing time

Figure.6 and Figure.7 are the key waveforms of the flyback converter with RCD snubber in DCM mode (discontinuous conduction mode operation). Measured waveforms are in good agreement with the expectations.

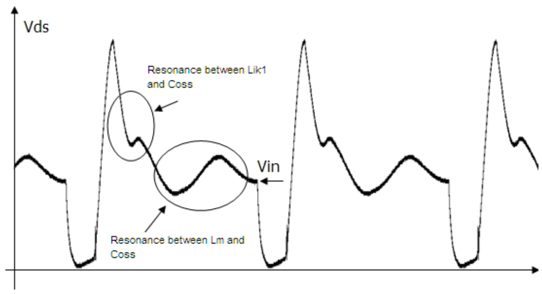

Figure 6. Voltage of main switch MOSFET Vds when transformer in DCM operation

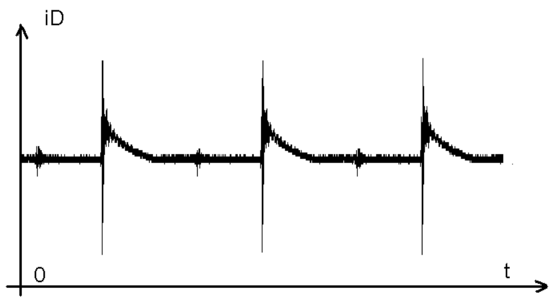

Figure 7. The output current iD when ransformer in DCM operation

IV. DISCUSSION AND IMPROVEMENT

Compare to conventional passive method, the active balancing method can rapidly balance low cells at the cost of removing energy from the entire pack. Disadvantages of this cell balancing method include complex magnetics and high parts count due to each secondary's rectifier [1].

In practical application, a lot of problems exist in the current evaluation board. The main problem is low efficiency. Also the transformer is too big. Here are some reasons: First, energy stored in the leakage inductance waste all in the snubber resistor of RCD circuit; secondary, the switch losses on the main switch (MOSFET) is large because of the high frequency; third, too much output windings lead to low convert efficiency between the magnetic and electric energy; forth, the loss on the secondary side rectifying diode is large. According to the above analysis, some improvements are proposed.

Compared to conventional hard-switched converters with fixed switching frequencies, the quasi-resonant converter (QRC) topology is a very attractive alternative. The increasing popularity of the QRC approach is based on its ability to reduce electromagnetic interference (EMI) while increasing power conversion efficiency. A resonant tank circuit has been added to the power switch section to make either the current or the voltage “ring” through a half a sinusoid waveform. Since a sinusoid starts at zero and ends at zero, the product of the voltage and current at the starting and ending points is zero, thus has no switching loss. There are two quasi-resonant methods: zero current switching (ZCS) or zero voltage switching (ZVS). ZCS is a fixed on-time, variable off-time method of control. ZCS starts from an initial condition where the power switch is off and there is no current flowing through the resonant inductor [4].

In magnetic design, there have been two distinct trends in power electronics systems. The first trend is to move continuously toward higher frequency in order to reduce the size of magnetic components. The second trend concerns the use of planar structures [6], with which much closer board spacing and lower profile can be achieved. Easier manufacturability due to the simpler conductor assembly methods makes planar structures prevailing in the power converter industry.

With these improvements, the next version will be high efficiency and small size.

V. CONCLUSION

In this paper, the active balancing method with flyback converter is carried out. A multi-output flyback DC/DC converter prototype is built and tested. The balancing effect in the experimental Li-ion batteries is obvious. Existent problems are analyzed. In order to improve the efficiency, the ZVS and planar transformer will be used in the next version.

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