

# Construction of power supply system using electric vehicle for stable power delivery from PV generation

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## Abstract

This research aims to propose a power supply system in which conventional photovoltaic (PV) system attains advanced functions. First, each household can use the power independently from the power system and load in the power system is reduced in the event of power shortage. Second, stable power is obtained from PV in which the output fluctuates due to the change in the amount of solar radiation. Third, PV output suppression is avoided when voltage of the distribution line is increased by the reverse power flow. Fourth, stable power is supplied to each household and refuge in the event of disaster. To achieve these, grid-connected and self-sustaining power supply system is developed by connecting a DC/DC converter between electric vehicle (EV) battery and conventional power conditioning subsystem (PCS) of PV system. In this paper, the power supply system model is presented. Also, the bidirectional DC/DC converter circuit is described in consideration of PV system installed in Kyushu Institute of Technology and of major EV in Japan. Finally, the hardware configuration of the proposed system is shown. It is considered that the effectiveness can be evaluated by constructing the proposed system.

*Keywords: Bidirectional DC/DC converter, EV, PCS, PV*

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## 1. Introduction

In Japan, introduction of the PV attracts wide attention among common people because of the global warming issue, the Great East Japan Earthquake and Feed-in tariff (FIT). On the other hand, EV attracts wide attention in the motor vehicle industry for the low carbon society. Moreover, EV is expected to play the role of an energy storage device and an energy transportation device because EV has large capacity of battery.

By controlling the PV output with EV, there is a contribution to the peak cut of power demand, compensation for the fluctuated power of PV and voltage regulation in the distribution network with large amount of PVs. Also, an independent power supply system can be constructed for a household or a refuge area in case of blackout [1] [2] [3]. Therefore, the goal of this research is to develop a grid-connected and self-sustaining power supply system by connecting a DC/DC converter between EV battery and conventional PCS of the PV system. Accordingly, it is expected that an EV with DC/DC converter can be connected to any PV system. The specification of PV system on the rooftop of a house is standardized on some level while the specifications of EV battery are wide-ranging. Thus, the DC/DC converter is the key to commercialize the system.

This paper proposes a configuration of DC/DC converter connected between the PV panel and the PCS to support the MPPT operation of PCS according to the change of voltage of PV panel. Details of designing the converter by considering the specified voltage of various commercialized EV batteries is described in this paper.

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## 2. Outline of the Grid-Connected and Self-Sustainable Power Supply System

### 2.1. Effectiveness of the grid-connected and self- sustainable power supply system model

Because the output of PV fluctuates with the amount of solar radiation, the output has bad influences to the power system. On the other hand, it is known that the surplus power is generated at the light load time of the power system. This causes voltage rise problem in the distribution network [4], [5]. At the present time, the power supply capacity is tight in Japan because of the cease of operations of nuclear power plants. If each household can use the power independently from the power system, these loads can be detached voluntarily from the power system at the event of power shortage. Therefore, in this case, there is a flexible operation of reducing the load in the power system and uninterrupted power supply to the load during power outage [6], [7]. Effectiveness of the grid-connected and self-sustainable power supply system is described as follows.

#### A. Normal situation

- In the event of power shortage, each household can use the power independently from the power system. Therefore, the load in the power system is reduced.
- The output fluctuation of PV is suppressed by the control of charging and discharging of EV battery. Therefore, consumer side can absorb the fluctuation and supply stable power to their load and the power system.
- When the voltage of the distribution line is increased by the reverse power flow, the charging of EV is increased. In this manner, suppression of PV output can be avoided.

#### B. Disaster situation

- It is difficult to achieve stable power from only PV because the output of PV fluctuates with the amount of solar radiation. However, our system can supply stable power to each household and refuge area by combination with EV.

In this research, the grid-connected and self-sustainable power supply system is developed to confirm the effectiveness in the above situations.

### 2.2. Grid-connected and self- sustainable power supply system model

Commercial PCS is a product that complies with the power system interconnection guidelines. The PCS is constituted by a boost chopper and a DC/AC inverter [8]. However, the EV cannot be connected to the DC coupling portion in the PCS. Also, in case of controlling the output side of PCS, a DC/AC inverter which complies with the power system interconnection guidelines is necessary. Therefore, a power supply system which is connected to the EV through the bidirectional DC/DC converter to the input of commercial PCS is proposed, as shown in Fig.1.

