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## Air-Cooled Full-SiC High Power Density Inverter Unit

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### Abstract

A 70 kVA/L air-cooled full-SiC three-phase inverter unit including power semiconductor modules, power capacitors, bus bars, gate drive circuits, a PWM wave generator and blower fans has been fabricated as a prototype for EV-use. SiC JFETs and SBDs of 1200 V were used. It has generated three-phase alternative power of 25 kVA to drive a 15 kW-class induction motor with only 190 W of dissipation. The module's temperature was at most 90 °C.

*Keywords: cooling, inverter, power density*

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### 1 Introduction

Silicon carbide (SiC) semiconductor device is expected as one of the most promising candidates for the next generation power device because of its higher conductivity and faster switching performance compared to those of silicon power device, which is now widely utilized in vehicles. Furthermore, it can withstand higher temperature than Si devices [1]. That implies for vehicle that we achieve a possibility to realize a high power density inverter without any liquid cooling system by using SiC. That will become necessary, for instance, to realize an integrated motor-inverter system packed in each wheel. Therefore, development of packaging technologies for high temperature power semiconductor device is the critical issue for future of electric-powered vehicles. This work will be a step toward it.

### 2 Structure

Figure 1 shows an external appearance of the prototype of three-phase air-cooled inverter unit. The size is 80 mm x 36 mm x 128 mm with neglecting terminals and screw heads. The volume can be calculated as 370cc. Figure 2 explains the exploded view of it. The unit

includes three SiC power modules with fins, a bus bar set consisting with a glass epoxy board with circuit wirings made of 0.3 mm-thick copper foils on both surfaces, ceramic capacitors of 20  $\mu$ F put on the backside of the bus bar set, a circuit board including gate drivers for six switches and a PWM wave generator, two 36 mm square blower fans, chassis and top cover. Power supplies for the circuits on the board and cooling fans are not included.

Figure 3 shows the internal structure of above-mentioned power module. Four 1200V-SiC JFET chips and four SiC-SBD chips manufactured by SemiSouth Laboratories Inc., are soldered on a ceramic circuit plate to construct 2-in-1 module and the plate is attached on a metal base unified with cooling fins and holding fixture. These chips are covered by silicone gel.

The temperature of this power module is expected to become more than 200 °C because SiC devices can safely be operated under such high temperature, which is one of the advantages of SiC devices compared to the conventional Si devices. However, most of the other parts in the unit cannot withstand such high temperature. Therefore, some countermeasures are prepared. The fixture part of each module is clamped to a crosspiece made of PPS, a heat-resistant plastic, and it is fastened to a

side of the chassis. As the result, the fins of the module can keep a slight distance to the chassis so as not to conduct heat to it directly. On the other hand, terminals standing up from the wirings on the ceramic base plate are electrically and physically connect to the copper foils on the epoxy board. That can be the second largest heat path. The board is fastened to both sides of the chassis by fixtures here again made of plastic. Furthermore, the power modules are arranged at the end of the air flow in the unit, and ceramic capacitors that should not be heated are arranged on the windward side in the unit.

Figure 4 in the next page is a photograph of the circuit board, which contains many parts being weak against high temperature. The air flow distributes also around the both sides of the circuit board especially to the side facing the bus bar set, which can become a high temperature. Signal lines from the board to each module run from the leeward side of the air flow, which cools the wires. There are five lines for each white connector. Three lines of it are from power supply outside of the unit to the driver circuit, and the rest two are the control lines run to the transistor in each module.

Most of technologies used in this system were derived from author's previous works [2-3], which had done for a national project of Japan (see Acknowledgement).

### 3 Experiment

Experiment to drive a 15kW-class three phase induction motor by this SiC inverter unit has executed. Figure 5 shows waveforms of the line voltage and two currents of the motor at a certain condition. The input dc voltage was 600 volts. PWM frequency was 8 kHz. The experiment executed with increasing the output power gradually as shown in Fig. 6 in the last page. Temperatures of the fin for each module, of the terminal connecting to the bus bar set and of the capacitors were measured by thermocouples. The ac output power reached to 15.9 kW and 24.8 kVA. The output current at the time was 36.3 A<sub>rms</sub> that is rather important for inverter system. The unit dissipation reached 190 W and the fin temperature at the condition was 90 °C. And when the input power was increased a little bit more as the next step, the dissipation exceeded the capacity of the cooling system.

