Conversion Circuit Technology for High Efficiency and Downsizing

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1. Introduction

Smaller converters with higher efficiency are demanded for industrial equipment, consumer appliances, and automotive devices because more energy needs to be saved and space is limited. To develop smaller converters with higher efficiency, conversion circuit and control technologies must make maximum use of the characteristics of advanced parts and material technologies (next-generation devices, magnetic components, and cooling parts). This paper describes conversion circuit technologies for high efficiency that help reduce the size and increase the efficiency, as well as a multiport circuit technology that optimizes the electric power flow from multiple power sources from the aspect of systems.

2. Circuit Technologies for High Efficiency

2.1 Circuit technology for AC-DC converters with higher efficiency

We have proposed AC-DC converters with gradationally controlled voltage inverters (GCVI) as shown in Reference (1) and has demonstrated that their charging operation is highly efficient by applying them to electric vehicle battery chargers. These inverters reduce the switching voltage and frequency and use high-performance low-voltage elements to improve efficiency. This section describes development examples of GCVI.

2.1.1 Gradationally controlled voltage inverters with voltage doubler rectification

Recently, devices to be connected to power supply systems need to be made compatible with AC input voltages (85 to 260 V) found worldwide. In the conventional gradationally controlled voltage inverters where only sub-converters (single-phase inverters) and short-circuiting switches were used for boost operation, how to improve the efficiency at an AC input voltage of 100 V, which was the condition of high boosting ratio operation, was a problem. Therefore, we have proposed AC-DC converters with gradationally controlled voltage inverters to which voltage doubler rectification shown in Fig. 1 was applied. Voltage doubler switches were added to the conventional circuit and voltage doubler rectification is carried out at an AC input voltage of 100 V. This voltage doubler rectification operation can reduce the DC voltage of the sub-converters and the voltage applied to the PFC inductor by 50% and can reduce the conduction interval of the short-circuiting switches. Although a new loss of 14 W is produced by the added voltage doubler switches compared to the conventional method, the conduction loss on the short-circuiting switches is reduced by 9 W, the switching loss on the sub-converters is reduced by 4 W, and the core loss on the current control inductor is reduced by 5 W. The total loss (the new loss minus the three loss reductions) is 4 W lower. Figure 2 shows the measured actual efficiency. The efficiency at 100 V (1.5 kW) was improved by 0.4 points thanks to the voltage doubler rectification and the efficiency was improved in the range of AC input voltage of 85 to 120 V to which the voltage doubler rectification was applied.

2.1.2 Simple gradationally controlled voltage inverters

We have proposed AC-DC converters with simple gradationally controlled voltage inverters to further simplify and downsize circuits while maintaining their

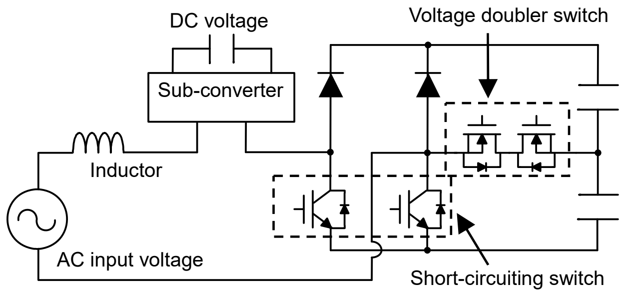

Fig. 1 AC-DC converter with gradationally controlled voltage inverter (GCVI) using voltage doubler topology

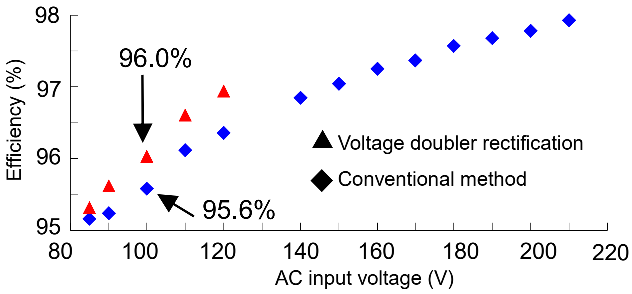

Fig. 2 Improvement of conversion efficiency with voltage doubler type GCVI

*Advanced Technology R&D Center **Nagoya Works high efficiency characteristic. Figure 3 shows the circuit diagram. In the conventional configuration, the sub-converters, short-circuiting switches, and AC input terminal are connected in series as shown in Fig. 1. As a characteristic of the simple configuration, the sub-converters, short-circuiting switches, and output capacitor are connected in parallel. This configuration reduced the amount of active semiconductors by 55% compared to the conventional method. In addition, the maximum efficiency in a demonstration using an actual system (AC input voltage of 200 V and electric power of 3.0 kW) was as high as 96.5%.

