Boost the Progress of Electrification with Compact, Lightweight Inverters!

IHI has developed one of the world's smallest inverters with an output density of 70 kW/*l* and 50 kW/kg

Inverters have been playing important roles in the development of technologies to save energy consumption and reduce greenhouse gas emissions. Meanwhile, Silicon Carbide (SiC) is attracting attention as a new semiconductor material that could replace silicon and boost energy efficiency. This article features IHI's original technologies for SiC drivers and compact, lightweight inverters that achieve both high efficiency and low noise.

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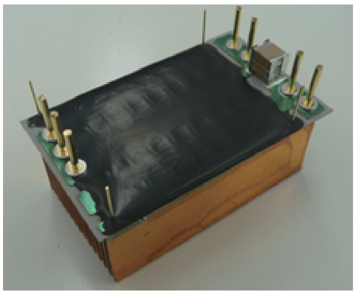
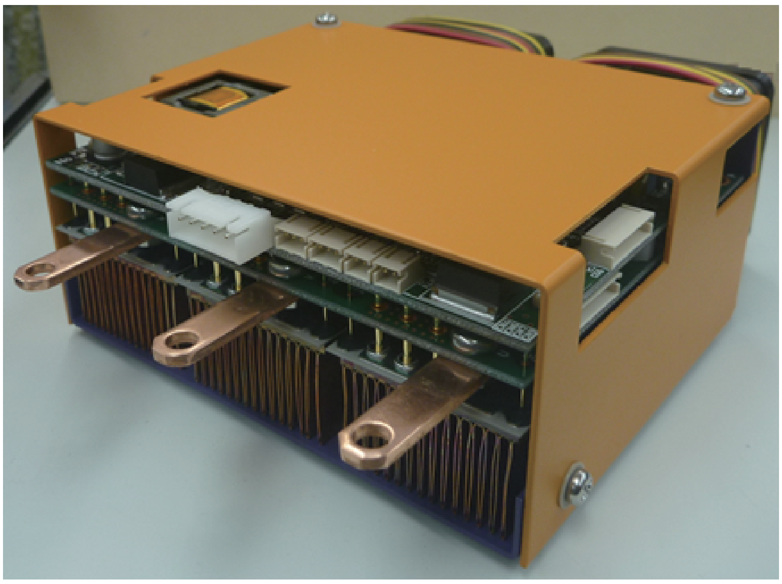
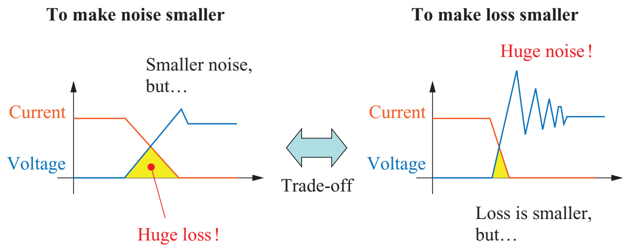




Compact, lightweight inverter (with an output of 35 kW, volume around 500 cc, and mass around 660 g)



The trade-off of switching

Inverters shaping the world of tomorrow

The recent development of emerging economies has been driving up the world's demand for power. More than 50% of global power demand is said to be for driving motors. In terms of industrial power consumption, measured by device used in manufacturing plants, roughly 60% of power is consumed by motors for driving compressors, pumps, fans, and other devices.

Inverters convert direct current to alternating current. These power conversion devices are widely used for efficient drive motors. They play important roles in our daily lives in home appliances. Practical examples include inverter air conditioners and inverter refrigerators.

Actually, Japan is a leading energy saver in the world. Japan's CO_2 emission per unit of GDP is roughly half that of the United States and as low as 1/10 that of China. One of the reasons for Japan's energy efficiency is the wide application of inverters in home appliances. Reduction of power consumption by air conditioners to a quarter of the level 20 years ago is a great achievement made possible by the advancement in inverter technology.

In recent years, the development and application of technologies has been underway in earnest to harness solar power, wind power, and other new sources of energy. Inverters are essential for connecting such new energy to AC power grids. The roles for inverter technology have been expanding, with a greater numbers of motors and inverters being employed to keep pace with the economic and industrial development in emerging economies.

The development of system electrification technology with the application of motors and inverters is also accelerated. Familiar examples of such electrification technology are Electric Vehicles (EVs) and Hybrid Electric Vehicles (HEVs). Electrification brings great benefits such as reduction of fuel consumption, better control performance, and smarter systems in combination with information and communication technology.

One of the biggest barriers to the electrification of existing systems like hybrid cars is the size and weight of inverters. Reduction in the size and weight of inverters is also important to add greater value through electrification of systems.

