Prospective Technology of Power Electronics

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1. Introduction

Mitsubishi Electric Corporation is involved in the business of power devices from small-capacity dual-in-line package intelligent power modules (DIPIPMs) to large-capacity thyristors, as well as power electronics systems using such power devices and related equipment. Small-capacity devices are used in houses and offices; intermediate-capacity devices in factories; and high-power devices for social infrastructure.

2. Performance Barometers and Technologies for Power Electronics Systems

Figure 1 illustrates the increase in performance of typical power electronics systems. The power density and injection efficiency (output/loss) have approximately trebled in 20 years. This improvement is thanks to the switching of elements from insulated gate bipolar transistors (IGBTs) to SiC-metal-oxide-semiconductor field-effect transistors (SiC-MOSFETs) and the establishment of a board level packaging technology that drives and protects high-speed elements and reduces surges. In addition, the speed frequency response has improved approximately ten-fold, thanks to more sophisticated arithmetic devices and the use of modern control theory.

In the past, development mainly targeted and power devices, converters, and control in particular. Currently, there is a need to develop elements and integration technologies for thermal and structural systems, with a good balance of technologies for key parts.

3. Advancement of Power Devices and Wide Band Gap Semiconductors

Power electronics systems dramatically spread after variable voltage variable frequency (VVVF) inverters entered practical use thanks to the development of self-turn-off power devices such as bipolar transistors and gate turn-off (GTO) thyristors. Today, IGBTs are used as main devices in diverse sectors from home appliances to electric power. Meanwhile, the development of wide band gap semiconductors such as SiC and GaN was started with the aim of enhancing their performance for practical

