Analysis of capacity fading effect on Lithium Cobalt cells caused by pulse current technique in fast charging methods

S Hafiz, S Arianto, R Y. Yunaningsih, N Majid and B Prihandoko
Lithium Battery Research Group, Research Center for Physics, Indonesian Institute of Sciences, Kawasan Puspiptek, Serpong, South Tangerang, Indonesia 15314

E-mail : sams012@lipi.go.id

Abstract. Charging a battery in a short time is important for portable devices. Many techniques have been developed to find out the proper method for fast charging. One of those techniques that has been patented in several fast charging methods is pulse current technique. This technique implements pulse current with adjusting pulse wide and voltage threshold in a certain values. In this paper, the capacity fading effects caused by the current pulse in lithium cobalt cells were investigated. The experiment was done by applying pulse current at high-level SOC to charge four cylindrical lithium cobalt cells. The Capacity of each cell was checked every 50 charge-discharge cycles. The experiment result shows that the changing capacity in each cell forms patterns alike. As if there was a slight increment on their capacities at first checking but rapidly decreasing at the next check. Then, their capacities continue to decrease slowly but the more often the charge-discharge cycling, the battery lifetime decreased. This research has provided analysis of pulse current effect on lithium cobalt capacity fading that should be noted as a reference in applying current pulse for fast charging methods.

1. Introduction
Fast charging is important in several lithium ion applications. The term of quick charge is commonly used in smartphone technology. A smartphone with built-in quick charge systems makes charging time shorter than conventional charging. In electric vehicle applications, users expect that the car can be charged in a short time.

There are many charging protocols which have been proposed that can be applied for fast charging, namely Single C-rate, Multi C-rate and Pulse Charging. Single C-rate applies a certain high constant current for charging until the target voltage of the cell is reached. Then the cell voltage is kept constant until the minimum charging current reached. Multi C-rate applies two or more high constant C-rate for charging [1]. And the last is Pulse Charging that applies a certain frequency and amplitude pulse currents or voltages for charging.

Pulse charging is one of the most widely developed charging methods for fast charging. Several researchers implemented fixed charge-discharge pulse frequencies and the others implemented varied charge-discharge pulse frequencies. Chen L R et al. claimed that varied charge-discharge pulse frequency technique gives better charging performance than conventional fixed frequencies [2]. The others only implemented charge pulse without discharge pulse, Keskin N and Liu H replaced discharge pulse phase by a short periods rest phase in their charging technique [3].
There are many analyses of pulse charging impacts to lithium-ion batteries. Several researchers revealed the relation of pulse charging to lithium chemistry behavior inside the cell and claimed that pulse charging is helpful in eliminating concentration polarization, increasing the power transfer rate, and lowering charge time [4]. Chiasserini et al. and Di Yin et al. claimed that the use of a pulse discharge profile with carefully selected amplitudes and rest periods can increase both specific energy and specific power of the cell. Furthermore, Despic A R et al. studies indicated that pulsing the potential of the electrode enables a control of the thickness of the equivalent diffusion layer and hence limits the concentration over-potentials [7]. There were also other researchers that had revealed pulse charging impacts to lithium-ion batteries by simulation and validated it to experimental test analysis [8]. Most of them agreed that pulse charging protocol has a positive impact to fast charging.

Temperature increment of cells becomes one of main concerns in lithium-ion cell application. Implementing fast charging usually causes a higher temperature beyond in standard charging. The temperature increment rates of cells vary based on lithium-ion chemistries. Cobalt base lithium-ion cell is one of poor thermal stability but offers higher electrochemical performance compared to other base-materials. Its temperature rises quicker compared to other chemistry base cells in a same charge-discharge procedure [9]. All of those literatures have not revealed undesirable battery states affected by pulse charging implementation. In this paper, we present several unwanted battery state possibilities affected by pulse charging implementation.

2. Experimental
Four LCO (cobalt-base lithium ion cells) commercial cells with a code “CGR17500” from Panasonic were used to test pulse charging implementation impact in low level SOC and high level SOC of lithium ion cells. Based on the datasheet, the cells have 830 mAh capacities in fresh condition and 2.5 to 4.2 Volt range operation of charge-discharge. In this test, all cells were in first use (not second use) but were more than 3 years old. Therefore, all cells need to be initiated because their properties were not like in the datasheet. First, the capacity of each cell was checked by a same charge-discharge procedure. The charge-discharge procedure was a CC-CV charging with 200 mA constant current, 4.2 Volt constant voltage and 50 mA cut-off current. The voltage characteristic of the cells and initial capacity of each cell are shown in figures 1(a) and 1(b), respectively.

![Figure 1](image)

**Figure 1.** Verification of (a) the voltage characteristic and (b) initial capacity of each cell.

In accordance with cell datasheet, the safe operating area (SOA) of the cell is ranging between 2.5 and 4.2 Volt. Therefore, the maximum high level voltage (HVL) of the cell is 4.2 Volt. In this experiment, pulse charging test was carried out by taking high current charge-discharge with various frequencies. In the settings, cell voltage was kept below 4.2 Volt and pulse charging current was set 2000 mA at maximum.
In the present study, 16 Channel Battery Analyzer BTS8-16-10V2A-IR as programmable charge–discharge device and its software KTBS93en were utilized to record voltage (V) and current (I) data. Digital IC DS18B20 and Arduino as a data logger were utilized in order to capture temperatures.

