Low-cost AC-direct Battery Charger with Balancing Feature

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ABSTRACT

In BMS, the battery cell-balancer and charger are separated, which increases the cost, circuit volume, and control burden. In this paper, a low-cost AC-direct battery charger with balancing feature is proposed. By utilizing a switch-matrix and single current regulator with an AC-DC rectifier, battery cells are gradually balanced during the charging process. As a result, the circuit volume and complexity are reduced. The simulation shows that the battery cells are balanced within 1% SOC difference and all cells are fully charged at the end of the charging process.

Keywords: battery cell-balancing, integrated balancing, AC direct, off-line battery charger.

1. INTRODUCTION

In most battery applications, battery cells are connected in series to increase the voltage level of the DC bus. Due to the different characteristics among cells, a balancer is used to equalize the energy of cells and prevent over-charging or over-discharging. Usually, the battery balancer is separated, which increases the circuit volume and cost and limits the application of high efficiency balancing methods.

Various balancing methods that combine the cell balancing operation into the charging process have been introduced. In [1], a switch-matrix and two external balancers are utilized to equalize the energy of cells during the charging process. Meanwhile, a multi-port charger is used to individually charge the battery cells [2]. Besides, a switch-matrix and a flyback converter are used to transfer the energy from the high SOC cell to the low SOC-level cells in order to equalize the energy of cells [3]. All the conventional methods require complex external circuits for the cell balancing, which increases the cost, volume, and weight of the circuit.

To resolve that issue, this paper proposes a low-cost AC-direct battery charger with a balancing feature. The operation principle is described in section 2, simulation results are shown in section 3, and the conclusion is made in section 4.

2. PROPOSED METHOD

The proposed method includes a switch-matrix and a current regulator, which is shown in Fig. 1. A voltage sensor is used to measure the rectified AC line voltage, while every cell voltage is monitored by an MCU. To charge batteries, the current regulator is used to control the charging current. With the switch-matrix, the charger can be connected to any cell in the series string. Based on the measured AC voltage and the cell voltage, the MCU determines the switching decisions.

The theoretical waveform of the charging process is presented in Fig. 2 for the 4-cell battery string case, and Fig. 3 demonstrates the control flowchart of the charging strategy. One process cycle consists of 3 activation intervals and 4 rest intervals from t_0 to t_7 and can be classified into 7 modes of operation as Table 1. The operation procedure is described as the following:

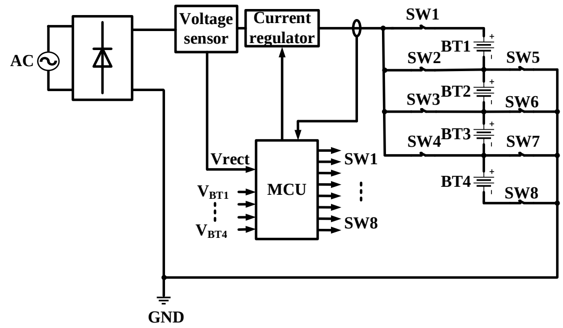


***Figure 1**: Proposed structure.*

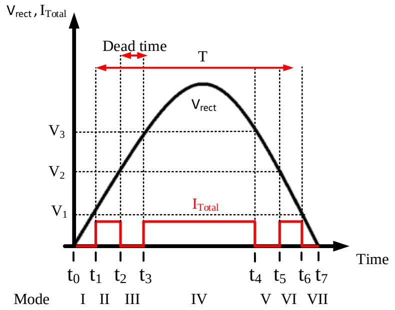


***Figure 2**: Theoretical waveforms of the proposed method following the rectified AC voltage.*

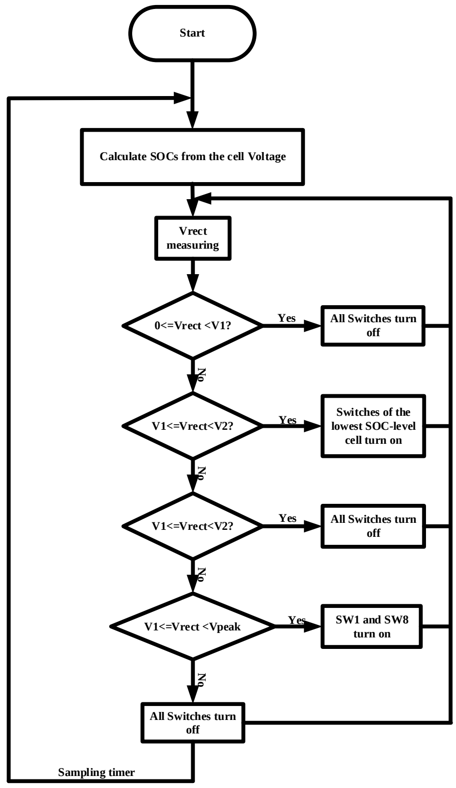
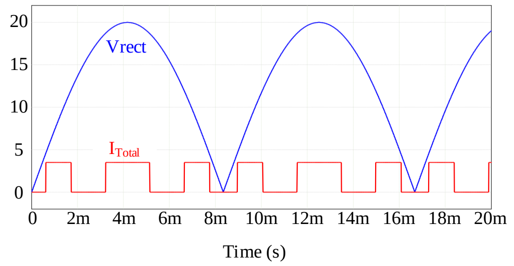
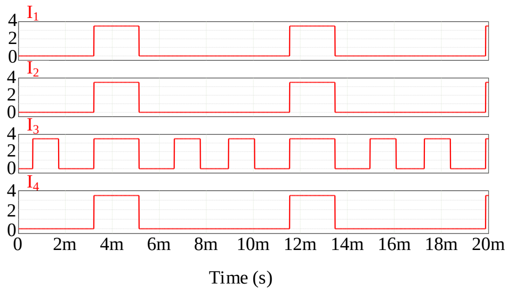


