Part + 01 _

Developing a Battery Control System

Estimating the State of Charge for Lithium Iron Phosphate Cells

Many technologies make it possible to provide robust, long-lasting and safe battery cells for a variety of applications.
Lithium ion batteries that use lithium iron phosphate ($LiFePO_4$) as the positive electrode material have a much longer operating life than batteries using other types of positive electrode material. Therefore, the potential for application lies not only in automotive but also in industrial settings where operating life is a very important consideration.
GS Yuasa was one of the first manufacturers to embark on developing an iron phosphate lithium ion battery cell with lithium iron phosphate as the positive electrode and graphite as the negative electrode (referred to below as an LFP battery cell)[1]. In 2012, we presented results on the operating life and stability of a large format LFP battery cell (●Fig. 1). Moreover, we continued development where we devised various control techniques for fully utilizing this kind of battery cell.
This article will provide an overview of the LFP battery cell and introduce techniques for estimating the state of charge (hereafter, "SOC"), which is essential for controlling these kinds of batteries.

1. Properties of an LFP Battery Cell

LFP battery cells are known to be durable under repeated charge-discharge cycles and in high temperature environments, and are known to maintain high capacities over long periods. These battery cells are also very safe, even in automotive accidents where the batteries could be crushed or in system malfunctions where the battery could be overcharged[2].
LFP battery cells also have a wide plateau region (●Fig. 2), i.e., a usage range where the battery voltage changes minimally in accordance with the changes in the SOC. Therefore, power may be stably supplied from the battery over this wide usage range.

2. Estimating the SOC for an LFP Battery Cell

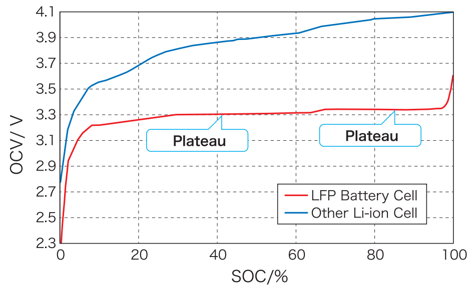
The techniques used to calculate the SOC must be quite accurate in order to properly determine the amount of electrical energy that may be discharged from or added to the battery and to optimally control the LFP battery cell. The SOC of a battery is usually determined using a so-called open-circuit voltage (OCV) method. With this method, the battery OCV is measured and the SOC is determined on the basis of the correspondence relationship between the SOC and OCV (●Fig. 2).
However, it tends to be difficult to determine the SOC from the OCV in the plateau region of the LFP battery cell. Assume, for instance, that the measurement precision of the voltage sensor used to measure the OCV is ±5 mV. The width of the SOC corresponding to an OCV range of 3.310 V ±5 mV in the plateau region near 50% SOC is roughly 24% (●Fig. 3). In other words, measurement errors have a greater effect within the plateau region, which tends to make it difficult to provide a definitive SOC from the OCV measurement value.

●Fig. 1 Large-format LFP Battery Cell

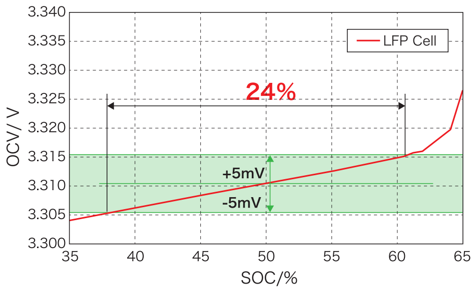
50Ah Class

20Ah Class

●Fig. 2 SOC-OCV Profile of an LFP Battery Cell



●Fig. 3 Plateau Region (Detailed View)



Another method of determining the SOC is the current integration method. The current integration method measures and integrates the current flowing through the battery and uses the same to estimate the SOC. However, measurement errors from the current sensor also affect the current integration method, and thereby the accuracy of the SOC estimation gradually decreases as time passes.

3. Correcting the SOC during the Transition Region

As can be seen from ●Fig. 2, the SOC-OCV profile of an LFP battery cell includes regions of relatively large changes in the OCV that accompany changes in the SOC; these transition regions are, namely, below 30% SOC, near 65% SOC, and above 95% SOC. The SOC can be properly determined via the OCV method within these transition regions. The current integration method and the method of using the OCV technique within a transition region may be combined to improve the accuracy of SOC estimation for an LFP battery cell. More specifically, estimation of the SOC via the current integration method would begin at the same time the battery starts being used. Once the OCV enters the transition region, the estimation method would change from current integration to OCV. The SOC value estimated would be corrected to the value determined via OCV.

