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Development of Battery Self-Traction System for N700S Shinkansen High-Speed Train

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Abstract

This paper presents the development of a novel lithium-ion battery self-traction system for emergency such as power failures of the catenary. The system will be introduced in the new Shinkansen train "N700S," which will enter the commercial service in 2020. The purpose is to enable the train to propel itself at the low speed when an earthquake strikes or other long-hour power supply failures occur. The system will also be utilized for shunting trains at the rolling stock depots in night-work maintenance.

In this paper, we overview the downsizing and lightweight efforts of SiC-applied traction system that enable us to install the lithium-ion battery traction system. Then, we explain the concept and the basic structure of the system. Finally, the running test results by using the N700S Shinkansen prototype train for confirmation tests are reported. This lithium-ion battery application to the high-speed train's traction system is the first case in the world.

Keywords: high speed train, battery self-traction, Lithium-ion battery, SiC device, compactness and weight reduction, traction sysytem

1 Introduction

The Tokaido Shinkansen high-speed trains have evolved for improving high-speed transportation, riding comfort and eco-friendliness by introducing the cutting-edge technologies such as power electronics since its inauguration in 1964 [1]. The new Shinkansen train "N700S," which will make a commercial debut in the summer of

2020, Tokyo Olympic year, adopts the latest power device “silicon carbide (SiC)” in the conversion system of the traction system for downsizing and weight reduction. As a result, compared with the former series of Shinkansen train “N700,” the width of conversion system in the traction system is reduced to be a half and the total weight of traction systems in a train is lighten by 20% [2].

Meanwhile, the recent global climate changes sometimes cause the unprecedented natural disasters, which results in train cancelations and delays. Therefore, it has been becoming more important to enhance passenger service quality when catenary power supply failures occur in natural disasters. As for application of batteries to transportations, the hybrid vehicles and electric vehicles with lithium-ion batteries have spread in the automobile industry. In railways, the lithium-ion battery application started to be widely utilized in many ways such as battery hybrid diesel trains, battery-powered trains, battery-power-supply facilities for emergency and others [3,4,5].

With these backgrounds, we developed a novel lithium-ion battery traction system to power the train at low speed in an emergency such as catenary power failure or earthquake [6]. The system is installed in the space released by adoption of the SiC-applied compact lightweight traction system. In this paper, we overview the downsizing and lightweight efforts of SiC-applied traction system that enable us to install the lithium-ion battery traction system. Then, we explain the concept and the basic structure of the system. Finally, the running test results by using the N700S Shinkansen prototype train for confirmation tests are reported.

2 Downsizing and Lightweight efforts of SiC-Applied Traction System

In the design of high speed trains, aiming at higher performance, lightweight and compactness of the traction systems is one of the most important issues in term of train functionality, energy consumption, environmental friendliness and design flexibility of underfloor equipment layouts. Therefore, we developed the silicon carbide device (SiC device) applied traction system to pursue further weight reduction and compactness. The weight reduction and downsizing effects are shown in Fig. 1. The width of developed conversion system for the Series N700S is reduced to a half of conventional one for the Series N700. In terms of weight, the developed traction system for N700S is lightened by 20%, compared with N700.

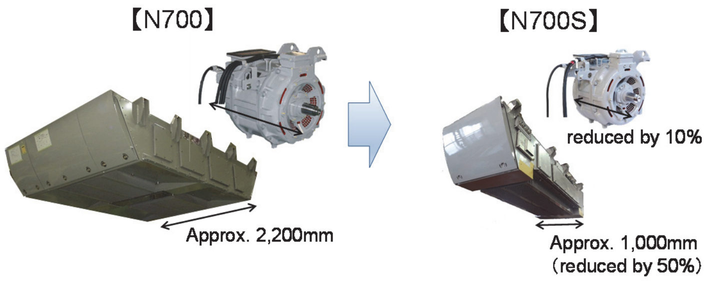

Figure 1: Weight reduction and downsizing results of SiC-applied traction system.