***Figure 3**: Control flowchart of charging strategy.*



(a)



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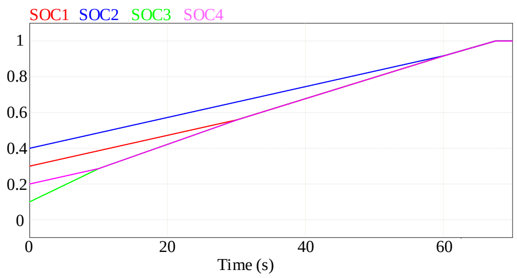

(c)

***Figure 4**: Simulation results: (a)* V_{rect} *and* I_{Total}*; (b) Cell currents; (c) Overall SOC profile for each cell.*

a. Mode I (t_0 – t_1, $0<=V_{rect}<V_1$): when the rectified line voltage V_{rect} is near the zero-crossing region, all the switches are turned off and no current flow into the batteries.

b. Mode II (t_1 – t_2, $V_1<=V_{rect}<V_2$): when the V_{rect} becomes larger than V_1, MCU turns on the switches for the lowest SOC-level cell. Besides, the current regulator regulates the total current avoiding high current overshoot from damaging the battery.

c. Mode III (t_2 – t_3, $V_2<=V_{rect}<V_3$): when the V_{rect} becomes larger than V_2 but less than V_3, the system returns to the rest mode, where all switches are turned off.

d. Mode IV (t_3 – t_4, $V_3<=V_{rect}<V_{peak}$): when the V_{rect} is larger than V_3, SW1 and SW8 are turned on, while the others are kept off. All battery cells are charged under current regulation.

e. Mode V and VI are similar to Mode III and II by symmetry. And all switches are turned off in Mode VII.

Such a pattern repeats according to cycles of AC line voltage. The threshold voltage (V_3) to start Mode IV is set equal to the voltage of the battery string. The operating period of Mode IV is maintained to speed up the charging process. In Mode II, only the minimum SOC cell needs to be charged to equalize it with the other higher SOC cells. In every rest mode (Mode I, III, V, IV), the battery has an interval to recover the steady-state voltage to increase the SOC measurement accuracy.

***TABLE 1:** MODE OF OPERATION*

Time Interval	*Vrect*	*State of switches*	I_{Total}	*Mode*
t_0~t_1	$[0, V_1)$	*All switches =0*	*0*	*I (Rest)*
t_1~t_2	$[V_1, V_2)$	SW_x *of* $SOC_{min}=1$*, others = 0*	I_{Total}	*II (Cell charging)*
t_2~t_3	$[V_2, V_3)$	*All switches =0*	*0*	*III (Rest)*
t_3~t_4	$[V_3, V_{PEAK})$	$SW_1=SW_8=1$*, others = 0*	I_{Total}	*IV (Series charging)*
t_4~t_5	$[V_2, V_3)$	*All switches =0*	*0*	*V (Rest)*
t_5~t_6	$[V_1, V_2)$	SW_x *of* $SOC_{min}=1$*, others = 0*	I_{Total}	*VI (Cell charging)*
t_6~t_7	$[0, V_1)$	*All switches =0*	*0*	*VII (Rest)*

3. SIMULATION RESULT

The simulation is implemented in PSIM for a battery string consisting of four 18650 (3.6V/ 2600mA) cells in series. For simplicity, the battery capacity is scaled down by 100 times, and the AC line voltage is set to 20V/60Hz. If the line input voltage is increased by 10 times, the number of cells should be proportionally increased.

The total current, cell current, and the rectified line voltage are shown in Fig. 4. The waveforms in Fig. 4(a) match well with seven modes of operation in Fig. 2. The current waveform of each cell is shown in Fig. 4(b). Cell #3 is charged in Mode II, IV, and VI; while cell #1, 2, 4 are only charged in Mode IV. The overall SOC profiles of the cells are illustrated in Fig. 4(c) where the SOC difference is equalized with 1% after 60 seconds and all cells are fully charged at the end of the charging process.

4. CONCLUSION

This paper proposes an AC-direct battery charging method. The proposed method selectively utilizes the AC voltage to simultaneously achieve charging and a balancing feature. With the 220V/60Hz AC line, we can charge the battery system with 45 cells in series. Since the proposed method requires only one current regulator and one MCU, the full-scale circuit will also have cost-effectiveness.

5. ACKNOWLEDGMENTS

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