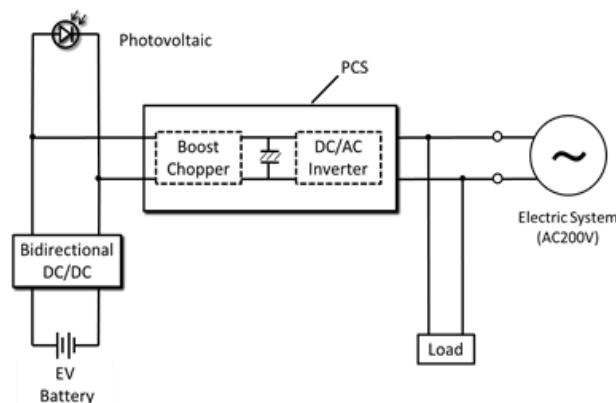


Fig.1. Outline of the power supply system model.

### 3. Circuit Configuration of Grid-Connected and Self-Sustainable Power Supply System

#### 3.1. PV and EV

PV and EV considered in this research are described below. PV system is installed at laboratory building of Kyushu Institute of Technology (Kyutech) as shown in Fig. 2. The circuit of PV is shown in Fig. 3. There are sixteen cells in this circuit in which one cell has a maximum voltage of 23.6 V and minimum current of 7.36 A. Eight cells are arranged in series and there are two columns in parallel. Therefore, the capacity of the PV under study has 2.88 kW [9]. In this research, this PV is assumed for residential use.

Some information of major EV in Japan are shown in Table 1. As shown in Table 1, there are various types of major EV (PHV) of Japan. With regard to the battery voltage, 72 V COMS battery voltage is the smallest while 360 V LEAF battery voltage is the largest. Therefore, a circuit configuration which is able to connect these EV battery voltage ranges is considered.



Fig. 2. Kyutech PV system.

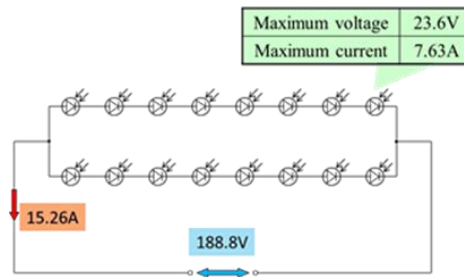


Fig. 3. Circuit diagram of Kyutech PV.

Table 1. Major EV in Japan

Car Model	COMS	PRIUS(PHV)	i-MiEV	LEAF
Company	TOYOTA Auto Body	TOYOTA	Mitsubishi Motors	Nissan Motor
Passenger Capacity [persons]	1	5	4	5
Vehicle Weight [kg]	approx.40	approx.1400	approx.1000	approx.1400
Storage Battery				
Type	Lead storage battery	Nickel hydride battery	Lithium ion battery	Lithium ion battery
Total Voltage [V]	72	207	330	360
Total Electric Energy [kWh]	3.744	4.4	16	24

#### 3.2. Bidirectional DC/DC converter circuit

The bidirectional DC/DC converter plays an important role in achieving the proposed system. Some conditions for constructing the bidirectional DC/DC converter circuit are shown below.

- PV generation capacity = 2.88 kW
- PV maximum output operating voltage = 188 V (dc)
- PCS input minimum voltage = 60V (dc)

- EV (PHV) of Japanese companies battery voltage: 72 V (dc) (COMS), 207 V (dc) (PRIUS), 330 V (dc) (i-MiEV), 360 V (dc) (LEAF)

PV and PCS are installed in Kyutech in which the EV voltage ranges from the minimum and maximum voltage of major EVs in Japan. The magnitude relationship of the PV voltage and the EV battery voltage is shown in Table 2.

As can be seen from Table 2, when a high voltage EV battery is connected to the proposed system, a general bidirectional DC/DC converter can be used to determine the direction of the buck-boost converter. However, it is necessary to reverse the buck-boost of bidirectional DC/DC converter in case of  $V_{\text{batt}} = 72$  V (dc).

Table 2. Magnitude relationship of PV-EV voltage

$V_{\text{batt}}$ \ $V_{\text{PV}}$	Kyutech-PV system voltage range	
	60[V]	188[V]
72[V](COMS)	$V_{\text{PV}} < V_{\text{batt}}$	$V_{\text{PV}} > V_{\text{batt}}$
207(PRIUS)[V]	$V_{\text{PV}} < V_{\text{batt}}$	
330(i-MiEV)[V]		
360(LEAF)[V]		

Bidirectional DC/DC converter circuit shown in Fig. 4 is taken into account in this research to consider the previously mentioned situations. This circuit is constructed with 2 phases of general bidirectional DC/DC converter circuit with two switches in each phase. In other words, this circuit has a total of four switches.

