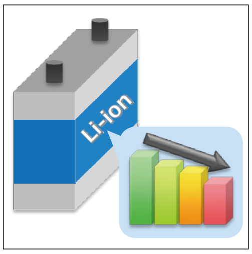

Real-Time Deterioration Diagnosis Technology for Stationary Storage Batteries

Shoji YOSHIDA*, Ryo OHSHIMA, and Masato OKITA

Stationary storage batteries using lithium-ion batteries are expanding for the effective utilization of renewable energy and for power supply during disasters. Understanding the health and characteristics of these batteries, especially in relation to degradation from charging, discharging, and aging, is extremely important for stable operation of the system. To diagnose the storage battery on-site and in real-time, a battery deterioration diagnosis technology based on the battery's transient response characteristics is being researched and developed. This paper introduces the features of battery degradation diagnosis using transient response analysis and the results of verification related to its application in stationary storage batteries.

Keywords: battery deterioration diagnosis, lithium-ion battery, real time, operational data, transient response analysis

1. Introduction

Growing efforts are under way to promote the use of renewable energy and use energy in an efficient way with the aim of implementing carbon neutrality. Solar and wind power sources involve the issue of supply stabilization because of their dependence on weather for the amount of generated electricity. As a solution to this issue, the pace of the installation of storage batteries is growing. In this regard, in particular, grid storage batteries play a significant role as a buffer for power grid stabilization and supply-demand adjustment. In addition, for the creation of a decarbonized society, demand for storage batteries is growing in many sectors to use them as a storage of surplus power and as an emergency power supply in the event of a natural disaster.

For use in stationary storage battery applications, lithium-ion batteries, are the mainstream. Background factors to this include the high energy density, superb lifespan characteristics, high charge-discharge efficiency, and input-output performance of the lithium-ion batteries. Thus, they are used in a wide range of sectors.

Because they are electrochemical batteries, lithium-ion batteries are subject to deterioration due to repeated charge and discharge cycles and passage of time after installation. It is vitally important to track the state of deterioration particularly for stationary applications because in such uses the battery is required to function stably for a long period of time. Consequently, battery deterioration diagnosis enables the operator to determine when to replace batteries and review their operation for extended service life.

This paper reports on what approaches are taken at Sumitomo Electric Industries, Ltd. in order to apply the lithium-ion batteries deterioration diagnosis technology to stationary storage batteries.

2. Battery Deterioration Diagnosis Technology

With the aim of diagnosing the state of deterioration of lithium-ion batteries, many techniques are being tested not only for stationary applications but also for small consumer and in-vehicle applications.

The most general method of highly accurately identifying the state of deterioration of a storage battery is the capacity check test, which measures the discharge capacity (Ah) by fully charging and then fully discharging the storage battery. To conduct a capacity check test, however, it is necessary to request the battery manufacturer to conduct testing while stopping the operation of the stationary storage battery for a long period of time, which will incur a high diagnostic cost.

Another method is charge curve analysis,[1] which enables the tester to estimate the internal state, including material deterioration. Charge curve analysis is a technique of analyzing variation in the form of a battery charge curve. This method enables the tester to obtain more detailed information about the state of deterioration than that available by the capacity check test. Nevertheless, it requires charging and discharging at a low current, necessitating the battery to be shut down similarly to or longer than necessary with the capacity check test.

A diagnosis technique that requires a relatively short amount of time is the alternating current (AC) impedance method.[2] The AC impedance method applies a slight AC current/voltage at different frequencies to the storage battery and measures voltage and current responses, followed by conducting fitting analysis on the obtained data, using an equivalent circuit. Although this method can diagnose the state of deterioration in detail, it has a lot of issues when applied to the diagnosis of a stationary storage battery, which incorporates a large number of battery cells, because the method is intended for the diagnosis of individual battery cells.