2.2 Circuit technology for DC-DC converter with higher efficiency

As more and more DC applications are used, DC-DC converters are becoming more important. Smaller DC-DC converters with higher efficiency are demanded to save the energy consumed by the entire system and to make it easier to mount. Figure 4 illustrates a boost DC/DC converter with SiC devices that boosts the DC voltage of a storage battery for driving vehicles to the DC bus voltage of an inverter for driving motors. In this circuit, an SiC-metal-oxide-semiconductor field-effect transistor (SiC-MOSFET) module was used and the device was driven at 50 kHz, which was three times that of the conventional method using an Si device (insulated gate bipolar transistor (IGBT)). In addition, the 2-phase interleaved converter reduced the required capacities of inductors and input and output capacitors that have a high occupied volume ratio, achieving the power density of 22.1 kW/L (under continuous rated power of 54 kW when the volume was 2.44 L and the water temperature was 60°C). Figure 5 shows details of the loss. The values have been standardized relative to the loss with the conventional Si device as 100. The use of an SiC-MOSFET reduced the switching loss by 51%, the conduction loss by 58%, and the diode conduction loss by 94%. The loss of the magnetic component was reduced by 38% thanks to the reduced core loss due to the reduced capacity and size. As a result, the total loss was effectively reduced by 53.6%.

