Technologies to Reduce Size and Weight of Power Electronics Equipment for Rolling Stock

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ABSTRACT

Recently, there have been strong demands for power electronics equipment mounted on devices and units to be installed in rolling stock to have a smaller size, less weight and also to save energy. Fuji Electric has been meeting these demands by improving its cooling and equipment mounting technologies. For isolation transformers, which had limitations in terms of their downsizing, we have adopted a medium-frequency isolation circuit technology and direct current power supply system and implemented an optimized design to reduce the ratio of their installation space to the unit volume, thereby realizing further size and weight reduction. We offer in Japan and overseas power electronics equipment that uses the latest technologies such as propulsion systems and auxiliary power supplies for rolling stock including the Shinkansen.

1. Introduction

In recent years, the power electronics equipment mounted to devices and units installed for improving passenger services and vehicle functions of electrical rolling stock have been required to be not only energy efficient, but also more compact and lightweight. In order to meet these demands, Fuji Electric has enhanced its cooling technology and equipment mounting technology, while also adopting and optimizing the design of medium-frequency isolation circuit technology. In this paper, we describe the size and weight reducing technologies of our power electronics equipment by providing application examples, which include the traction converter for Shinkansen trains (bullet trains) operated by Central Japan Railway Company (JR Central) and the auxiliary power supply for rolling stock operated by Hokkaido Railway Company (JR Hokkaido).

2. Power Electronics Equipment for Electrical Rolling Stock

Power electronics equipment for electrical rolling stock (see Fig. 1) are required to meet a diversity of demands ranging from social requirements which include energy conservation and harmonization with the environment to railroad company requirements which include a reduced cost, higher output, compactness, lightweigh, easier maintainability, lower noise and improved control performance, while also having the safety and reliability features required of public transportation.

Fuji Electric has been working on the development of next-generation technology for its electrical rolling stock propulsion system (drive system including the traction motor, control unit, traction converter and traction transformer), auxiliary power supply and electrical driven doors (side sliding door closing device). In particular, our propulsion system for Shinkansen trains has been continuously adopted starting with the first Series Zero Shinkansen train up to the latest N700A Shinkansen train, so we have a history of providing the propulsion system for the Shinkansen train all throughout its successive generations. The system is reliable and safe, and it has gained a high reputation in Japan as a product with a proven track record. Furthermore, we have also been providing propulsion systems and auxiliary power supplies for conventional railroad lines in both the Japanese and overseas markets since the 1950s.

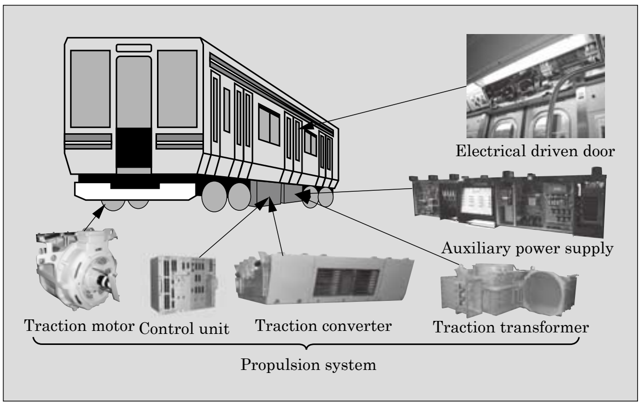

Fig.1 Power electronics equipment for electrical rolling stock

3. Size and Weight Reducing Technology

In this section, we will describe the downsizing and weight reducing technologies of our propulsion systems and auxiliary power supplies for electrical rolling

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stock.

3.1 Improved cooling performance for the traction converter of Shinkansen trains

We will give a brief description of the cooling technology and equipment mounting technology adopted for the traction converter of the latest N700A Shinkansen train (see Fig. 2) operated by JR Central.

The traction converter, as shown in Fig. 3 is configured with a 3-level pulse width modulation (PWM) converter and 3-level variable voltage variable frequency (VVVF) inverter. The system is driven by combining 4 traction motors connected in parallel with the single VVVF inverter. It is designed to have enhanced efficiency and a reduced weight by adopting a low-loss snubber-less system mounted to a high blocking voltage, large-capacity, low-loss insulated gate bipolar transistor (IGBT) module (3,300 V, 1,200 A).

