Featured Articles

Modular Power Conversion Technology for Global Manufacturing and Operations

Yuichi Mabuchi, Ph.D.
Daisuke Matsumoto
Hiroshi Kamizuma
Yukio Hattori
Tomonori Ichikawa
Ryohei Miyagawa

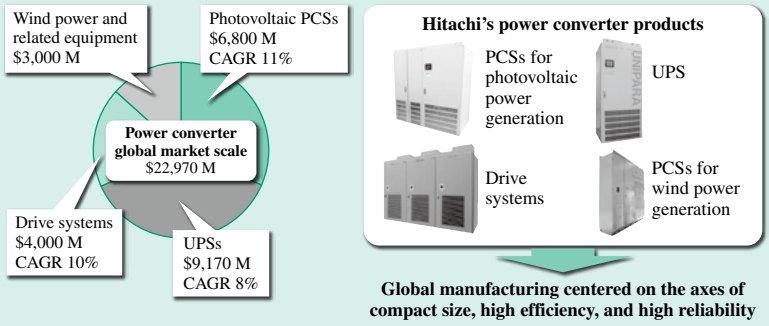
OVERVIEW: Recently, demands for space-saving and easier maintenance have been growing among the equipment features demanded by the power converter market. To meet these demands, Hitachi has developed excellent technology in the form of a modular power conversion unit that supports various types of power converters and uses double-sided cooled power modules that provide outstanding cooling performance. By using double-sided cooled power modules, which have excellent heat dissipation and are smaller than conventional single-sided cooled power modules, the developed unit can house all of the key components needed for power conversion in a 55% smaller volume than conventional units, achieving better maintainability in a more compact size. Hitachi will continue working on global manufacturing, initially with UPSs equipped with this developed unit, and later by incorporating the unit into other power converters.

INTRODUCTION

POWER converters utilizing technology that converts from alternating current (AC) to direct current (DC) power and conversion technology that does the reverse are used in various places in our lives, such as power infrastructure equipment and other equipment. Familiar examples include power conditioning systems (PCSs) for photovoltaic power generation, drive systems that drive motors, and uninterruptible power systems (UPSs) that provide backup power during power failures. These systems have become important equipment underpinning our daily lives.

Fig. 1 shows the scale of the global market for power converters and the power converter-related products made by Hitachi[(1)–(3)]. The economic growth of emerging economies represented by China and India and their increasing use of renewable energy have resulted in forecast annual growth rates of 8 to 11% in the global power converter market for these power conversion products. Hitachi is developing a lineup of power converter-related products centered on the three axes of compact size, high efficiency, and high reliability, and is working to incorporate them further into global manufacturing in the future.

UPS is one type of power converter that is becoming indispensable equipment at data centers, banks, and other facilities. A loss of power from a power failure at these facilities can cause serious problems, such as lost customer data and aborted transactions, etc.



UPS: uninterruptible power system PCS: power conditioning system CAGR: compound annual growth rate

Fig. 1—Power Converter Global Market Scale (2014) and Hitachi's Power Converter-related Products.
The global power converter market is expected to continue growing at an annual rate of 8 to 11%. Hitachi is expanding its global manufacturing of power converter-related products centered on the three axes of compact size, high efficiency, and high reliability.

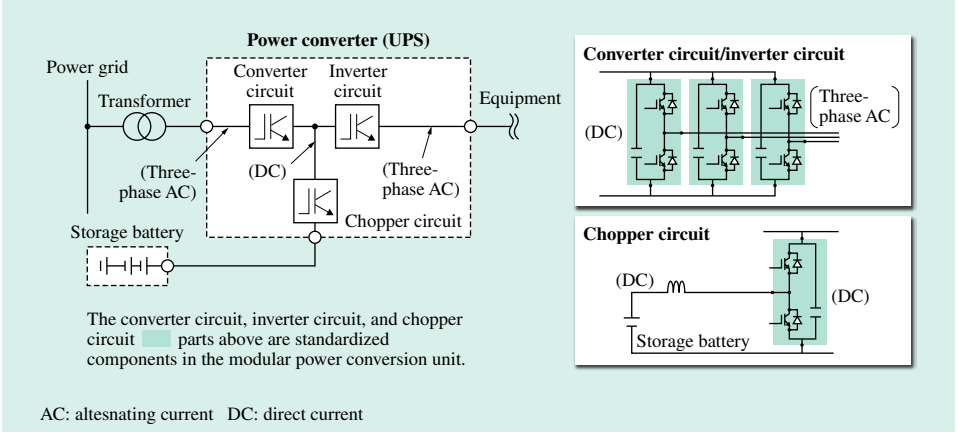


Fig. 2—Main Circuit Configuration of Power Converter Using a UPS as an Example.
The main circuits in a UPS (a type of power converter) consist of a converter circuit, an inverter circuit, and a chopper circuit.

