Power Electronics Equipment for Railcars Contributing to Safe, Secure, and Comfortable Public Transportation in the World

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ABSTRACT

Fuji Electric provides traction equipment and electric door systems for railcars that utilize the latest power electronics technology. We have developed compact and lightweight on-board equipment with low-power consumption to save energy and fully active damper drive systems to improve passenger comfort. In addition, we have reduced the failure rate and enhanced the safety of our electric door systems by improving the component configuration and the maintenance processes. We have been actively promoting these products in Japan and overseas markets, such as North America and Asia, and are pursuing to meet overseas standards and to increase local production.

1. Introduction

In order to prevent global warming, various efforts are being made worldwide to reduce greenhouse gas emissions. Transportation-related CO_2 emissions account for approximately 20% of the total CO_2 emissions in Japan. The automotive sector, which accounts for a large portion of the emissions, is rapidly becoming electrified. In addition, railways are an economical means of mass transportation with a small environmental impact that continue to evolve toward the development of a sustainable society by increasing the speed of railcars and achieving weight and energy savings of railcars.

Fuji Electric is contributing to the realization of a sustainable society by reducing environmental burdens through the supply of the latest power electronics products for use in railcars. In this paper, we describe electrical equipment for railcars, such as traction equipment for railcars (main power converters, traction motors, and main transformers), fully-active damper drive systems, and electric door systems, as shown in Fig. 1.

2. Downsizing and Weight Reduction of Traction Equipment for Shinkansen Trains

To achieve energy saving in railcars, it is essential to reduce power consumption by decreasing the mass of the railcars and on-board equipment.

