Bidirectional Charging Unit for Vehicle-to-X (V2X) Power Flow

Tatsuya IZUMI*, Masayoshi HIROTA, Kenichi HATANAKA, Yoshikazu ISOYAMA, Katsuhiko SANO and Koichi TAKAYAMA

The concept of vehicle-to-X (V2X), which transmits electricity from an on-board battery to infrastructure, is expected to be a key to smart grids. With V2X technology, we can use electricity stored in large-capacity batteries of electric vehicles (EVs) and plug-in hybrid electric vehicles (PHEVs) when necessary. To realize this concept, Sumitomo Electric Industries, Ltd. has developed various technologies related to EVs, PHEVs, and infrastructure. This paper outlines our EV and PHEV bidirectional charging unit to be used for “V2X” power flow.

Keywords: electric vehicle (EV), plug-in hybrid electric vehicle (PHEV), V2X (V2G/V2H/V2L), bidirectional charger, on-board charger

1. Introduction

Due to demand for decreasing CO_2 emission and improving fuel-efficiency of vehicles, research and development of electric vehicles (EVs) and plug-in hybrid electric vehicles (PHEVs) is being revitalized worldwide. In advance of widespread use of EVs and PHEVs, Europe, United States and Japan have cooperated and worked on the international standardization of the vehicle charging system. We have participated in this standardization activity since 2009.

Conventionally, such standardization has pushed forward a viewpoint to charge on-board batteries with grid power. In contrast, in the near future, the concept of vehicle-to-X (V2X), which transmits electricity from an on-board battery to infrastructure, is expected to spread. V2X is a collective term for such as, vehicle to live (V2L), vehicle to home (V2H), and vehicle to grid (V2G) and expresses the power flow from vehicles to others (**Fig. 1**). For example, V2L is expected, as an emergency power source, to supply electricity from a vehicle to electric appliances directly. V2H and V2G technologies have started to be put to practical use, with the aim of demand peak-cut control, power distribution at electricity failure, and stabilization of grid power. Various demonstration experiments have been carried out and such technologies are now partly in use.

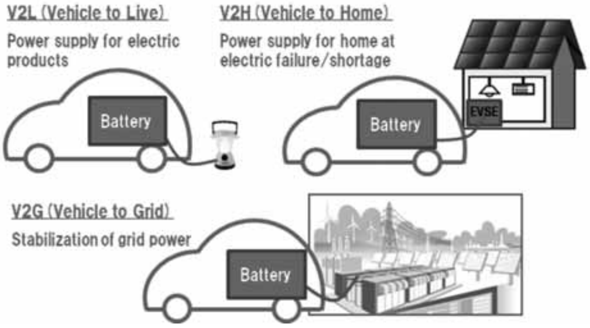

Fig. 1. Concept of V2X

To realize these concepts, we have developed various technologies related to EVs, PHEVs and infrastructure, such as wiring harness, connectors, communication units and electric power converters. This paper introduces our EV and PHEV bidirectional charging unit to be used for “V2X” power flow.

2. Overview of Bidirectional Charging System

Figure 2 shows the system block diagram of the bidirectional charging system. This system is comprised of a vehicle side (EV/PHEV) and an infrastructure side (EVSE: Electric Vehicle Supply Equipment), and both are connected through a charge cable and connector. Conventional vehicles and EVSE support only the charge function based on a control pilot signal*1 defined in IEC 61851-1. In contrast, we added a bidirectional charging unit which can charge an on-board battery and discharge from an on-board battery to support “V2X” function.

The information communicated between a vehicle and EVSE is gathered to the charge control electronic control unit (ECU). The charge control ECU manages the charge and discharge functions, based on the control pilot signal and state of charge (SOC) information of the on-board battery. This ECU takes roles, such as wakeup and sleeping instruction to various units, demand and reply confirmation. By communication with a smart phone, the charge control ECU supports the remote operation of the charge and discharge functions, and remote monitoring of a charger status. Each unit works concertedly because the charge control ECU summarizes various communication messages.