UPSs therefore need to be highly reliable, supplying uninterrupted power to equipment during power failures. With the recent rapid spread of the Internet, the scale and required power capacity of the equipment used in network environments and data centers has been growing rapidly. This growth has created demand for UPSs with excellent expandability, reliability, and redundancy that can be added to meet the demand or required scale without a power shutdown, and have excellent maintainability. The increasing trend of urban data centers in recent years has also resulted in demand for maximizing effective use of facility floor space. This trend has therefore created demand for UPSs that are also as compact and space-saving as possible.

Modular design[4] is one method for developing UPSs and other power converter products that satisfy these demands. Modular design is a block design theory that starts with designing a small number of highly interchangeable parts or units (modules) that can be produced on limited manufacturing equipment, and then combining these modules to create a wide range of products. This design method can be used not only to create products with excellent expandability from a small number of parts, but also to improve maintainability by standardizing maintenance parts at the same time. By using the double-sided cooled power module Hitachi developed in 2011[5] for power semiconductors (a key component of power converters containing UPSs), Hitachi has developed a modular power conversion unit with half the volume of conventional units. This has enabled it to reduce the size of key components in UPSs, while improving maintainability at the same time.

This article provides details of the developed modular power conversion unit, explains the UPSs that use it, and ends with a discussion of future development.

DEVELOPMENT OF MODULAR POWER CONVERSION UNIT

Fig. 2 shows the configuration of the main circuits that compose a power converter, using a UPS as an example. A power converter contains a power conversion circuit composed of a converter circuit that converts AC power to DC power, a chopper circuit that supplies power from a storage battery to a DC circuit inside the power converter during a power failure, and an inverter circuit that converts the DC power in the power converter to AC power and supplies it to the equipment being powered by the converter. The modular power conversion unit developed by Hitachi standardizes these circuits.

Fig. 3 shows the double-sided cooled power module developed by Hitachi. This power module provides excellent cooling performance compared to conventional single-sided cooled power modules by dissipating heat from both sides of the module, and it also has a smaller volume than conventional

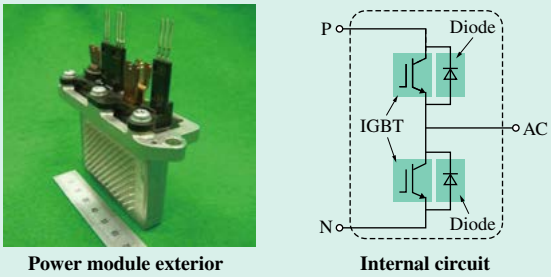


Fig. 3—Double-sided Cooled Power Module.
This module dissipates heat from both sides, achieving better cooling performance compared to conventional single-sided cooled power modules.

single-sided cooled products. Using this power module makes it possible to reduce the size of the modular power conversion unit. Developing a modular power conversion unit that uses double-sided cooled power modules requires the following three technologies:
(1) Air-cooling technology suited to double-sided cooled power modules
(2) Current-equalizing wiring technology enabling a thinner modular power conversion unit
(3) Busbar mounting technology that makes parallel unit placement easy

These three development technologies are described below.

Air-cooling Technology Suited to Double-sided Cooled Power Modules

The structure and cooling system of conventional single-sided cooled power modules are described first. Conventional air-cooled single-sided cooled power modules have a semiconductor element, lead frame, insulation, and base plate layers on one side, and have a structure that dissipates the heat generated when the semiconductor element operates (see Fig. 4). Fig. 4 also shows the temperature distribution (obtained from a thermal fluid simulation) of a cooling system using a conventional single-sided cooled power module and air-cooling fins. This temperature distribution shows that heat is not sufficiently dispersed up to the edges of the heat-dissipating fins, and the fins have portions that are not being used effectively.