For these reasons, inverters must be made smaller and lighter in the future. Two key challenges for achieving this goal are reduction in energy loss and improved cooling performance. Reduction of the loss makes it possible to reduce the sizes of heat sinks, pumps for the cooling system, and other cooling systems, as well as to shrink semiconductor devices. Moreover, enhanced cooling performance makes it possible to reduce the size of cooling systems while maintaining the conversion power. Smaller cooling systems and semiconductor devices are able to make inverters smaller and lighter.

The trade-off of semiconductor switching

Inverters and other power conversion systems employ semiconductor devices to repeat on-off switching to achieve high efficiency power conversion. Unfortunately, such fast transients in the voltage and current by the switching operations might cause noise problems.

As mentioned earlier, reduction in energy loss is an important step to make inverters smaller and lighter. However, there is a trade-off between low loss and low-noise switching in general.

As shown in the figure, slower switching can reduce noise by moderating the transient in current and voltage. But, the energy loss gets bigger during the longer transient period during the slower switching. The increase of loss results in low efficiency, greater cost, as well as larger heat sinks, water cooling systems, and other cooling systems.

In contrast, faster switching to reduce the loss produces greater noise as a result of the fast transients in current and voltage. This large amount of noise diminishes reliability and increases the cost of making systems as well as their size because of the noise filters, noise shields, or other additional devices that must be installed to suppress the noise.

It is essential to overcome the trade-off between energy loss and noise to create smaller inverters.

The breakthrough offered by SiC

SiC, Gallium Nitride (GaN), and other wide band gap devices have been attracting interest as new semiconductor materials that could replace silicon. GaN devices are used in the new efficient lighting devices known as Light Emitting Diodes (LEDs).

SiC devices offer advantages over conventional silicon semiconductors. Major examples are as follows:

(1) Less loss
(2) Faster switching
(3) Easy to get higher blocking voltage

In converting the same amount of electric power, SiC devices generate less heat than silicon devices because of the smaller losses. Less generated heat makes it possible to downsize heat sinks and other cooling devices, and thereby provide smaller and lighter inverters.

In addition, the faster switching capability of SiC devices enables turning on-off at very high frequency, and controlling motors better. Moreover, the higher breakdown voltage of

SiC makes it easier to make high-voltage devices, which is promising for the simplification of conventional high-voltage systems and greater efficiency achieved by accommodating higher voltages.

Measures against switching noise hold the key to effective application of faster switching enabled by SiC devices.

Hence, IHI has developed its own SiC drive technology and compact SiC power module to develop smaller and lighter inverters achieved by the advantages offered by SiC devices.

Compact, lightweight SiC inverters

To realize smaller and lighter inverters, IHI developed the following two key technologies by employing SiC devices.

(1) An original SiC drive technology
(2) A compact SiC power module

The first step was the development of IHI's original SiC gate drive technology for loss reduction. Gate drive technologies in the semiconductor industry refer to circuit technologies for controlling on-off operations of semiconductor devices. There is demand for gate drive technology with switching that has little loss. After developing its own gate drive technology, IHI developed a compact power module combining enhanced cooling performance and a structure with high thermal conductivity. These two technologies need to be applied while ensuring low-noise performance.

As mentioned earlier, there is a trade-off between low energy loss and low-noise switching. The SiC gate drive technology developed by IHI overcomes the trade-off and makes it possible to perform switching with less loss and less noise.

As demonstrated in the figure on the top right, proper adjustment of switching speed during the switching transient can reduce loss and noise.

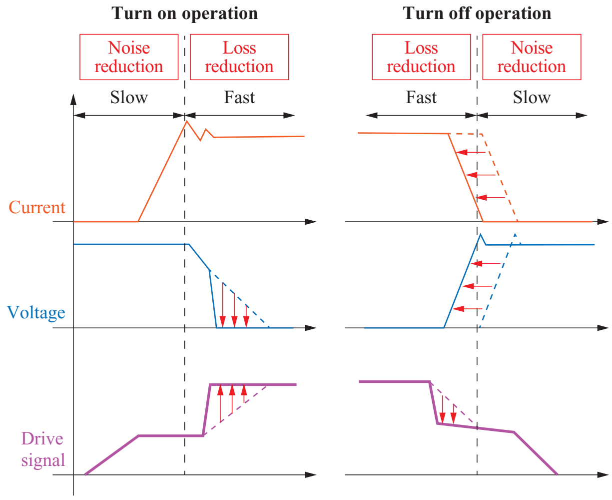
For instance, in a turn on operation (switching a semiconductor from off to on), switching is performed slowly in the initial phase as more noise tends to appear in this stage. Switching is speed up for suppressing loss in the latter half of the switching operation as less noise appears in this stage.

In a turn off operation (switching a semiconductor from on to off), switching is performed fast to minimize energy loss in the initial phase as small changes in current and voltage tend to generate less noise. Switching is slowed down in the latter half of the switching operation in order to suppress the noise that tends to appear in this stage.

