

40 kW/L High Switching Frequency Three-Phase 400 Vac All-SiC Inverter

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Abstract

We, the R&D Partnership for Future Power Electronics Technology (FUPET), have reported a forced-air-cooled 600 Vdc three-phase 400 Vac inverter built with SiC-JFETs and SiC-SBDs and designed to attain an output power density (OPD) of 40 kW/L with a switching frequency (f_{sw}) of 50 kHz. This paper reports the test results of this inverter attaining an OPD of 40 kW/L in operating a 3-phase motor with $f_{sw} = 50$ kHz, and an OPD of more than 60 kW/L in operating an equivalent circuit with $f_{sw} = 20$ kHz by adopting specialized high speed drive circuit boards.

Introduction

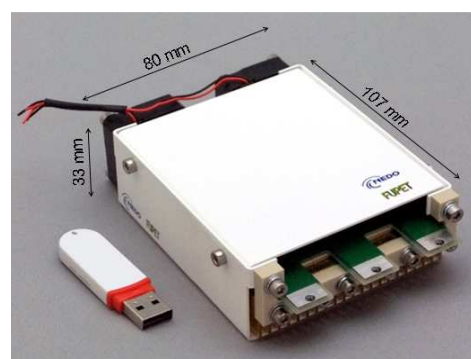
SiC-based semiconductor devices are expected to reduce losses as well as the size of power electronics applications like inverters or DC/DC converters taking advantage of their characteristic low resistance and high switching speed. In this paper, we demonstrate the OPD of the newly designed inverter [1] evaluated from a continuous switching test and actual loading test using a 3-phase induction motor.

Specifications and Configuration

An inverter unit having specifications and an appearance shown in Fig. 1 was fabricated. These JFETs and SBDs were selected because of the performance of low resistance as well as high reliability. Power modules integrated with heat sinks, dc link capacitors and cooling fans are included in the size of 250 cc. Controllers, sensors and gate drivers were excluded from the size. Ceramic capacitors (100nF) which were connected to the gate and source of JFETs were integrated in the power modules. This capacitor plays an important role in stabilizing the gate voltage of JFETs while the other arm is turning on [2].

Input	DC600V
Output	3 ϕ – AC400V
Size	107mm \times 80mm \times 33mm \approx 250cc
FETs	SJEC120R025 (1200 V, $R_{ds}=25$ m Ω) ※SemiSouth
Diodes	SDC30S120 (1200 V, 30 A) ※SemiSouth

a) Specifications



b) Inverter unit

Fig. 1: Specs and appearance of 3-phase inverter

Configuration of the gate drive circuit and control unit is illustrated in Fig. 2. This gate drive circuit consists of two gate-driver ICs. One of these gate-driver ICs amplifies PWM signals isolated by the photo-coupler. Another amplifies a 200ns pulse signal during turn-on transition.

