Traction Energy Storage Systems Supporting Energy-Saving, Safe, and Resilient Railway Infrastructure

● SATAKE Nobuhiko

Railway systems are positioned as a key means of transportation for reduction of the burden on the environment and are expected to contribute to the realization of railway infrastructure with enhanced energy saving, safety, and resilience from the viewpoint of achieving the Sustainable Development Goals (SDGs).

Toshiba Infrastructure Systems & Solutions Corporation has been developing traction energy storage systems (TESS) equipped with its SCiB™ lithium-ion battery and supplying them for use in railway ground systems. We have confirmed that the TESS supplied to the Yui Rail Line of Okinawa Urban Monorail, Inc. achieves high energy-saving performance, as well as ensuring an emergency power supply to propel rolling stock to the nearest station in the event of a wide-area blackout. Through sampling inspections of our SCiB™ battery modules for the TESS of Tobu Railway Co., Ltd. operating as a battery bank, we have also confirmed that the TESS can achieve stable long-term operations. The application of TESS to railway infrastructure is now beginning in both the Japanese and overseas markets.

1. Introduction

Since the Sustainable Development Goals (SDGs) were adopted by the United Nations in 2015, initiatives for the SDGs have been increasingly deployed worldwide. In Japan as well, many businesses and organizations are accelerating activities toward achieving the SDGs. This trend is also evident in the railway industry, particularly in terms of exploring various zero-carbon energy solutions to realize railway infrastructure with enhanced energy conservation, safety, and resilience.

Toshiba Infrastructure Systems & Solutions Corporation has been developing storage battery systems as one of the solutions to satisfy these requirements and supplying them to railway operators in Japan and abroad. Our storage battery systems combine our well-proven railway technologies with the SCiB™ lithium-ion battery featuring enhanced safety, long life, and thousands of charge/discharge cycles, satisfying stringent railway requirements. A traction energy storage system (TESS) is a type of stationary land-based storage battery system.

Figure 1 shows the mechanism of a TESS, which converts the regenerative energy produced during braking into electricity and transfers it to a land-based storage battery via an overhead wire so that it can be reused by other trains for acceleration. The TESS saves energy by reusing the regenerated energy that was previously dissipated as heat. In addition, the TESS serves as an emergency battery system that supplies electricity to trains in the event of a blackout. Furthermore, the TESS can be used as a battery bank to replace a substation.

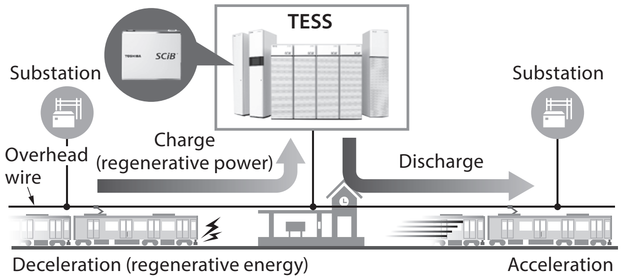

Figure 1. Mechanism of TESS
The TESS converts the regenerative energy produced during braking into electricity and stores it in a land-based battery panel so that it can be reused for acceleration. The TESS not only saves energy but also acts as an emergency power supply in the event of a blackout and as a replacement for a substation.

We have also inspected the performance deterioration of our SCiB™ battery modules for the TESS being used for commercial railway operation. This report describes several examples of TESS application in Japan and abroad and the results of battery deterioration inspections.

2. TESS for Yui Rail Line

2.1 Reduction in power consumption

In 2017, a TESS was installed at the Sueyoshi Substation for the Yui Rail Line operated by Okinawa Urban Monorail, Inc. This TESS has a rated output of 500 kW and a battery capacity of 291 kWh. Our TESS was adopted to replace a regenerative resistor system that was previ-

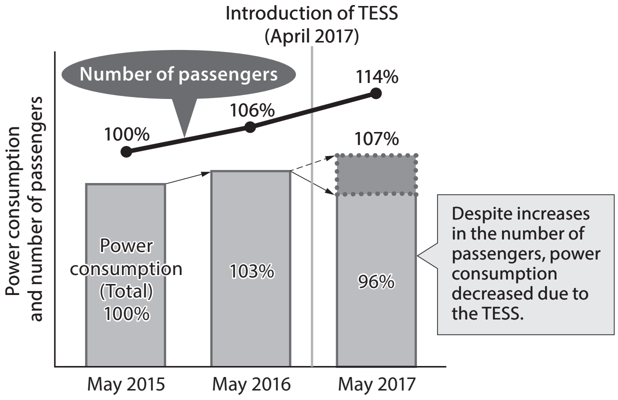

Figure 2. Example of energy-saving effect of TESS installed at Sueyoshi Substation

The TESS provided an 11% reduction in power consumption relative to the power consumption estimated based on the increase in the number of passengers.

