

# VVVF Inverters Using SiC Hybrid Modules for Renovated 5000 Series Railcars of Sanyo Electric Railway Co., Ltd.

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To cope with the environmental issues such as global warming, energy saving in the transportation equipment has been proceeded. In railcars, the energy losses in power electronic equipment such as variable voltage variable frequency (VVVF) inverters for propulsion and auxiliary power supplies have been steadily reduced. In this situation, Fuji Electric has developed a compact and lighter VVVF inverter applicable to urban and commuter railways using own developed low-loss semiconductor devices.

The inverter has employed SiC hybrid modules, combining silicon carbide-Schottky barrier diodes (SiC-SBDs) and insulated gate bipolar transistors (IGBTs), and significantly reducing the inverter losses. In addition, the speed sensorless vector control improves the system reliability by eliminating the speed sensor.

## 1. Features

The main features of this product are as follows:

- (a) Fuji Electric's SiC hybrid modules with 3.3 kV and 1,200 A ratings have significantly reduced the inverter losses.
- (b) The highly efficient fin structure of the cooling system, utilizing the airflow in traveling, has eliminated the heat pipes.
- (c) Speed sensorless vector control has been developed to control a motor without a speed sensor by estimating the actual speed based on the voltage and current.

With these technologies, the product achieved a 64% volume reduction and a 45% mass reduction from the conventional product.

## 2. Commercial Application

This product was applied to propulsion systems for the renovated 5000 Series railcars of Sanyo Electric Railway Co., Ltd. Figure 1 shows the appearance of the renovated 5000 Series railcars, and Table 1 shows the major specifications. Figure 2 shows the train consist (car formation) and the details of the renovation. Out of six-car-set, No. 1 and No. 2 cars (Hanshin Umeda side), previously adopting the superimposed field excitation control, were renovated. Car No. 1 was converted to a trailer, and this VVVF inverter was



Fig.1 Renovated 5000 Series railcars

Table 1 Specifications of Renovated 5000 Series railcars

Item		Specifications
Electric system		1,500-V DC overhead wire system
Railcar performance	Acceleration	2.8 km/h/s
	Deceleration	Service: 4.0 km/h/s max. Electrical braking: 3.2 km/h/s
	Maximum speed	110 km/h
Control method		Speed sensorless vector control 1C2M × 2 group 2-level VVVF inverter
Inverter cooling system		Traveling airflow cooling system
Traction motor		Induction motor, 180 kW rating, 4 poles, 1,100 V, 120 A
Braking method		Electrically controlled pneumatic brake combined with regenerative brake

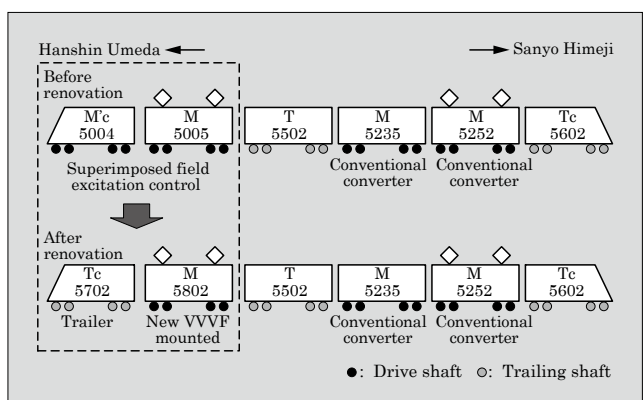


Fig.2 Train consist (car formation) and renovation

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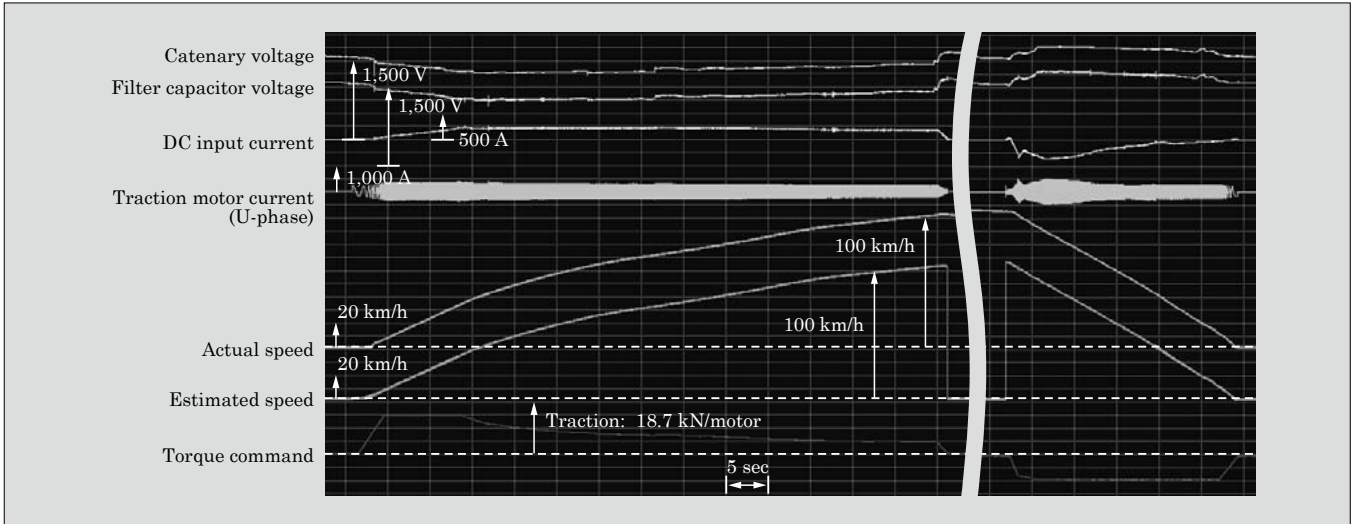


Fig.3 Acceleration and deceleration data from main track test run

mounted on Car No. 2.