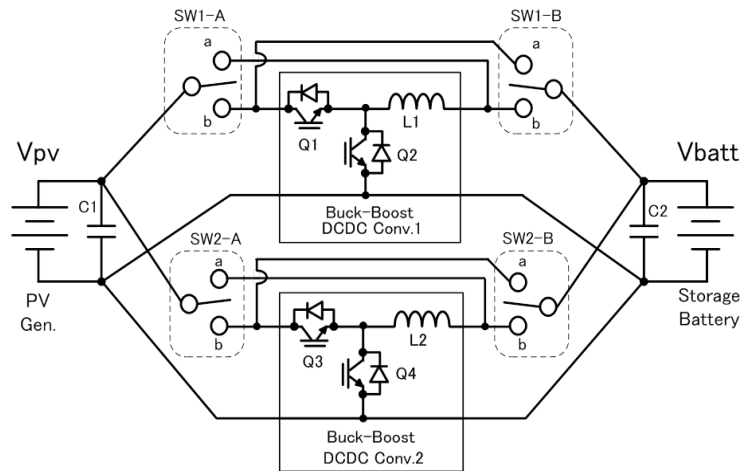


Fig. 4. Bidirectional DC/DC converter circuit.

When these switches are connected to side a, EV battery charging is set to buck. On the other hand, when these switches are connected to side b, EV battery charging is set to boost. Therefore, EV with high voltage battery can be connected to the bidirectional DC/DC converter by using one phase in which two switches are connected to side a. Moreover, COMS can be connected to the bidirectional DC/DC converter by using one phase in which two switches are connected to side a, and another phase in which two switches are connected to side b.

### 3.3. Grid-connected and self-sustainable power supply system overall configuration

The grid-connected and self-sustainable power supply system overall configuration is shown in Fig. 5.

As can be seen on Fig. 5, the grid-connected and self-sustainable power supply system is constructed with PV, PCS, bidirectional DC/DC converter, EV, gate-circuits, control mode select circuit, detector circuits and isolated regulator. Gate-circuits drive semiconductor module of the bidirectional DC/DC converter. Control mode select circuit gives some directive to control the charging and discharging of the

EV battery. Detector circuits monitor PCS input and output and voltage and current of EV battery. Isolated regulator is the power source of their circuit.

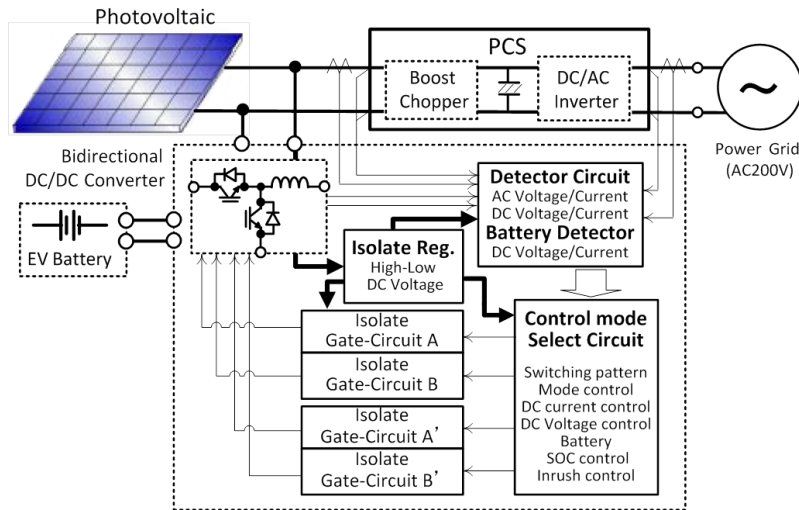


Fig. 5. Hardware configuration of the proposed system.

In this configuration, it is considered that DC voltage and current of PCS input side can be detected and EV battery can be set to charge and discharge power to suppress PV output fluctuation. Therefore, the proposed system can absorb PV output fluctuation in power consumer side.

Also, increased voltage of the distribution line caused by reverse power flow is controlled by suppression of reactive power and active power [5] [10]. However, these methods are likely to reduce the power generation potential of PV. In place of these methods, the proposed system controls the charging of EV battery from PV depending on the AC voltage, AC current and phase of PCS output side. Therefore, it is considered that the proposed system can contribute to the reduction of voltage rise problem in the distribution network. Also, the proposed system can result to an efficient use of PV output in comparison with the conventional PV system.

#### 4. Conclusions

In PV generation, CO<sub>2</sub> is not emitted and it is considered that energy is almost an inexhaustible supply. Given these characteristics, PV attracts wide attention and the global operation capacity reached to 100GW in 2012. However, it is difficult to get the stable power from only PV because the output of PV fluctuates with the amount of solar radiation. Moreover, introducing a large amount of PVs might disturb the balance of the electric power supply and demand.

In this paper, the grid-connected and self-sustainable power supply system is proposed. The system can utilize the EV in a conventional residential PV system. By introducing this system to each household installed with PV, it is considered that rapid changes in demand-supply balance at localized area are alleviated. In addition, the system can provide stable power to each household and refuge area during power outage by disaster.

Future plans for this research include construction of circuits of the proposed system and to evaluate the effectiveness of the grid-connected and self-sustainable power supply system through demonstration experiments.

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