BMS Part 03

Developing Technologies for Battery Management

Estimating the Full-Charge Capacity of an LFP Battery Cell In Situ

Lithium ion cells (LFP battery cells) are cheaper to manufacture because they do not use precious rare metals; instead, LFP battery cells use lithium iron phosphate ($LiFePO_4$) as the positive electrode. Therefore, use of LFP battery cells can be increasingly found in a wide variety of technologies, for instance, electric vehicles and energy storage systems (ESS). GS Yuasa employs LFP battery cells in its automotive 12V battery pack[1].

A battery gradually deteriorates—thus, the full-charge capacity of the battery decreases—over time or over the number of charge-discharge cycles. The full-charge capacity of the battery can be measured accurately with a prescribed measurement apparatus if the battery is removed from the system, e.g., from the electric vehicle; however, the system must be shutdown during this kind of measurement. The ability to appropriately measure the full-charge capacity of a battery without shutting down the system is sorely needed.

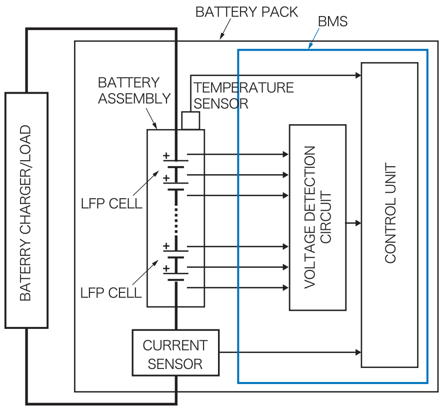
This article will explore techniques and technologies developed by GS Yuasa for estimating the full-charge capacity of an LFP battery cell while the host system remains operational.

1. The Basic Configuration of the Battery Pack

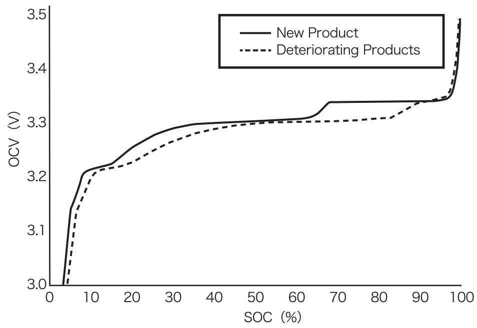
A battery pack includes a battery assembly in which multiple LFP battery cells are connected in series (●Fig.1). This kind of battery pack can be installed in, for instance, an electric vehicle or a hybrid electric vehicle. As the battery pack discharges, it supplies power to a load, and a charger device connected to the battery pack charges the cells of the battery assembly. The battery pack has a battery management system (BMS) and the BMS monitors the status of the battery assembly.

The BMS includes a voltage detection circuit and a control unit. The voltage detection circuit measures the voltage of each of the LFP battery cells, and outputs a signal to the control unit representing the voltage measured. The control unit additionally receives signals from a temperature sensor that measures the environmental temperature of the battery assembly or the LFP battery cells, and from an electrical current sensor that measures the current flowing through the battery assembly. The control unit integrates the time-series data received from the current sensor to compute the amount of electrical energy charged (ampere-hour, Ah) with the charging of the battery assembly, and the amount of electrical energy discharged (Ah) with the discharging of the battery assembly.

●Fig. 1 Basic Configuration of a Battery Pack



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

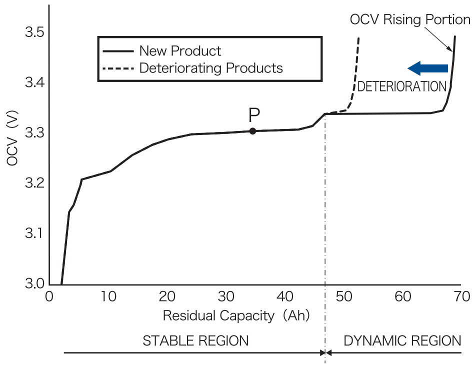


2. Properties of an LFP Battery Cell

The SOC-OCV profile (i.e., the curve representing the relationship between the charge state and the open-circuit voltage) changes as the cell deteriorates (● Fig.2). Therefore, it is difficult to estimate the full-charge capacity with high accuracy using conventional estimation techniques that use two points on the curve (e.g., the voltage difference technique).

●Figure 3 is a graph of the residual capacity-OCV profile of an LFP battery cell. The vertical axis represents the OCV and the horizontal axis represents the amount of electrical energy that remains in the battery (residual capacity). The rising portion at the right end of the curve shifts leftward as the LFP battery cell deteriorates. This shift is a result of the change in the potential difference between the positive electrode and the negative electrode of the LFP battery cell. The residual capacity-OCV profile of an LFP battery cell (●Fig. 3) can be seen as having two regions—a stable region, in which there is almost no change to the shape of the curve, and a dynamic region in which the curve changes with deterioration of the cell. In the stable region, the residual capacity and OCV at an arbitrary point P are substantially constant regardless of the degree of deterioration of the battery cell.