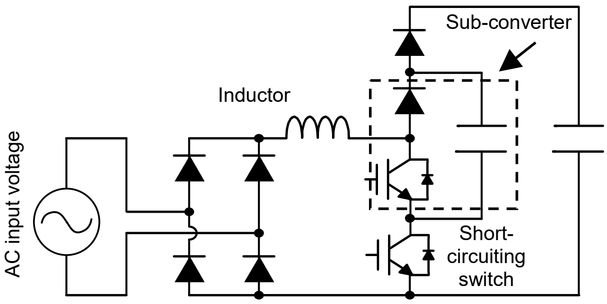

Fig. 3 AC-DC converter with simple GCVI

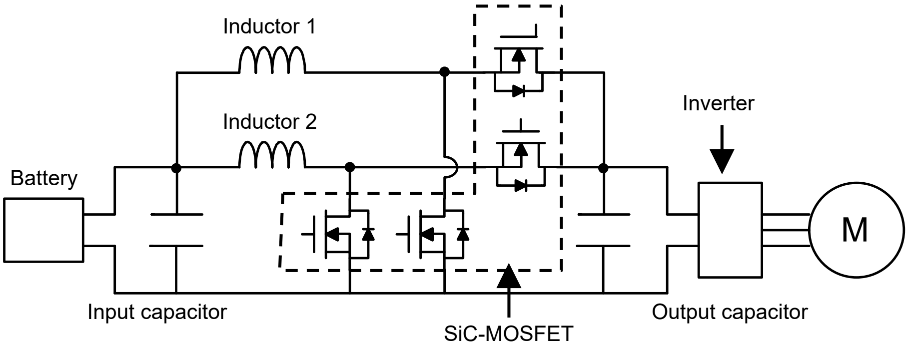

Fig. 4 Boost DC-DC converter using SiC-MOSFET

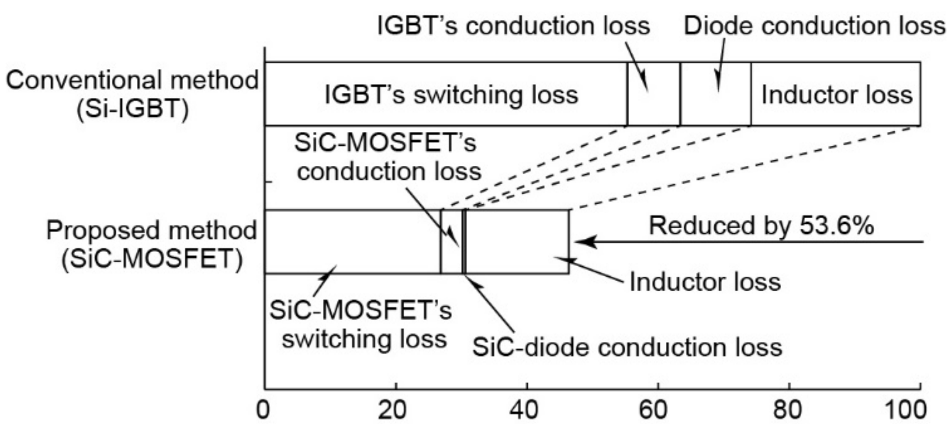

Fig. 5 Loss reduction effect

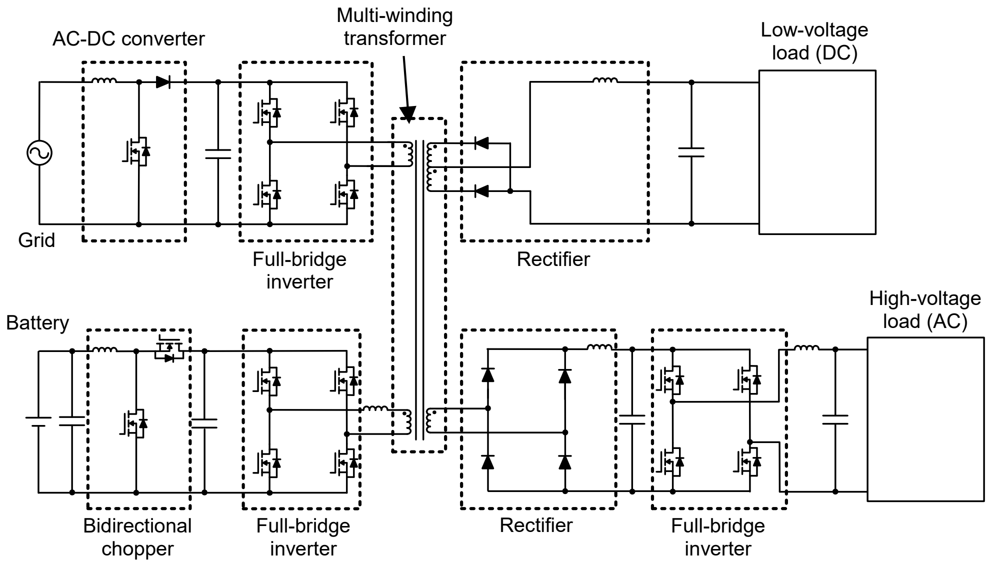

Fig. 6 Circuit configuration of a multi-port converter

3. Multiport Circuit Technology

We have succeeded in downsizing converters themselves and improving their efficiency as mentioned above. We have also developed a multiport circuit technology that optimizes the electric power flow in a system consisting of multiple power sources.

Figure 6 is the circuit configuration of the developed multiport converter. A multiport converter has a multi-winding transformer consisting of five winding wires and one core. Each winding wire is connected to each of the converters connected to grid, battery, low-voltage load, and high-voltage load. By using a single isolation transformer of the multiport converter for insulation between the ports, the number of converters and isolation transformers included in a system can be reduced compared to the conventional multiple-power source system that has an insulated converter between each of the battery, grid, low-voltage load, and high-voltage load. As a result, the efficiency of the electric power flow of the multiple-power source systems is improved. By controlling the voltage output phases and duty ratios of the full-bridge inverters connected to the grid side and the battery side of the multi-winding transformer, we have achieved electric power flow to supply power to the low-voltage load and high-voltage load from the grid and battery at the same time, as with the conventional system.

4. Conclusion

This paper described technologies for downsizing converters and improving their efficiency along with the multiport circuit technology to optimize the electric power flow from multiple power sources in a system. Conversion circuit technologies for downsizing and high efficiency are at the heart of energy conservation that supports the recycling-oriented society of the 21st century. We will continue to contribute to the development and sophistication of parts and material technologies as well as applications.

Reference

(1) Kaneyama T., et al.: "High Efficiency Isolated AC/DC Converter with Gradationally Controlled Voltage Inverter for On-board Charger, Mitsubishi Electric ADVANCE, 145, 8–10 (2014)