The use of Fuji Electric's SiC power semiconductor

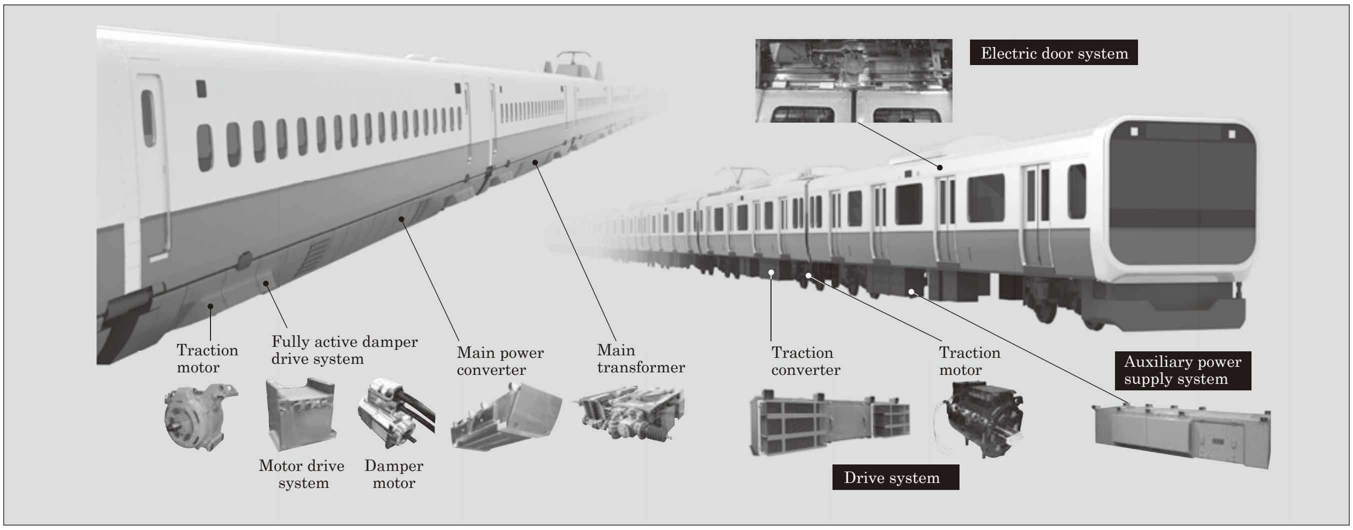

Fig.1 Electrical equipment for railcars

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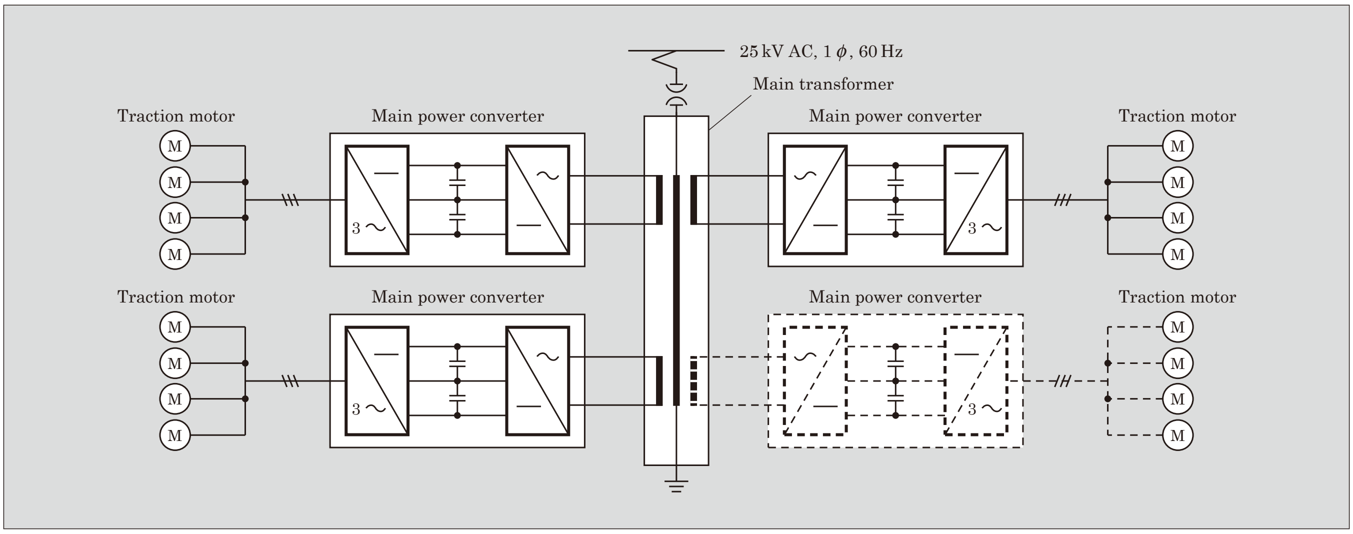


Fig.2 System configuration of traction equipment

modules and optimization of cooling systems have contributed to downsizing and weight reduction as well as achieving a standard railcar of Shinkansen trains*.

We have reduced the size and weight of the main circuit electrical equipment used in the N700S Series Shinkansen trains of Central Japan Railway Company as follows. Figure 2 shows the system configuration of the traction equipment, Table 1 shows the equipment specifications, and Fig. 3 shows the appearance of the traction equipment.

(1) The main transformer was designed to reduce copper loss, using aluminum wires for the windings, and adopted a unit-type cooling system, all of which resulted in 12% smaller and 10% lighter main transformer (in case of secondary winding 4-split types).

(2) The main power converter uses SiC power semiconductor modules that combine low-loss and high-heat-resistant silicon carbide Schottky barrier diodes (SiC-SBDs) and insulated gate bipolar transistors (IGBTs) as power devices to reduce the size and weight of the cooling system.
We optimized the structure and conductor configuration in the power unit and all of which resulted in 9% smaller and 14% lighter main power converter.

(3) For the traction motor, we increased the number of poles from four to six and utilized a low loss iron core material, all of which resulted in 11% smaller and 17% lighter traction motor.

