Development of Power Storage System with Improved Workability

YAMADA Junichiro, OUCHI Yusuke and ETO Gun

Renewable energy is an important low-carbon energy source that can contribute to energy security. A surplus electricity purchase system was started in 2009 to promote the spread of renewable energy. Since then, the purchase price has fallen, while the electricity price has risen. Therefore, the power storage system is attracting attention from the viewpoint of self-consumption in which photovoltaic power generation electricity is stored instead of being sold and used when needed. Moreover, attention is being paid to power storage systems in preparation for power outages caused by such natural disasters as typhoons and earthquakes. This time, we developed the power storage system (KPBP-A) aiming at reducing the initial introduction cost by improving workability. For the power conditioner used in the power storage system, we applied a housing that is smaller than the conventional model. Because of the effects of miniaturization and increased output capacity, heat generation has become an issue. We aimed to improve efficiency by applying SiC-MOSFET to non-isolated bidirectional DC/DC converter and optimizing the switching pattern of inverters. As a result, a small housing could be applied, and workability could be improved.

1. Introduction

Renewable energy is paid attention to as an important domestic energy source that does not emit greenhouse effect gas and can contribute to energy security[1). A surplus electricity purchase system for photovoltaic power generation was started in 2009 to promote the spread of renewable energy. The surplus electricity purchase system is the system that electric power companies purchase surplus electricity that cannot be completely consumed at home among electricity generated by a photovoltaic power generation facility[2). The cost required for purchasing by electric power companies in the surplus electricity purchase system is covered by a renewable energy power generation promotion levy (renewable energy levy)[3). Electricity generated by renewable energy purchased by electric power companies is supplied as a part of the electricity used daily. Therefore, the renewable energy levy is widely collected from electricity users and collected in the monthly electric charge. The renewable energy levy is increasing year by year and forecasted to also increase hereafter. On the other hand, the purchase price of generated electricity is decreasing year by year. At the beginning of the surplus electricity purchase system, although the purchase price for residences was 48 yen/kWh, it was 19 yen/kWh in 2021, meaning a decrease to half the price or less[4). In addition, since the surplus electricity purchase system is the system that purchases at a fixed price during a certain period after the installation of a voltaic power generation facility, the purchase period is expiring sequentially from 2019, and the period to expire will reach about 1.65 million cases by 2023[5). Although the surplus electricity after the expiration of the purchase period can be sold to electric power companies and electric industrialists, the purchase price is cheaper than that during the purchase period.

In the background to the electric charge rise and reduction of the purchase price, a self-consumption system in which a storage device is introduced to homes to store surplus electricity in a battery and consume it by discharging to the home load when needed attracts attention[6).

Furthermore, power outages caused by typhoons and earthquakes in the scale of several hundred thousand houses occur almost every year all over Japan. Outages occurred in about 480,000 houses from the Kumamoto earthquake in 2016, in about 2.4 million houses from Typhoon No. 21 in 2018, in about 2.95 million houses from the Hokkaido Iburi earthquake, and in about 930,000 houses from Typhoon No. 15 in 2019, and some cases among them were recognized in which the outage period continued for several days. Records that many power storage systems supported the life of victims when outages occurred due to these disasters were reported[7). Power storage systems are paid attention to from the viewpoint of preparation for outages during disasters.

Contact : *YAMADA Junichiro* junichiro.yamada@omron.com

In the above background, the shipping amount of power storage systems is increasing year by year, and the spread of these systems is steadily promoted.

However, in order to spread the power storage system independently even if no public support is obtained, the cost is a problem. The spread promotion study meeting for stationary power storage systems held by the Ministry of Economy, Trade and Industry studied target prices aiming for the independent spread of household power storage systems. It was shown that the construction cost occupies about 25% of the total expense of the price of a power storage system, including the battery and the construction cost in the household power storage system. Since creative originality by manufacturers is expected in order to reduce construction costs, it was proposed to add the construction cost to the target price[8]. For example, since it is difficult to carry by a person when weight or size is large, transportation by multiple persons is required. In addition, if transportation by manpower is difficult, the use of heavy machines, such as a crane, is required. These factors lead to the increase of installation costs.

In order to promote the spread of power storage systems, we developed and commercialized the flexible power storage system, the KPAC-A/B series, to be commonly used by households and industries. These series are systems that can be installed with batteries later for households that have already introduced photovoltaic power generation systems and that can realize self-consumption by utilizing generated power from already introduced photovoltaic power generation systems to charge daily surplus power.

This time, we developed and commercialized the multi-storage power storage platform, the KPBP-A series, of which workability was improved. One platform can deal with nine types of system configurations for the purpose of realization in the optimum device configuration to match the request and budget of end users. In addition, for the purpose of the ease of transportation and the elimination of restrictions on installation, and a small-size battery construction that enables easy transportation by divided structure was adopted. Moreover, in order to reduce person-hours by single person operation, the miniaturization and weight reduction of the power conditioner were realized.