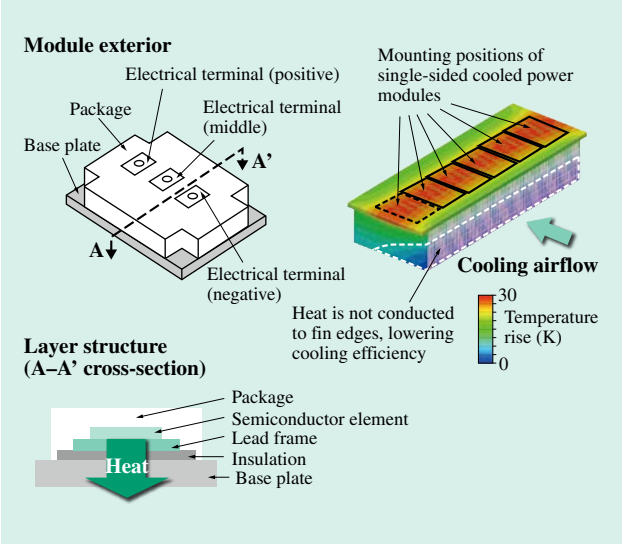


Fig. 4—Structure and Cooling System of Conventional Single-sided Cooled Power Module.
Single-sided cooled power modules only dissipate heat from one side. The cooling fins used with these modules have portions where heat is insufficiently conducted, lowering cooling efficiency.

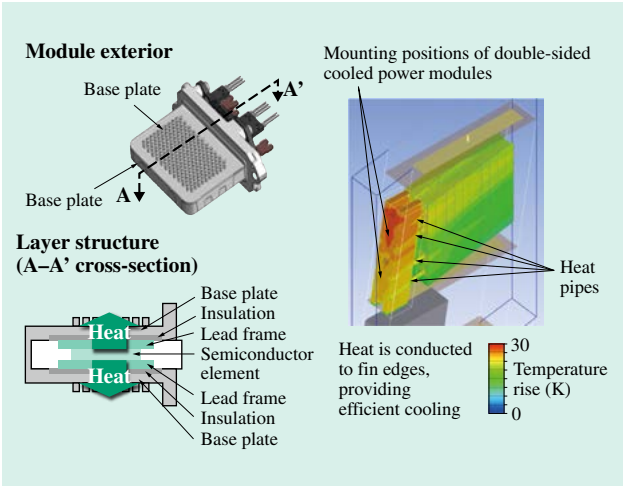


Fig. 5—Structure and Cooling System of Double-sided Cooled Power Module.
Double-sided cooled power modules dissipate heat from both sides. They are combined with high-efficiency fins that use heat pipes to enable a more compact size.

The double-sided cooled power modules and developed cooling method are described next. This module has a structure consisting of a semiconductor element surrounded on both sides by a lead frame, insulation, and base plate. The heat generated by the operation of the semiconductor element is dissipated from both sides of the module (see Fig. 5). As a result, the module reduces thermal resistance (an indicator representing resistance to heat conduction) by half compared to conventional single-sided cooled power modules.

To air-cool the double-sided cooled power modules, compact air-cooling fins able to efficiently dissipate heat from both sides of the power module needed to be developed. The fins were given an original structure with heat pipes that had excellent thermal conductivity placed on both heat-dissipating surfaces of the power module. Fig. 5 shows the result of a thermal fluid simulation for the developed air-cooling fins. The developed air-cooling fins disperse heat up to the edges and are 20% more efficient than conventional fins, which made it possible to reduce the volume of the cooling fins by about 50%.

Current-equalizing Wiring Technology Enabling Thinner Modular Power Conversion Unit

To make maintaining and adding power converters easy, the width of the modular power conversion unit itself was reduced, and the unit was given a

