Design of Overcharging Protection and Passive Balancing Circuits Using Dioda for Lithium-Ion Battery Management System

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***Abstract*— Currently, the type of battery that is widely used is a Lithium material battery. Lithium batteries have high power density than other materials, however lithium material is very toxic and dangerous, hence it requires special handling for operation. In this paper, a battery management system which can protect and do passive balancing of the battery from overcharging are carried out. The overcharging protection circuit is tested by monitoring the voltage and current values of each battery cell when it is charged, simultaneously. While the passive balancing circuit is conducted only by measuring the voltage value of each battery cell. Based on the measurements, the proposed circuit is able to protect from overcharging and to balance each battery cell at a voltage of 3.75 Volt with a charging current of 0.2 Ampere.**

Keywords— Overcharging Protection and Passive Balancing Circuits, Lithium-Ion Battery, Overcharging, Passive Balancing

I. Introduction

The use of electronic equipment on a mobile devices has been widely used today, for example on mobile phones, laptops, and even electric cars. The portable devices requires an electrical energy source compared to power outlets for operation. Hence, the electrical energy sources such as batteries or solar cells are very important. The reliability of solar cells is very limited because it requires continuous sunlight, so the use of batteries is more suitable.

The disadvantage of the lithium batteries is the greater potential hazard compared to the other types of batteries, because its material is a toxic and dangerous material for living things. In order to optimize the Lithium battery cells, i.e., operate safely, have good power capabilities, high cycles and long life; the battery should be managed properly.

Special handling for the lithium batteries in commercial use is commonly carried out using a battery management system (BMS) to protect the battery from overcharge, over-discharge, overcurrent, or overheat [1]. Hence, the battery cell is working under the optimum operating conditions of the Lithium-Ion battery.

The previous design of battery management circuits such as cell balancing circuits and overvoltage protection circuits have been developed in [2] and [3]. However, the cell protection circuit is designed with high complexity, large size and required microcontroller for operation. Therefore, in this study, the proposed circuits is designed with simple circuits using series three-cell Lithium-Ion batteries.

II. Proposed Circuits

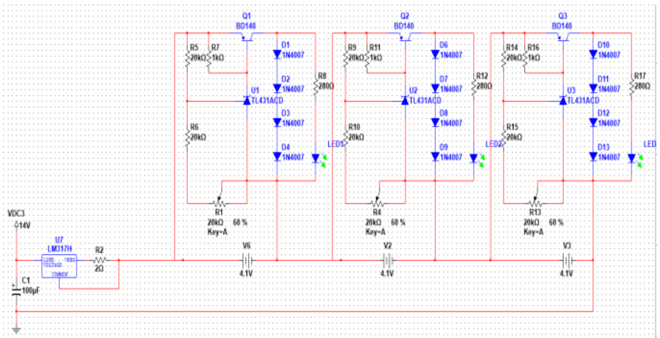

Fig. 1. Proposed overcharging protection and passive balancing circuits

Fig 1 shows the proposed circuit for overcharging protection and passive balancing for three-cells Lithium-Ion Batteries. The *LM317* is used to adjust the current entering the circuits. Since the maximum charging currents to the battery is 1.25/R2, the *R2* has to selected carefully. The zener diode of *TL431* is a switch which is closed when the reference voltage is 2.5 V. By using a voltage divider, the battery voltage value can be used as the input of *TL431*. The variable resistors *R1* is also used to allow the user to calibrate the maximum voltage of the battery.

