Analysis of effective pulse current charging method for lithium ion battery

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Abstract. Pulse charging methods has been developed as one of the fast charging methods for Lithium ion battery. This technique applies the continuous constant current pulse with certain pulse width until the battery fully charged. In this research, four Lithium polymer batteries of same type and capacity were used and subjected by several current pulses as a variable. The phenomenon of capacity loss as an effect of charging method was analysed every ten charge-discharge cycles. Four batteries were charged using constant current (1C) for 30 minutes to fill half of the total capacity, which then continued by pulse current of different pulse width in order to reach full capacity of each battery. Constant current charging for one hour was also applied to each battery as a comparison with that of pulse current charging data. The similar degradation patterns on battery capacity were observed. Nevertheless, the percentage of capacity loss is different. In conclusion, this method can be considered as one of the effective charging method, owing to the smallest capacity loss and shorter charging time.

1. Introduction
Recently, research on Lithium ion battery is one of the promising research field which attracts considerable attention due to its contribution for solving the issue of dependency on fossil fuels. Lithium ion battery provides superior advantages over other kind of rechargeable battery owing to its extremely large charge capacity for a given volume and weight. One of the challenging problems in lithium ion battery research field is battery charging which include of charger and charging technique for maximizing the battery capacity. All of battery user need the charger with short charging time or fast charging device and small capacity loss cell. Unfortunately, the conventional charging technique induces degradation of battery capacity when large of charging rate or high current value is used. The most widely used conventional charging technique for Lithium ion batteries is constant current – constant voltage (CC-CV) technique, where the charging current is kept constant until the specified voltage threshold in the CC phase, which is then continued with the constant charging voltage until the charging rate below a certain threshold CV phase [1,2]. Conventional charging technique uses high value constant current (CC) for charging the battery to specified voltage value and continues with constant voltage until the significant degradation current value occurs. This method is usually used in mobile device charger. However, the battery state of charge (SoC) cannot fully reached 100%, which is the main disadvantage of this method. On the contrary, the state of fully charged can be achieved when we apply constant current technique with small value of current (depends on the battery type). Multi step constant current charging is also used for shortening charging time and prolonging the cycle life of the battery[3]. Unfortunately, this technique can only be used for small charging current.
Development on charging techniques for lithium ion battery has been carried out by researchers who works in the field of Battery Management System (BMS). There are a several techniques for charging the lithium ion battery. Each technique gives different result, which depends on the battery type[4]. In general, the life cycle is strongly influenced by the value of charging and discharging currents. High charging current can deteriorate life cycle at every SoC. Research for determining the effect of different charging method on aging process of the battery has been done by Monem et al[5]. They used three techniques for charging the high power 7 Ah LiFePO$_4$ battery, i.e. constant current (CC), constant current – constant voltage (CC-CV) and constant current – constant voltage with negative pulse (CC-CVNP). The demonstrated that the CC-CVNP technique with low amplitude and fewest number of negative pulses is more effective than that of other techniques in reducing the concentrating resistance and the diffusion time constant.

Pulse charging is one of widely-used fast charging method for lithium ion battery. This technique is the powerful method for charging lithium ion, which can maximize the battery capacity. This technique is clearly different with that of conventional method for charging the lithium ion cell. The strong point of this technique lies on the utilization of certain value of current or voltage to charge the battery at the specified time (usually in second and minute order). The condition of fully charged can be indicated by the extent of voltage degradation when the charging is at the rest phase or count of charging pulse[6].

There are many researches and patents which develop the pulse charging technique and charger. One of these is US patent by Hagino which develop the charging method for rechargeable battery[7]. In that patent, the open circuit battery voltage was measured during periods of suspended charging and charging was resumed when the measured voltage drops below a specified voltage. When the period of suspended charging is longer than a specified time, open circuit battery voltage is compared to a minimum voltage. When the open circuit battery voltage is higher than the minimum voltage and the period of suspended charging is longer than the specified time, the battery is considered fully charged. When the open circuit battery voltage is less than the minimum voltage, even though the period of suspended charging is longer than the specified time, the battery is assumed to be removed from the system.

In this study, we investigate the role of charging current pulse widths and analyse the effect of these treatments to the capacity loss on the lithium ion battery after the pulse charging were done at several cycles.

2. Experiment
Four Lithium polymer batteries (marked as cell A, B, C, and cell D) were charged and discharged using Battery Analyser BST8-10A30V of MTI Corporation.

| Table 1. BTS8-10A30V Specification. |
|--------------------------------------|
| Item                                | Specification                        |
| Voltage measurement                 | Range: 0.03 – 30 V                   |
|                                     | Accuracy: +/- (0.1% of reading + 0.05% range) |
| Current measurement                | Range: 0.01 – 10 A                   |
|                                     | Accuracy: +/- (0.2% of reading + 0.1% of range) |
| Time range                          | 0 – 999 seconds                      |
| Cycle Measurement                  | 1 – 9999 times                       |
| Input Impedance                    | ≥ 10 mΩ                              |
| Channels                            | 8 Channels                           |
Battery analyser BST 8-10A30V specification in Table 1 is the suitable equipment for analysing the capacity of various battery types, such as pouch cell, cylindrical cell, and coin cell. It can also be used for small and big capacity cell, for research or industrial scale. It has an accurate measurement system, for both voltage and current. It can be used for long large cycle value. In this research, we used lithium polymer battery model PL-063048-10C, which is assembled by AA Portable Power Corp. All of the batteries was charged to the final voltage of 4.2 V with current of 10 mA using constant current – constant voltage technique and discharged to 2.75 V using 10 mA constant current technique to determine the capacity of the battery. All of the batteries were then charged using different technique. All of the batteries were charged using constant current technique at 1C for one hour and discharged in constant current methods at 1C. Cell A, B, C, and D were then charged using constant current of 1C for 30 minutes to fill half of their full capacity and then stopped for 1 minute. After stop condition, cell A was continuously charged and stopped again for 2 and 1 minutes, respectively, for 15 cycles, cell B was continuously charged and stopped again for 4 and 1 minutes, respectively, for 8 cycles, cell C was continuously charged and stopped again for 6 and 1 minutes, respectively, for 5 cycles, while cell D was continuously charged and stopped again for 8 and 1 minutes, respectively, for 4 cycles. All of the cells were charged at 1C constant current with different pulse width for about 30 minutes to fill the battery completely. Cell A, B, C, and D were then discharged at 1C using the same method for 50 cycles. The capacity loss were evaluated every 10 cycles and compared with constant current charge methods. The cell specification is presented in Table 2.