●Fig. 4 Sample OCV where SOC is Corrected[3]

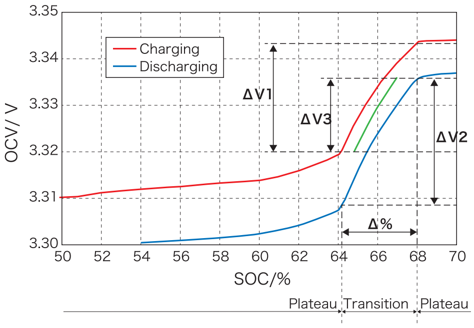
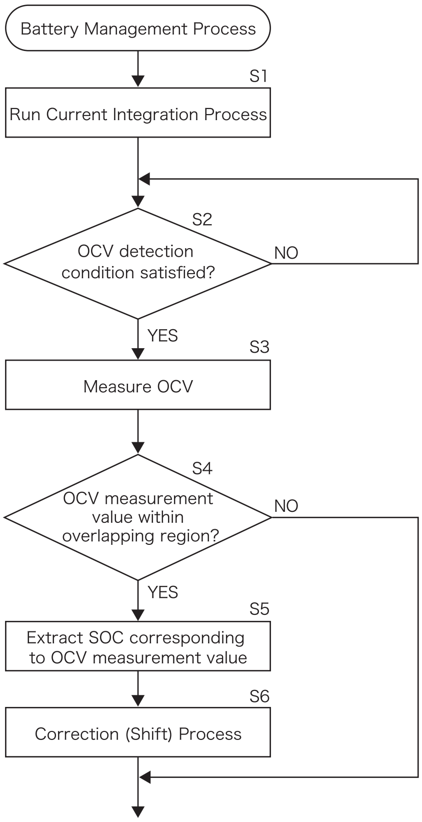


Fig. 4 is a detailed view of the area around 65% SOC in Fig. 2. The charging (red line, ●Fig. 4) and discharging (blue line, ●Fig. 4) SOC-OCV curves of the LFP battery cell are slightly shifted. This creates a region ΔV3 where the OCV range ΔV1 during charging and the OCV range ΔV2 during discharging overlap within the transition region. Here, the SOC, which up to this point is estimated via current integration can be corrected to a value estimated via the OCV method in the overlapping region ΔV3. This overlapping region ΔV3 makes it possible to obtain highly accurate estimates of the SOC regardless of whether the battery was charged or discharged prior to using the OCV method for estimation.

●Fig. 5 SOC Correction Flowchart



As illustrated in ●Fig. 5, first the current value is integrated (S1). It is then determined whether an OCV detection parameter is satisfied; e.g., if the charge current or the discharge current is at or below a reference value (Yes, at S2), the OCV of the LFP battery cell is then measured (S3). The SOC is determined via the OCV method (S5) when it is determined that the OCV measurement value is within a transition region i.e., the overlapping region ΔV3 (Yes, at S4), and the SOC value estimated via current integration is corrected (shifted) using the value obtained via the OCV method (S6).

It is possible to take advantage of the benefits of the current integration method and the OCV method using these techniques and thus maintain a high level of accuracy when estimating the SOC for an LFP battery cell. It is also possible to minimize the likelihood of amplifying the effects of any errors when the OCV method is used to estimate the SOC value at an unsuitable time. This kind of technique of correcting the SOC is also particularly effective when LFP battery cells are used, for instance, in a system integrated with a solar panel[4].

This article provided an overview of the LFP battery cell and discussed the techniques developed by GS Yuasa for estimating the SOC for the purpose of controlling this kind of battery. Part Two will discuss techniques for balancing the SOC for the cells in a battery assembly that combines multiple LFP battery cells.

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1. GS Yuasa Technical Report Volume 5, No. 2, published 2008
2. GS Yuasa Technical Report Volume 9, No. 1, published 2012
3. Japanese Patent No. 6155781, US Patent No. 9429626, Chinese Patent No. 201310163549.8 (Filed in 2012)
4. US Patent No. 9800086 (Filed in 2012)

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