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A NOVEL CHARGE AND DISCHARGE EQUALIZATION SCHEME FOR BATTERY STRINGS

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Abstract: A novel charge/discharge equalization scheme is proposed in this paper. According to the states of batteries, two equalizing methods are adopted for equalization during different charging and discharging phases. A switched capacitor is utilized during high rate charging and discharging. During the later period of charging and discharging, an auxiliary low power DC/DC converter and the inherent switch modules of a control/monitor unit are used. So it is very simple and efficient. With the developed equalizer, the lifetime of a series battery string can be extended.

Key words: charge, discharge, equalization, battery string
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INTRODUCTION

Series battery strings are widely utilized in many applications such as telecommunication power supplies, electric vehicles, uninterrupted power supplies and photovoltaic systems, etc. The lifetime of a battery is one of the major factors that limit the realization of an economical system. Deviation in chemical contents, operating temperature, and operating history of cells in a battery string lead to large non-uniformity in cell charge levels and correspondingly different cell terminal voltages during the charging period (Nasser et al., 1995). Some cells in a battery string may be fully charged before the overall battery terminal voltage reaches its nominal value. Continuous charging will lead to overcharging for these cells. As a result, series battery strings are prone to suffer reduced cycle lifetime and potential damage (Hang et al., 1993). On the other hand if the charging process is stopped when other cells are not fully charged, these undercharged cells may reverse polarity during deep discharge. In this case the capacity of the battery string will not be fully utilized. In other words, the weaker cells limit operations of the series battery string. Therefore, charge and discharge equalization is essential for series battery strings.

Different schemes and algorithms have been developed to achieve this task. One method uses bypass shunts to divert charging current around batteries with high terminal voltage (Bjork et al., 1986; Lindemark et al., 1986). Conceptually, it is equivalent to parallel connect a Zener diode to limit the voltage. As a result, the additional energy is being converted into additional losses in the shunt elements. With someone proposed method, many half-bridge converters are applied to divert charging current, but with an increase of the series cell number, the cost will increase. Another method proposed uses a set of multi-output power converters to send a charge selectively to the weaker cells, but design of the transformer with many secondary windings is rather difficult. A key limitation of all these methods is that they function only at the end of the charging process, after one battery is fully charged at least.

In this paper, a novel scheme is proposed (Fig.1), in which an improved switched-capacitor is used along with a low power output auxiliary DC/DC converter. In this proposed scheme, charge and discharge equalization can be achieved by using built-in switch modules. A control/monitor unit monitors the state of charge (SOC) of each cell and controls the equalizing action through the switch modules to maintain each cell at its optimal operating point, and extend battery lifetime.

PROPOSED CHARGE AND DISCHARGE EQUALIZATION SCHEME

As the terminal voltage of the battery varies due to the charge replenishment, especially during float charging and discharging, the SOC can be predicted from the terminal voltage. On the basis of this rule, different equalizing method can be adopted in different charging and discharging phases.

Fig. 1 shows a block diagram of the proposed charge and discharge equalization system consisting of a main AC/DC converter, an auxiliary DC/DC converter, switch modules, a voltage measurement unit, and a control/monitor unit.

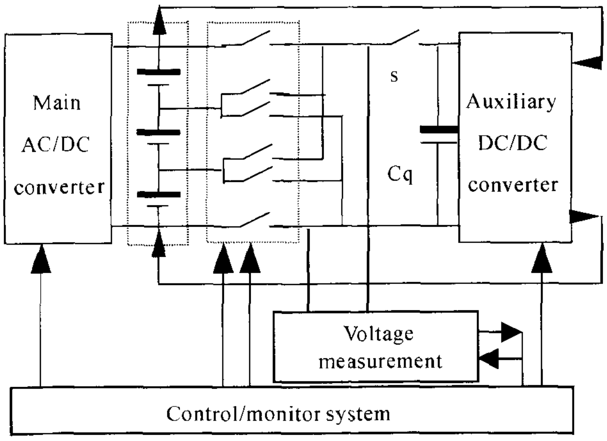

Fig. 1 Block diagram of the proposed system

In order to enhance the effect of equalization, different equalizing methods will be utilized in different charging and discharging phases. These different methods are summarized as following:

1 At start of charging—high rate charging phase

Fig. 2(a) shows the equivalent block diagram. During high rate charging, large current Ic charges all the cells in the series battery string. The main AC/DC converter supplies energy to the battery string, because of deviation in characteristics of the cells, the terminal voltages across different cells may be different. It is known that a few tens of millivolts of the terminal voltage imbalance among the cells will tend to alter the charge process. Therefore the equalization must be done periodically to avoid severe long time imbalance. A switched capacitor composed of a capacitor Cq and switch module serves as a key component for equalization.