Fig.2 N700A Shinkansen train (photo courtesy of Central Japan Railway Company)

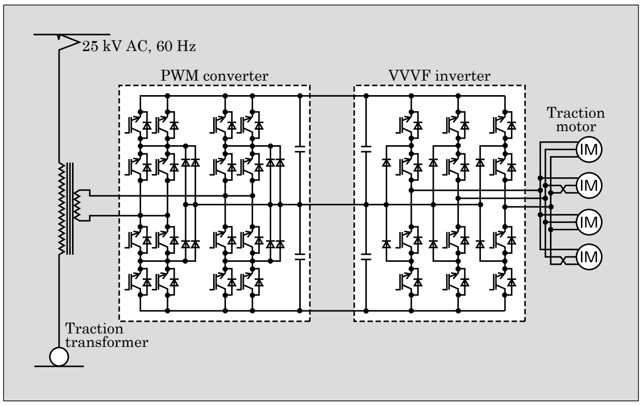


Fig.3 Configuration of traction converter for N700A Shinkansen trains

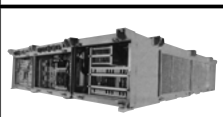
A comparison of traction converters for Shinkansen trains is shown in Table 1. The TCI3 model traction converter, which started being utilized in the Series N700 Shinkansen trains in 2007, has an optimized structure and has eliminated the need for a snubber circuit, and these enhancements have helped it realize a reduced mass of 43% and reduced unit volume of 22% compared with the TCI1 model traction converter used in the Series 300 Shinkansen trains. The cooling system is based on the same exact system used in the Series 300 and the Series 700 Shinkansen trains, combining forced air cooling by means of a blower and boiling cooling through use of a coolant.

The TCI100 model traction converter, which started being utilized in the Series N700 Shinkansen trains in 2008, makes use of a blower-less and coolant-less cooling system based on a simple aluminum cooling fin and traveling wind self-cooling system that actively utilizes wind as cooling air by means of the moving train. This has allowed the TCI100 model to have the exact same external dimensions as the TCI3 model traction converter, while reducing its mass by 12% (50% less compared with the Series 300). The blower-less system also reduces noise in the passenger compartment, while improving comfortability.

The TCI101 model traction converter, which started being utilized in the N700A Shinkansen trains in 2013, inherits the same exact blower-less cooling system adopted by the TCI100 model traction converter, while achieving a reduced unit volume of 25% (42% less compared with the Series 300) and a reduced mass of 17% (59% less compared with the Series 300). We were able to achieve the size and weight reductions by studying, in collaboration with our customers, the auxiliary circuit systems such as the charging circuit, as well as by reviewing the specifications of electronic components and changing the material of the aluminum cooling fin.

In the future, we plan to continue proposing and developing products that further reduce the size and weight of traction converters used in the N700A Shinkansen trains.

Table 1 Traction converter for Shinkansen trains

Shinkansen trains	Series 300	Series 700	Series N700	Series N700	N700 A
Traction converter	 TCI1 model	 TCI2 A model	 TCI3 model	 TCI100 model	 TCI101 model
Volume ratio (%)	100	82	78	78	58
Mass ratio (%)	100	74	57	50	41

3.2 Adoption and optimization of design of medium-frequency isolation circuit technology

(1) Challenges facing commercial frequency isolation systems (conventional systems)

The auxiliary power supply converts voltage from the overhead line (600 to 825 V) to a voltage that can be used by general devices and equipment. In order to ensure safety, the overhead line side and the load side need to be isolated. Up until now, isolation was generally performed by a transformer after the inverter makes conversion into an AC voltage of a commercial frequency (see Fig. 4).

However, advances in technology have enabled continued downsizing of power units and control units, but downsizing for commercial frequency transformers has reached its limits along the way.

Figure 5 shows the external appearance of an auxiliary power supply used by the Washington Metropolitan Area Transit Authority. This unit has achieved a smaller size than previous products of the same functionality by improving the arrangement of components, but this has also led to increased transformer occupancy (see Fig. 6).

(2) Application of medium-frequency isolation system and DC power feeding system

The following technology has been developed to reduce transformer occupancy, while further decreasing the size of the auxiliary power supply.

(a) Medium-frequency isolation circuit technology (approx. 10 kHz)

(b) DC power feeding system

Auxiliary power supplies developed for Hokkaido Railway Company are devices that take advantage of these size and weight reducing technologies (see Fig. 7).