### 4 Discussion



Figure 1: External appearance of the inverter unit

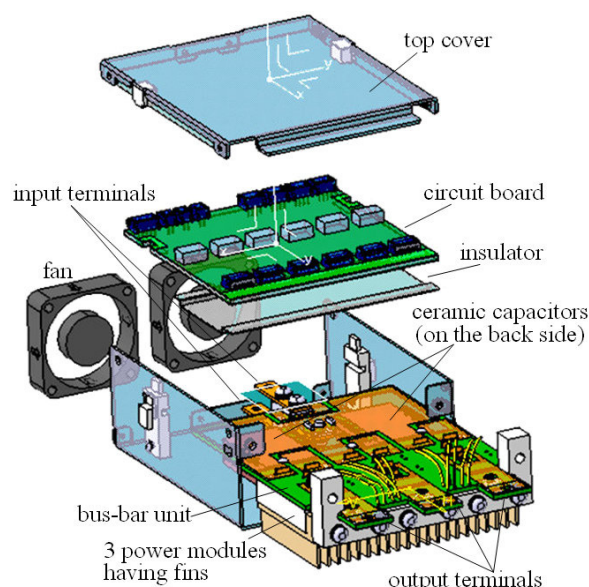


Figure 2: Exploded view of the inverter unit

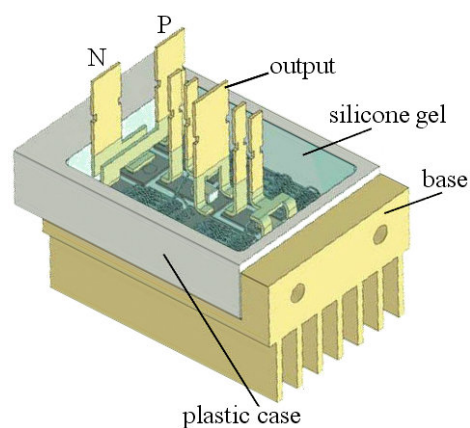


Figure 3: Internal structure of the power module

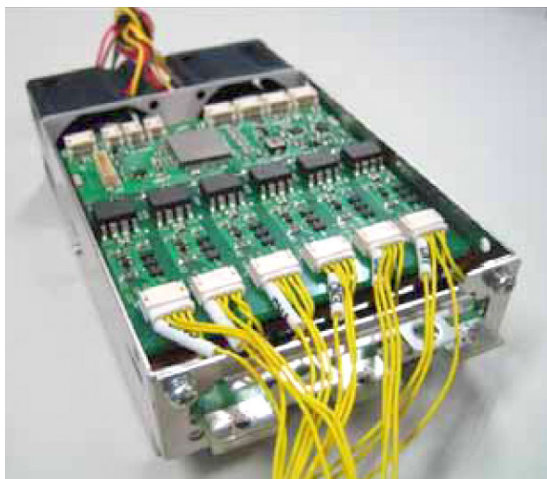


Figure 4: A view of the drive circuit board

Under a constant wind velocity, cooling capacity of the fin increases approximately in proportion to the fin temperature. But the conduction loss of SiC-JFET increases in proportion to more than square of its absolute temperature. Therefore, once the total dissipation exceeded the critical condition, the temperature of SiC devices can keep increasing by positive feedback of loss and temperature. As the proof, burnouts of SiC devices and wirings on the ceramic plate were found in plural modules by investigation after the experiment, in spite of the recorded low temperatures. If the ratio of the conduction loss in the total loss was lower, the unit could

increase its temperature stably and a premonition of the thermal runaway could be detected clearer and earlier.

## 5 Conclusion

A prototype of air-cooled full-SiC three-phase inverter unit for electric powered vehicle-use has been fabricated and demonstrated. It was able to generate three-phase alternative power of 25 kVA and to let a 15 kW-class induction motor output 15.89 W actually. The unit dissipated was 190 W, which means the efficiency was 98.8%. The final fin temperature was only 90 °C, which is far below the ability of SiC devices. Experiment with larger power capacity, for instance 80 kW, will be done in the future work.