The reference voltage on *TL431* can be set by varying the variable resistor resistance magnitude. By utilizing variable resistors, users are able to select the desired maximum voltage to prevent the battery from overcharging and increase the lifetime of the Lithium batteries. Based on the circuit configuration, the reference voltage on *TL431* is determined by,

$$V_{ref} = V_{cell} \times [(20\,k\Omega + R_{pot})/(20\,k\Omega + 20\,k\Omega + R_{pot})] \quad (1)$$

BJT *BD140* is used to connect the battery to the component dissipation i.e., diode. When the reference voltage of *TL431* is still below 2.5 volts, the emmiter base current cannot flow because *TL431* is switched-off and open circuit. Following the BJT working principle where the emmiter collector currents is controlled by the base emmiter current, hence the dissipation circuit does not dissipate power. Otherwise when *TL431* has been valued at 2.5 volts or more, the emmiter base currents flow and the emmiter collector currents can dissipate power towards the heat dissipation component i.e., four-parallel diodes. The dissipation circuits are also equipped with LED as an indicator for individual cells which are already fully charged.

III. MEASUREMENTS

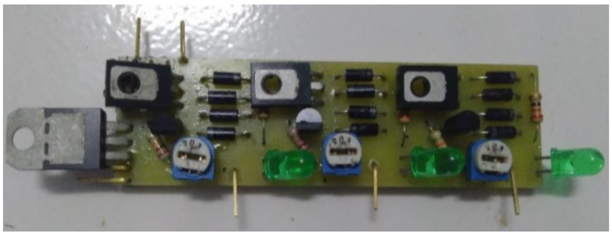

Fig. 2. PCB design of the proposed circuits

Fig 2 illustrates the realization of the proposed circuits in PCB. The proposed circuits control three units of Lithium 3.7 V batteries which are connected in series. The type of battery used is a type of Lithium 18650 battery that has a diameter of 18 mm and a length of 65 mm.

Fig 3 shows the measurement results of the charging battery voltage and current using proposed circuits. By using *R2* of 2 Ω, the charging current entering the circuit from the charger is 0.6 A. As shown in the Fig 3, the charging voltage of each battery cell does not stop at the desired voltage. Hence, we need to modify a proposed circuit by adding a parallel diode as dissipation components as well as modify the *R2*.

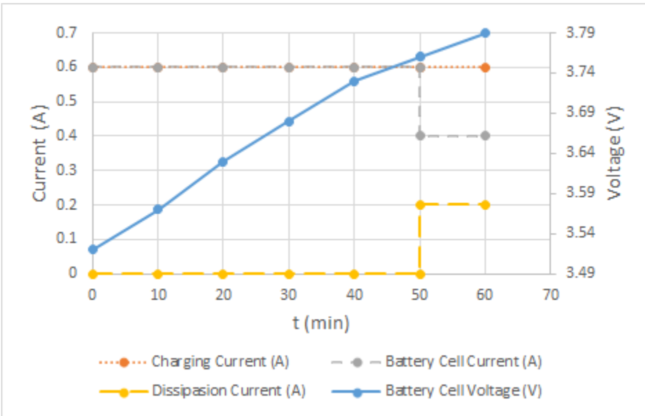

Fig. 3. Measurement results of proposed circuits

TABLE I. PARALLEL DIODE MODIFICATION

Parallel Diode	Dissipation current before the desired battery voltage of 3.75 V	Dissipation current after the desired battery voltage of 3.75 V
1	0 A	0.2 A
2	0 A	0.4 A
3	0 A	0.6 A

The addition of the number of parallel diodes can improve the ability of circuit dissipation so that the circuit is able to protect cells from overfilling as illustrated in Table I. In order to obtain 0.6 A of dissipation current, the triple parallel diode is required. However, the addition of the parallel diode as dissipation component produces enormous heat in the operation. Therefore, it is necessary to add a heat sink to remove heat, so that the size of the circuit becomes larger.

Since our research target is developed simple and compact circuits, we performed another modification by changing the *R2* value to control the charging current.