As shown in Fig. 8, this unit adopts the medium-

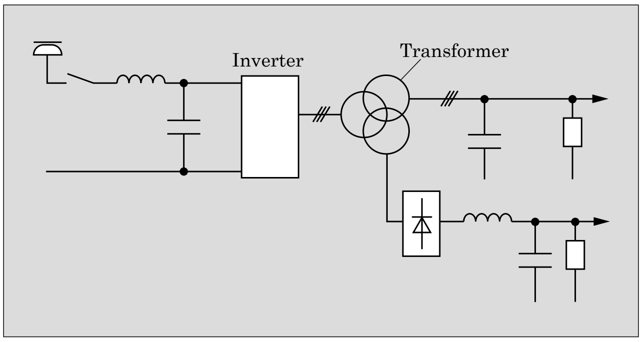


Fig.4 Configuration of general auxiliary power supplies

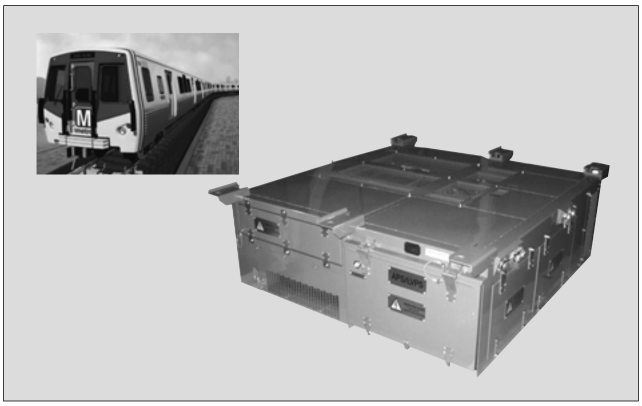


Fig.5 Auxiliary power supply used by Washington Metropolitan Area Transit Authority

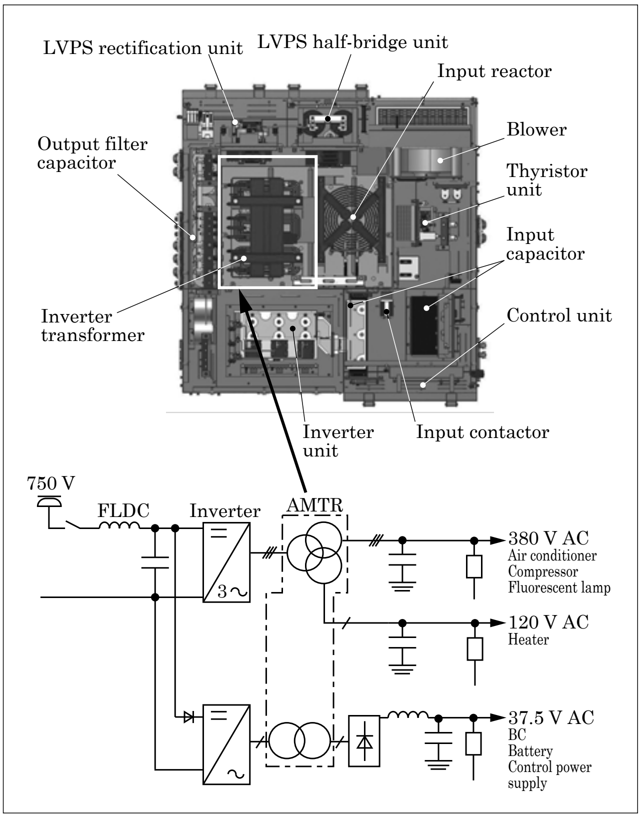


Fig.6 Configuration of auxiliary power supply used by Washington Metropolitan Area Transit Authority