3 Concept of Battery Self-traction System

To enhance service quality for passengers and reduce maintenance work, we developed a novel battery self-traction system for emergency. The system is installed in the space released by adoption of the SiC-applied compact lightweight traction system. The purpose is to propel itself at up to 30km/h and to have a capability of going through the all tunnels and bridges of the Tokaido Shinkansen line from Tokyo to Shin-Osaka as shown in Fig.2. The Traction system of Shinkansen consists of the main transformer, the conversion system and motors. In the normal mode, the system is being charged by the auxiliary power unit as shown in Fig.3. When changing into the self-traction mode, the battery self-traction system gets connected with the conversion system to supply power.

Figure 2: Examples of the usage of self-traction battery system.

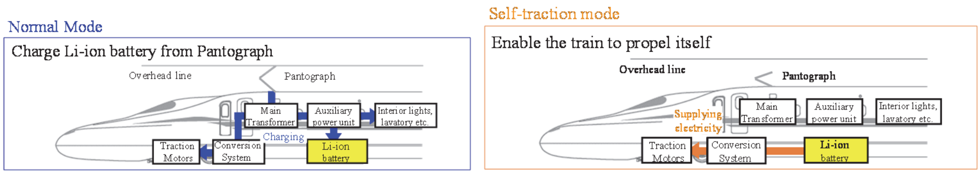

Figure 3: Configuration of battery self-traction system.

4 Configuration of Battery Self-traction System

We adopted the lithium-ion battery whose negative electrode uses lithium titanate oxide for pursuing higher safety, because it has the characteristic to prevent intensive discharging in case of inner short circuit.

Figure 4 shows the simplified circuit diagram of battery self-traction system. The self-traction battery unit mainly consists of a lithium-ion battery unit, line breakers and a control unit. The system itself is designed to be compact and lightweight enough to be mounted on released underfloor space as shown in Fig. 5. In the self-traction mode, the batteries with the voltage of DC750V get connected to the DC link of the conversion system, which is DC 3000V in its normal mode, by changing the combinations of on-off states of the line breakers. To secure safety of the system, the control units supervises on-off states of the line breakers and monitors the temperatures and voltages of each battery cell.

The numbers of the systems equipped in a train was studied in consideration of the capable running distance and the startup of the steepest gradient of the Tokaido Shinkansen alignment. We finally decided to install eight battery self-traction units in a train set. From view point of efficiency and operation procedures, the maximum operation speed is determined to be 30km/h by the running simulation results.

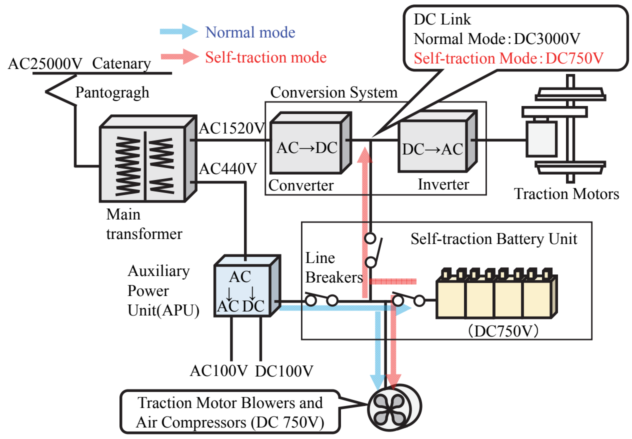

Figure 4: Circuit diagram of battery self-traction system.

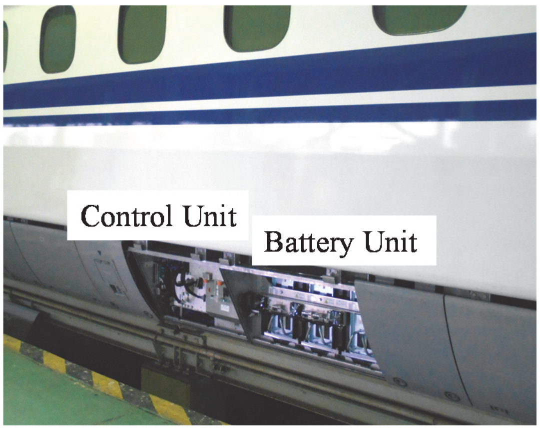

Figure 5: Self-traction battery unit mounted on N700S prototype train.