**Table 2. Polymer Lithium ion battery specification.**

| Item                  | Specifications          | Remark                              |
|----------------------|-------------------------|-------------------------------------|
| Nominal Capacity     | 750mAh±5%               | 0.2C5A discharge, 25°C              |
| Nominal Voltage      | 3.7V                    | Average Voltage at 0.2C5A discharge |
| Standard Charge Current | 0.2C₅A                | Working temperature: 0~40°C         |
| Max Charge Current   | 1C₅A                   | Working temperature: 0~40°C         |
| Charge cut-off Voltage | 4.2V                   | CC/CV                               |
| Discharge Current    | Continuously 10C₅A     | Working temperature: 0~60°C         |
| Discharge cut-off Voltage | 2.75V               |                                       |
| Cell Voltage         | 3.7-3.9V                | When leave factory                  |
| Impedance            | ≤40mΩ                   | AC 1KHz after 50% charge, 25°C      |
| Weight               | Approx 19g              |                                       |
| Storage temperature  | ≤1 month: -10~45°C      | Best 20±5°C for long-time Storage   |
|                      | ≤3 month: 0~30°C        |                                       |
|                      | ≤6 month: 20±5°C        |                                       |
| Storage humidity     | 65±20% RH              |                                       |

3. **Result and Discussion**

The effect of charging method on the capacity loss of four batteries were measured using two charging method, i.e. constant and pulse current charging. First, the capacity of batteries were measured using constant current – constant voltage (CC-CV) method at 10 mA. Since the average capacity was 700 mAh for all batteries, thus the 1C value was 700 mA. This value was then used as a charging and discharging current.
In order to evaluate the charging method, the batteries were charged using constant current charge and discharged using 1C rate value. This value was then compared with that of initial capacity value. Figure 1 shows the charge-discharge plot of the batteries at 1C rate using constant current method for 1 hour. CC charging method affects different SoC values, which are smaller than the initial SoC value, i.e. 629.8, 487.5, 607.4, and 473.6 mAh for cell A, B, C, and D.

Different technique to charge lithium ion battery was effect the different SoC value to the battery. Figure 1 shows that CC technique only affects the increase of cell voltage to the cut off voltage, yet, the SoC of the cells can only reach 89.9%, 69.64%, 86.77%, and 67.66% for cell A, B, C, and D, respectively. When pulse charging method was applied with variation of pulse width, the SoC values reached 97.1% for cell A, B, C, and D. Although CC charging was applied for one hour, not all of the lithium ions released from anode could reach cathode. Furthermore, this charging method increased the cell system entropy and temperature, which lead to the formation of gas bubbles within the battery.

Figure 1. CC charging graph used 1C for cell (a) A, (b) B, (c) C, and cell (d) D.
Figure 2 shows the effect of different pulse width on the cell capacity. Cell A, B, C, and D were charged using constant current of 1C for 30 minutes to fill the half of their full capacity, which were continued by the stop state for 1 minute. After stop condition, cell A were continuously charged and stopped for 2 and 1 minutes, respectively until 15 cycles. Cell B were continuously charged and stopped for 4 and 1 minutes, respectively until 8 cycles. Cell C were continuously charged and stopped for 6 and 1 minutes, respectively until 5 cycles. While, cell D were continuously charged and stopped for 8 and 1 minutes, respectively until 4 cycles. The difference between the pulse width of current charging and stop state lead to the difference of total charging time for each battery. In this research CC charging by 1C for 30 minutes to fill half of the cell maximum capacity, followed by recharging with 30 minutes total charging time, means that the total charging time is 1 hour at 1C charging rate so that the battery SoC is 100%. It is found that after discharging, the filled capacity was 680 mAh or 97.1% of the maximum capacity. These results indicate that pulse charging is more effective for maximizing the cell capacity and charging time. The smallest charging time is obtained for pulse charging using 8 minutes pulse width and 1 minute stop time.

Figure 3. Efficiency as cycle function for (a) A, (b) cell B, (c) cell C, (d) cell D.
Although using the same charging time, pulse charging has higher efficiency for transporting more lithium ion anode to cathode. Charge-discharge efficiency of all pulse charging patterns were not changed for 500 cycles, as shown in figure 3. Figure 2 and 3 (pulse current charging method) show that no capacity loss occur for all cells. On the contrary, CC technique with high charging rate generates the capacity loss for the battery.

4. Conclusion
In this paper, the effective pulse charging method for Lithium ion batteries is analysed. We analyse the effect of pulse width current to the charging efficiency of lithium ion battery and consider the capacity loss effect. The result shows that charging using 8 minute pulse width current is the effective method for charging the lithium ion cell since it can reduce the charging time and decrease the capacity loss of the cell.

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