Table 1 Specifications of traction equipment

Item		Specification
Nominal distribution voltage for railways		25 kV AC, single-phase, 60 Hz
Main transformer	System	Single-phase shell-type atmospheric pressure oil-sealed system (Secondary winding: Three-split or four-split)
Main power converter	Circuit configuration	3-level PWM converter 3-level PWM inverter
	Power device	SiC power semiconductor modules
	Cooling system	Natural air in traveling cooling system
Traction motor	System	Squirrel cage induction motor
	Number of poles	6 poles
	Rated voltage	2,300 V AC
	Rated output	305 kW (Continuous rated output)

* A standard Shinkansen railcar can flexibly accommodate the number of railcar consist by reducing the size and weight of the traction equipment under the floor.

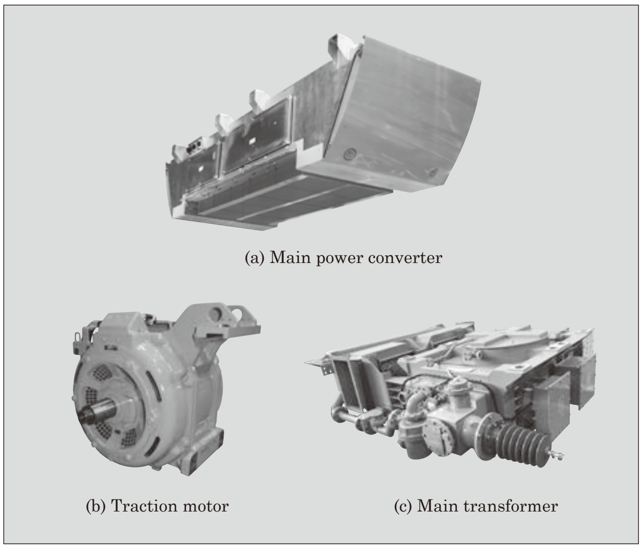


Fig.3 Appearance of traction equipment

The N700S prototype train, equipped with these traction equipment, started running tests in March 2018. Commercial train equipped with equipment enhanced based on these test results has started commercial operations from July 2020 (see Fig. 4).[1]

Fig.4 N700S Series Shinkansen train
(Photo courtesy of Central Japan Railway Company)

3. Improvement of Riding Comfort of Shinkansen Trains Using Fully Active Damper Drive Systems

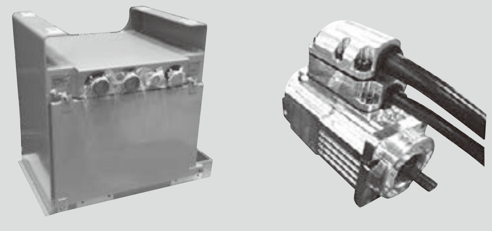
Fully active damper drive systems are installed in the first-class cars (i.e., green cars) of N700S Series Shinkansen trains and control the lateral vibration of the railcar to improve passenger comfort. Fuji Electric has been supplying fully active damper drive systems, consisting of a built-in damper motor and motor drive unit, to be integrated into the fully active damping control systems. The damper motor drives a hydraulic pump that supplies hydraulic pressure to the damper to suppress the lateral vibration of the railcar, improving riding comfort.

Table 2 shows the specifications of the system and Fig. 5 shows the appearance of the system. The following innovations were made in the development of the system.[1]

(1) The motor drive system enclosure has a sealed structure and its internal equipment are cooled only by air circulation inside the enclosure. This reduces the number of parts that need to be replaced periodically, such as filters.
(2) The damper motor has been downsized so that it can be outfitted in the limited space in the bogie.
(3) The damper motor has been improved in vibration resistance to be mounted in the bogie.