The KPBP-A series is applied with a housing smaller than that for the KPAC-A/B series concerning power conditioners and provided with a higher output capacity. This paper will report the technical issues and applied technology for miniaturization and weight reduction of the power conditioner.

2. Features of Multi-power Storage Platform

Main concepts of the KPBP-A series that realized the improvement of workability are as follows:

- Capable of selecting at will
- Capable of installing freely
- Capable of using automatically

2.1 Capable of Selecting at Will

The feature of the KPBP-A series is that one platform can deal with nine types of system configurations. Fig. 1 shows the options for nine types of system configurations.

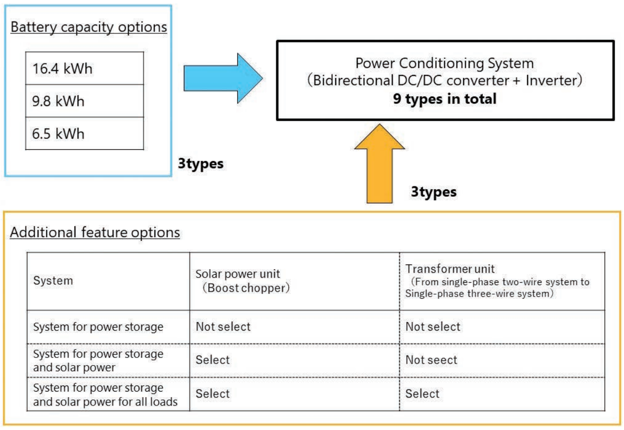

Fig. 1 Options for System Configuration

It can deal with three types of systems consisting of a system for power storage, a system for power storage and solar power, and a system for power storage and solar power for all loads, depending on the choices of optional function addition using the power conditioning system composed of a bidirectional DC/DC converter for performing charge/discharge with a battery and inverter performing the power conversion with the system power supply (hereafter system) as a platform, and it can select from three types of battery capacities for each system. Therefore, it can deal with nine types of system configurations depending on application.

The system for power storage is composed of a battery unit and a power conditioning system. At the time of an outage, the power discharged from the battery can be supplied to the particular household electric appliance determined in advance.

The system for power storage and solar power is composed by further adding a PV unit to a system for power storage. The PV unit has the function to output the generated power to the multi-power storage power conditioner. At the time of an outage, the discharged power from the photovoltaic power generation and battery can be supplied to the particular household electric appliance determined in advance.

The system for power storage and solar power for all loads is composed by further adding a transformer unit to a single system for power storage and solar power. The transformer unit has the function to supply power to all household electric appliances at home by transforming the single-phase two-wire 200 V output from the multi-power storage power conditioner to a single-phase three-wire 200/100 V output at the time of an outage.

It is possible to introduce devices in steps depending on the occasional needs. For example, it is possible to install a system for power storage additionally for the user having an existing photovoltaic power generation system. In addition, if the existing photovoltaic power generation system fails, it is possible to compose a system for power storage and solar power by adding a PV unit to replace the existing system after the failure of the existing photovoltaic power generation system and to extend to the composition of system for power storage and solar power for all loads by further adding a transformer unit.

2.2 Capable of Installing Freely

The feature of the KPBP-A series battery unit is to be of small size that supports indoor/outdoor installation and where the installation place can be selected flexibly. The feature of the battery unit of 16.4 kWh and 9.8 kWh is to have a divided structure and to be able to alleviate restrictions at the time of installation and construction. Even the system for power storage and solar power for all loads (16.4 kW) composed of the largest number of devices has a size capable of loading into a light van and has a structure that can be transported by dividing. Therefore, even if it has a large capacity, it can be carried without using a crane vehicle and enables cost reductions in terms of construction.

2.3 Capable of Using Automatically

The feature of the KPBP-A series is that the switching of the power supply at the time of an outage and recovery is performed automatically and that the charge amount at night can be automatically controlled by AI. When an outage occurs, power is automatically supplied to the household load without requiring operation by the user.

3. Configuration and Specification of Power Conditioner

Fig. 2 shows the appearance of the KPBP-A series multi-power storage power conditioner, and Fig. 3 shows the circuit structure for the multi-power storage power conditioner, PV unit, transformer unit, and power distribution board connected to the system.

The multi-power storage power conditioner is composed of a non-insulation type bidirectional DC/DC converter and inverter as the power transformer, control circuit section for performing control of various protective functions, and power transformer and relay section that switches output at the time of the power supply at the interconnection and outage (hereafter, at the time of independence). The charge/discharge control of the battery is performed by a non-insulation type bidirectional DC/DC converter depending on the information on CAN communication with a battery unit and the measurement of the power receiving point of the system. In addition, DC power from the non-insulation bidirectional DC/DC converter and boost chopper is inversely transformed to AC power by the inverter. Furthermore, the inverter also performs the rectifying transformation from AC power to DC power and system interconnection control matching the condition of the voltage and frequency of the system. Various protective functions, such as bidirectional DC/DC converter control, system interconnection control, and the AICOT® independent operation detection function and abnormality detection are loaded on the control circuit section.