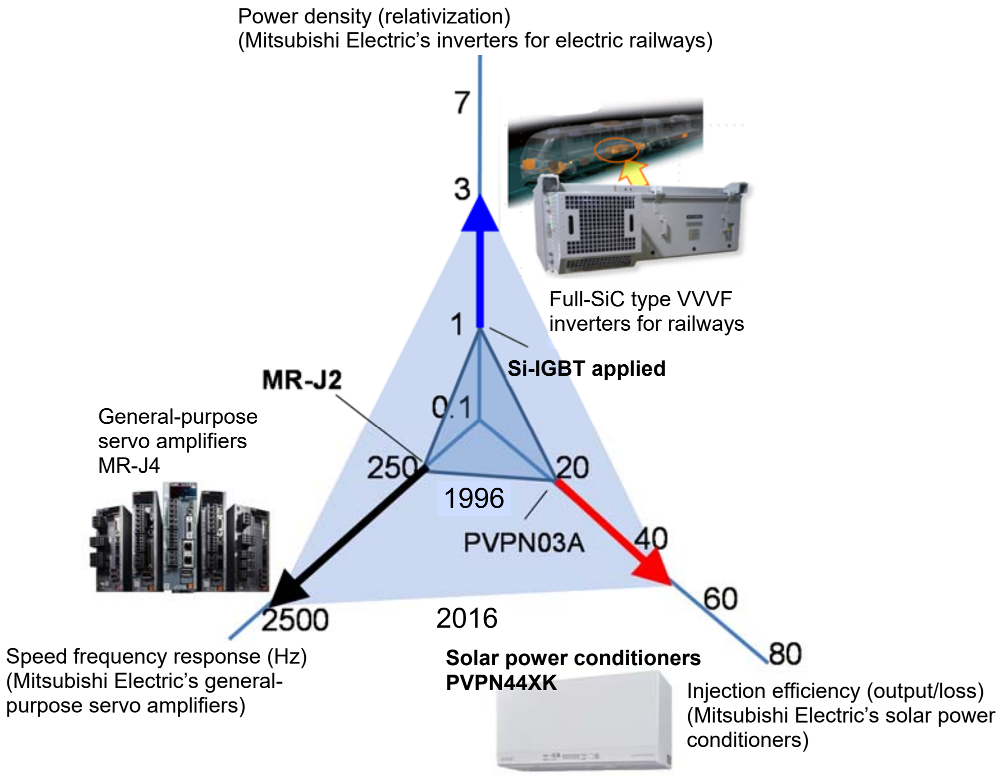

Fig. 1 Evolution of performance barometer of power electronics products

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application. Regarding SiC, Schottky barrier diodes (SBDs) and MOSFETs have been commercialized. Although bipolar devices are the mainstream for Si, unipolar devices are the mainstream for wide band gap semiconductors. Figure 2 is a map of products that include Mitsubishi Electric's SiC devices. The history of SiC began with the application of SBDs. The first type of products to use SiC were room air conditioners. Then, SiC started to be used for inverters for railways and FA equipment. Mitsubishi Electric commercialized propulsion control systems for railway vehicles using SiC-MOSFETs for the first time in the world. Furthermore, Mitsubishi Electric has applied SiC to solar power conditioners and air conditioners.

SiC devices started to be used for applications where it was considered that energy-saving and downsizing were important. To spread them further, the functions need to be improved and the costs reduced. Many researchers have been working to develop packaging technologies and trench gate MOSFETs that can operate at high temperatures and high speed, which are the strong points of SiC devices. In addition, regarding application to high-voltage power electronics systems, 6.5-kV-MOSFET modules and over 10-kV devices are under development. SiC devices are strongly expected to help reduce power consumption. Mitsubishi Electric will continue sophisticated development to help spread SiC devices further.

4. Converters and Integration Technologies

In addition to standard two-level converters, three-level converters and gradationally controlled voltage inverters have been adopted depending on the application. Recently, modular multilevel converters (MMCs) with more levels have been under development. The conventional two-level method has a problem with voltage dividing of elements. In MMC converters, cell modules are connected in series and the cell voltage is controlled to be stable. The phases output from the cells are shifted, so as to achieve waveforms with little harmonics for the entire arms. It is easy to increase the voltage of MMC converters and they are used for self-excited VAR systems.

In more and more cases, step-up choppers are installed in the DC sections to optimize the input voltage of inverters, but this lowers the efficiency. For a cooperatively controlled converter as shown in Fig. 3, when the voltage of the PV cells is higher than the system voltage, only the inverter switches; and when it is lower, only the chopper switches. These behaviors form sine waves as a whole. There is no period during which both chopper and inverter switch, which reduces losses and increases the efficiency.

Recently, 3-kW two-way noncontact power transmission systems for charging onboard batteries have been gaining attention as an application of wireless power supply converters. For such a system, the DC/DC

