

Efficiency Improvement of Boost Converter for Fuel Cell Bus by Silicon Carbide Diodes

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ABSTRACT

The adoption of silicon carbide (SiC) power semiconductors is regarded as a promising means of improving the fuel efficiency of all types of electrically powered vehicles, including plug-in, electric, fuel cell, and hybrid vehicles (PHVs, EVs, FCVs, and HVs). For this reason, adoption in a wide variety of vehicles is currently being studied, including in the fuel cell (FC) boost converter of an FC bus. The FC boost converter controls the output voltage of the FC up to 650 V. In this research, SiC Schottky barrier diodes (SiC-SBDs) were adopted in the upper arm of an FC boost converter. Since the forward voltage (V_f) of SiC-SBDs is smaller than conventional Si-PiN diodes (Si-PiNDs), the conduction loss of SiC-SBDs is correspondingly smaller. Recovery loss can also be reduced by at least 90% compared to Si-PiNDs since the recovery current of SiC-SBDs is substantially smaller. Lowering the recovery current of the upper arm has the effect of reducing the superimposed current when the silicon insulated gate bipolar transistors (Si-IGBTs) in the lower arm turn on. As a result, the turn-on loss of the lower arm can be reduced by approximately 70%. It was confirmed that installing SiC-SBDs in the upper arm of the FC boost converter improved efficiency by 0.5% in the load range over 50%.

CITATION: Sugiura, T., Tanida, A., and Tamura, K., "Efficiency Improvement of Boost Converter for Fuel Cell Bus by Silicon Carbide Diodes," *SAE Int. J. Alt. Power*, 5(2):2016, doi:10.4271/2016-01-1234.

1. INTRODUCTION

The development and popularization of hybrid vehicles (HVs) is continuing to relieve environmental issues. Power electronics components such as the motor, generator, high-voltage battery, and power control unit (PCU) are key parts of all environmentally friendly vehicles (Fig. 1). In particular, research is currently examining ways of reducing the size and loss of the PCU by improving the performance of its main power module and silicon (Si) power semiconductor components. However, with Si power semiconductors close to inherent material performance limits, focus has shifted to the adoption of next-generation silicon carbide (SiC) power semiconductors.

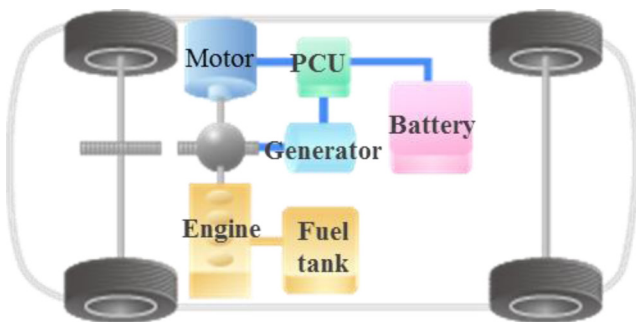


Figure 1. Hybrid system configuration

SiC power semiconductors are capable of reducing conduction and switching loss compared to conventional Si semiconductors. Using this characteristic, SiC is regarded as a promising material for helping

to improve the fuel efficiency of HVs and other environment-friendly vehicles, as well as for reducing the size of power converters such as the PCU [1][2].

Extending beyond HV systems, this research studied the installation of SiC Schottky barrier diodes (SiC-SBDs) in the boost converter that controls the FC voltage of a bus equipped with a new type of FC system. This FC bus (called as the Toyota Oiden Bus) started operation along a route in Toyota city on January 9, 2015. (Fig. 2, Tab. 1)

This paper describes the efficiency improvement of adopting SiCSBDs in an FC boost converter supported by the data obtained during operation of the FC bus.



Figure 2. New FC bus with SiC power semiconductor



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Table 1. New FC bus specifications.