Fig. 2 Appearance of Power Conditioning System

The PV unit is composed of the connection box function section consisting of the circuit breaker and backflow prevention diode, boost chopper as the power transformer and control circuit section that controls the various protective functions, and the power transformer. Maximum power point tracking control (MPPT) that maximizes power generated by solar cells, boost chopper control, and various protective functions such as abnormality detection are loaded on the control circuit section.

The transformer unit is composed of the non-insulation transformer that transforms single-phase two-wire 200 V to single-phase three-wire 200/100 V.

Either one of the transformer units for all loads and that for a particular load can be selected depending on the purpose of the user. Although the connection in Fig. 3 shows the transformer

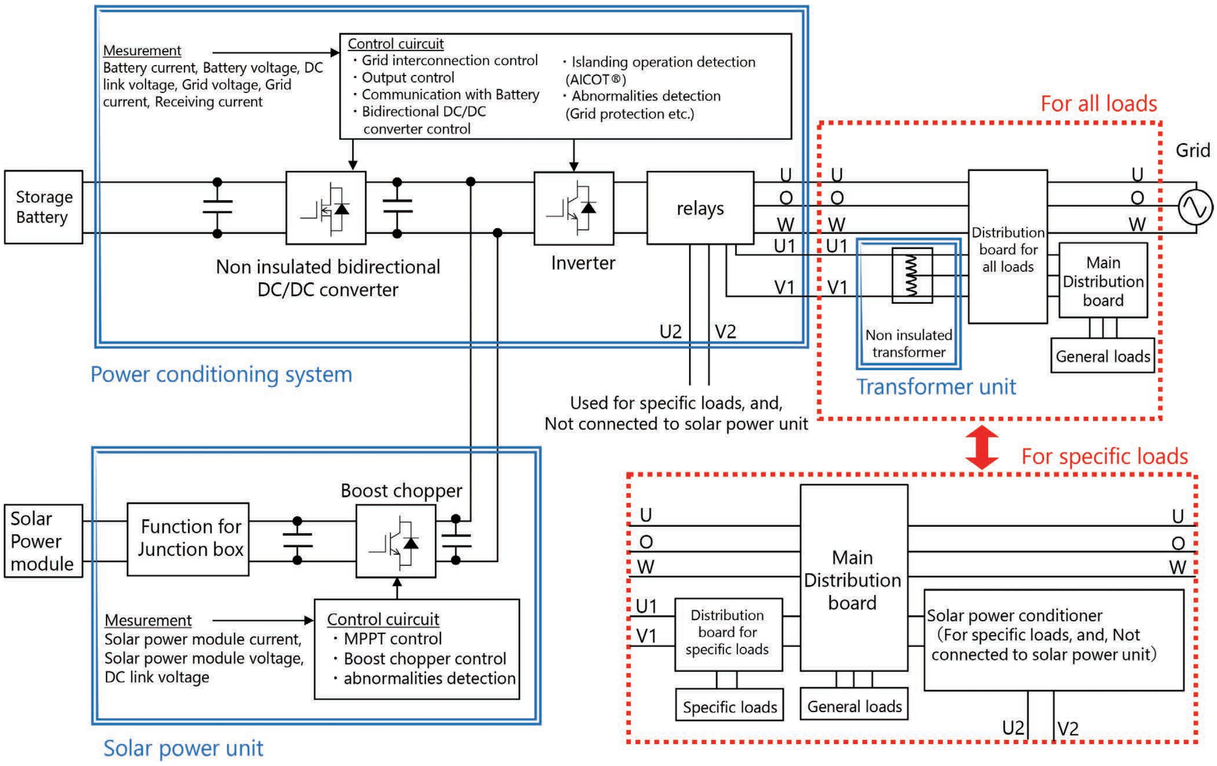

Fig. 3 Circuit Structure of KPBP-A Series

Table 1 Comparison of Main Specification

Item			KPBP-A series			KPAC-A series (conventional)		KPAC-B series (conventional)
Battery	Electric energy		16.4 kWh	9.8 kWh	6.5 kWh	9.8 kWh	6.5 kWh	4.2 kWh
AC output	Interconnection (single function) (power factor 1.0)		5.9 kW	4.0 kW	2.5 kW	4.0 kW	2.5 kW	2.5 kW
	Interconnection (hybrid) (power factor 0.95)		5.6 kW			No response		No response
	Independent (particular load)		2.0 kVA (100 V)			2.0 kVA (100 V)		2.0 kVA (100 V)
	Independent (all loads)		4.0 kVA (200 V)			No response		No response
Power conversion efficiency		Charge	95.5%	95.5%	95.0%	94.0%	93.0%	95.0%
		Discharge	96.0%	95.5%	95.0%	94.0%	93.0%	95.0%
External dimension (width × height × depth)			450×562×232 mm			650×493×222 mm		650×493×222 mm
Weight (main body)			About 21 kg			About 29 kg		About 29 kg

unit for all loads, the connection for a particular load is obtained by replacing that for all loads with that for a particular load in the red dotted line frames.