Table 2 Specifications of fully active damper drive system

Item		Specification
Motor drive system	Input voltage	100 V AC
	Output voltage	100 V AC (three-phase)
	Structure	Sealed enclosure, waterproof and dustproof
Damper motor	System	Synchronous motor
	Voltage	100 V AC (three-phase)
	Rated torque	1.1 N·m
	Rated rotational speed	3,000 r/min



(a) Motor drive system (b) Damper motor

Fig.5 Appearance of fully active damper drive system

4. Actions to Achieve Safety and Reliability in Electric Door Systems for Conventional Lines

The safe and secure operation of railways is achieved through the daily maintenance of railway companies. However, there is an urgent need to revise maintenance approaches in order to cope with the expected future decline in Japan's workforce. Electric door systems have many advantages over conventional pneumatic door systems in terms of safety, ease of installation, operation, and maintenance, as shown in Table 3.

Fuji Electric has been delivering electric door systems for the Series E235 trains of East Japan Railway Company. The motor of this door system uses fewer permanent magnets than existing electric door systems using linear motors, resulting in a 14% weight reduction for the entire system. By reducing the number of

Table 3 Comparison of electric and pneumatic door systems

	Electric door system	Pneumatic door system
Safety	In case of power failure, the locking device can maintain the door closure. Its highly sensitive door obstruction detection control function uses a servo motor to reduce the risk of being trapped the doors.	In case of power failure, there is a risk of door opening due to loss of air pressure. Its door obstruction detection sensitivity is low, and the risk of being trapped the doors is high.
Mountability	It consists of only electrical wiring and modular mechanical parts, making it easy to mount and dismount equipment.	It has mechanical parts, air piping, wiring for solenoid valves, and other components, making it hard to mount and dismount equipment.
Operability	The operation patterns and conditions can be modified based on assumed passenger behavior using control software.	The operation pattern and conditions cannot be modified easily due to mechanical limitations.
Maintainability	The life cycle cost can be kept low due to the minimized lubrication and maintenance for the mechanical parts.	A wide range of maintenance tasks are required, including those for mechanical parts, piping parts, and compressors.

mechanical adjustment points and parts, we have reduced the life cycle cost and the failure rate.

Figure 6 shows the configuration of the electric door system, and Fig. 7 shows the principle of operation.

This door system consists of a motor that serves as the power source for opening and closing door panels, a main unit that houses a rack-and-pinion mechanism that transmits the motor power to the door panels, a locking device that ensures locking when the door is closed, a controller that controls the motor and locking device, a sliding door rail and a door hanger that holds the door panel. In particular, by co-axial mounting of the pinion to the motor shaft, the permanent magnet motor directly drives the upper and lower racks. Without transmission gear, this simple mechanism reduces the number of parts and maintenance costs.

The locking device consists of a lock pin, solenoid, and an unlocking handle. With the door panel in the door closed position, the lock pin is lower position going through the lock hole on the door side to keep the door panel closed. When opening the door, the solenoid lifts the lock pin to unlock the door through an opening command from the controller. In case of maintenance or emergency, the door is unlocked by pulling up the lock pin using the unlocking wire through operating the unlocking handle.