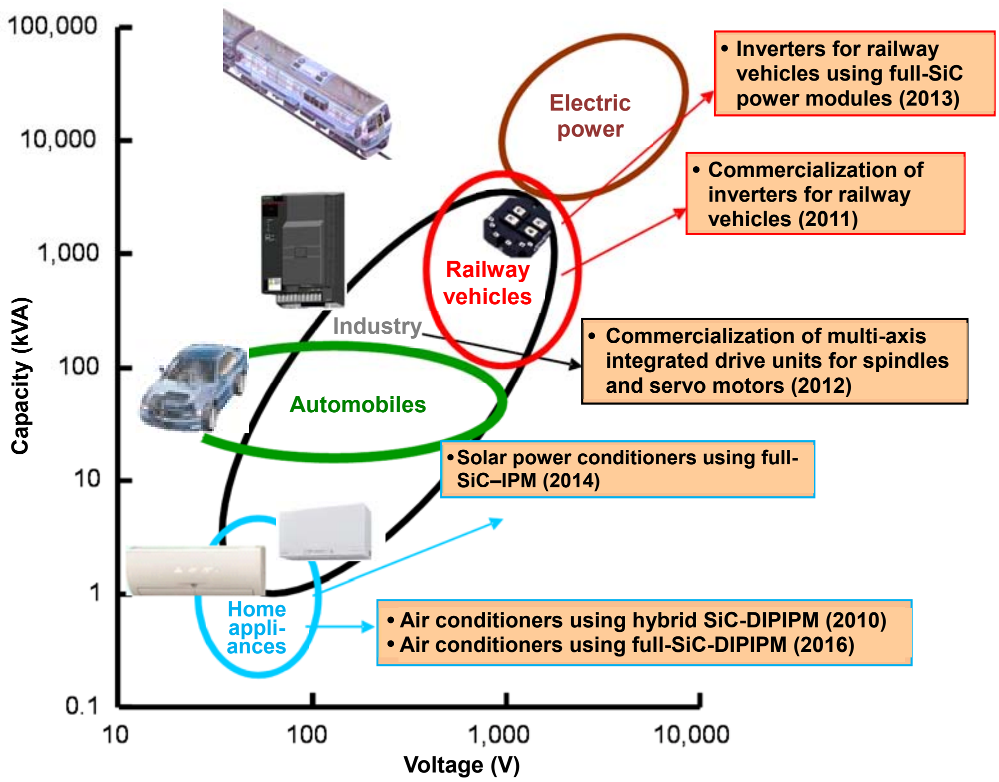

Fig. 2 Product map of SiC applications

converter on the sending side controls electric power, the inverter on the sending side controls output phases, and the DC/DC converter on the receiving side makes adjustments to raise the efficiency; the efficiency is 84% or higher even when the position of the power-sending coil deviates from the receiving coil by 15 cm.

Noise is a problem with high-speed, high-frequency switching, and much work is being done to develop measures to suppress noise after equipment has been completed. One developed technology can estimate complicated frequency characteristics of the attenuation of noise filters by electromagnetic field analysis and automatically calculate an equivalent circuit constant for noise. This technology allows noise countermeasures to be taken in advance, thus reducing the total development period.

To downsize equipment, integration technologies that consider the arrangement of elements, filters, and coolers are required. Figure 4 is a configuration example in which a control board, elements, wires, and base and fin for cooling have been integrated. Molded resin is used to house the electronic components, which enhances the reliability. A single cooling route using a heat-conducting sheet can reduce the entire thermal resistance. The size was reduced to two thirds compared to the conventional type.

5. Control Technologies

For position sensorless adaptive magnetic flux observer control used for permanent magnet synchronous motors, control in low speed ranges where the induced voltage was low was difficult. A new method has been developed to identify inductance and estimate the position by superimposing high-frequency waves to output waveforms in low-speed ranges using the dependence of motor inductance on position.

For driving large-capacity AC motors, multiple inverters are connected using large and expensive reactors in some cases. Figure 5 shows the configuration of a driving system for a double-winding permanent magnet synchronous motor for which a single motor can be driven by multiple inverters without any reactors. When electric currents are controlled by the inverters separately, the control becomes unstable due to the union between the winding wires. To counter this problem, a stable, high-response control system which incorporates the influence of the union between winding wires into a control model has been developed.

6. Technology of Key Parts

As the frequency of converters has been increasing, it has become important for magnetic parts to reduce the loss at high frequency. Figure 6 shows a planar transformer for which the arrangement of the winding wires and core was optimized using a printed board. The