Table 1 shows the comparison of the main specifications between the power conditioning system of the KPBP-A series and the KPAC-A/B series of the conventional model. The KPBP-A series has a smaller size and lighter weight than the KPAC-A/B series. In addition, AC output at the time of normal operation (hereafter, at the time of interconnection) and at the time of independence is higher than those of the KPAC-A/B series.

4. Technical Issues and Solution Policy

4.1 Study of Small Size Housing

Upon the development of the KPBP-A series, we aimed to apply the same housing as that for power conditioners (hereafter KPW-A etc.) of the KPV series, the KPR-A series, and the KPW-A series for single-phase outdoor installation type photovoltaic power generation systems that are conventional models. The housing size for the KPW-A etc. is smaller than that for the conventional model KPAC-A/B series. The following two points can be mentioned as advantages for adopting this housing.

First, the improvement of workability can be mentioned. Weight that enables construction by one person was realized by performing miniaturization and weight reduction in comparison with the housing for the conventional model KPAC-A/B series. Second, the suppression of a cost increase by the adoption of a semiconductor device to be described later can be mentioned. Although the cost increase from internally mounted parts (semiconductor device) that are used to realize a small size housing is a concern, a cost reduction is expected by the common use of the housing for the KPW-A etc.

4.2 Issue

The issue caused by using the same housing as that for the KPW-A etc. is heat generation. The housing for the KPW-A etc. is small and the volume ratio is 82% of the KPAC-A/B series. Since the components, such as the circuits, are the same as that for the KPAC-A/B series, while the external size is smaller, the condition is that more heat is accumulated in the housing. Furthermore, since the output at the time of the interconnection and the output capacity at the time of independence of the KPBP-A series are larger than those of the KPAC-A/B series, the condition of more severe heat generation arises. That is to say, the heat quantity that warms the internal air increases from the increase in the output capacity, in addition to the reduction in the space volume inside the power conditioner, thus the temperature inside the power conditioner rises significantly.

Various print circuit boards and multiple parts mounted on the print circuit boards are loaded inside the power conditioner. Some of these parts have an end of life, and it is necessary that the temperature specification of each part is satisfied, and the life of each part satisfies the expected design life of the power conditioner in order to satisfy the reliability and expected design life of the power conditioner. The temperature of parts depends on the self-heat generation of parts, thermal conduction from print circuit boards, and ambient temperature of parts, and the internal temperature of the power conditioner affects all mounted parts. Therefore, how to suppress the rise of internal temperature of the power conditioner is important to satisfy the temperature specification of each part and the life of the parts.

The loss of a switching element affects the internal temperature of the power conditioner most. The loss of switching element occupies about 50% to 60% of the total loss of the power conditioner. Although the heat quantity of the loss of the switching element is dissipated to the exterior of the power conditioner through the heat sink, all of the heat quantity is not dissipated, and a part of heat quantity results in raising the internal temperature of the power conditioner. Therefore, the reduction of the loss of the switching element is required to suppress the rise of the internal temperature of the power conditioner.

4.3 Policy for Solving Issue

Application of SiC-MOSFET that is effective for the reduction of continuity and the switching losses as switching elements for a non-insulation type bidirectional DC/DC converter and inverter was studied using power loss simulation and thermal fluid analysis. As a result, it was found that the application of SiC-MOSFET only to a non-insulation type bidirectional DC/DC converter but not to an inverter provides the best balance of cost and performance to reduce the loss of the switching element. In addition, it was found that the reduction of the loss of heat generating parts other than the switching element and the implementation of heat dissipation to the internal sheet metal of heat generating parts of relays and the power supply, in addition to the reduction of the loss of the switching element of the non-insulation type bidirectional DC/DC converter enables the application of a small housing at the time of interconnection. On the other hand, the switching pattern that can supply power with low harmonic distortion to the household electric appliance load at home is adopted at the time of independence. Therefore, since the further reduction of the loss of the reactor composing inverter, in addition to the countermeasure for heat generation at the time of interconnection, is required, the reduction of reactor loss was implemented by devising the switching pattern of the inverter.

4.4 Technology for Application of SiC-MOSFET to Non-insulation Type Bidirectional DC/DC Converter

The Si-IGBT has been adopted for the non-insulation type bidirectional DC/DC converter of the conventional model KPAC-A/B series. Since SiC-MOSFET has a high insulation breakdown electric field intensity characteristic in comparison with the Si-IGBT, a low ON-resistance characteristic is obtained, and low continuity loss can be realized. Moreover, since the tail current at switching is not generated, in principle, high speed operation is possible. Therefore, switching loss lower than that of the Si-IGBT can be realized. Fig. 4 shows the circuit diagram of the non-insulation type bidirectional DC/DC converter and the arrangement of the gate, source, and drain of the Nch type SiC-MOSFET. The KPBP-A series is applied with the Nch type SiC-MOSFET. The right side of the non-insulation type bidirectional DC/DC converter shown in Fig. 4 is connected to the DC side of the inverter, and the left side is connected to the battery.