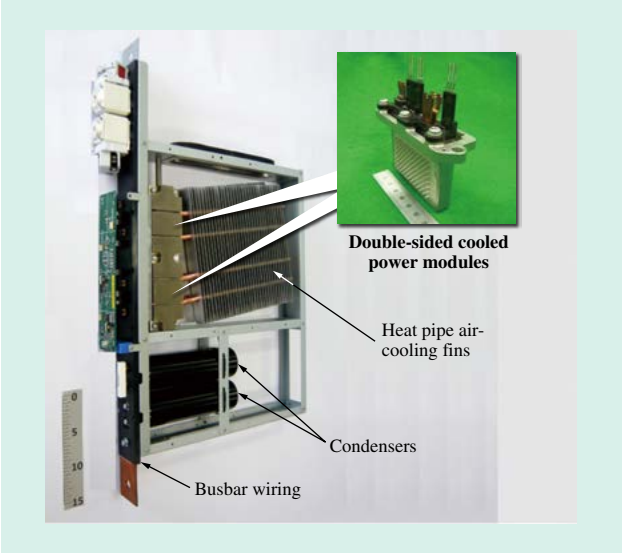


Fig. 6—Modular Power Conversion Unit.
Two power modules and condensers are placed in a straight line, enabling a lighter weight and thinner design with a width of 5 cm.

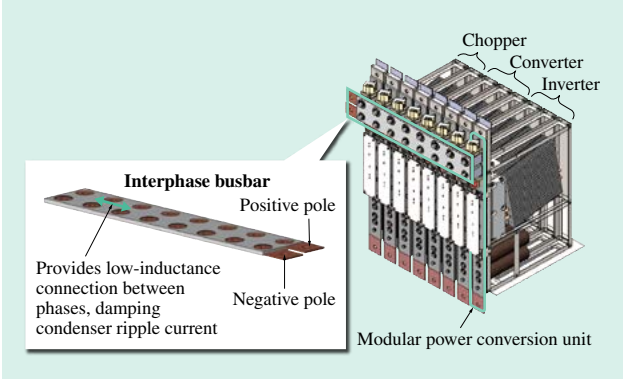


Fig. 7—Mounting a Busbar that Makes Parallel Connection of Modular Power Conversion Units Easy.
The busbar damp the resonance between units and provides a low-inductance connection between units, damping ripple current and enabling smaller condensers.

thin structure to enable it to slide in and out of the front panel of the power converter. Fig. 6 shows the structure of the developed modular power conversion unit. The problem with this structure is that two power modules and condensers are placed in a straight line, making it difficult to make the distances between the condensers and two power modules equal. The electric current therefore tends to flow unevenly to the power module nearer the condensers. To solve this problem, Hitachi used electromagnetic field analysis to develop wiring mounting technology that equalizes the electric current flowing to multiple power modules by taking the wiring thickness into account, in addition to the wiring width and shape.

The measured results showed that the electric current imbalance of each power module was reduced to within 2%. This technology enabled the manufacture of thin units with a width of 5 cm.

Busbar Mounting Technology that Makes Parallel Unit Placement Easy

Thin modular power conversion units needed to be placed next to each other in order to reduce the size of the power converter. To achieve this aim, it was necessary to mount components in a way that considered not only the inverter and converter circuits, but also the electrical interference between the modular power conversion units composing the U, V, and W phases within each circuit.

When the operating frequency of the power conversion units was close to the resonance frequency between the units during power converter operation, it would result in excessive resonance current being generated between the units, adversely affecting converter operation. At the same time, the units needed to connect with low inductance in order to damp the ripple current (a high-frequency current in condensers), which was a factor in lowering the service life of condensers mounted in the modular power conversion units. To handle these issues, Hitachi used electromagnetic analysis and circuit simulations to develop a busbar (Fig. 7) to connect the modular power conversion units. The developed busbar damped the resonance between the units and provided a low-inductance connection between them, reducing condenser ripple current by 43% compared to conventional busbar connections. This technology enabled the use of small-capacity condensers, and reduced the volume needed for mounting the condensers by about 50%.

The developed technologies described above reduced volume by 55% compared to conventional products, enabling a thin modular power conversion unit with a width of 5 cm.