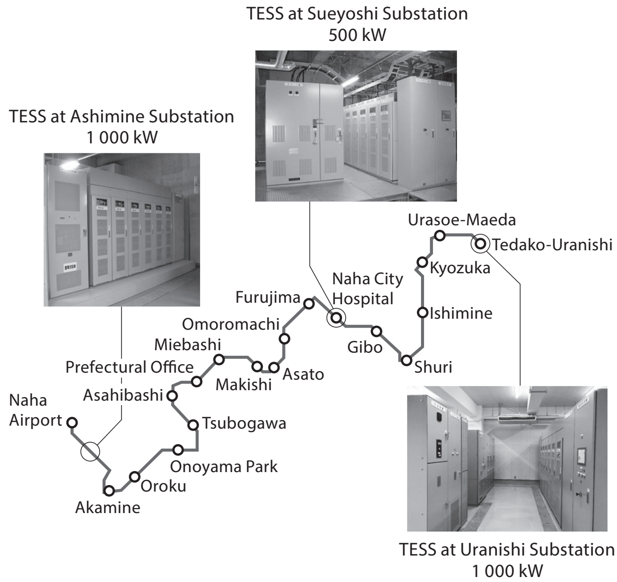

Figure 3. Additional TESS installed on Yui Rail Line

Accompanying the extension of the Yui Rail Line, two sets of TESS were installed at the Uranishi and Ashimine Substations.

ously installed at the Sueyoshi Substation and to serve as an emergency power supply system. The regenerative resistor system dissipates the regenerated energy from trains as heat whereas the TESS reuses it as electric power. Furthermore, the TESS contributes to a reduction in the power consumed for air-conditioning of the substation as it reduces the amount of heat generated at the substation.

Figure 2 shows the energy-saving effect of the TESS at the Sueyoshi Substation. The relationships between the power consumption and the passenger count of the Yui Rail Line before and after the introduction of the TESS are presented in the figure. The number of passengers on the Yui Rail Line has been rising every year. For example, the passenger count increased by 6% from May 2015 to May 2016. As a result, the power consumption of the Yui Rail Line increased by 3% over the same period. The number of passengers in May 2017 showed a 14% increase from the May 2015 level. The power consumption of the Yui Rail Line was therefore expected to increase as well. On the contrary, however, the power consumption decreased to 96% of the May 2015 level as a result of the introduction of the TESS in April 2017. This equates to an 11% reduction relative to the power consumption estimated based on the increase in the passenger count.

2.2 TESS as emergency power supply in event of wide-area blackout

In the face of a further increase in passengers, Okinawa Urban Monorail needed to increase the transportation capacity of the Yui Rail Line by such measures as reorganizing its timetables. In addition, it extended the Yui Rail Line by 4.1 km from Shuri Station to Tedako-Uranishi Station and increased the number of trains from 12 to 19. In light of this situation, Okinawa Urban Monorail installed two more sets of TESS (**Figure 3**), which commenced commercial operation on October 1, 2019[1]. Their purpose is twofold: to further save energy and to increase the emergency power supply capacity so as to be prepared for the need to evacuate passengers to the nearest station in the event of a wide-area blackout.

We performed a test to determine whether the TESS units have the capacity to allow all of the trains to continue running to the nearest station in the event of a blackout. Since the Yuri Rail Line runs on an elevated track, there is no safe place for passenger evacuation. If passengers become trapped in trains for a prolonged period, they could suffer from heat stroke or other health problems. It was therefore crucial to perform an emergency running test using the TESS.

Table 1 shows the conditions for the emergency running test. **Figure 4** shows an image of a train and changes in the state of charge (SOC) of each TESS during the

Table 1. Conditions for emergency running test using TESS

Condition	Specification	Remarks
Number of TESS units	3	One 500 kW unit and two 1 000 kW units
Battery SOC range used	5 to 90%	
Number of trains operated simultaneously	3	
Traveling distance	34 km per train	One round trip (17 km each way), stopping at every station
Auxiliary vehicle systems	Yes	Continuous use of air conditioners and lighting apparatus

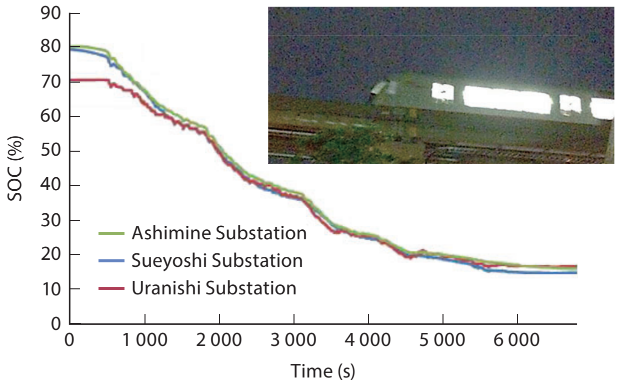

Figure 4. Changes in SOC of each TESS during emergency running test
We performed an emergency running test using power supplied only from the TESS units. The TESS units at the three substations exhibited almost the same changes in SOC.