A. R2 of 10 Ω

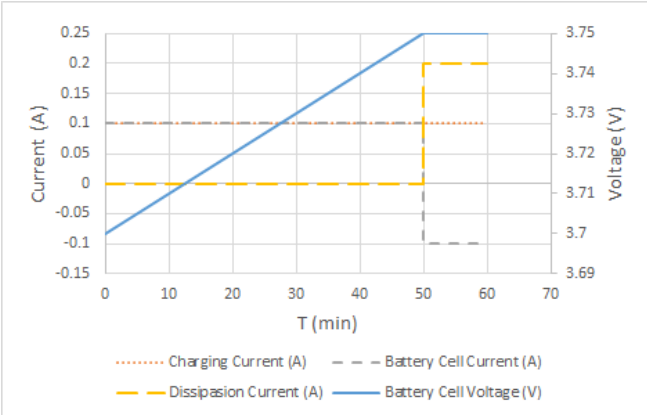

Fig. 4. Measurement of proposed circuits by modifying *R2* of 10 Ω

Modifying *R2* at 10 Ω is performed to limit the charging current to be 0.1 A. As depicted in Fig. 4, when the battery cell voltage has reached 3.75 V, the charging current of 0.1 A flows from the charger and the dissipation circuit dissipates a current of 0.2 A to the dissipation components as a heat. The voltage value of each battery cell will stop at the desired voltage.

B. R2 of 6 Ω

Since the charging current using R2 of 10 Ω is only 0.1 A, we conducted another modification to increase the charging current. The *R2* of 6 Ω is selected and evaluated to limit the charging current to be 0.2 A.

As illustrated in Fig. 5, the battery cell voltage will stop at 3.75 V as expected in the charging process. The dissipation circuit dissipates a current of 0.2 A into the dissipation components as a heat. In addition, when the battery cell has reached 3.75 V, the current flowing in a battery is 0 A. It means that, the proposed circuits is effective to protect the battery cells from the overcharging.

C. R2 of 4 Ω

The *R2* of 4 Ω is selected to obtain the charging current as 0.3 A. Fig. 6 shows the measurement of proposed circuits by modifying *R2* of 4 Ω. When the battery cell voltage has reached 3.75 V, the battery cell voltage continues to increase as charging continues. From the results, it is found that the dissipation circuit dissipates a current of 0.2 A to a heat and the remaining 0.1 A is still charging the battery.

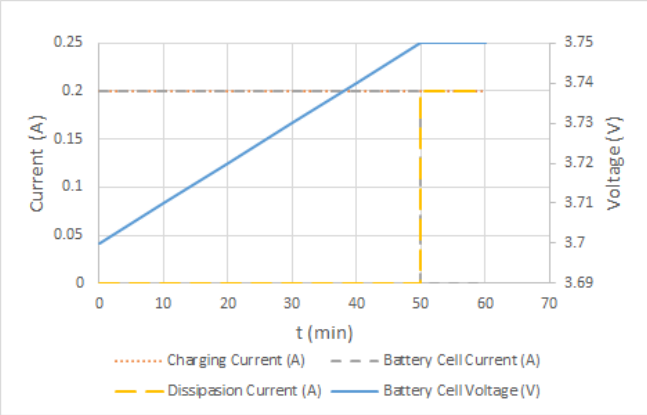

Fig. 5. Measurement of proposed circuits by modifying *R2* of 6 Ω

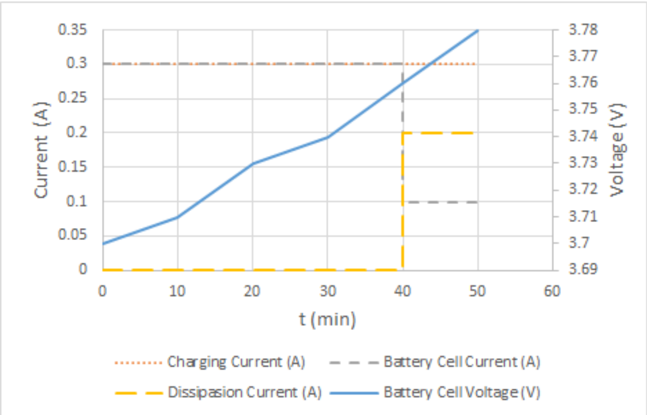

Fig. 6. Measurement of proposed circuits by modifying *R2* of 4 Ω

Based on three modifications, it was concluded that the proposed circuit was only able to dissipate a maximum current of 0.2 A. In order to work as an overcharging protection circuit, the optimal R2 value of the proposed circuit is 6 Ω.