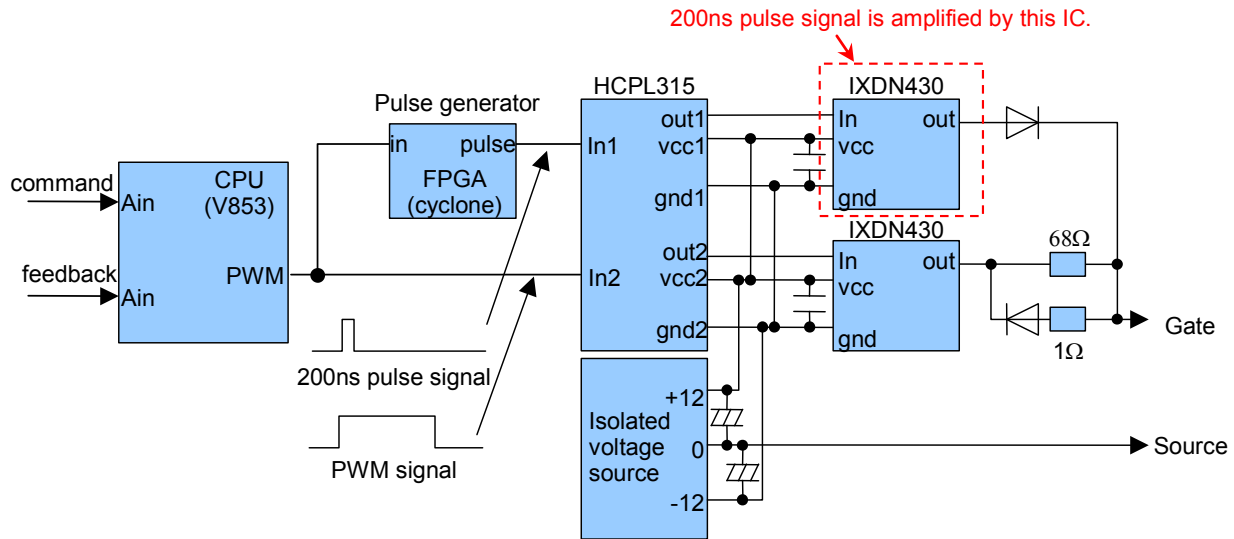


Fig. 2 : Configuration of gate drive circuit

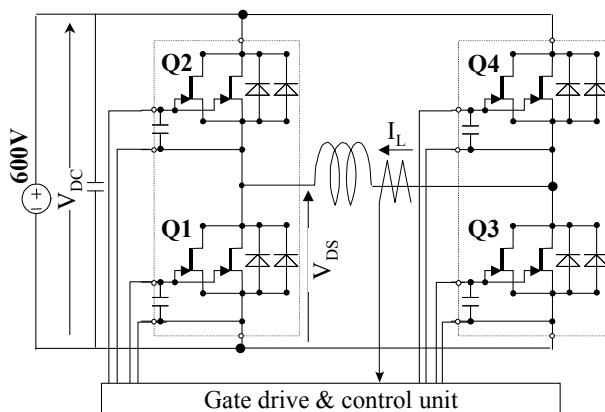


Fig. 3: Circuit of continuous switching test

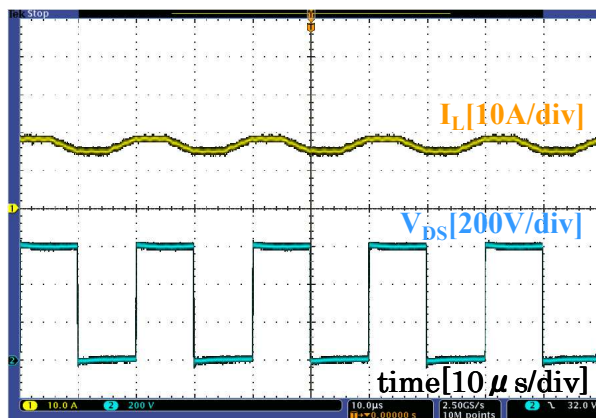


Fig. 4: Waveforms in continuous switching test

Test results of continuous switching test

The test circuit of the continuous switching test is shown in Fig. 3. Inductive load was connected to a pair of 2-in-1 power modules. Transistors Q1 and Q4 were operated by width controlled gate pulses having 90-degree phase difference each other. The effective load current (I_L) was kept a certain constant value by a feedback control. This test can simulate the same losses of a transistor as an operating actual load. We evaluated OPD of this inverter by using this test under several f_{sw} and I_L condition.

Fig. 4 shows an example of the switching waveforms of V_{DS} and I_L for a low-side switching block. The switching frequency was 50 kHz. The I_L was 16.5 Arms, which was the same level of current stress for transistors as operating a 10 kW 3-phase induction motor under a power factor of 0.85. In this test, the temperature of the power module saturated at 190 °C. Temperature of power module was measured on heat sink. Because the heat resistance between heat sink and ambient is much higher than the heat resistance between devices and heat sink, device temperature becomes almost same as heat sink temperature. For this result, this inverter attained an OPD of 40 kW/L at $f_{sw} = 50$ kHz.

Fig. 5 shows the test results of module temperatures according to certain conditions of f_{sw} and I_L . This inverter can attain an OPD of 60 kW/L at $f_{sw} = 20$ kHz with a module temperature of under 150 °C. Even higher OPDs are expected at a power module temperature of over 200 °C.