Although various semiconductor manufacturers commercialized SiC-MOSFET, the performance of the product varies depending on the manufacturers. In order to realize the design target of loss reduction of the switching element obtained by a power loss simulation and thermal fluid analysis simulation this time, we selected the SiC-MOSFET that could obtain the desired low ON-resistance characteristic among the lineup of various products from semiconductor manufacturers. In addition, for the purpose of not limiting the high-speed operation of the SiC-MOSFET as much as possible, we performed the realization of low switching loss by reducing parasitic inductance and giving the gate voltage protection circuit, as well as the reduction of body diode loss, of SiC-MOSFET created by switching the pattern design.

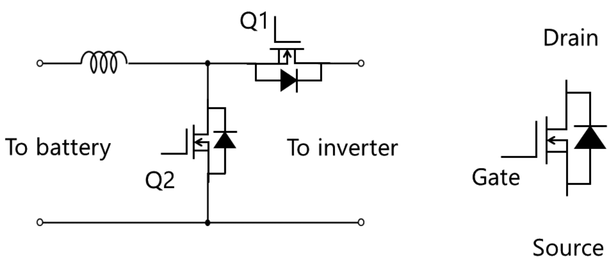

Fig. 4 Non-insulation Type Bidirectional DC/DC Converter and SiC-MOSFET

4.4.1 Reduction of Parasitic Inductance

In order to realize the minimization of switching loss of SiC-MOSFET, it is necessary to realize a quick switching operation without limiting the switching operation of SiC-MOSFET by gate resistance as much as possible. However, when we are going to realize the quick switching operation, there is a possibility of the generation of surge voltage at voltage Vds between the drain and the source and the voltage Vgs between gate and the source. This generation of surge voltage may cause an overvoltage breakdown of SiC-MOSFET, a malfunction due to noise increases, and a deviation from the domestic standard.

In order to suppress the surge voltage of the main circuit and the gate circuit, the minimization of the current loop area formed by the peripheral parts to be mounted on SiC-MOSFET and the printed circuit board is required. Therefore, SiC-MOSFET module that enables the expectation of minimizing the current loop area was adopted. In the minimization of the current loop area in the main circuit, the reduction of parasitic inductance was performed by optimizing the arrangements of chips inside the SiC-MOSFET module and pins, in addition, the snubber circuit was arranged close to the SiC-MOSFET module. Regarding the gate circuit, the reduction of parasitic inductance was performed by optimizing the arrangements of the chips inside the SiC-MOSFET module and the pins of the SiC-MOSFET module, in addition the gate resistance and gate driver parts to be mounted on the printed circuit board are arranged close to the SiC-MOSFET module. Furthermore, the reduction of parasitic inductance of the loop wiring itself in which current flows is also an effective means. Therefore, the reduction of parasitic inductance is performed by securing the wide width of the wiring pattern, making wiring patterns with different current flow directions close to each other, and mutually offsetting the magnetic field generated by each current on the printed circuit board. For the SiC-MOSFET module, the reduction of parasitic inductance was performed by performing wire bonding and making the number of pins multiple.

When studying the reduction of parasitic inductance of the printed circuit board and SiC-MOSFET, optimization was performed by calculating the parasitic inductance using electromagnetic field analysis simulations.

4.4.2 Gate Voltage Protection Circuit

It is known that gate threshold voltage reacts sensitively and is affected by the trap that exists in the gate oxide film interface in the voltage Vgs between the gate and the source of SiC-MOSFET. Therefore, the recommended range of use of the voltage Vgs between the gate and the source is narrower than that of the Si-IGBT, and the phenomenon of lower limit voltage of negative side is especially significant. The main factors in the generation of surge voltage of the negative side are the following two phenomena. Furthermore, we will describe focusing on the operation of high side switching element Q1 shown in Fig. 4.

(1) Ringing of Q1 gate voltage due to parasitic inductance of the gate circuit when Q1 shown in Fig. 4 is turned OFF
(2) Fluctuation of Q1 gate voltage generated by the flowing of the discharge current of Q1 output capacity through the gate circuit of Q1 when the current flows in the body diode of Q1 due to turning OFF of Q2

For the ringing phenomenon of the (1) above, the countermeasure of the reduction of the afore-mentioned parasitic inductance was implemented. On the other hand, for gate voltage fluctuations of the above-mentioned (2), the suppression of the surge voltage of the negative side was implemented by giving the gate voltage protection circuit to the gate circuit, in addition to the countermeasure from the reduction of parasitic inductance.