●Fig.3 Residual Capacity-OCV Profile of an LFP Battery Cell



3. Estimating the Full-Charge Capacity of an LFP Battery Cell In Situ

In some situations a battery pack may be charged while the system is running until the battery cell is fully charged (red dots in ●Fig. 4). The control unit in the BMS (●Fig. 1) determines if each LFP battery cell is fully charged based on the voltage and the electrical current being monitored (●Fig. 5, S1). Subsequently, the control unit measures an accumulated charge-discharge amount X starting from the fully charged state (●Fig. 5, S2), by taking the amount of electrical energy discharged from the battery assembly as a positive value, and the amount of electrical energy charged to the battery assembly as a negative value, and adding the two values together.

With this, the accumulated charge-discharge amount X, which is from the fully charged state to point P, can be obtained (●Fig. 4)[2]. When a battery is new, X is a large value and the value of X decreases as the battery deteriorates.

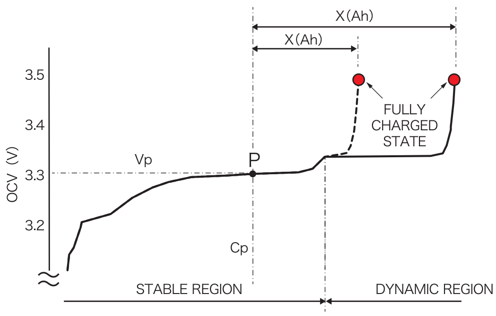
Next, the control unit determines if the current flowing through the battery assembly is at or below a given threshold (●Fig. 5, S3). If the electrical current is at or below the threshold (YES at S3), then the control unit measures the OCV Vp at point P (●Fig. 5, S4) to determine if point P is in the stable region (●Fig. 5, S5). If the control unit determines that point P is still in the dynamic region (NO at S5), then the control unit continues to measure the accumulated charge-discharge amount X and returns to the determination at S3.

If point P is in the stable region (YES at S5), then the control unit computes a residual capacity Cp (●Fig. 4). The residual capacity Cp is calculated based on, for instance, a residual capacity-OCV table for the stable region (this table being stored, for example, in the control unit's memory), and the measured voltage Vp. Thus, the residual capacity Cp and the accumulated charge-discharge amount X (●Fig. 4) can be added together to obtain the full-charge capacity. Moreover, to account for measurement errors of Vp by the voltage detection circuit, the accumulated charge-discharge amount X may be added to each value over a range of values where the Cp computed is a median to thereby obtain a range that includes the full-charge capacity.

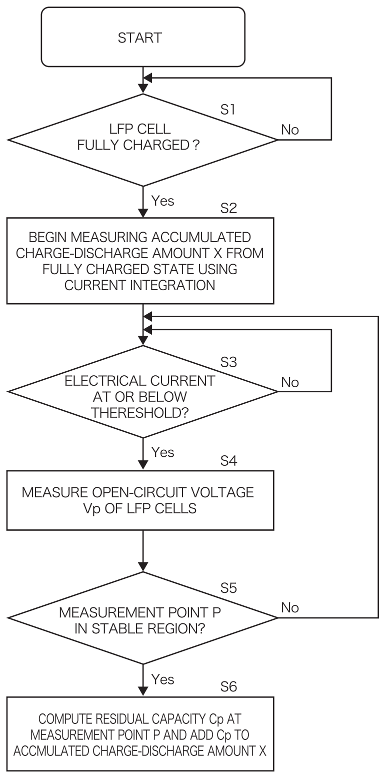
Consequently, the full-charge capacity of the LFP battery cell can be estimated with high accuracy with these methods without having to employ any specialized sensors or add any other components. Moreover, this highly accurate estimation can be performed while the host system, such as a vehicle is still running.

This article explored techniques and technologies we developed to estimate the full-charge capacity of a typical LFP battery cell in situ, with high accuracy and simple calculations. GS Yuasa will continue to turn our expertise into battery management technology that provides our customers with highly reliable products.

●Fig.4 Accumulated Charge-Discharge Amount starting from Fully Charged States



●Fig.5 Flowchart for Estimating Full-Charge Capacity



1. https://www.gs-yuasa.com/jp/technology/making_history/pdf/no12.pdf
2. Japanese Patent No. 6714838, US Patent No. 10,330,735, Chinese Patent No. 106257737, European Patent No. 3106892 (filed in 2016)

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