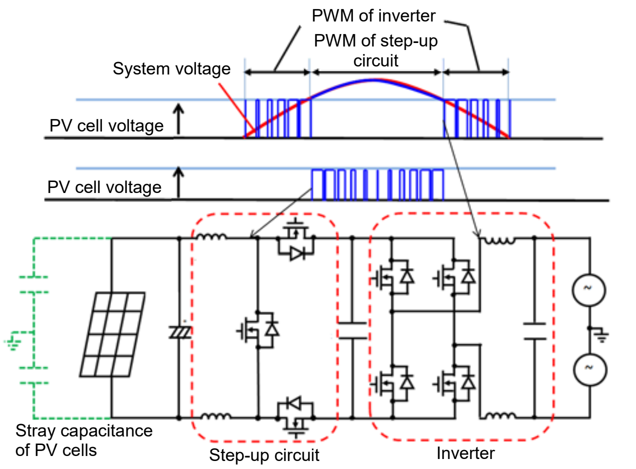

Fig. 3 Cooperatively controlled PV inverter

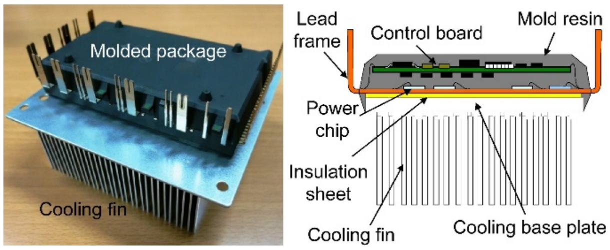

Fig. 4 High integration inverter

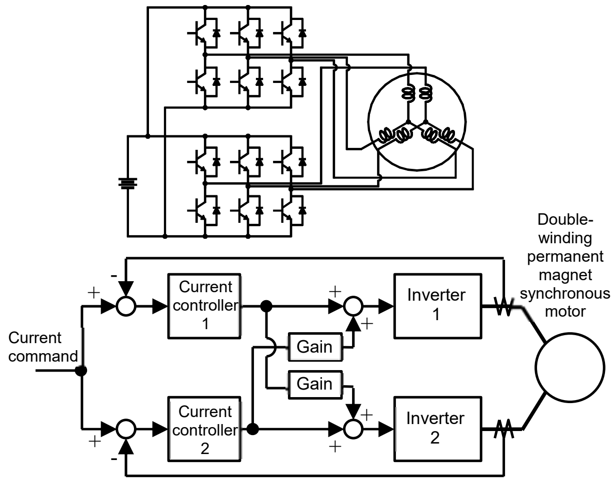

Fig. 5 Driving control of double-winding permanent magnet synchronous motor

primary and secondary winding wires are formed as patterns on a multilayer board and the core with the circuit board inserted forms a magnetic circuit. The coupling coefficient is high and the skin effect is minimal, so eddy-current loss can be significantly reduced. In addition, the length of the magnetic circuit of the core is shorter, thus reducing the volume and core loss.

7. Power Electronics System Products that Support Humans and Society

Power conditioners for electric vehicles (EVs) control three types of electric power simultaneously—EVs, PV power generation (PV), and

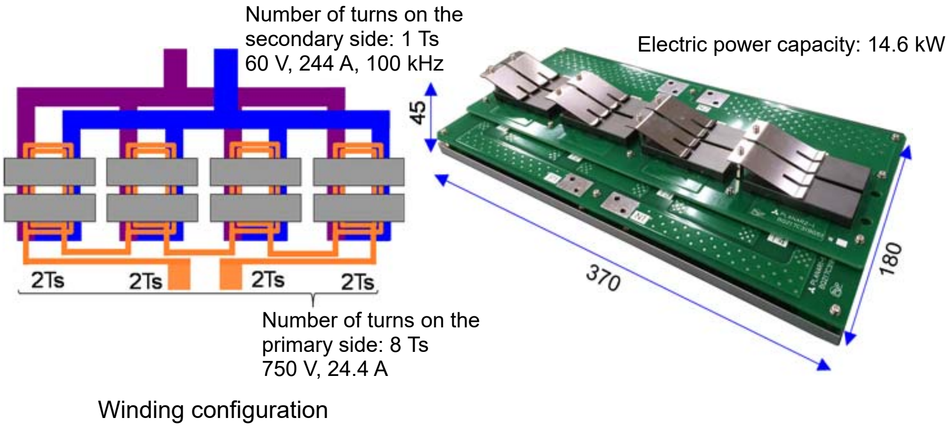

Fig. 6 Planar transformer

commercial power supply systems—and they use EVs to store electric power. A power conditioner for EVs has a built-in two-way converter that charges and discharges an EV and a built-in inverter that supplies electric power from the EV to the electric power system and house. When an electric power system fails, PV can supply power to the home and can charge an EV, and the EV can supply power to the house.

Station energy-saving inverters use regenerated energy from railway vehicles effectively at stations. Surplus power regenerated through a 1,500-V wire is converted to high-frequency electric power with a resonant-type high-frequency inverter. The electric power is converted to direct current with a rectifier via a transformer. The DC is converted to commercial alternating current with an SiC inverter, which is used in the station building.

More and more servo motors have been applied to enhance the performance of systems and shorten the cycle time. Servo motors that rapidly output large torque require large instantaneous power. Servo motor drive systems with circuits for energy assistance are available. Condenser units and step-up/step-down choppers work to compensate for changes in electric power on DC bus bars which varies due to increases and decreases in the output from the servo motors. As a result, the maximum electric power supplied from the power source side to the converters is decreased, which reduces the burden on power facilities.

8. Conclusion

To spread more energy-saving systems using power electronics technologies, the loss of the systems themselves needs to be reduced, system costs and size need to be reduced, and the value of systems needs to be enhanced.