The first test was implementing pulse charging with low frequency (0.03 Hz) at high level SOC. This test was intended to investigate undesirable battery state possibilities at high level SOC in terms of voltage response and rising temperature. Before pulse charging current was applied, all cells were fully charged in normal CC-CV with a constant current 500 mA and a cut-off current 40 mA. After that, all cells were discharged 10 minutes by 1C-rate current, and then pulse charging is applied after rest for 30 minutes. The test procedure is illustrated by flowchart in figure 2(a).

The second test was intended to investigate undesirable possibilities at higher level SOC affected by pulse charging implementation. The test procedure was similar with the first test but only different in its pulse frequencies. Where the pulse frequency was set by 1 Hz and the discharge time period was shortened to 10 minutes. The test procedure is illustrated in figure 2(b).

The third test was intended to investigate fading capacity effects of pulse charging implementation at high level SOC. The procedure is similar with the first test, but only added looping procedure at pulse charging step. The total capacity of each cell was checked every 50 cycles. One cycle has two steps which are discharge 10 minutes and pulse charge steps. The procedure is illustrated in figure 3.

---

**Figure 2.** Flowcharts of the experimental procedure of (a) first test and (b) second test.

**Figure 3.** Flowcharts of the experimental procedure of third test.
3. Result and Discussion

3.1. Voltage responses
Control of pulse charging is not easy. As shown in figures 4(a) and 4(b), the voltage of both procedures were set not to exceed 4.2 Volt. But the voltage responses exceeded the maximum of preset voltage value (4.2 Volt). For the low-frequency pulses illustrated in figure 4(a), its response voltage is still in tolerable limits, whereas the high-frequency pulse described in figure 4(b) shows that its voltage response reached too far from safe limit values and even exceeded 5 Volt. This condition is quite risky and if allowed continuously, it could damage the batteries.

![Figure 4](image)

**Figure 4.** Voltage responses of all cells by (a) low frequency pulse and (b) high frequency pulse.

3.2. Rising temperatures
Implementation of fast charging technique usually causes an increasing temperature higher than in standard charging. Lithium cobalt is a battery type that has poorer thermal properties than other types like phosphate based lithium-ion [9]. Its temperature changes rapidly. 10 minutes of pulse charging periods was enough to make its temperature rose 10 °C higher relative to the room temperature. As shown in figures 5(a) and 5(b), the red marked step 3 below is 10 minutes pulse charging step that causes their temperatures change rapidly. The low frequency of pulse implementation caused the increment of cell temperatures to be higher than the implementation of frequency pulse.

![Figure 5](image)

**Figure 5.** Temperature increment of pulse charge-discharge of step 3 (a) using 1 Hz and (b) using 0.5 Hz relative to the room temperature.
3.3. Capacity fade
Fading capacity caused by the implementation of pulse charging on the high level of SOC on each cell is rather unique, at the first 50 cycles checking, their capacities increased whereas after 100 cycles, their capacities declined continuously in significant values. Only in 450 cycles, the capacity of one cell (cell B) has reduced to less than half of its initial capacity. As shown in figure 6, the implementation of pulse charging is not always going to cause decreasing capacity dramatically; it depends heavily on how well the cell was fabricated.

![Figure 6](image-url) Fading capacity of cells caused by pulse charging implementation.

4. Conclusion
The implementation of pulse charging technique as an alternative of fast charging method is not always profitable. If the selection of pulse charging pattern is not appropriate to the type of batteries, it could damage the batteries. Excessive temperature increment and rapid capacity fade are the impacts. Implementation of pulse charging at high level SOC is improper technique, as it tends to cause uncontrollable over-voltage of the lithium ion batteries.

References
[1]. Awwad R, Ripan D, Arabi T and Hajj H 2012 Int. Conf. on Energy Aware Computing (USA: IEEE) p 1
[2]. Chen L R 2009 IEEE T. Ind. Electron. 56 480
[3]. Keskin N and Liu H 2014 IEEE Wireless Power Trans. 24 44
[4]. Li J, Murphy E, Winnick J and Kohl P A 2001 J. Power Sources 102 302
[5]. Chiasserini C F and Rao R R 1999 IEEE Wireless Communications and Networking Conf. (Cat. No. 99TH8466) vol 2 (USA: IEEE) p 636
[6]. Yin M D, Youn J, Park D and Cho J 2015 Ninth Int. Conf. on Frontier of Computer Science and Technology (FCST 2015) (USA: IEEE) p 40
[7]. Despic A R and Popov K I 2002 J. Appl. Electrochem. 1 275
[8]. De Jongh P E and Notten P H L 2002 Sol. State Ion. 148 259
[9]. Nguyen J and Taylor C 2004 Annual Int. Telecommunications Energy Conf. (USA: IEEE) p 146