

An Experimental Survey of Li-Ion Battery Charging Methods

Abdullah AL-Refai and Osamah Rawashdeh
Oakland University

Rami Abousleiman
Fiat Chrysler Automobiles

ABSTRACT

Lithium-Ion batteries are the standard portable power solution to many consumers and industrial applications. These batteries are commonly used in laptop computers, heavy duty devices, unmanned vehicles, electric and hybrid vehicles, cell phones, and many other applications. Charging these batteries is a delicate process because it depends on numerous factors such as temperature, cell capacity, and, most importantly, the power and energy limits of the battery cells. Charging capacity, charging time and battery pack temperature variations are highly dependent on the charging method used. These three factors can be of special importance in applications with strict charging time requirements or with limited thermal management capabilities. In this paper, three common charging methods are experimentally studied and analyzed. Constant-current constant-voltage, the time pulsed charging method, and the multistage constant current charging methods were considered. Charge capacity, charge time and temperature variations vary based on the selected charging method. These variations are compared and contrasted. The presented results help engineers to better choose a more suitable charging method based on the design requirements and the system constraints that they are facing.

CITATION: AL-Refai, A., Rawashdeh, O., and Abousleiman, R., "An Experimental Survey of Li-Ion Battery Charging Methods," *SAE Int. J. Alt. Power*. 5(1):2016, doi:10.4271/2015-01-9145.

INTRODUCTION

Lithium-Ion (Li-Ion) batteries have become the rational selection for many portable applications that require onboard energy storage unit(s). Applications range from power tools such as construction drills, toys such as radio controlled planes and cars to military applications such as unmanned aerial vehicles. Hybrid and electric vehicles depend heavily on lithium-ion batteries. More recently Li-Ion batteries are being used by aerospace industries as in the Boeing 787 Dreamliner [1, 2, 3, 4, 9]. Their popularity is due to the fact that these batteries possess high energy density, slow self-discharge rates, and high nominal cell voltage.

One of the major drawbacks of Li-Ion batteries is the precautions that must always be taken when charging and discharging these batteries. Exceeding the current, voltage, or power thresholds might result in damaging the battery cells and causing a dangerous thermal runaway state [5, 6, 7, 8, 10].

Li-Ion batteries can be charged using different charging methods. Some methods lead to high charging capacity while others lead to shorter charging times. Based on the desired application, charging needs, and expected life usage of the battery, manufacturers might use different or sometimes proprietary charging methods. In this paper, we present a custom setup for a Li-Ion battery charger with a dynamic intelligent controller that uses National Instruments Data Acquisition (NI-DAQ) system. This developed system is controlled

by an algorithm that is implemented using Mathworks' Simulink model. This setup is used to experimentally study three different charging techniques for a 3-cell lithium ion battery. We compare and contrast charge time completion, charge capacity, and temperature variations for the three presented methods. The presented results help designers and engineers to select the appropriate charging method that best fits their specific application.

This paper is structured as follows: in the next section, we will overview Li-Ion batteries, followed by the test setup, and a brief discussion on the different Li-Ion battery charging methods. Experimental results and discussions will then be presented before ending the paper with an analysis and a conclusion.

LITHIUM-ION BATTERIES

Li-Ion batteries have numerous advantages over other battery chemistries that are currently used in the market. For example, Li-Ion batteries can store up to three times the amount of energy than Ni-Cd batteries of the same volume and weight. Li-Ion batteries also have low self-discharge rates and long shelf lives [11, 12, 13, 14, 15, 16, 17, 18, 19]. It should be also noted that the nominal voltage of a Li-Ion cell is 3.7 V. This is more than three times the nominal voltage of nickel based cells, which have a nominal voltage of about 1.2 V. Furthermore, the typical internal resistance of a Li-Ion battery is much higher to that of a Ni-Cd, which could be compared at 100 mΩ for Li-Ion and 5 mΩ to 20 mΩ for Ni-Cd. This makes Li-Ion batteries even more suitable for

low energy operations [20]. Li-Ion batteries need to be charged in a distinct way to make sure that the current, voltage, temperature, power, and energy limits are never crossed. In the next section, the experimental setup is presented and then some of the most common Li-Ion charging methods are analyzed and discussed.