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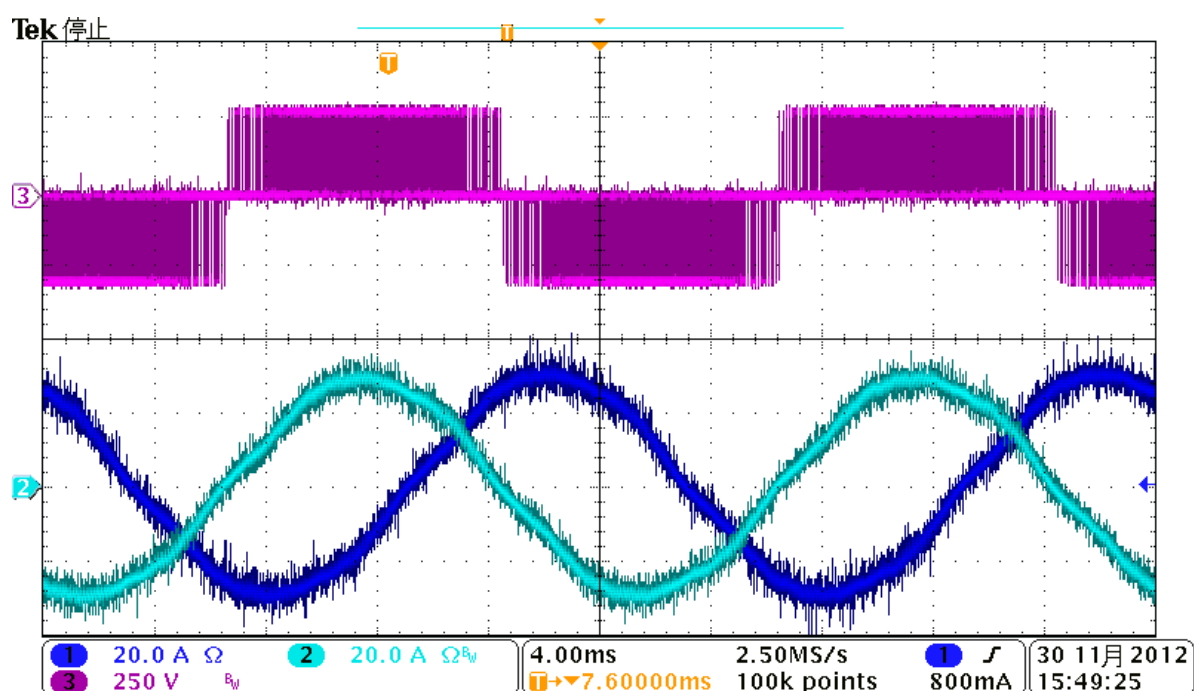


Figure 5: Voltage and currents waveforms of inverter during operating an induction motor



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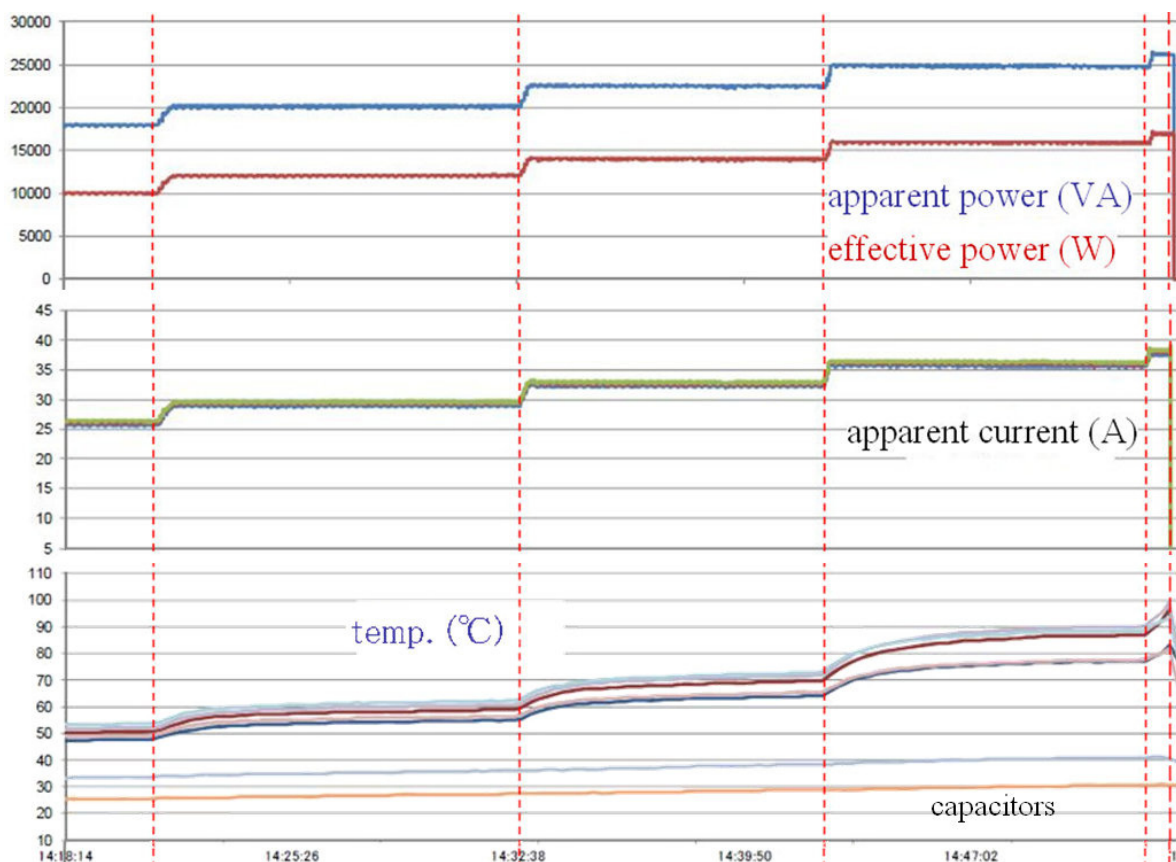


Figure 6: Waveforms of applied powers, current and temperatures of some points in the unit.