Additionally, an excellent technique in terms of on-site and real-time performance is capacity integration. Capacity integration estimates deterioration by integrating the current capacity of the storage battery during discharge and dividing that current capacity by the nominal capacity, thereby determining the number of charge-discharge cycles in a pseudo manner. However, this technique involves the issue of poor accuracy, the cycle life determined based on the integrated capacity being often in poor agreement with measured cycle life; the reason is that charge-discharge cycles have greatly varying effects on deterioration depending on charge-discharge conditions, as in repeated shallow charge-discharge cycles and repeated deep charge-discharge cycles.

With stationary storage batteries, a stoppage for the purpose of deterioration diagnosis has economic impacts such as the loss of electricity sales opportunities, to say the least; if an outage occurs during the stoppage, the business continuity plan (BCP)*1 cannot be implemented. Therefore, it is necessary to develop a technique that will enable the tester to accurately diagnose the state of deterioration on site and in real time without causing the battery to be shut down.

3. Use of Transient Response Analysis for Verification of Battery Deterioration Diagnosis

As a solution to the above-described issues, we have developed a transient response analysis technology,[3] which conducts deterioration diagnosis through equivalent circuit analysis based on the inherent transient response characteristics of lithium-ion batteries. The transient response analysis technology calculates the internal impedance of an equivalent circuit, using z-conversion based on the transient response characteristics of lithium-ion batteries observed in charge-discharge cycles. Operational data during charging and discharging can be used to conduct deterioration diagnosis by observing changes in internal impedance that occur along with the deterioration of lithium-ion batteries. Therefore, to apply the transient response analysis technology to the deterioration diagnosis of a stationary storage battery, a fundamental verification was conducted as well as a verification using a stationary storage battery.

3-1 Fundamental verification of transient response analysis technology

Accelerated aging was used on square lithium-ion battery cells to be used in stationary storage batteries to prepare four cells with varying degrees of deterioration. They were used to conduct a capacity check test and transient response analysis for the ascertainment of correlation. In addition, AC impedance measurement was conducted for the purpose of comparison with other deterioration diagnosis techniques.

In the capacity check test, the discharge capacity (Ah) was measured by fully charging and fully discharging the battery at a charge rate (C-rate)*2 of 1.0 C and 25°C. Subsequently, the ratio of the discharge capacity under test to the discharge capacity in undeteriorated condition was determined as the state of health (SOH).*3

Following the capacity check test, the battery was charged to a state of charge (SOC)*4 of 50% at 25°C. After a break of 1 h, a 10 s pulse discharge test was conducted at 1.0 C to obtain data for transient response analysis. Then, the internal resistance R_i was calculated through transient response analysis using the equivalent circuit illustrated in Fig. 1.

Furthermore, the AC impedance was measured at 50% SOC at 25°C, followed by fitting analysis on the obtained data to obtain the internal resistance R.

Figure 2 shows the correlation between internal resistance calculated using transient response analysis as well as using AC impedance measurements and SOH determined based on the capacity check test results. Although the values of internal resistance determined these different techniques were not completely identical because of differences in equivalent circuit used, durations subject to analysis, sampling intervals, and other factors, both techniques revealed increases in internal resistance dependent on decreases in SOH. These results prove that deterioration of lithium-ion batteries can be diagnosed by calculating the internal resistance R_i through transient response analysis.