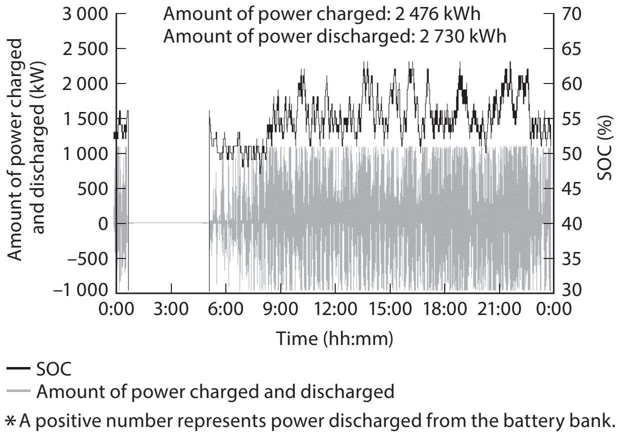

Figure 5. Operation states of TESS installed at Omiya Koen Battery Bank
We confirmed that the TESS is charged and discharged frequently throughout the operating hours of the Tobu Urban Park Line.

emergency running test.

In this test, three trains succeeded in making a round trip on the 17 km, 36-station line while stopping at every station without any speed constraint. As a result, we confirmed that all of the trains can safely continue running to the nearest station even if their power supplies are cut off between stations as a result of a major blackout. The emergency running test also revealed that equalizing the charge-discharge characteristics of the three battery banks helps to even out the discharge from, and therefore the load on, the TESS units. During this test, the three TESS units supplied a maximum combined power of 1 500 kW, which is sufficiently lower than their maximum instantaneous output capability of 2 500 kW.

The emergency running test demonstrated that the TESS units constitute a resilient power supply system capable of propelling all of the trains on the line to the nearest station even in the event of a major blackout.

3. Investigations of performance deterioration of SCiB™

As discussed in Section 2, the TESS makes a significant contribution to the realization of railway infrastructure with enhanced energy conservation, safety, and resilience. It was also necessary, however, to verify that it satisfies the long-term performance requirements of railway operators. Although the SCiB™ features a longer life than conventional lithium-ion batteries, the realization of highly safe and reliable railway infrastructure depends on how long the SCiB™ sustains its performance when incorporated into a TESS.

In order to satisfy such battery requirements, we performed sampling inspections of the SCiB™ modules for a TESS delivered to Tobu Railway Co., Ltd. and measured their performance deterioration(2). This TESS was installed in December 2014 at Unga Station on the Tobu Urban Park Line for the purpose of traction voltage compensation. Its operation was suspended temporarily after the Unga Substation was constructed near the station in March 2016. Then, in February 2017, the TESS was relocated to Omiya Koen Station close to the terminal of the Tobu Urban Park Line to be used as a battery bank for overhead wire voltage compensation.

Figure 5 shows the operation states of the TESS at the Omiya Koen Battery Bank. Since this TESS is used for voltage compensation at the terminal end of a railway line, it is frequently charged and discharged throughout the day, with its SOC varying between 48% and 63%.

Figure 6 shows the layout of the Omiya Koen Battery Bank and the positions of the battery modules subjected to sampling inspections. Since the service life of storage batteries generally depends on their temperature, we sampled three battery modules to measure their deterioration: Battery Modules A and B located at a distance from the air conditioner and thus exposed to a greater temperature rise than other modules, and Battery Module C located near the air conditioner.

Figure 7 shows the results of performance deterioration measurements of these battery modules after roughly five years of use. As metrics of battery performance, we measured their capacity and internal resistance. All three battery modules exhibited no capacity deterioration, maintaining a nominal capacity of 40 Ah. On the other hand, Modules A and B exhibited a slight increase in internal resistance from the factory shipment value because of their exposure to relatively high temperatures (with Module A showing an 8.6% increase and Module B showing a 9.7% increase). In contrast, Module C maintained almost the same internal resistance as the factory shipment value, with only a 0.4% increase. Although the increase in internal resistance slightly differed depending on the temperature condition, the changes in internal resistance were well below the permissible limit (twice the

