Part 02

Developing a Battery Control System

Techniques for Balancing Lithium Iron Phosphate Cells

Multiple large format lithium ion battery cells are often combined and used as a battery assembly (●Fig. 1). It is therefore necessary to balance the state of charge (below, SOC) or the cell voltage for a plurality of cells to bring out sufficient performance of a battery assembly comprised of battery cells connected in series. Battery assemblies with lithium iron phosphate cells (LFP battery cells) in particular require special balancing techniques.
This article will outline the techniques used for balancing SOC, and introduce the SOC balancing techniques developed by GS Yuasa that are most effective for battery assemblies comprised of LFP battery cells.

1. Techniques for Balancing SOC

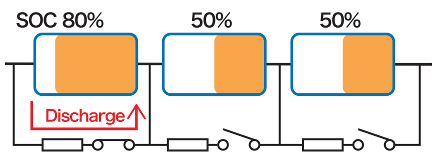
Each of the cells in a battery assembly has minute variations in starting capacities and deterioration rates. Consequently, the SOC for the cells become unequal with repeated charging and discharging of the battery. Each of the cells may be charged to an SOC of 100% by connecting both ends of the battery assembly to a charger. However, because the cell with the higher SOC will be the first to be fully charged, the remaining cells cannot fully charge. This imbalance makes it difficult to fully utilize the charging and discharging functions of the battery assembly. Here, a discharge circuit (hereafter, the balancer) is often connected in parallel with each cell to balance the SOC in the battery assembly. The balancer switch for a cell closes when SOC for that cell is higher than other cells, discharging the cell so that the SOC and voltage for that cell is equal to other cells in the battery (●Fig. 2).
The SOC correlates to the voltage of the battery cell. Therefore, it is usually possible to detect when the SOC of the cells are not equal by measuring and comparing the voltages of the multiple cells.

●Fig. 1 Large-format Lithium-Ion Cell for Battery Assembly

2. SOC and the LFP Battery Cell

As discussed in Part One of this series, LFP battery cells have a wide plateau region (A, ●Fig. 3) i.e., a usage range where the battery voltage changes minimally in accordance with the changes in the SOC. Therefore, each of the cells in battery assembly made up of a combination of LFP battery cells has its own wide plateau region. However, measuring the voltage of each of the battery cells in the battery assembly will only find a small difference in the plateau regions of the cells; thus, it tends to be difficult to detect whether or not the SOC of the multiple cells is balanced. In addition, the voltage does not decrease in the plateau region even when a certain cell discharges via the balancer to reduce its SOC; therefore, it also tends to be difficult to determine whether or not the SOC of that cell has dropped to the same level as the SOC of the other cells.

●Fig. 2 The Balancer at Work



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3. Practical Methods for Balancing LFP Battery Cells

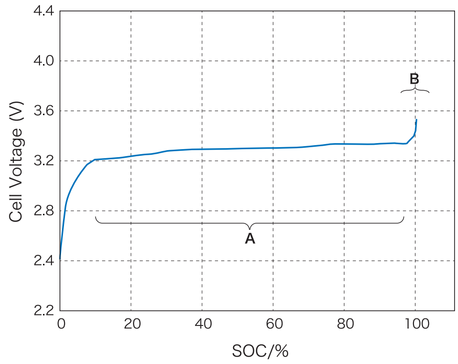
The OCV of an LFP battery cell changes to a relatively large extent with changes in the SOC in regions of 95% SOC or more (B, ●Fig. 3). We proposed to search within a transition region for the cell that had the highest SOC, and to then use the balancer to discharge the cell until the voltage difference between the cell and other cells was sufficiently small[1]. The voltage of the cell decreases quickly when the balancer is used in a transition region. This technique makes it possible to accurately detect the SOC imbalance among multiple battery cells and quickly reduce the differences in SOC. Consequently, the individual capacities of the cells may be used effectively to fully utilize the charging and discharging functions of the battery assembly as a whole.

●Fig. 4 illustrates another practical method for balancing LFP battery cells. That is, the multiple LFP battery cells may be connected in series. When the SOC of the cells in the battery assembly become unequal while charging, a given battery cell will reach a reference voltage before the remaining battery cells which reach the reference voltage some time thereafter (top, ●Fig. 4). One plausible solution is to have the battery assembly cause the balancer to operate in a transition region at or above the aforementioned 95% SOC. Here, charging the battery assembly stops the moment a single cell enters the transition region and the balancer begins discharging that cell. However, the actual imbalance remains and is not addressed since there is virtually no difference in voltage between the cells at this point, and the balancer stops operating immediately. We therefore proposed to monitor the order in which the cells reach the reference voltage and deploy the balancer to vary the discharge time of the cells in accordance with the arrival order[2].

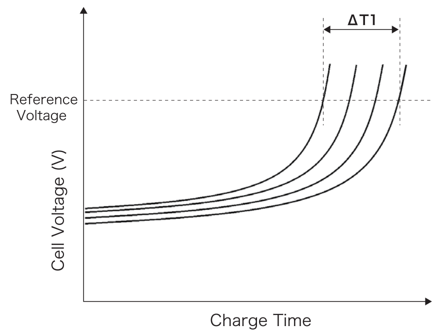
More specifically, the order in which the cells arrive at the reference voltage can be mapped to a discharge time and the mapping stored in the battery system's memory, e.g., as a lookup table (bottom, ●Fig. 4). A cell arriving earlier at the reference voltage (i.e., a cell with a higher order in the table) would be discharged for a longer time using the balancer based on the lookup table. A cell arriving later at the reference voltage (i.e., a cell with a lower order in the table) would be discharged for a shorter time or not at all. With this, each of the cells may be discharged for a discharge time established for the order in which the cell arrived at the reference voltage; this ensures that cells discharge via the balancer for a certain time, thereby balancing the SOC of the cells.

This article provided an overview of the techniques used for balancing SOC in a battery assembly, and discussed the techniques developed by GS Yuasa that are most effective for battery assemblies comprised of LFP battery cells. Part Three will discuss control technologies for idling stop vehicles that employ an LFP battery assembly.

●Fig. 3 SOC-Voltage Relationship in an LFP Battery Cell



●Fig. 4 Order of Arrival and Discharge Time



Order	Discharge Time (secs)
1	60
2	40
3	20
⋮	⋮
N	0

1. Japanese Patent No. 5573075 (Filed in 2009)
2. Japanese Patent No. 6106991, US Patent No. 9225180, Chinese Patent No. 201210323500.X (Filed in 2011)

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