In addition to protection circuit, the proposed circuits is also able to use as a passive balancing circuit for balancing the voltage values of each Lithium Ion cell. A calibration of the voltage balancing value is performed by using a potentiometer where each potentiometer is calibrated with the similar value. Therefore, the circuit can stop the charging current towards the battery when each battery cell reaches a value of 3.75 V by adjusting the potentiometer at a value of 20 kΩ. In order to evaluate the balancing battery cell voltage in the proposed circuits, the charging process is carried out with a charging current of 0.2 A. Then, the measurement of the voltage value will then be carried out on each cell against time as illustrated in Table II and Fig 7.

From the measurement as depicted in Table II and Fig 7, it is found that the voltage value of each battery cell increases when it is charged, and stop at the desired voltage of 3.75 V because the circuit diverts the charging current from the charger and battery to the dissipation circuit.

TABLE II. MEASUREMENT OF BALANCING BATTERY CELL VOLTAGE

t (hour)	Battery cell voltage 1 (V)	Battery cell voltage 2 (V)	Battery cell voltage 3 (V)
0	3.5	3.47	3.48
0.2	3.52	3.5	3.5
0.4	3.54	3.52	3.52
0.6	3.56	3.54	3.54
0.8	3.58	3.56	3.57
1	3.6	3.58	3.59
1.2	3.62	3.6	3.61
1.4	3.64	3.62	3.63
1.6	3.66	3.64	3.65
1.8	3.68	3.66	3.67
2	3.71	3.68	3.7
2.2	3.73	3.71	3.72
2.4	3.75	3.74	3.74
2.6	3.76	3.76	3.75
2.8	3.75	3.75	3.75
3	3.75	3.75	3.75

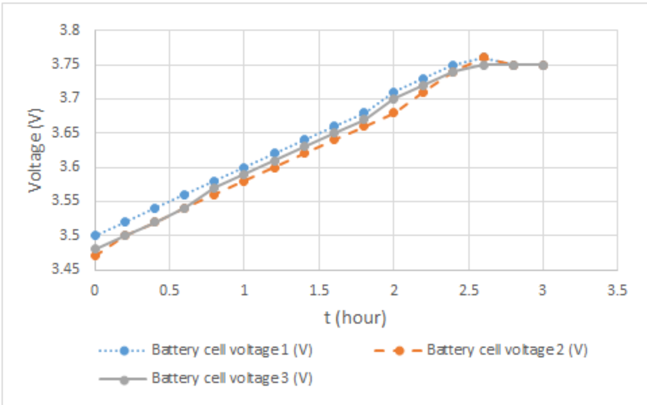

Fig. 7. Illustration of balancing battery cell voltage versus time

IV. CONCLUSION

Based on the measurement results, it can be concluded that the proposed circuit is able to protect the battery cell from overcharging and balancing the three-cell Lithium Ion batteries connected in series effectively. In addition, the optimum *R2* of the proposed circuits is 6 Ω to protect a series three-cells Lithium Ion battery with a charging current of 0.2 A. The proposed circuits is able to use in power banks or portable medical devices, where the number of circuits can be compared with the number of batteries needed.

Furthermore, in the device operation, the charging current will be completely dissipated into a heat when the battery has reached the regulated voltage. Ideally, the battery charging resource should be revoked when the LED is on so that no electrical energy is wasted. In the future works, the overcharging and passive balancing protection circuits will be developed which can overcome the waste of electricity when the LED indicator lights up.

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ACKNOWLEDGMENT

This publication is supported by "Hibah Publikasi Internasional Terindeks Tugas Akhir (HIBAH PITTA B)" Number NKB-0753/UN2.R3.1/HKP.05.00/2019 from Universitas Indonesia.