EXPERIMENTAL SETUP

In previous works [21, 22, 23, 24, 25] we used Mathworks Simulink, National Instruments Data Acquisition's (NI-DAQ) D/A and A/D converters, and an Operational Amplifier (Op-Amp) based current source circuit to present a programmable charger that allowed the implementation and testing of different charging methods for multi-cell Li-Ion batteries. Fig 1 shows the high level system design of the charging system. Fig 2 shows the Op-Amp current source circuit. For more information on this implementation refer to reference [21].

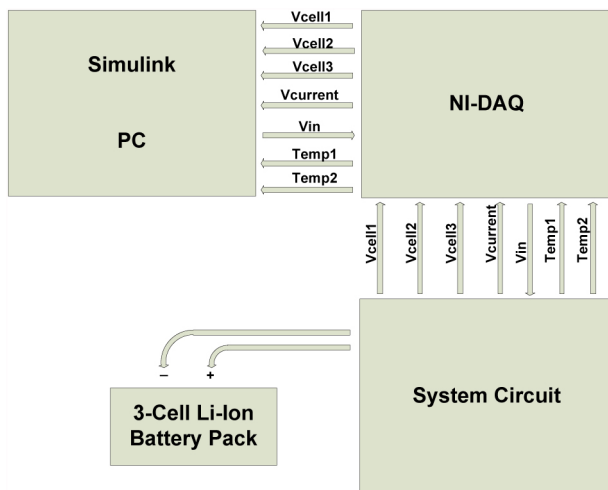


Figure 1. High level system design.

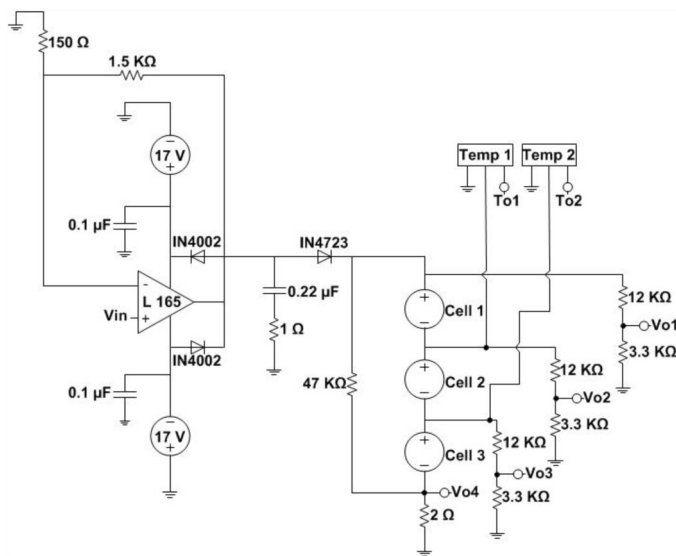


Figure 2. Op-Amp based current source circuit.

In our experiment, 3-cell 0.8 Ah LiCoO₂ battery was used. Using the A/D converter capabilities of the NI-DAQ; we were able to monitor voltage, current, and temperature variations of the battery in a Simulink environment. The next sections will discuss the 3 different charging methods, experimental results, and analysis.

LI-ION BATTERY CHARGING METHODS

There are numerous methods to charge Li-Ion batteries. These methods change depending on several factors such as: charging capacity, charging time, and cell temperature variations. Analyzing each factor can help choose the most suitable charging method that will satisfy design requirements. Furthermore, there are many boundaries that must be considered to avoid damaging the cells. These boundaries are mainly the cell voltage and the cell temperature. The minimum and maximum cell voltages are 2.8V and 4.2V, respectively. The cell charge temperature needs to be between 0°C to 45°C (32°F to 113°F) [22-23]. The next sections will describe the 3 different methods used in this work.

A. Constant Current-Constant Voltage Charging Method

The Constant Current-Constant Voltage Charging (CC-CV) method is the most typical approach that is generally applied to Li-Ion batteries. The main idea behind this approach is that the charging logic, as the name suggests, is divided into two phases, a constant current phase followed by a constant voltage phase (Fig. 3(a) and 3(b)).