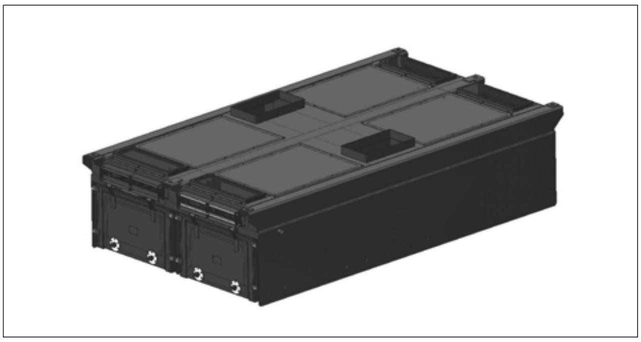


Fig.7 Auxiliary power supply for Hokkaido Railway Company

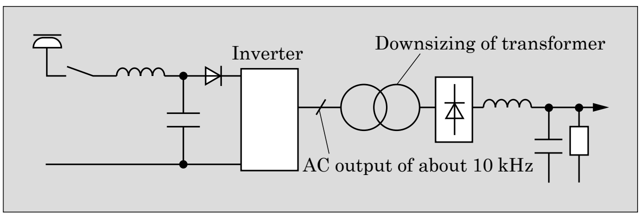


Fig.8 Medium-frequency isolation circuit system

frequency isolation circuit system that is designed so that the inverter converts DC to a medium-frequency AC, and after isolation is made by the medium-frequency transformer, rectification is implemented by means of a diode bridge. Higher-frequency enhancements have enabled the transformer to achieve a reduced size by reducing the size of the core via a lower magnetic flux density as well as by decreasing the number of coil windings, while also making it possible for the inverter to attain a reduced size by applying a resonance circuit. By doing this, significant size and weight reductions have been achieved (75% reduction compared with previous products), and as a result, transformer occupancy has been decreased to 5%.

Furthermore, power has generally been supplied by an AC voltage of a commercial frequency for load devices such as the inverter air conditioner, which becomes a load for the auxiliary power supply, but we have worked in partnership with Hokkaido Railway Company, and as a result, we have been able to change the specifications of the load devices and are now utilizing a DC power feeding system (see Fig. 9). This has resulted in a reduction of not only AC output circuits (inverter circuits) for the auxiliary power supply, but also rectification circuits for the load devices, and this enhancement has contributed to reducing the size of the auxiliary power supply and the overall weight of the train.

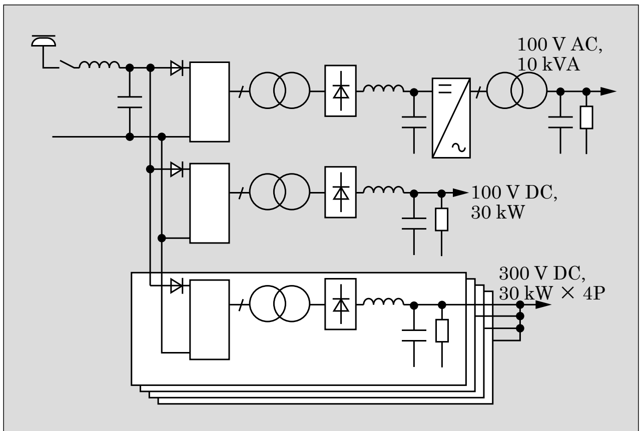


Fig.9 Configuration of medium-frequency auxiliary power supply in DC power feeding system

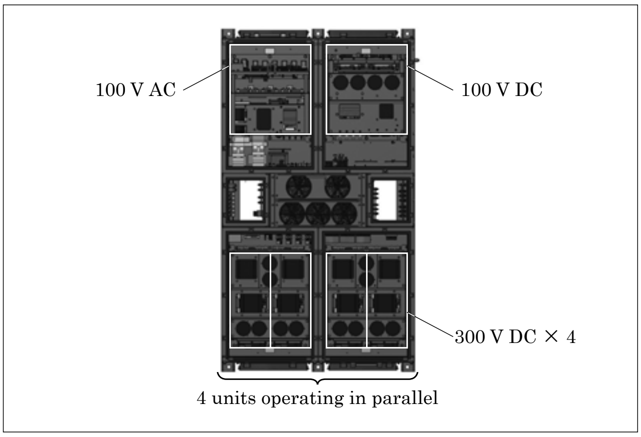


Fig.10 Medium-frequency auxiliary power supply

The medium-frequency isolation circuit can be applied to relatively small-capacity devices. Therefore, by connecting in parallel 4 optimally designed compact devices with a capacity of 30 kW, this unit can achieve the features of a high-capacity device, while being smaller and lighter than conventional units (see Fig. 10). Auxiliary power supplies need to be compatible with the various output specifications required of the power feeding systems of electrical rolling stock, but this unit makes it possible by simply changing the number of parallel connections.

4. Postscript

This paper described the size and weight reducing technologies used in power electronics equipment for electrical rolling stock. These fields are based on the most advanced power electronics technology, and in addition to features such as being small, lightweight, high performance, highly functional, maintenance friendly and comfort enhancing, they are also becoming increasingly important in response to social themes such as contributing to the conservation of the global environment.

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

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