2-1 Description of charge and discharge sequence

The bidirectional charging system, shown in **Fig. 2**, can support, not only the EVSE with the communication function that is expected to be widespread from now, but also the conventional EVSE without communication function.

On connecting a charge connector into the vehicle inlet, the charge control ECU wakes up. Monitoring the

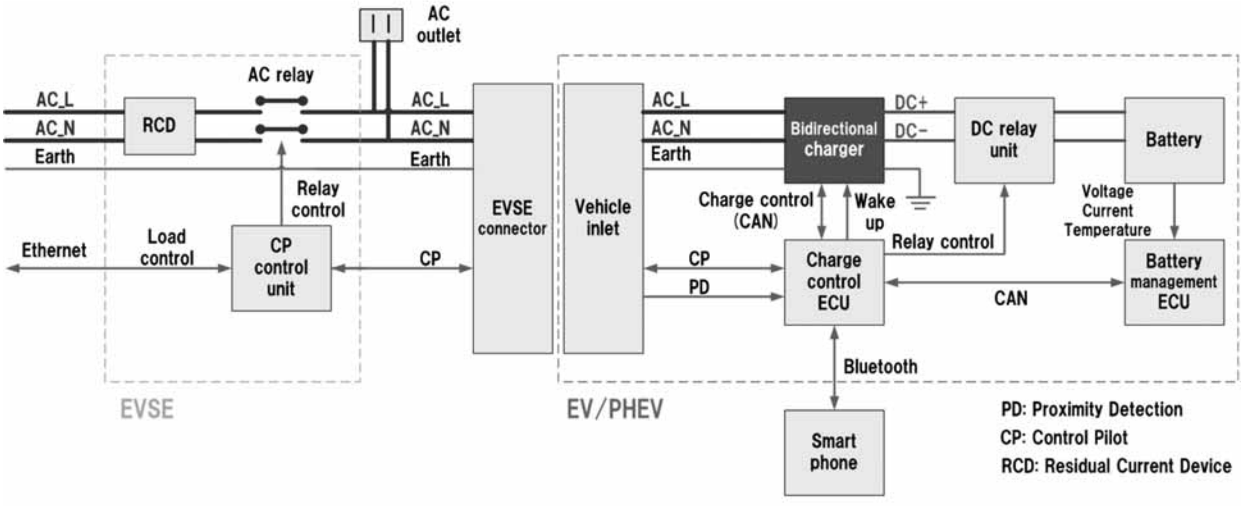

Fig. 2. System block diagram of a bidirectional charging system

duty cycle of the control pilot signal, the charge control ECU selects the operation mode (1) without EVSE communication or (2) with EVSE communication.

(1) Charge without EVSE communication

The charge control ECU wakes up the bidirectional charger and transmits the charge indication via controller area network (CAN) communication. The bidirectional charger operates with the charge mode based on the indication. Output power of the charger is arranged by the charge control ECU in consideration of the maximum current, based on the control pilot signal and SOC of the on-board battery.

(2) Charge or discharge with EVSE communication

The charge control ECU communicates with the EVSE based on ISO 15118, and wakes up the bidirectional charger. The bidirectional charger selects the charge or discharge (V2X) mode, based on the indication via CAN communication. Output power and operation mode of the charger is arranged by the charge control ECU, in consideration of the requirements from the EVSE and SOC of the on-board battery.