Fig. 5 shows the operation of the gate voltage protection circuit and the circuit structure.

When Q2 is turned OFF, the energy accumulated in the reactor shown in Fig. 4 and the energy of the battery flow to the inverter side through the body diode of Q1. The discharge current of the output capacity of Q1 (parasitic capacity between drain and source) flows in the path shown in Fig. 5 (a) through the input capacity of Q1 (parasitic capacity between the gate and the source and the parasitic capacity between the gate and the drain) and the gate circuit when the body diode of Q1 is turned ON. Although the gate voltage fluctuation is suppressed by input capacity, the gate voltage of Q1 is shifted to the negative side by the voltage fluctuation generated by the gate driver circuit and the gate resistance.

Therefore, the reduction in the gate voltage fluctuation of the negative side was performed by giving the gate voltage protection circuit shown in Fig. 5 (b) to suppress the current that flows in the gate driver circuit and gate resistance.

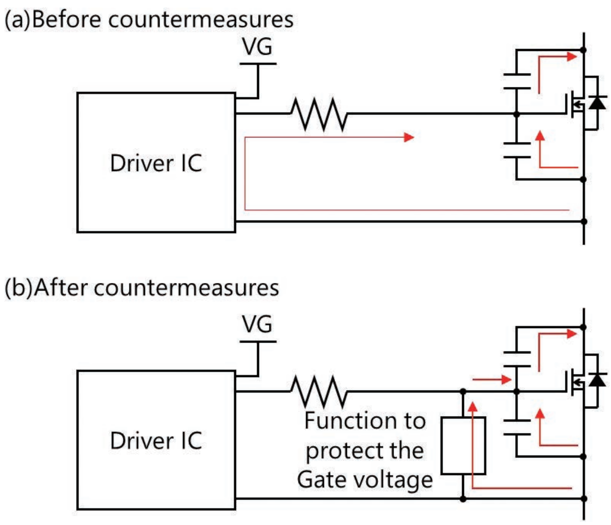

Fig. 5 Function to Protect the Gate Voltage

Fig. 6 shows the waveform of the Q1 gate voltage when Q2 is turned OFF. This is the waveform of the phenomenon where the gate voltage is shifted to the negative side of Q1 when Q2 is turned OFF and current flows in the body diode of Q1. The reduction of the gate voltage fluctuation of the negative side by the application of the gate voltage protection circuit enabled the satisfaction of the recommended gate voltage specification of SiC-MOSFET.

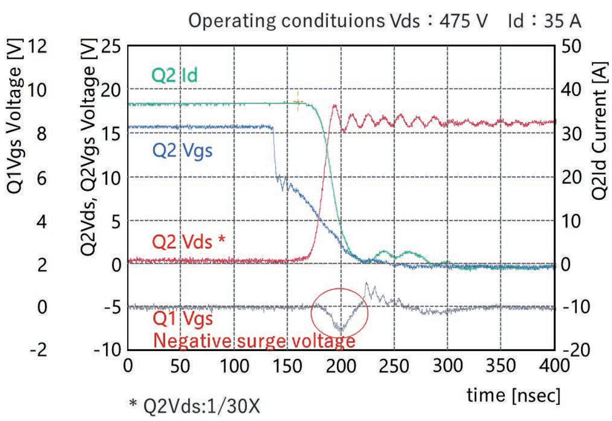

Fig. 6 Gate Voltage waveform

4.4.3 Switching Pattern

Since the bandgap of SiC-MOSFET is wide, the forward direction voltage Vf of the body diode is larger than that of the circulation diode that is connected to Si-IGBT in parallel as the characteristic of the body diode. The continuity loss is greatly deteriorated and affected by this. Therefore, we performed the reduction of the loss of the body diode by minimizing the period of the current flowing in the body diode and adopting synchronous rectification to increase the period of current flowing to the SiC-MOSFET having the low ON resistance characteristic. Specifically, this is the switching pattern system that makes the current in Q1 and Q2 flow to the SiC-MOSFET side by turning SiC-MOSFET ON in the period where current flows in the body diodes of Q1 and Q2.

Fig. 7 shows the effect of synchronous rectification in SiC-MOSFET based on the loss of Si-IGBT. This is the simulation of the loss at an output of 5.9 kW and a carrier frequency of 20 kHz. Loss was obtained in three types of Si-IGBT, SiC-MOSFET (without synchronous rectification), and SiC-MOSFET (with synchronous rectification). It is found that if SiC-MOSFET is applied without applying synchronous rectification, the loss is deteriorated in comparison with Si-IGBT due to the conduction loss of the diode part. On the other hand, since the conduction loss of the diode part can be greatly reduced when synchronous rectification is applied, we enabled the reduction of the total loss of the switching part and the diode part more greatly than the case of applying Si-IGBT.