Adjusting the speed in the switching transient in this manner can overcome the trade-off between energy loss and noise to achieve a reduction of both.

The figure on the top left on the next page compares the switching loss involved in one switching operation with a SiC device under 400 V and a current of 100 A. Here, IHI's drive technology succeeded to reduce the switching loss almost in half as compared to the loss caused by conventional drive technologies.

The combination of a SiC device and IHI's gate drive technology was able to reduce the switching loss down to about 1/8 of the loss caused by conventional silicon devices.



IHI's SiC gate drive technology

The figure on the top right on the next page is a picture of a compact power module developed by IHI.

One of its more prominent features is the black resin housing the SiC device mounted inside and there is a built-in condenser for suppressing noise. The condenser is arranged very close to the SiC device to maximize the noise mitigation capacity and to properly facilitate fast switching by the SiC device.

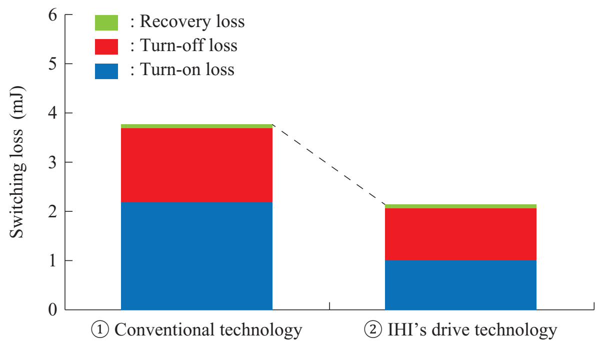
In addition, a circuit pattern for boosting the cooling performance was formed on an insulating substrate made of a highly thermally conductive material. Additionally, a cooling fin was directly mounted on the back side of the power module. This design made it possible for the SiC device to efficiently release the heat and convert a large amount of power while using a small cooling system.

The table on the next page presents the specifications of the compact, lightweight inverter that employed the IHI's SiC gate drive technology and a compact SiC power module. In the past few years, various institutes and manufacturers have effectively employed SiC devices to make compact inverters and reported output densities over 50 kW/*l*. The inverter developed by IHI also achieved an output density of 70 kW/*l* and 50 kW/kg. This is one of the world's smallest and most lightweight inverters, and it has achieved a maximum efficiency of 98% or greater.

Brushing up element technologies to cater to various needs

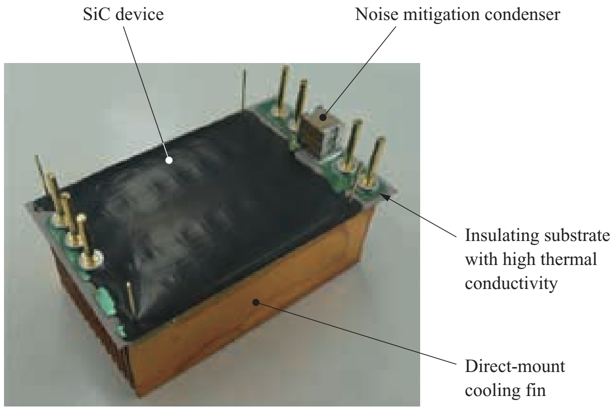
Development so far has been focused on making smaller and lighter inverters. In the process, IHI gained element technologies for achieving low-loss and low-noise drive, fast drive, power modules with high thermal conductivity, compact mounting, and so on. In order to develop competitive products, we need to brush up each of these element technologies and tailor them to market needs.

At the moment, SiC devices are more expensive than silicon devices. Many people naturally worry about the



(Note) The loss is around 18 mJ with a silicon IGBT as a conventional device (according to IHI's evaluation).

Effect of IHI's drive technology



Compact power module made by IHI

Item	Compact, lightweight SiC inverter	Conventional inverter
Output	35 kW	15 kW
Size	104 × 110 × 45 = 514 cc	Approx. 5 000 cc
Mass	660 g	Approx. 6 kg
Output density	70 kW/*l*, 50 kW/kg (20 times!)	3 kW/*l*, 2.5 kW/kg
Efficiency	98% (2% increase!)	96%
Cooling	Forced cooling	Water cooling

Comparison between a compact, lightweight SiC inverter and a conventional inverter

higher system cost. Nevertheless, the rise in the cost of a semiconductor device can be absorbed by the smaller size of the inverter, which translates into reduced costs of periphery elements and cooling systems (e.g., not needing to install a cooling water circulation system). The fast switching performance of SiC devices promises simplification of filters and other components for suppressing noise. In this manner, a reduction in the total system cost can be reasonably expected with the application of a SiC device.

In further pursuit of an energy-saving society, IHI would be more than pleased to cooperate with you if you have any products or projects in which our compact and lightweight inverter technology can be effectively combined with new semiconductor devices.

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