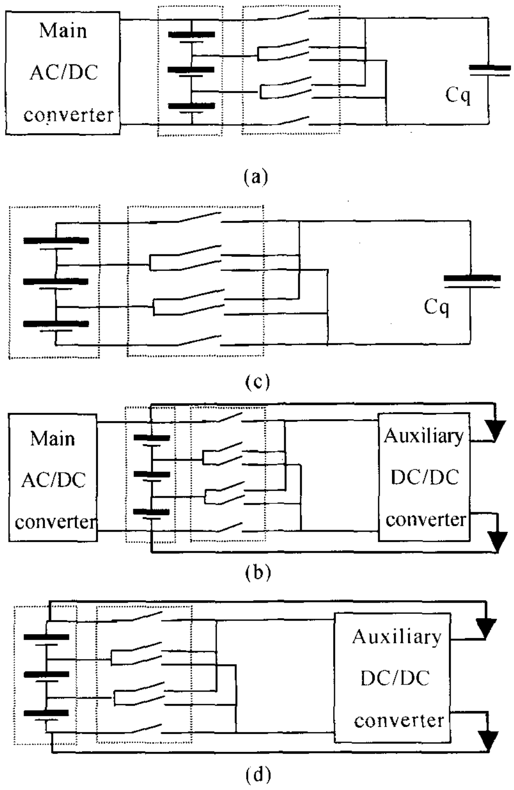

Fig. 2 The equivalent block diagram of the equalization system
(a) during high rate charging phase
(b) during later period of charging
(c) during high rate discharging phase
(d) during later period of discharging

During this period, the auxiliary DC/DC converter does not work, because the current supplied by the main AC/DC converter is much larger than that supplied by the auxiliary converter which has little influence on the equalization.

During equalization, every moment only one battery is connected to the capacitor Cq through two switches: one is connected to the positive terminal of the equalized cell and the other to the negative terminal. The switch modules are controlled by the control/monitor unit. If the terminal voltage of one cell is higher than of the capacitor Cq, the cell will be discharged and the capacitor will be charged. Contrarily the cell will be additionally charged by the capacitor. During one cycle of equalization, each cell will be sequentially connected to the capacitor and charges will be transferred from the cells with higher terminal voltage to ones with lower terminal voltage. After several cycles, each cell will reach identical terminal voltage.

If unit equalizing time equals t, there should be $N \times t$ that needed for one cycle for a battery string composed of N cells. So a suitable frequency has to be ensured.

2. Later period of charging

After the high charging rate phase, most of the cells are close to the state of full charge and the current supplied by the main charger must decrease to a lower level. But some cells may still need to be further charged. In this case the auxiliary DC/DC converter supplied by the main charger will take over this task, because it can supply much more energy to these under-charged cells. According to the different terminal voltage of each cell the auxiliary charger will charge at different charging rate, therefore, some cells with lower voltage will gain more energy from the auxiliary converter. The equivalent block diagram is shown in Fig.2 (b).

The switch modules controlled by the control/monitor unit act in the same way as previously described. Each cell is also connected to the auxiliary DC/DC converter through two switches sequentially. By this method every battery will reach its state of full charge respectively.

3. High rate discharging phase

During high rate discharging, the battery discharges a large current to supply energy to loads. Because of deviation in characteristics of cells again, the terminal voltage imbalance among series cells may also appear. In order to maintain identical terminal voltages of all cells all the time, the switched capacitor is also utilized for equalization. Because the battery string supplies all energy during discharging, the auxiliary DC/DC converter does not work either. The equivalent block diagram in this period is shown in Fig.2 (c).

Operation of the switched capacitor is the same as that during the high rate charging phase. What is different from before is that now cells having larger energy assist weaker cells to discharge.

4. Later period of discharging

During later period of discharging, the energy of the battery may tend to be exhausted. But some cells may still have much energy while some weaker cells are already exhausted. In order to utilize the energy fully, the auxiliary converter starts working. It will transfer charge from the better cells to the weaker cells, and weaker cells will obtain new discharge ability to avoid going into excessive deep discharge. The equivalent block diagram is shown in Fig.2 (d).

IMPLEMENTATION

The circuit of the auxiliary DC/DC converter is shown in Fig. 3. It is a double-switch forward topology. The output capacitor of the converter can be utilized as the switched capacitor for equalization.

