FAST CHARGING STRATEGY FOR LITHIUM ION BATTERY

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Abstract

In this paper, an advanced charging strategy for improving the charging performance of the Li-ion polymer battery is proposed, which is based on the battery characteristic. Simulation results show that the proposed charging current pattern can improve the charging speed of battery in comparison with the standard CC-CV (constant current - constant voltage) charging strategy and the pulse-charging strategy.

1. Introduction

Due to the development of portable electronics, the power source for these devices, which is a rechargeable battery, has received a lot of attention. Lithium batteries have many advantages over other types such as high power density, long life-cycle, and no memory effect. So, they are one of the most popular rechargeable batteries these days.

The most substantial issue in battery management systems is a battery charging [1]. The conventional charging methods include constant current, constant trickle current, constant current constant voltage modes. These methods are easy and safe to be implemented but only suitable for slow charge. To accelerate the charging process, many charging strategies have been proposed. A pulse-charging strategy provides a pulse current or voltage and resting period for the diffusion and evenly distribution of electrolyte's ions. This method was proved to have better charging performance and shorten the charging time. In [2], a variable-duty voltage pulse charger was proposed, which utilized the electrochemical characteristic of battery. However, this method uses the constant voltage pulses, which is not suitable for rapid charging. For improving the pulse-current charging strategy, Taguchi algorithm was also used to optimize the charging pattern for multi-step current method [3]. The improvement of these methods has been verified. However, the process to search for the optimized charging current pattern is complicated and the experiment tests are required.

In this paper, a fast charging method based on the electrochemical characteristic of Lithium battery is proposed. The simulation results have verified the performance and safety of the proposed method, in which the charging time by the proposed method is about 49.6% and 52.3% compared to those of by the CC-CV and pulse-current charging methods, respectively.

2. Proposed Method

First of all, the electrochemical characteristic of Lithium battery is briefly reviewed in this section. In [2], the effect of concentration at the surface of the electrode on the battery-charging efficiency has been presented. According to this research, the concentration factor can be varied by charging strategy. Especially, in pulse charging, the resting period can provide the idle time for the ions to distribute more evenly,

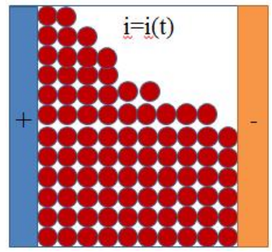

Fig. 1. Concentration distribution of a Li-ion battery.

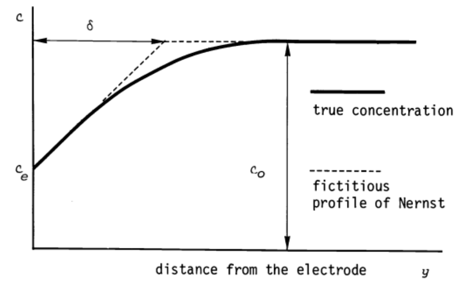

Fig. 2. Concentration profile in the vicinity of electrode during charging.

which results in the change of the battery concentration. When the resting time is longer, the charging efficiency is better. However, the charging time becomes longer, too.

In this paper, a rapid method based on the characteristic of battery during charging without using the discontinuous charging is proposed.

Fig. 1 and 2 show the concentration profile of the surrounding of electrode during charging, respectively. The region with the constant concentration C_0 is the bulk region and this constant concentration is denoted as the bulk concentration. The diffusion layer is the region surrounding the electrode, where the concentration C_e is different from the bulk concentration.

According to Nernst's equation, the concentration profile can be approximately represented by

$$C_0 - C_e = \frac{i\delta}{n_{Li^+} FD} \tag{1}$$

where F is the Faraday constant (96,487 As/mol), n_{Li+} is the valence charge of the ion (valence of Li is 1), D is the diffusion coefficient, cm^2/sec, i is charging current, and δ is the length of the diffusion layer.

From (1), the maximum rate of deposition, or limiting current density, is given by the condition when $C_e = 0$, and

$$i_{\max} = \frac{C_0 n_{Li^+} FD}{\delta} \tag{2}$$

and based on Sand's equation, the surface concentration can be simplified as [4]

$$C_e = C_0 - 1.1285 N_d \sqrt{\frac{t}{D}} \tag{3}$$

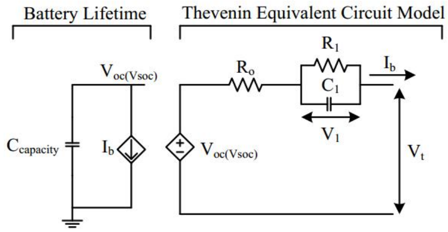

Fig. 3. Battery model.

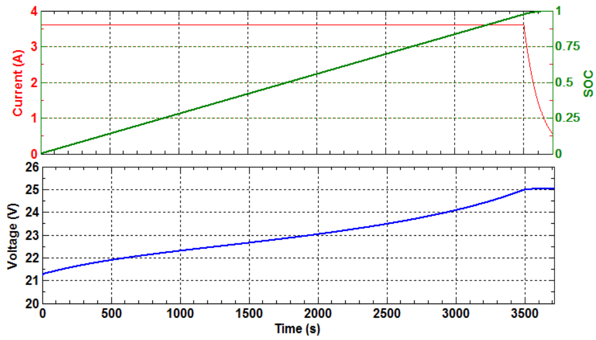

Fig. 4. Battery current and voltage by CC-CV charging strategy.