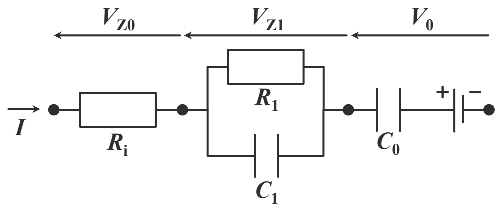

Fig. 1. Equivalent circuit for lithium-ion batteries analysis

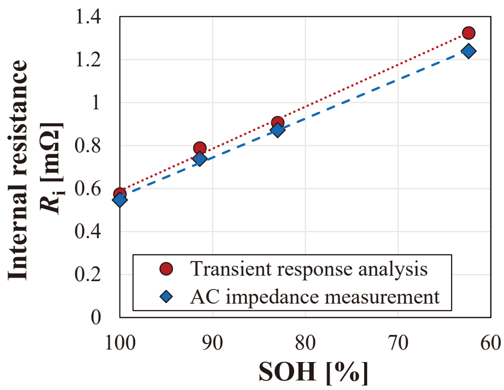

Fig. 2. Correlation between SOH and internal resistance

3-2 Prototype board for battery deterioration analysis

The preceding section indicated that the internal resistance R_i calculated through transient response analysis of data obtained by pulse discharge testing conducted under identical conditions has a correlation with SOH. Nevertheless, it is rare in actual operation that ideal charge-discharge data, as with pulse discharge waveforms, is available, and various charge-discharge waveforms are conceivable. Therefore, for deterioration diagnosis using operational data, it is important to obtain stable internal resistance with a low degree of variation even from varying waveforms.

Transient response analysis is conducted based on electric current data and transient response voltage data collected in an instance of shifting from standby state where no charge or discharge is taking place to the rapid application of a charge or discharge current.

Accordingly, a prototype board (Photo 1) was developed, equipped with the following functions: logging of measurement data obtained by measuring sensors, deterioration diagnosis based on transient response analysis technology, and data extraction for extracting suitable charge-discharge data for transient response analysis. The prototype board has a compact size (200 mm wide and 160 mm deep) suitable for installation in a stationary storage battery container.

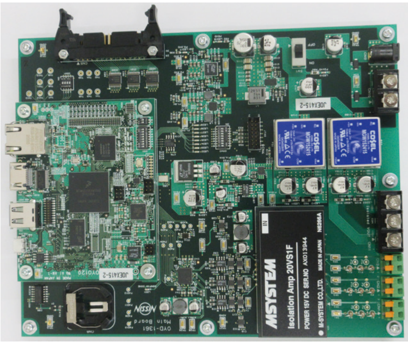

Photo 1. Newly developed prototype board for battery deterioration analysis

3-3 Verification using a stationary storage battery

Using the newly developed prototype board and transient response analysis technology, deterioration diagnosis was conducted on an in-house stationary storage battery (equipped with 27.4 kW of lithium-ion batteries), as illustrated in Photo 2.

In addition to the prototype board, measuring sensors were installed on a lithium-ion battery cell in the storage battery container. Charge-discharge data that met certain prescribed conditions was extracted from the measurement data obtained with the measuring sensors during the period from June 2022 to February 2025 to conduct a transient response analysis. Because the temperature of the cells changed due to temperature changes inside the storage battery container, a temperature correction formula was derived in advance after evaluating the temperature dependence of the internal resistance R_i; then, correction was made for calculation as the internal resistance at 25°C $R_{i@25deg}$. Although no increases in internal resistance were observed during the verification period, more than 90% of the calculated values of the internal resistance $R_{i@25deg}$ fell within an error rate range of ±5%, as depicted in Fig. 3, substantiating stable determination of internal resistance.(4) Note that the reason for the absence of data in certain periods (from March to December 2023 and from November 2024 to January 2025) is that the verification was temporarily suspended due to modification of the prototype board and other reasons.

Photo 2. In-house stationary storage battery used for verification

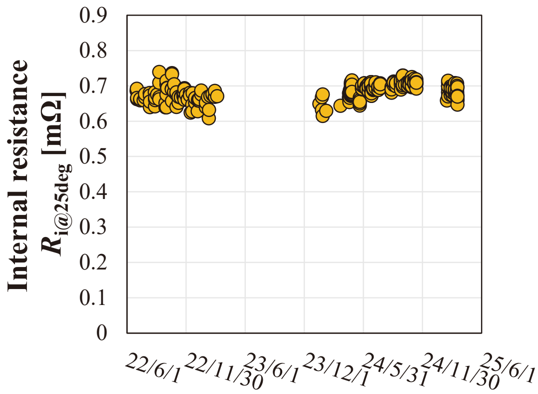

Fig. 3. Results of transient response analysis based on data obtained by measuring sensors

Using measurement data obtained by measuring sensors for transient response analysis, it becomes possible to reduce variation in the internal resistance R_i owing to the high accuracy of the measurement data. However, the installation of measuring sensors involves cost increases and other issues.