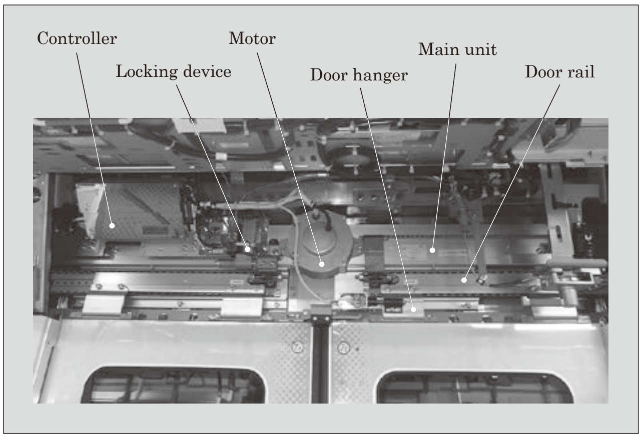


Fig.6 Configuration of the electric door system

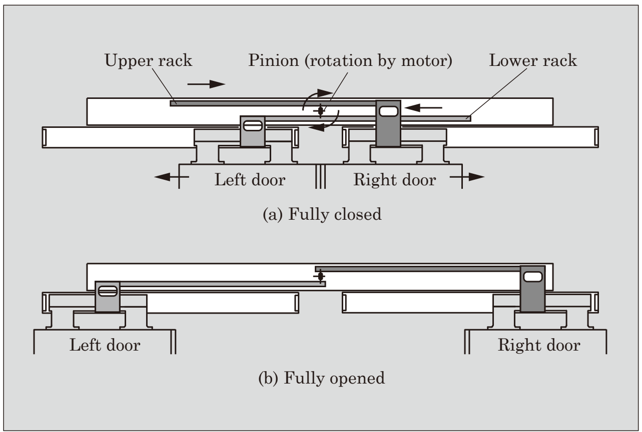


Fig.7 Principle of electric door system operation

Fig.8 Series E235 train
(Photo courtesy of East Japan Railway Company)

This simple locking device structure expands the flexibility of the operation sequence in locking and unlocking operations.(2)

As a result of applying the latest door obstruction detection sequence to this locking device, we were able to prevent the pilot lamp (which indicates whether the train is permitted to run or not) from lighting up momentarily when a thin obstacle is trapped by the doors. This functionality improves safety and is more sensitive than Fuji Electric's existing system in detecting door trapping and dragging.

The control unit also has a status monitoring function and a fault diagnosis function of the door system. The railway companies can use these data of the door system for their condition based maintenance (CBM) through on-board transmission system.

This electric door system is mounted on the Series E235 trains of East Japan Railway Company. The Series E235 trains (see Fig. 8) for the Yokosuka and Sobu Express Lines are equipped with advanced equipment developed using the knowledge gained from the Series E235 trains of the Yamanote Line. These trains started operation from December 2020.

5. Actions for Overseas Market

The demand for railcars in the market outside Japan is expanding, mainly due to the renewal of existing lines in North America and the construction of new lines in Asia. To meet this market requirements, Fuji Electric is working to comply with overseas standards and establish maintenance systems through local production and local affiliates companies in order to actively promote expansion into overseas markets.

5.1 Compliance with international and overseas standards

For the North American market, Fuji electric updated the rating of system software to comply with capability maturity model integration (CMMI) in 2019 through the formal assessement by certified personnel. We will continue our efforts to improve the design quality by updating and upgrading our rating based on the latest regulations.

For the Asian market, compliance with functional safety standards are also required. We have our internal and external audit personnel perform audit activities according to the target functions and levels required in each region, while also promoting product development.

In addition, we are using the knowledge gained from these activities in North America and Asia to design standard product concepts and improve our daily operations.

5.2 Establishment of local production and maintenance service systems

Railways are an important infrastructure for public transportation. It is necessary to establish maintenance systems for railcar equipment that can handle inquiries about operation and maintenance and respond to emergencies in the case of malfunction. Fuji Electric has established a system that our affiliates and subcontractors located near the offices of major customers provide maintenance services in the United States, and Asia. Furthermore, local production has become necessary to meet customer requirements. In particular, we established Fuji SEMEC to strengthen our local production and maintenance service systems in the United States to meet the demands of overseas customers for door systems.

6. Postscript

In this paper, we described power electronics equipment for railcars that contribute to safe, secure, and comfortable public transportation in the world. The products used in this field contribute to the protection of the global environment by achieving compactness, weight savings, high performance and high reliability operation based on the leading edge power electronics technology. They are also helping to realize a sustainable society through the development and maintenance of safe, reliable, and comfortable public transportation by integrating social needs and various technologies to ease and reduce maintenance and improve availability.

We will continue actively pursuing research and development forwarding of social and market needs such as those involving energy saving and environmental protection, while offering products that contribute to reducing the overall environmental burden of society.

References

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(2) Fujita, K. et al. Passenger Door System for Series E235 Train of East Railway Company (Yamanote Line) Designed to Improve Transportation Quality. FUJI ELECTRIC REVIEW. 2018, vol.64, no.1, p.44-48.

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