Part 01

Developing Battery Simulation Technologies

Estimating the Storage Battery Temperature

In recent years computational simulation has been used as a way to more efficiently construct storage battery systems. Various mathematical models and algorithms have been proposed to represent the diverse elements to be simulated such as the battery structure or the electrochemical reactions in the storage battery.
One important factor that greatly impacts the characteristics or deterioration performance of a battery cell in a storage battery system is temperature. A battery module, which is made up of multiple battery cells, typically contains a few (one or two) temperature sensors with the output from these sensors taken as the temperature of the battery cells.
Here, we will introduce technical concepts for using simulation to more precisely estimate the temperature of an energized storage battery with a simple and easy configuration (●Fig. 1).

1. Simulating the Thermal Behavior of the Battery Cell

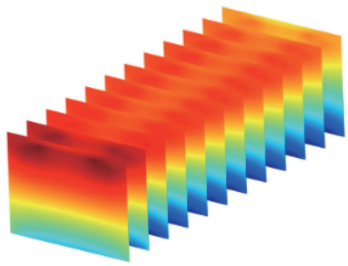
Beyond measuring the external (ambient) temperature around the battery cell, estimating the temperature of a cell also requires accounting for the heat-absorbing and heat-generating behavior of the cell itself. Joule heating and heat absorption and heat generation accompanying the chemical changes in the cell make up the thermal behavior of a battery cell.

The amount of joule heating is proportional to the current flowing in a battery cell and to the time the current flows in the battery cell (energization time). The size of the current, the energization time and the voltage of the energized battery cell may be measured and used to calculate the amount of joule heating of the entire battery cell. More specifically, the voltage of a battery cell with no load connected (open circuit voltage, OCV) may be estimated via known techniques, and the difference between the OCV and the voltage of the energized battery cell computed. The amount of joule heating is obtained by multiplying the difference with the size of the current and the time the battery cell is energized.

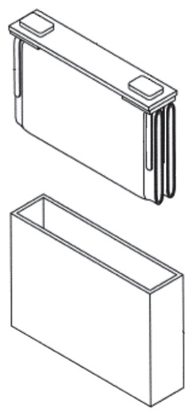
The size and direction of the current, and how long the cell is energized may also be used to estimate the changes to the state of charge (SOC); it is then possible to estimate the amount of heat absorption or heat generation that accompanies chemical changes in the cell by referencing a relationship, determined in advance, between the changes to the SOC and the amount of heat absorption or heat generation. Thus, the thermal behavior of the battery cell may be simulated using the current flow, energization time, battery cell voltage, OCV, and SOC to obtain a heat value without adding temperature sensors to the cell.

As illustrated in ●Fig. 2, the internal structure of the battery cell is non-uniform. A battery case contains sections where the electrode assembly acts as a heat-absorbing or heat-generating element, where there are metal parts, and where there are spaces filled with electrolyte or air with no electrode assembly or metal part present. There are also sections where the difference in constituent materials encourages a rise in temperature or the propagation of heat. Therefore, the temperature varies inside a battery cell. It is difficult to understand the variations in temperature inside the battery cell by only detecting the outer surface temperature of the case using a few temperature sensors.

●Fig. 1　Temperature Estimation via Simulation



●Fig. 2　Internal Structure of a Battery Cell



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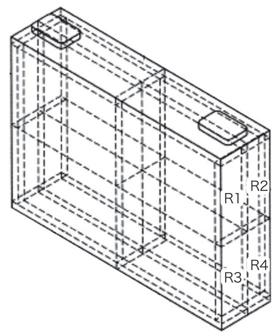
Consequently, the battery cell may be seen as divided into multiple internal regions (●Fig. 3). Thus, the amount of heat absorption and heat generation in each internal region may be estimated by assigning each internal region a proportion of the overall heat value calculated for the battery cell in accordance with the proportion of volume taken up by a given element, e.g., the electrode assembly, in the internal region.

●Fig. 3 Example of the multiple internal regions

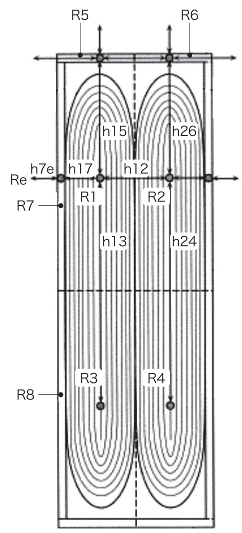


2. Accounting for Heat Transfer between Regions

The heat generated in a given internal region in a battery cell does not remain in that region if there is a difference in temperature with a neighboring region; the heat generated moves to another internal region or moves outside the battery cell. Heat outside the battery cell will move to an internal region of the battery cell when the temperature outside the battery cell is higher than the temperature inside the battery cell.

Therefore, the amount of internal heat transfer, i.e., the amount of heat moving between neighboring internal regions (e.g., between R1 and R2 in ●Fig. 4), and the amount of external heat transfer, i.e., the amount of heat moving between an internal region and an external region (e.g., between R7 and Re in ●Fig. 4) must be computed to more fully understand the transition in temperature in the battery cell from a first point in time to a second point in time.

●Fig. 4 Establishing a heat propagation coefficients for internal regions[1].



Neighboring internal regions (e.g., R1 and R2) and an external region and its neighboring internal region (e.g., R7 and Re) may be assigned a heat propagation coefficient (h12 and h7e, respectively). Each of these inter-regional heat propagation coefficients may be established as appropriate by accounting for the internal structure, the electrochemical reactions, and the external environment of the battery cell.

The temperature of each of the regions at a second point in time may be computed using the temperature of the regions at a first point in time, the amount of heat absorption and heat generation assigned to a region from the first to the second point in time, and the amount of heat transfer between regions from the first to the second point in time.

As above described, it is possible to continue to more exactly estimate the temperature of an energized battery cell by calculating the amount of heat absorption and heat generation of the battery cell from a first point in time to a second point in time, and successively calculating the changes in the temperature due to the movement of heat between different regions.

This article introduced some techniques of using simulation to estimate the temperature of an energized battery cell without a complicated structure or adding temperature sensors. More specifically, we discussed the concepts of: simulating the thermal behavior using the current flow, energization time, battery cell voltage, OCV and SOC to estimate the heat value; accounting for the non-uniform internal regions of the battery cell; and accounting for inter-regional heat transfer. GS Yuasa will continue to make full use of these and other simulation techniques with the goal of more efficient construction of storage battery systems.

1. Japanese Patent No. 6544489, International Publication No.WO2018/025965 (Filed in 2016)

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