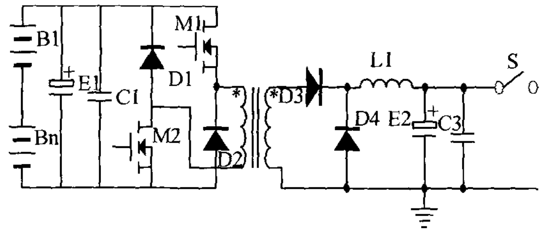

Fig.3 An auxiliary DC/DC converter

The switch modules are used for both equalization and voltage measurement. Current may flow through these switches in both directions. One switch circuit of the switch modules is shown in Fig.4. The actual circuit consisting of two switches that are connected to the positive and negative terminal of a cell respectively is shown in Fig.5(see next page).

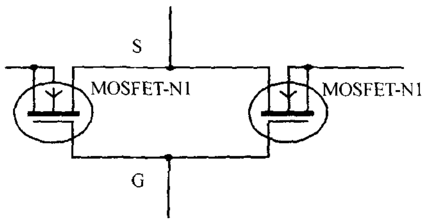

Fig.4 A two-directional switch

EXPERIMENTAL RESULT

In order to verify the performance of the proposed scheme, an auxiliary 20W/80kHz DC/DC

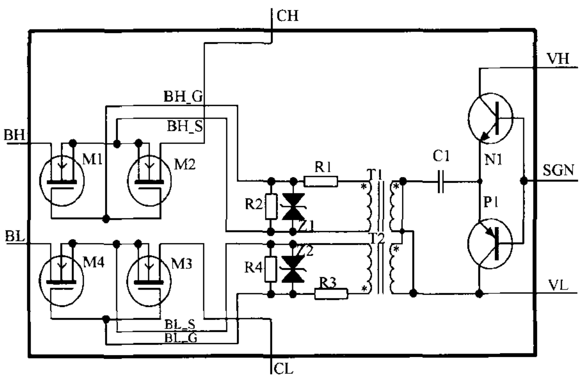

Fig.5 The actual circuit of two switches

converter, six switches comprised of a switch module and three 6v 4Ah/20h VRLA (Type: 6M4LC) cells were used in this experimental setup.

Fig.6 and Fig.7 show the terminal voltage of the cells in a series battery string during charging and discharging of series cells. From Fig.6 and Fig.7 it can be concluded that the equalizer works well all the time and improved the discharging ability of the weaker cells.

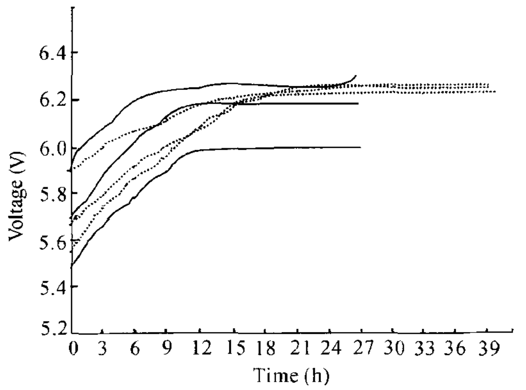

Fig.6 Terminal voltage of cells in a series battery string
— charging without equalizer
···· charging with equalizer

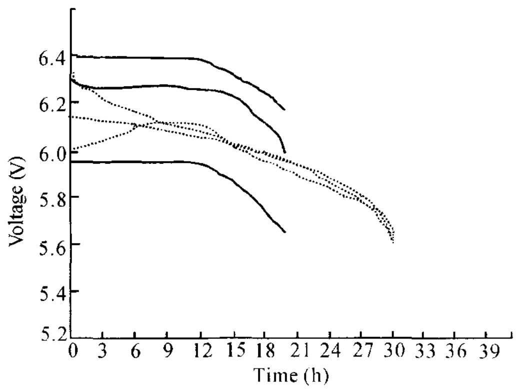

Fig.7 Terminal voltage of cells in a series battery string
— discharging without equalizer
···· discharging with equalizer

CONCLUSIONS

This paper presents a novel charge and discharge equalization scheme for series battery strings. According to the states of the batteries, different equalizing methods are adopted during different charging and discharging phases. In this proposed scheme, A switched capacitor is utilized for equalization during high rate charging and discharging phases, and an auxiliary DC/DC converter along with switch modules are employed to achieve equalization during the later period of charging and discharging. Only one auxiliary DC/DC converter with low power rating is added. The proposed equalizer uses the inherent switch modules of a control/monitor unit, which can be also used for voltage measurement. Experimental results verify the effectiveness of the proposed equalizer.

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