Figure 3 shows the acceleration and deceleration data from the main track test run. Figure 3 shows that the estimated speed followed the actual speed, and the testing railcars performed good acceleration (at powering) to the maximum operating speed of 110 km/h and deceleration (at braking).

### 3. Background Technology

#### 3.1 Own developed SiC hybrid module

Figure 4 shows the appearance of the SiC hybrid module mounted on the VVVF inverter. Figure 5 compares the energy losses between the SiC hybrid module and the conventional Si-IGBT module. In addition to the energy losses reduced in the semiconductor devices, we have adopted the traveling airflow cooling system to cool the radiator of the inverter circuit with the traveling airflow, and reduced the volume and weight of the VVVF inverter by 64% and 45%, respectively.

Figure 6 shows the appearance of the VVVF inverter with a traveling airflow cooling system.

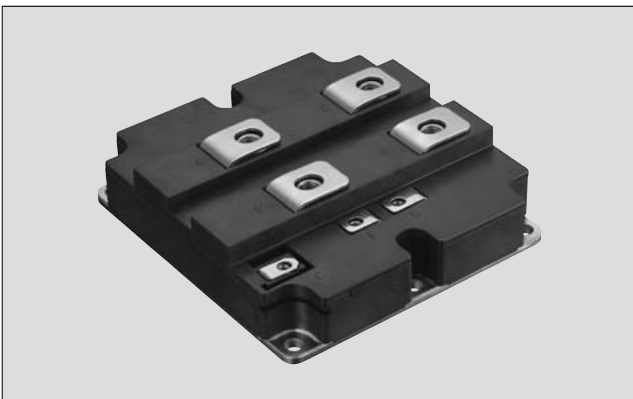


Fig.4 SiC hybrid module (3.3 kV/1,200 A)

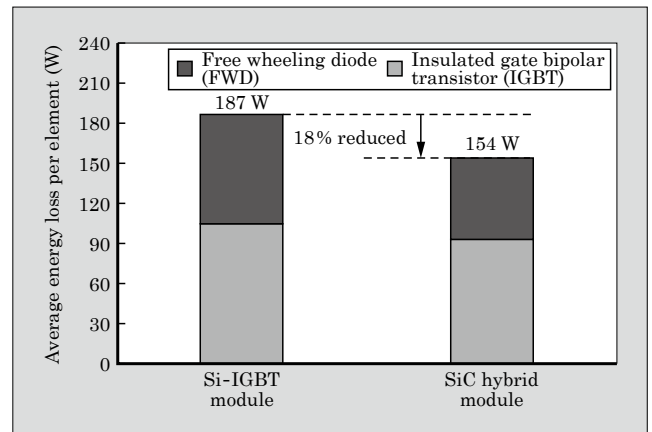


Fig.5 Energy loss comparison

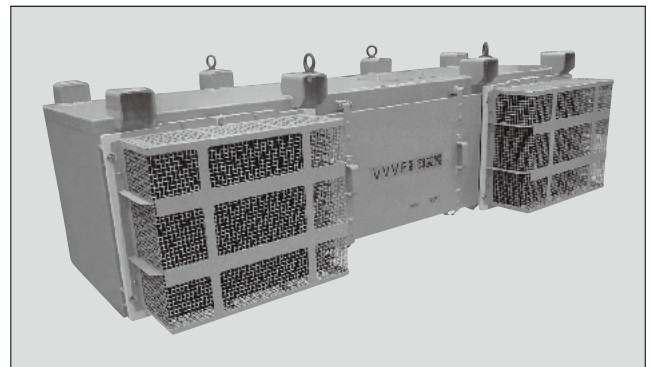


Fig.6 VVVF inverter

#### 3.2 Speed sensorless vector control

Figure 7 shows a block diagram of the speed sensorless vector control. This control improves the system reliability through

- Estimating the actual speed by the flux estimation from the voltage and current, and
- Controlling a motor speed without using an external speed sensor.

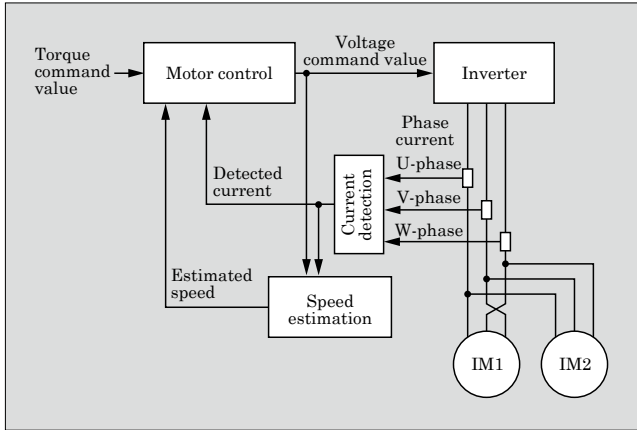


Fig.7 Block diagram of speed sensorless vector control

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