Charging starts with the constant current phase. The maximum constant charging current might be of any value as long as it does not exceed the boundaries set by the battery manufacturer. A charging rate between 0.25C to 1.0C is recommended. The CC-CV method was tested using 1C, 0.81C, 0.63C and 0.44C, respectively, where C is defined as the charging rate of the battery. For example a charging rate of 0.25C will charge the battery in 4 hours (1/0.25) given 100% battery charging efficiency.

In the constant current phase, the battery is charged with constant current. The cell voltage starts to rise with time until it reaches the maximum value (i.e., 4.2 V). Once this occurs the constant voltage phase is initiated [22-23]. In this phase the target is to keep the cell voltage around 4.2 V. Typically, a proportional-integral-derivative (PID) controller is applied on the charging current to keep the voltage at the target set point. Fig 3 (a) shows the CC-CV method current profile and Fig 3 (b) shows the expected rise of the cell voltage with time. Charging is terminated when the battery current reaches a predefined level (generally set from 3% to 10% of the maximum charging current level) [24-25].

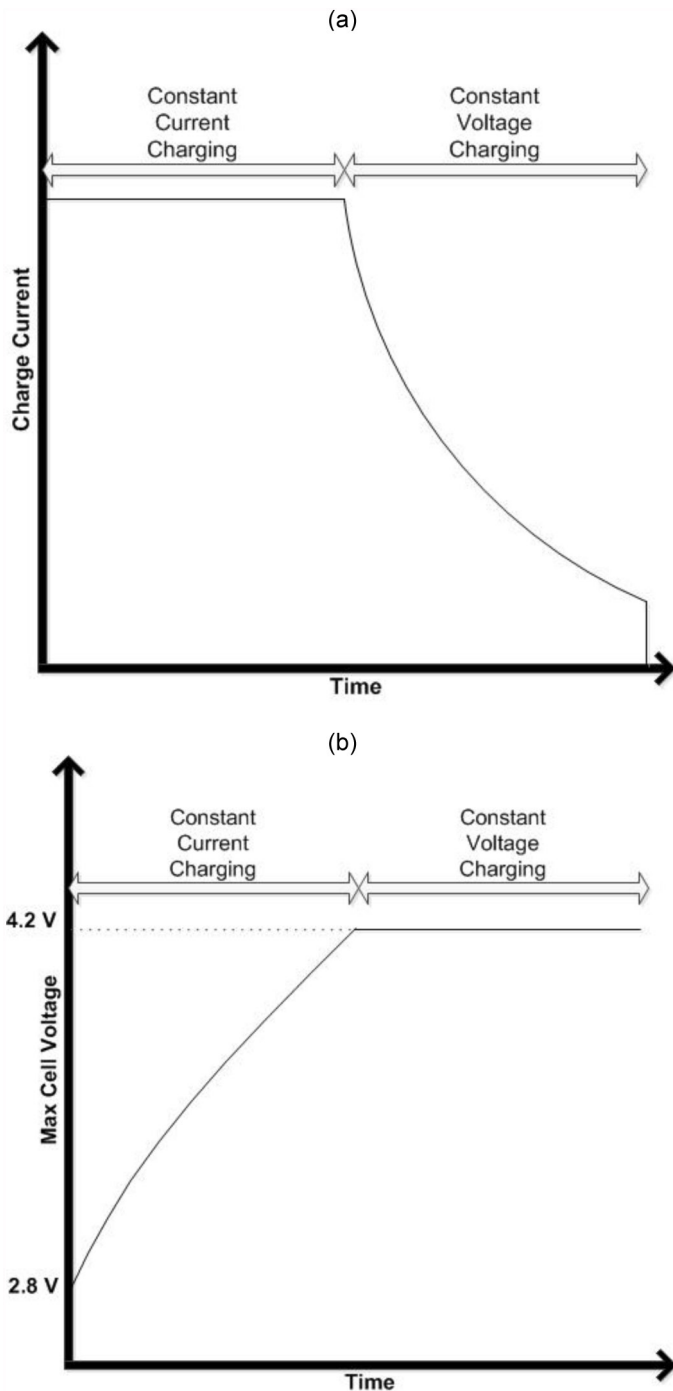


Figure 3. a) Typical CC-CV charging current profile of the Li-Ion cell. b) Typical cell voltage increase of the Li-Ion cell.