N_d is the rate of mass transfer.

With the assumption that N_d and δ are independent of the rate of diffusion, from (3) we can deduce that the lower the concentration, the higher the exchange current density. Since the concentration is increased with square root of time, the proposed method utilizes the current profile which decreases accordingly,

$$\frac{I_{t=t_2}}{I_{t=t_1}} = \frac{\sqrt{t_1}}{\sqrt{t_2}} \tag{4}$$

where $t_2 = t_1 + T_s$, and T_s is the sampling time.

This method can be regarded as a multi-step charging strategy, where the number of step is significantly high and the step duration is very fine.

3. Simulation Results

The parameters of the battery, of which electrical model is shown in Fig. 3, can be identified by an experiment, where the collected data from Kokam HEP06S01Pl Lithium polymer battery was adopted. The nominal capacity of the battery is 3.6 Ah and its nominal voltage is 22.2 V. The maximum charging voltage is 25.2V. The battery model and the method to obtain its parameters were introduced in [5].

Fig. 4 shows the current profile and SOC (state of charge) of battery using CC-CV charging strategy, respectively. The charging process consists of two states, which are the constant current period of 1C (3.6A) and the constant voltage period of 25 V. The charging time by this strategy is 3,712 s.

Fig. 5 shows the results of the pulse charging method. The duty ratio of the charging current is 75%. By this method, the charging time is 3,520 s (5% lower than that of using the CC-CV method).

The simulation results with the proposed method are shown in Fig. 6. At first, the high current at 4C charges the battery during the particular time of 150s. Then, the charging current is decreased with square root of time. The response terminal voltage and SOC are also shown. It can be seen in Fig. 6 that

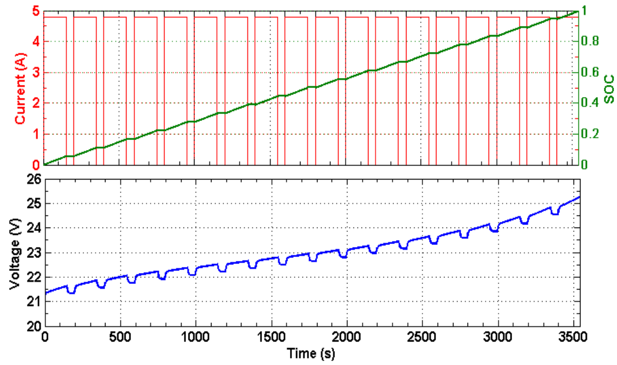

Fig. 5. Battery current and voltage by pulse-current charging strategy.

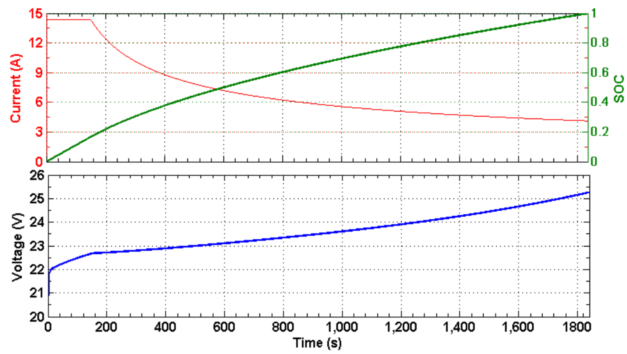

Fig. 6. Battery current and voltage by proposed charging method.

the charging time is very short, which is just 1,840 s, about 49.6% and 52.3% compared with those of by the CC-CV and pulse-current charging methods, respectively.

4. Conclusions

This paper has proposed a new charging strategy for Li-ion polymer battery, where it can apply to any type of Lithium-ion family. Based on the characteristic of battery during charging, the current profile, which decreases with square root of time, has been utilized to charge the battery. The charging time by the proposed method is about 50% lower than those of the conventional methods with the CC-CV and pulse-current charging strategies, which has been proved by the simulation results.

References

[1] A. A.-H. Hussein and I. Batarseh, "A review of charging algorithms for nickel and lithium battery chargers," *IEEE Trans. on Vehicular Technology*, vol. 60, no. 3, pp. 830–838, 2011.

[2] L. R. Chen, "Design of duty-varied voltage pulse charger for improving Li-ion battery-charging response," *IEEE Trans. Ind. Electron.*, vol. 56, no. 2, pp. 480–487, Feb. 2009.

[3] Y.H. Liu, Y.F. Luo, "Search for an optimal rapid- charging pattern for Li-ion batteries using the Taguchi approach", *IEEE Trans. Ind. Electron.*, vol. 57, no. 12, pp. 3963–3971, Dec. 2010.

[4] C. W. Tobias, M. Eisenberg, and C. R. Wilke, "Diffusion and Convection in Electrolysis - A Theoretical Review", Journal of the Electrochemical Society, vol. 99, no. 12, Dec. 1952.

[5] M. Chen, and G. A. Rincon-Mora, "Accurate electrical battery model capable of predicting runtime and I-V performance," *IEEE Trans. Energy Convers.*, Vol. 21, No. 2, pp. 504-511, Jun. 2006.