2-2 Bidirectional on-board charger

Conventionally, a battery's charge and discharge functions are comprised of the other unit. In contrast, we have developed a bidirectional on-board charger. It can charge and discharge on the same circuit, which realizes a smaller and more inexpensive unit. (**Fig. 3**, **Photo 1**)

Fig. 3. Concept of a bidirectional on-board charger

Photo 1. Prototype of a bidirectional on-board charger

Figure 4 shows the system block diagram of a bidirectional charger. **Table 1** shows the major specifications of the prototype. We have set the development target of achieving an efficiency of more than 90%. The bidirectional charger consists of three bridge circuits and coil units (reactor, transformer, choke coil), and bridge circuits have four insulated gate bipolar transistors (IGBTs) per bridge. Each circuit and coil takes a different role at charge mode and discharge mode, controlling ON / OFF of IGBTs precisely by a digital signal controller. In addition, a high-

Table 1. Major specifications of the prototype

Mode	Item	Value
Charge	Input voltage	AC 85 - 264 V
	Output voltage	DC 250 V (typical)
	Rated output power	1 kW / 2 kW
Discharge	Input voltage	DC 250 V (typical)
	Output voltage	AC 85 - 132 V / AC 180 - 264 V
	Rated output power	1 kW / 2 kW

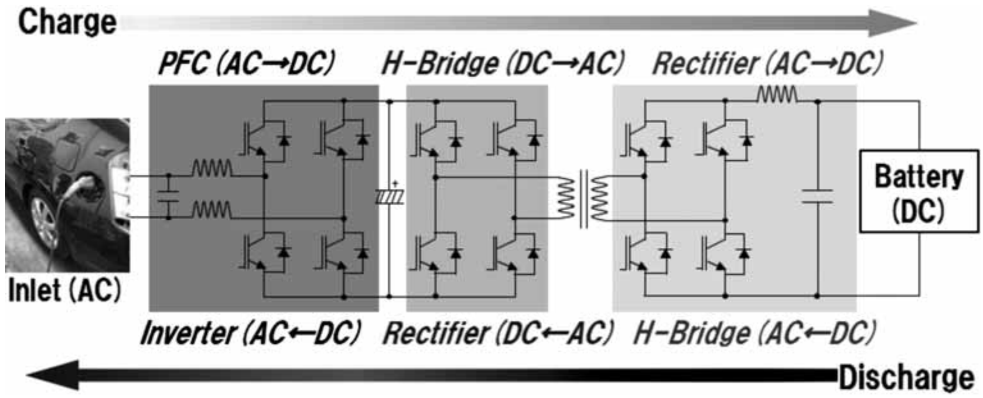

Fig. 4. System block diagram of the bidirectional charger

frequency transformer enables the balance of the insulation and bidirectional charge functions.

(1) Charge function

Input AC voltage, which is supplied by the EVSE through a charging cable, is converted into DC voltage by a boost power factor correction (PFC)[*2] circuit. Then, an H-bridge[*3] circuit converts the DC voltage into high-frequency AC voltage. A high-frequency transformer regulates transformation and insulation. Rectifier and smoothing circuits convert the high-frequency AC voltage into DC voltage and charge the battery. To follow output indications from the charge control ECU, the bidirectional charger supports various control modes, such as constant power (CP) mode, constant current (CC) mode and constant voltage (CV) mode.

(2) Discharge function

Input DC voltage, supplied from the on-board battery, is converted into high-frequency AC voltage by a boost H-bridge circuit. Then, a high-frequency transformer, rectifier and smoothing circuits convert the high frequency AC voltage into DC voltage. The inverter circuit, which converts the DC voltage into AC voltage, supports both a self-sustained operation (V2L) and a system interconnection operation (V2G, V2H). The self-sustained operation mode regulates the voltage and frequency, and the system interconnection operation mode regulates the current that is synchronized to the voltage waveform. The bidirectional charger selects the operation mode based on the indication from the charge control ECU.

(3) Additional function for "V2X"

A system interconnection mode (V2G or V2H) needs to be linked to a power system, so the bidirectional charger must be compliant with grid-interconnection code (JEAC 9701-2012) in Japan, and IEEE 1547 in the United States. Power quality control and power system protective functions, which are not required with conventional in-vehicle components, become important. **Table 2** shows an example of the additional functions that we have implemented. In addition to conventional protective functions, such as overvoltage, overcurrent and overheat protection, we realized a function for the prevention of islanding operation[*4]. The test system of the bidirectional charger is shown in **Fig. 5**.