Vehicle	Length/width/height	10,525/2,490/3,340 mm
	Capacity (seated, standing, and driver)	77 (26+50+1)
FC stack	Name	Toyota FC Stack
	Type	Solid polymer electrolyte
	Max output	114 kw $\times$ 2 units/155 PS $\times$ 2 units
Motor	Type	AC synchronous
	Max output	110 kw $\times$ 2 units/149.5 PS $\times$ 2 units
	Maximum torque	335 N-m $\times$ 2
High-pressure hydrogen tank	Type	Compressed hydrogen
	Maximum filling pressure	70 MPa
	Number	8
Drive battery	Type	Nickel-metal hydride
	Maximum output/voltage	9.8 kw/DC300 V

2. SYSTEM OUTLINE

2.1. FC System Outline

Figure 3 shows the FC system for a bus that includes two individual FC systems. The voltage of the FCs is boosted up to 650 V by the boost converters, and it is converted into alternating current (AC) by the PCUs to drive the motors.

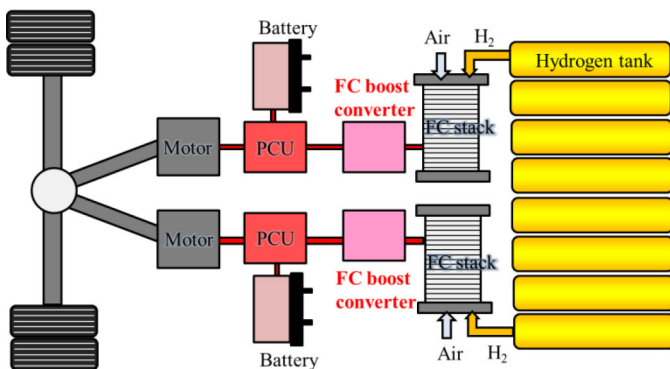


Figure 3. New FC bus system.

2.2. Boost Converter

Figures 4 and 5 show a simplified circuit diagram and the external appearance of the FC boost converter, respectively. In the boost circuit, the reactor current generated by the silicon insulated gate bipolar transistors (Si-IGBT) in the lower arm flows in the diodes of the upper arm.

Figure 6 shows the installed SiC-SBDs and an image of the power module. The installed SiC-SBDs (6mm $\times$ 6mm) are roughly half the area of conventional Si-PiN diodes (Si-PiNDs). Multiple power modules were installed inside the FC boost converter upper arms shown in Fig. 4. Lower arm diodes are Si-PiNDs, because the role of the lower diodes is protection of Si-IGBTs.

This installation method (without changing the control or structure of the system) was selected to isolate the effect of the SiC-SBDs.

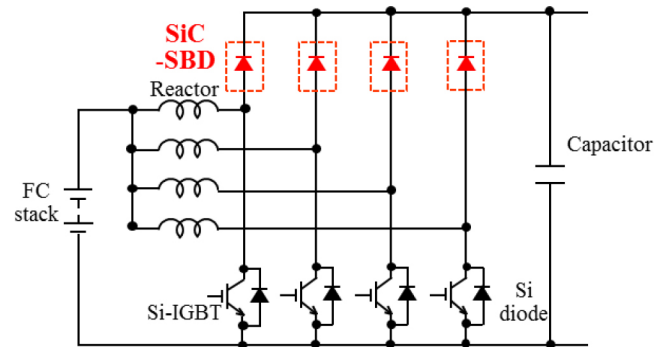


Figure 4. Electronic circuit diagram of boost converter.



Figure 5. FC boost converter.

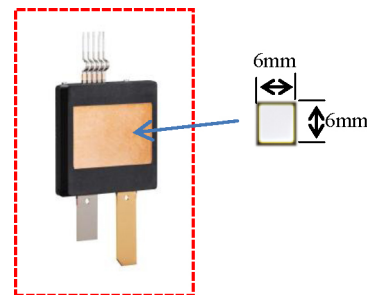


Figure 6. Power module and SiC-SBD.

3. TEST RESULTS

3.1. Forward Characteristics

Figure 7 compares the forward characteristics (V_f) of conventional Si-PiNDs and the installed SiC-SBDs. Since the variation of V_f of SiC-SBD according to current and temperature is smaller than those of Si-PiND, the forward conduction loss of SiC-SBDs is correspondingly smaller.

Figure 8 shows the temperature characteristics of the forward voltage V_f at the rated current. Si-PiNDs have negative temperature characteristics, i.e., the V_f decreases as the temperature rises. Consequently, the current imbalance between parallel-connected devices becomes larger. In contrast, SiC-SBDs have positive temperature characteristics, i.e., the V_f increases as the temperature rises. As a result, the current imbalance between devices driven in parallel is smaller than with Si-PiNDs.