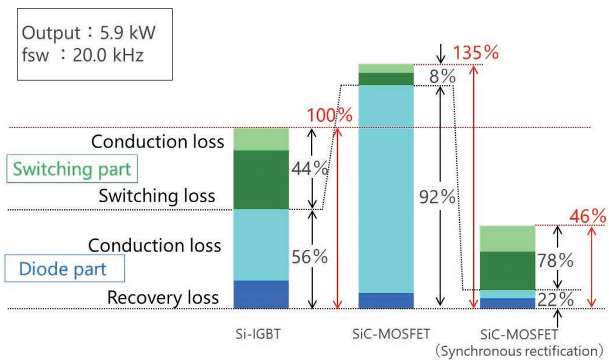

Fig. 7 Effect of synchronous rectification

4.5 Optimization Technology for Switching Pattern of Inverter

The output rated voltage at the time of independence is 100 V/2 kVA in the KPAC-A/B series. On the other hand, the voltage for all loads in the KPBP-A series is 200 V/4 kVA. Since the concern is that the output voltage from the power conditioner is distorted and a stable power supply is impossible when power is supplied to the rectification load of the capacitor input type that generates harmonic distortion from the power conditioner and to the nonlinear household electric appliance loaded with phase control, such as the thyristor and TRIAC during outages at the time of independence, the switching pattern of a bipolar system that does not switch the switching pattern in the positive and negative sides of the output voltage was adopted. Therefore, the switching patterns of inverter output at the time of interconnection and independence are made different from the viewpoint of stable power supply. Fig. 8 shows the circuit structure of the inverter part. UH, WH, UL, WL, US, and WS show the switching elements. This inverter circuit is composed of a full bridge inverter part that converts DC power to AC power (UH, WH, UL, and WL), short circuit part (US and WS), and a reactor[9].

Since the AC output voltage of the inverter is generated based on the DC voltage that is entered in the inverter, it is necessary that the DC voltage entered in the inverter is also heightened to match the increase in the output voltage specification when the output voltage specification of the inverter increases from 100 V to 200 V.

When the DC voltage entered in the inverter is heightened, the amplitude of the pulse output voltage transmitted from the inverter increases. Therefore, when the pulse pattern adopted by the KPAC-A/B series of the conventional model is adopted by the KPBP-A series as is, pulse output voltage applied to the reactor also increases. Thus, the deviation from the temperature specification due to deterioration of iron loss of the reactor was a concern. Therefore, we generated an independent switching pattern capable of reducing the pulse output voltage applied to the reactor to perform the reduction of loss of the inverter applied to the reactor.

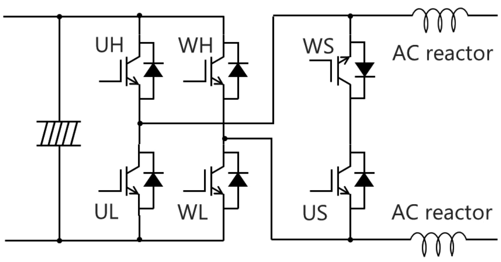

Fig. 8 Circuit Structure of Inverter Part

Fig. 9 shows the switching pattern at the time of independence in the KPAC-A/B series of the conventional model. This is a system where the dead time for preventing arm short circuits is provided, UH/WL and UL/WH are made to operate exclusively, while the short circuit part is not made to operate. This switching pattern has adopted a switching pattern of a two-level system of +DDV and −DDV assuming DC voltage DDV in which the pulse output voltage applied to the reactor is entered in the inverter as amplitude.

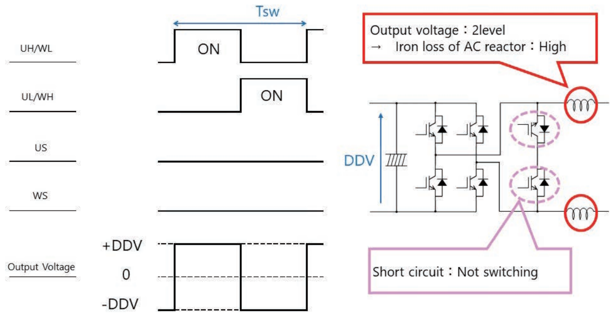

Fig. 9 Conventional System

Fig. 10 shows the switching pattern that was applied to the KPBP-A series and studied to reduce loss. This is a system where the dead time for preventing arm short circuits is provided, UH/WL and UL/WH are made to operate exclusively, while the short circuit part WS/US is made to operate, and this WS/US makes the AC current flow back. This switching pattern adopted the pattern of a three-level system of +DDV, −DDV, and 0 V assuming DC voltage DDV in which the pulse output voltage applied to the 0 V reactor is entered in the inverter as amplitude.

Since the iron loss of reactor is affected by applied voltage, we enabled to reduce the iron loss of reactor and satisfy temperature specification by adopting switching pattern in which pulse output voltage applied to reactor is of 3-level system for KPBP-A series.