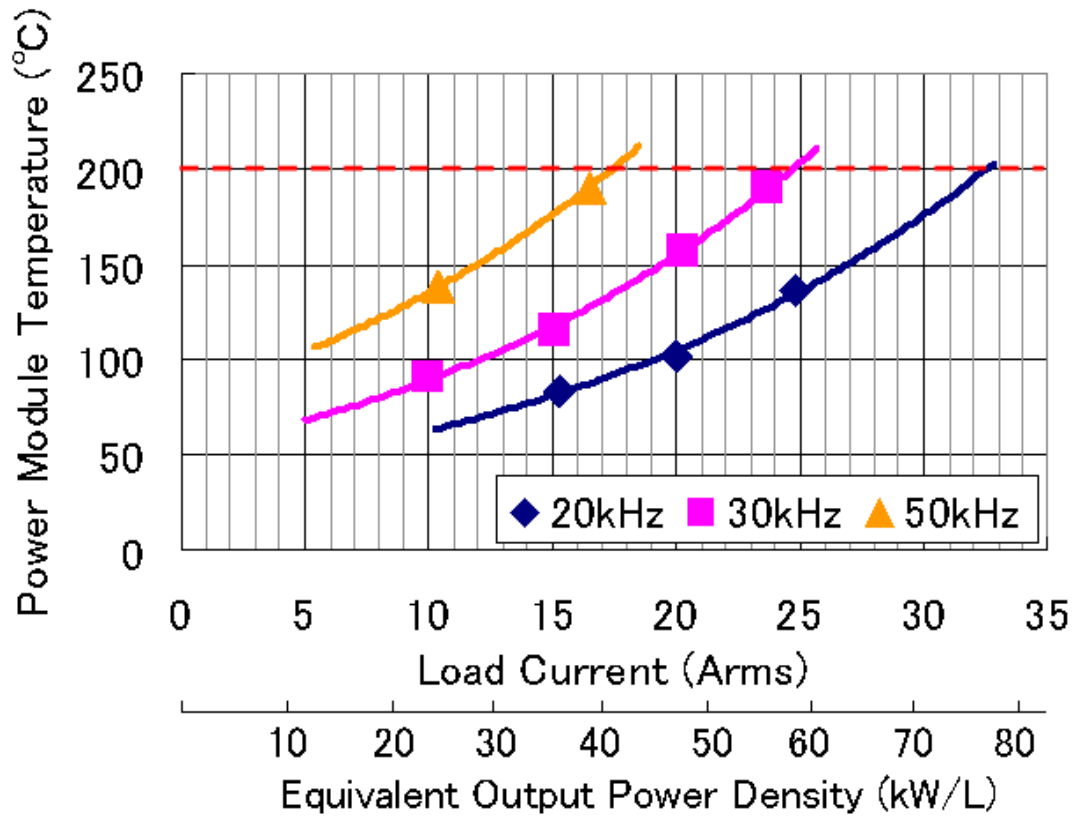
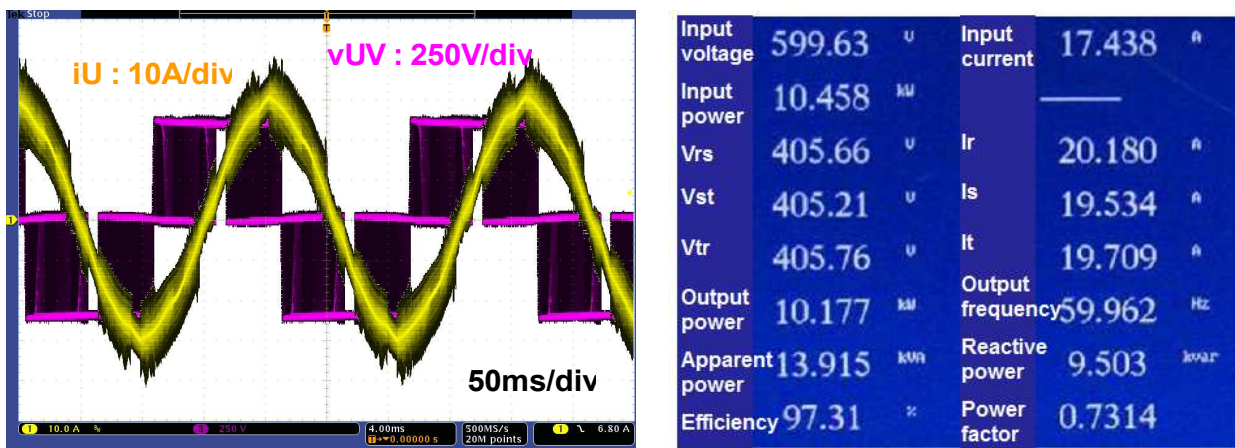


Fig. 5: Experimental result of continuous switching test

Test result of operating 3-phase induction motor as an actual load

Next, we evaluated whether this inverter could attain an OPD of 40 kW/L in operating actual load. Fig. 6 shows the waveforms and conditions of operating a 3-phase motor test and indicates that this inverter can operate a 3-phase motor of 10kW stably at $f_{sw} = 50$ kHz. In this result, this inverter attained an OPD of 40 kW/L at $f_{sw} = 50$ kHz in operating actual load. In addition, the energy conversion efficiency here was 97.3%.



a) Operating waveforms

b) Operating conditions

Fig. 6: Experimental result for 10 kW induction motor as a load ($f_{sw} = 50$ kHz)

Summary

A forced-air-cooled DC 600 V three-phase AC 400 V all-SiC inverter newly designed and fabricated has attained an OPD of 40 kW/L with $f_{sw} = 50$ kHz in operating actual AC motor. The efficiency was 97.3%. Furthermore, an OPD of more than 60 kW/L with $f_{sw} = 20$ kHz in operating an equivalent circuit.

Acknowledgement

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