5 Running Test Results

We conducted running tests by using the Series N700S prototype train for confirmation tests as shown in Fig 6. To confirm the basic performances of the system, we installed four battery self-traction units in the 16-car train for experiments, whereas series-production of N700S will have eight of the units. Figure 7 shows the results of the test running up to a speed of nearly 30km/h. The battery output current was controlled to be larger at speeds of up to 3km/h in considering of steep gradients and then to be constant to keep output power constant. We also confirmed that the decrease in the state of charge (SOC) was also sound enough as we expected. The Series N700S is successfully equipped with its first battery-powered self-traction system using a lithium-ion battery for the world high-speed rail.

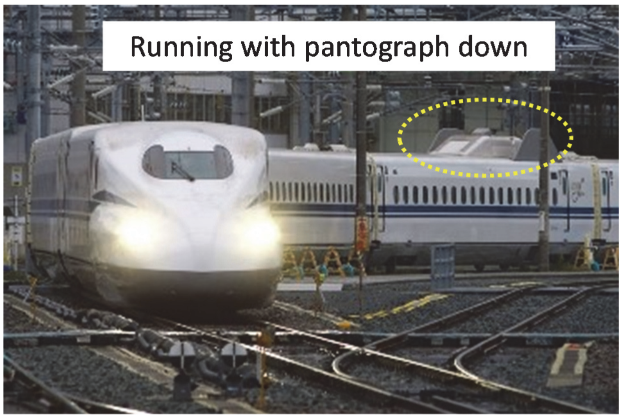

Figure 6: Battery self-traction tests.

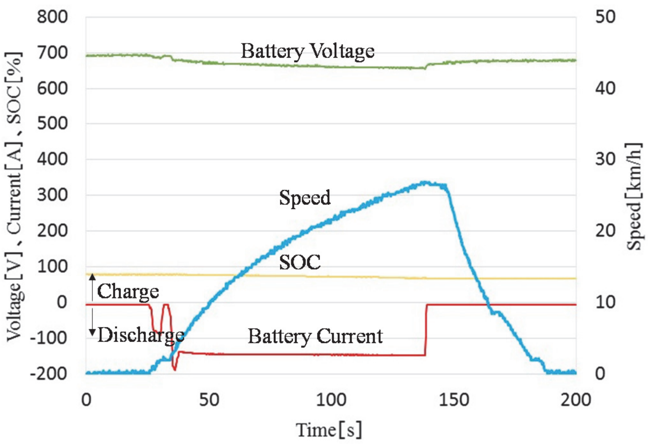

Figure 7: Running test results.

6 Conclusions and Contributions

We developed the silicon carbide device (SiC device) applied traction system to pursue further weight reduction and compactness for the new Shinkansen train N700S. The width of developed conversion system is reduced to a half of conventional one for the Series N700. In terms of weight, the developed traction system for is lightened by 20%.

By utilizing underfloor spaces released by adopting the compact and lightweight SiC-applied traction system, we developed and introduced a novel lithium-ion battery self-traction system for emergency such as power failures of the catenary. The purpose is to propel itself and to have a capability of going through the all tunnels and bridges of the Tokaido Shinkansen line from Tokyo to Shin-Osaka at maximum speed of 30km/h. The system will also be utilized for shunting trains at the rolling stock depots in night-work maintenance.

The battery self-traction itself is simple, compact and lightweight. In the normal mode, the system is being charged by the auxiliary power unit. Once changing into the self-traction mode, the battery self-traction system gets connected with the conversion system to supply power. The eight battery self-traction units will be installed in series-production of 16-car N700S to meet required performances such as statup at steep gradient and running distances. To ensure the safety of the system, we designed the functions which supervises the line breakers and monitors the battery cells.

We conducted running tests by using the Series N700S prototype train for confirmation tests. The results are sound enough to confirm that the performances are what we expected. The battery self-traction system will go into actual used in series-production N700S, which will debut in July 2020. The introduction of the SiC applied traction system and the battery self-traction function to the high-speed train's traction system is the first time in the world.

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