Meanwhile, stationary storage batteries consisting of lithium-ion batteries have a battery management system (BMS),*5 which also measures the current, voltage, and temperature of the battery. If BMS data is usable for battery deterioration analysis, it will make it easier to diagnose the deterioration of the battery. Hence, using an in-house stationary storage battery, we verified whether BMS data is usable or not.

The in-house stationary storage battery is designed to produce BMS data that is coarser than that obtained by measuring sensors by about an order of magnitude in terms of resolution and measurement intervals. Additionally, BMS data has the issue of occasional timing inconsistency between current and voltage data during charge-discharge cycles due to the lack of recording time synchronization. As a result, transient response analysis performed on raw BMS data could not be as accurate as required for deterioration analysis, with the determined internal resistance R_i indicating abnormal values.

As a solution to this issue, before transient response analysis, raw BMS data was corrected, such as by synchronizing the current and voltage. To ascertain the effect of correction, we conducted transient response analysis on data obtained by periodically applying charge pulses—which have suitable waveforms for transient response analysis—and looked at the calculated internal resistance

$R_{i@25deg}$. Moreover, for comparison purposes, transient response analysis was also conducted on data obtained by measuring sensors. The results of the transient response analysis conducted on the corrected BMS data revealed that the internal resistance was calculated within approximately ±10% of variation with reference to the average, although the values were more varying than the results produced by using data obtained by measuring sensors, as presented in Fig. 4.

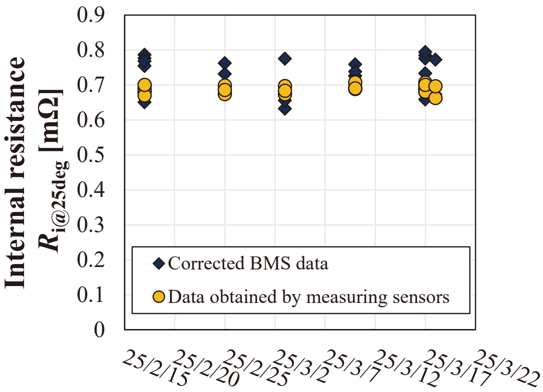

Fig. 4. Results of transient response analysis on corrected BMS data

4. Conclusion

The project identified the potential to conduct battery deterioration analysis through transient response analysis using data obtained from the BMS of a stationary storage battery. Whereas, conventionally, deterioration analysis using data obtained by installed measuring sensors was considered, we intend to continuously pursue studies with the aim of determining internal resistance stably using not only pulse charge data but even various charge-discharge waveforms observed during operation because the use of BMS data allows deterioration analysis to be conducted more easily.

Meanwhile, in April 2025, we started a verification using a stationary storage battery, installed outside the company's premises, consisting of recently increasingly adopted lithium-iron-phosphate batteries. In that project as well, deterioration analysis verification through transient response analysis is ongoing, acquiring two types of data obtained by measuring sensors and BMS. Going forward, we will look at the usefulness of deterioration analysis based on transient response analysis, using different types of lithium-ion batteries.

Technical Terms

*1 Business continuity plan (BCP): A plan intended to continue or recover early a company's core business while minimizing impact or damage sustained by the company in the event of a disaster and other emergency situations.

*2 C-rate: A relative measure of the magnitude of an electric current, used to indicate the rate of charge or discharge. A 1C rate is defined as the current value at which a fully charged battery is fully discharged in 1h.

*3 State of health (SOH): An indicator representing the degree of health or deterioration state of a storage battery. The SOH indicates the ratio of the current capacity to the initial capacity.

*4 State of charge (SOC): The ratio of the current state of charge to the full-charge capacity.

*5 Battery management system (BMS): A system designed to monitor and control storage batteries in a safe and efficient manner.

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