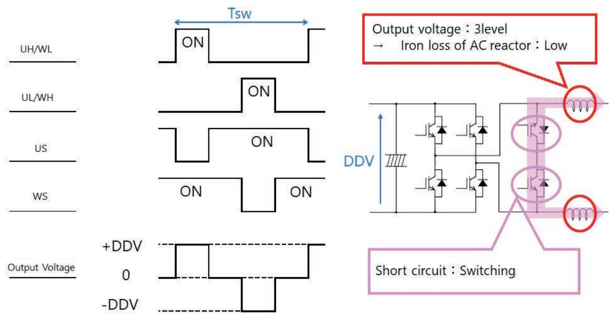

Fig. 10 System Devised for Reducing Loss

5. Result of Development

Table 2 shows the verification results of efficiency measurements in actual equipment with different switching elements of the non-insulation type bidirectional DC/DC converter.

Table 2 Comparison of Efficiency with Different Switching Elements

Output power [W]	Efficiency [%]	
	SiC-MOSFET	IGBT
2500 W (6.5 kWh type rated output)	97.32%	96.48%
4000 W (9.8 kWh type rated output)	97.96%	97.36%
6000 W (16.4 kWh type rated output)	98.93%	98.55%

In the power conditioning system of the KPBP-A series, conversion efficiency was measured from the input voltage of the battery and the output voltage of the non-insulation type bidirectional DC/DC converter. In the system for the power storage system not connected to the PV unit, the comparison in measurement was performed in an output power of 2500 W/ input voltage of 100 V, output power of 4000 W/input voltage of 150 V, and output power of 6000 W/input voltage of 200 V so that the maximum output power of the AC side was equivalent to the nominal voltage of the battery side when batteries of 6.5 kWh, 9.8 kWh, and 16.4 kWh were connected. We recognized that the effect of loss reduction was found and matched the design target by the application of SiC-MOSFET in any condition.

Table 3 shows the verification results of efficiency measurements with different switching patterns of the inverter at the time of independence.

Table 3 Comparison of Efficiency with Different Switching Patterns

System	Efficiency [%]
Conventional system	93.16%
System studied for reducing loss	93.47%

In the power conditioning system of the KPBP-A series, conversion efficiency was measured based on the measuring method of the standard from the input power from the battery and the output power to the transformer unit. As shown in Table 3, we recognized that the efficiency of this system was improved by about 0.3% in comparison with the conventional system. As a result, we enabled the reduction of the internal temperature of the power conditioner by about 5°C. As mentioned above, since the reduction of power loss enabled the suppression of the rise of internal temperature of the power conditioner and satisfaction of the temperature specification of each part and the life of parts, the application of the same housing as that for KPW-A etc. of the conventional model was realized. As a result, the external dimensions of the KPBP-A series are 450×562×232 mm, that is to say, miniaturization by approx. 82% in volume ratio was realized in comparison with 650×493×222 mm of the KPAC-A/B series of the conventional model. In addition, the weight of the KPBP-A series is approx. 21 kg, which means miniaturization by approx. 72% in weight ratio in comparison with approx. 29 kg of the KPAC-A/B series of the conventional model, resulting in the realization of one-man construction.

6. Conclusions

This paper described the power storage platform of the KPBP-A series that realized common use of the same housing as that of the KPW-A of the conventional model.

The KPBP-A series encountered an issue of heat generation because of the miniaturization of the housing and the increase in output capacity. However, the application of small-sized housing was realized by higher efficiency from the reduction of power loss thanks to the technology of application of SiC-MOSFET to the non-insulation type bidirectional DC/DC converter and the optimization technology for the switching pattern at the time of independence of the inverter. These technologies for higher efficiency realized the miniaturization and size reduction by approx. 82% and a weight reduction by approx. 72% in comparison with the KPAC-A/B series of the conventional model. Since the KPBP-A series can achieve a reduction in construction costs from the improvement of workability by the realization of the common use of small-sized housing of the conventional model, it contributes to a reduction in user costs for introducing the power storage system, and the contribution to the further spread of the power storage system can be expected.

Hereafter, we would like to study the expansion of the development of the platform of which future application is considered. For example, if we consider how to deal with the insulation type bidirectional DC/DC and total structure of the system, including the communication system to external devices, the room for improvement exists as a platform. We intend to perform the development of a power conditioner capable of responding to the growth of renewable energy and further social needs to contribute to the realization of a sustainable society.

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About the Authors

YAMADA Junichiro
Product Development Department
Energy Solutions Business H.Q.
OMRON SOCIAL SOLUTIONS CO.,LTD.
Speciality: Electricale Engineering, Control Engineering

OUCHI Yusuke
Product Development Department
Energy Solutions Business H.Q.
OMRON SOCIAL SOLUTIONS CO.,LTD.
Speciality: Electricale Engineering, Control Engineering

ETO Gun
Product Development Department
Energy Solutions Business H.Q.
OMRON SOCIAL SOLUTIONS CO.,LTD.
Speciality: Electricale Engineering, Control Engineering