DEVELOPMENT OF UPS INCORPORATING MODULAR POWER CONVERSION UNIT

Using double-sided cooled power modules, Hitachi incorporated its smaller and thinner modular power conversion units into a large-capacity UPS. This UPS is a space-saving device with a 30% smaller size and 30% smaller installation footprint compared to conventional products (see Fig. 8). UPS capacity

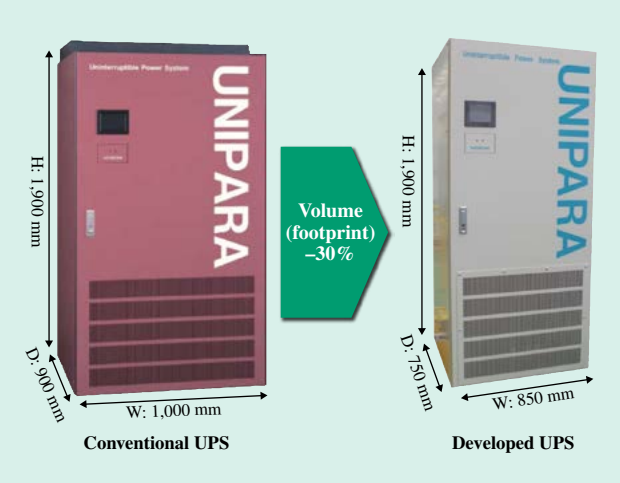


Fig. 8—UPS (100-kVA Capacity) Incorporating Modular Power Conversion Unit.
Using modular power conversion units in this UPS saved 30% of the space and improved maintainability compared to conventional products.

can be added just by connecting the required number of modular power conversion units in parallel. Furthermore, the units are accessible from the front panel, enabling the easy replacement of units, and they are also light enough to enable servicing by a single technician, improving maintainability compared to conventional products. UPS products with capacities of 100 to 300 kVA have been released that use the developed modular power conversion unit.

CONCLUSIONS

Hitachi has developed excellent technology in the form of a modular power conversion unit using double-sided cooled power modules that provide outstanding cooling performance. UPSs that use this unit are more space-saving than conventional products, and offer improved expandability and maintainability.

Hitachi is working on incorporating the developed modular power conversion unit into other power electronics products such as PCSs and drives, in order to develop products that satisfy customer demands for high reliability, compact size, space-saving, and improved maintainability. Even if the modular power conversion unit is manufactured overseas, its modular design will enable easier mounting in product lineups and easier assembly than conventional design methods, and the unit's reliability and quality will also be easier to maintain. Hitachi will leverage these features, and continue working on global manufacturing that incorporates this modular power conversion unit.

REFERENCES

(1) IHS Technology PV Inverters Report - 2014, IHS Technology (Mar. 2014).
(2) "Global uninterruptible Power Supply Market 2011–2015," TechNavio (Dec. 2012).
(3) "Medium Voltage AC Drives Global Market Outlooks," ARC Advisory Group (Mar. 2014).
(4) Japan Modular Design Institute, http://www.modular-design-institute.jp/ in Japanese.
(5) Hitachi News Release, "Prototyping of a Power Module Using Direct Water and Double-Sided Cooling Technology Contributing to the Scaling Down of Inverters for Electric and Hybrid Automobiles" (Nov. 2011), http://www.hitachi.co.jp/New/cnews/month/2011/11/1121a.html in Japanese.

ABOUT THE AUTHORS

Yuichi Mabuchi, Ph.D.
Power Electronics Systems Research Development, Center for Technology Innovation – Controls, Research & Development Group, Hitachi, Ltd. He is currently engaged in the research and development of power electronics products. Dr. Mabuchi is a member of the Institute of Electronics, Information and Communication Engineers (IEICE), and the Japan Institute of Electronics Packaging (JIEP).

Daisuke Matsumoto
Power Electronics Systems Research Development, Center for Technology Innovation – Controls, Research & Development Group, Hitachi, Ltd. He is currently engaged in the research and development of power electronics products.

Hiroshi Kamizuma
Power Electronics Systems Research Development, Center for Technology Innovation – Controls, Research & Development Group, Hitachi, Ltd. He is currently engaged in the research and development of power electronics products. Mr. Kamizuma is a member of the IEICE.

Yukio Hattori
Power Electronics Systems Research Development, Center for Technology Innovation – Controls, Research & Development Group, Hitachi, Ltd. He is currently engaged in the research and development of power electronics products.

Tomonori Ichikawa
Power Electronics Design Department, Industrial Products Business Unit, Hitachi, Ltd. He is currently engaged in the development of power electronics products. Mr. Ichikawa is a member of the Institute of Electrical Engineers of Japan (IEEJ).

Ryohei Miyagawa
Power Electronics Design Department, Industrial Products Business Unit, Hitachi, Ltd. He is currently engaged in the development of power electronics products. Mr. Miyagawa is a member of the IEEJ.