Table 2. Example of V2G function

	Item	Specification
Power quality	Power factor	> 0.95
	Harmonics	Individual: < 3%
		Total: < 5%
	Synchronization condition	Voltage: rated value ± 10%
		Frequency: rated value ± 1%
Power system protective function	Voltage	Overvoltage (OVR)
		Undervoltage (UVR)
	Frequency	Overfrequency (OFR)
		Underfrequency (UFR)
	Islanding	Passive method
		Active method

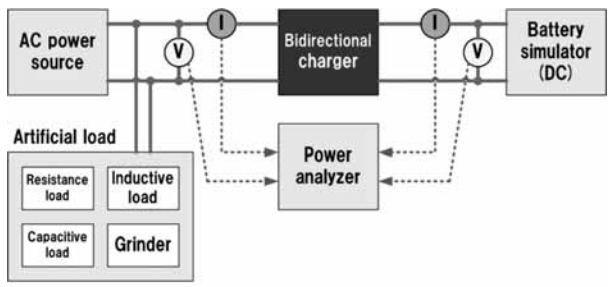

Fig. 5. Test system of the bidirectional charger

The prototype of the bidirectional charger can charge and discharge on the same circuit, which realizes a smaller and more inexpensive unit. At the rated output of 2 kW, the bidirectional charger demonstrated an efficiency of about 92% and power factor of 99% or more, achieving our original development goal.

3. Conclusion

We have developed a bidirectional charger to be used for "V2X" power flow. A prototype has demonstrated that charging and discharging with one unit are theoretically possible. International standardization of technologies related to EVs and PHEVs is currently progressing. We are contributing to these standardization activities, and continue to improve these technologies for commercialization.

· Bluetooth is a registered trademark of Bluetooth SIG, Inc.

Technical Terms

*1 Control pilot signal: Pulse Width Modulation (PWM) signal which is defined in IEC61851-1. EV/PHEV and EVSE manage the charging sequence based on the peak-voltage and duty cycle of PWM signal.

*2 Power Factor Correction (PFC): Power factor is defined as the ratio of active power to apparent power. PFC is designed to control the phase angle between voltage and current and reduce harmonics.

*3 H-bridge circuit: An electronic circuit which can create a high frequency AC voltage, by switching ON/OFF of power devices.

*4 Islanding operation: The condition that the inverter continues to output power, even after power from the electricity grid has been cut off. To ensure the safety of maintenance service workers, an islanding prevention function must be implemented.

References

(1) Hirota et al., "Development of New AC/DC Converter for PHEVs and EVs," SEI Technical Review, No. 73, pp. 68-72 (October 2011)

(2) Zheng et al., "Downsized High-Heat-Dissipation Choke Coil Designed with Powder Cores," SEI Technical Review, No. 75, pp. 55-61 (October 2012)

(3) IEC 61851-1 Ed. 2.0 b: 2010, Electric vehicle conductive charging system - Part 1: General requirement

(4) ISO 15118-1: 2013, Road vehicles – Vehicle to grid communication interface – Part 1: General information and use-case definition

(5) SAE J2894-1: 2011, Power Quality Requirements for Plug-In Electric Vehicle Chargers

(6) JEAC 9701-2012, Grid-interconnection Code, The Japan Electric Association

(7) IEEE 1547-2003: IEEE Standard for Interconnecting Distributed Resources with Electric Power Systems

Contributors (The lead author is indicated by an asterisk (*).)

T. IZUMI*

• Assistant Manager, Advanced Automotive Systems R&D Center

M. HIROTA

• Assistant Manager, Advanced Automotive Systems R&D Center

K. HATANAKA

• Manager, Advanced Automotive Systems R&D Center

Y. ISOYAMA

• Senior Assistant General Manager, Advanced Automotive Systems R&D Center

K. SANO

• Senior Assistant General Manager, Advanced Automotive Systems R&D Center

K. TAKAYAMA

• General Manager, Advanced Automotive Systems R&D Center