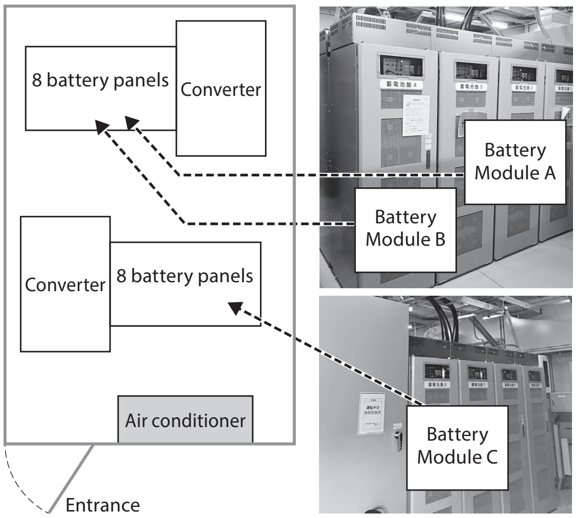

Figure 6. Positions of battery modules subjected to sampling inspections
The temperatures of the battery modules depend on their distance from the air conditioner.

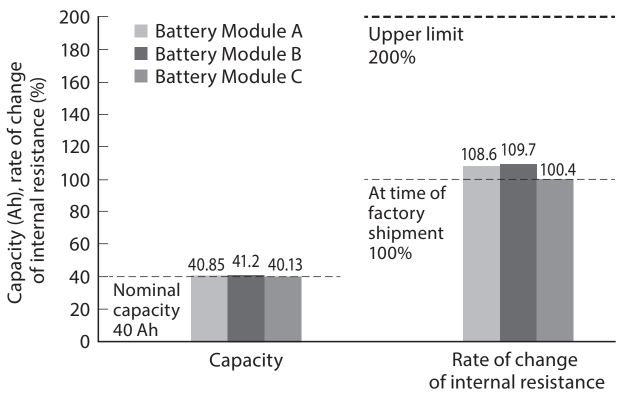

Figure 7. Results of battery performance deterioration measurements
The deterioration of battery performance varied slightly, depending on the temperature. However, the performance of each battery module did not deteriorate significantly from the level at the time of shipment.

resistance of the initial value) for all three battery modules. As a result, we confirmed that all three of the battery modules inspected were in good condition.

The inspection results indicate that the deterioration in performance of the SCiB™ is well below the permissible design limit, demonstrating that our TESS equipped with SCiB™ modules provides high long-term reliability.

4. Overseas deployment of TESS

Following our development of the TESS, we have been offering it to domestic railway operators as described in Sections 2 and 3. Moreover, since 2020, we have been undertaking a project for Dhaka Mass Rapid Transit (MRT) Line-6 in Bangladesh.

Accompanying the economic growth of Dhaka, the capital of Bangladesh, its population has exceeded 15 million. This has led to increased traffic congestion and severe air pollution, which is now having a negative impact on socioeconomic development. MRT Line-6, one of the first urban electrified railway lines in Bangladesh, is being developed to assist in solving these issues. MRT Line-6 will consist of 16 stations along approximately 20 km of elevated tracks extending from the north to the south of Dhaka. We will deliver eight sets of TESS to Dhaka MRT Line-6 (2 MW × 7 and 500 kW × 1).

For this project, we have developed a new user-friendly human-machine interface (HMI) to enable intuitive system monitoring for overseas operators. **Figure 8** shows an example of an HMI display of the TESS. It allows monitoring operations to be performed via a tablet while viewing the HMI screen.

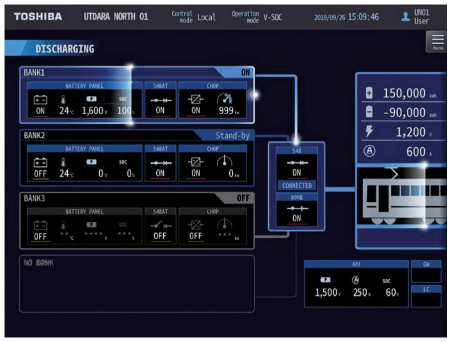

Figure 8. Example of user interface display of TESS
We have developed and released an intuitive graphical user interface for the TESS.

5. Conclusion

This report describes examples of the application of TESS in Japan and abroad and the results of inspections of SCiB™ module deterioration, in which it has been verified that the SCiB™ exhibits little deterioration in performance over time. We will continue to contribute to the realization of a sustainable society both in Japan and abroad while enhancing the value of railway systems.

References

(1) Ieiri, I. "Addition of Traction Energy Storage Systems and Enhancement of Emergency Running Function to Accommodate Urasoe Extension" (in Japanese). *Railway & Electrical Engineering*, 2020 (31)1: 31–37.

(2) Matsumoto, K., Yamaguchi, H. "Operation States of Omiya Koen Battery Bank of Tobu Railway Co., Ltd. and its Performance Deterioration Analysis" (in Japanese). *Railway & Electrical Engineering*, 2021 (32)1: 45–48.

SATAKE Nobuhiko
Railway Systems Div., Global Railway Systems Engineering Dept., Toshiba Infrastructure Systems & Solutions Corp.