B. Time Pulsed Charging Method

In the Time Pulsed Charging (TPC) method, charging current is forced into the battery in pulses leaving zero current gaps. This allows the battery cells to have short periods of relaxation time that permit stabilization. There is no recommended frequency for the pulsed current. Some of the smartphone chargers use the TPC method. We tested various smartphone chargers and found that they used around 55 seconds charge time and 5 seconds rest time.

Accordingly, in our TPC method experiment, current was switched

ON for 55 seconds and OFF for 5 seconds. This cycle was repeated until charging was completed [26]. The same terminating condition as the CC-CV method was applied.

Fig 4 (a) shows the TPC charging method current profile and Fig 4 (b) shows the TPC charging method voltage profile.

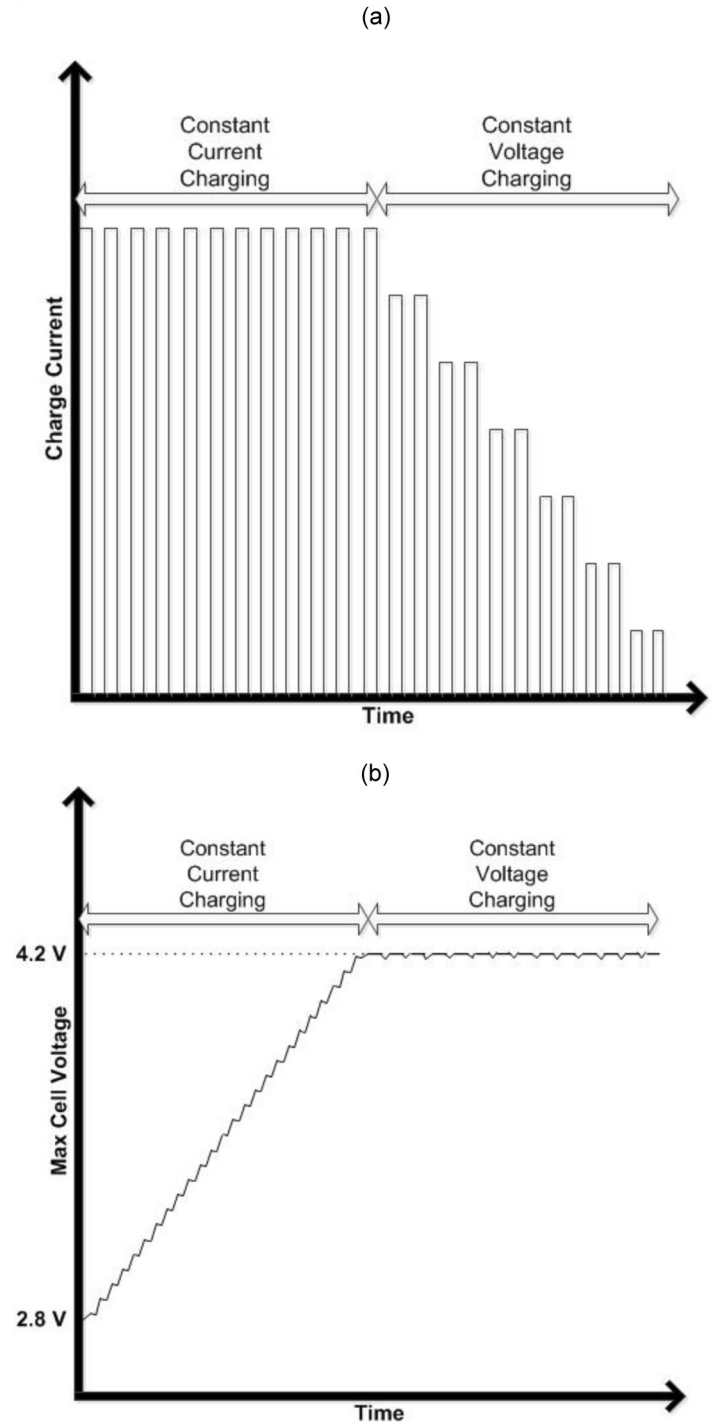


Figure 4. a) TPC charging current profile of the Li-Ion cell. b) TPC charging voltage profile of the Li-Ion cell.