An Evaluation of Charging Power Balance of EV Battery for Household Distributed Power System

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Abstract- The control of CO_2 emission is a global urgent issue, and the decarbonizing is being promoted in various fields. Also at residences, the electricity consumption is increasing instead of fossil fuels because of the electrification of heat source, shifting from gasoline car to EV and so on, therefore the reduction of the increasing burden of commercial power generation caused by the increase of electricity consumption at residence is extremely important task. Distributed power systems for households that can supply necessary electricity by renewable energy to each house is considered to be an effective solution. In order that the distributed power system which is desirable to be able to use various renewable energy become widely used for households, independent and autonomous operation of each power source is an important factor. This paper presents the behaviour of the power control in parallel operation of dc-dc converters directly connected to the dc bus with battery and the power behaviour of whole system. As a result, it was found that when multiple conditioners are connected to the dc bus in a renewable energy system for household, it is possible to realize autonomous charging with good balance even without the current balance control. It is important to expand use of the combination of dc bus and autonomous converters to utilize various renewable energy sources in the EV society coming in the near future.

Keywords dc-dc converter, distributed power system, renewable energy system for household, battery charger.

1. Introduction

In recent years, the control of CO_2 emission is a global urgent issue, and the decarbonizing is being promoted in various fields. Also at residences, the electricity consumption is increasing instead of fossil fuels because of the electrification of heat source, shifting from gasoline car to EV and so on, therefore the reduction of the increasing burden of commercial power generation caused by the increase of electricity consumption at residence is extremely important task [1, 2].

For that purpose, distributed power systems for households that can supply necessary electricity by renewable energy to each house is considered to be an effective solution [3-5]. From the viewpoint of efficient electric power management, the dc bus is regarded as a mainstream in the distributed power system for household use, it is expected to be widely implemented in the future [6-12]. The dc bus can perform charging the battery from the PV power with the minimum necessary conversion without going through the complicated steps that is needed with the ac bus system in which converting dc power of PV to ac power is performed first then converting ac to dc again and charging the battery [13-15]. Therefore, improvement of power efficiency can be expected with the dc bus.

In the distributed power system for households, it is common to supply electric power to the house with combination of the battery and power source by renewable energy, and to compensate for the difference between the power generation and the load with charge and discharge of the battery [16-20].

Here, when charging the battery of the EV with the distributed power system for households, since the battery is charged with a comparatively large current, when the single power source based on renewable energy is not sufficient, it is necessary to use multiple power sources.

Figure 1 shows the configuration of distributed power system with multiple renewable energy source.

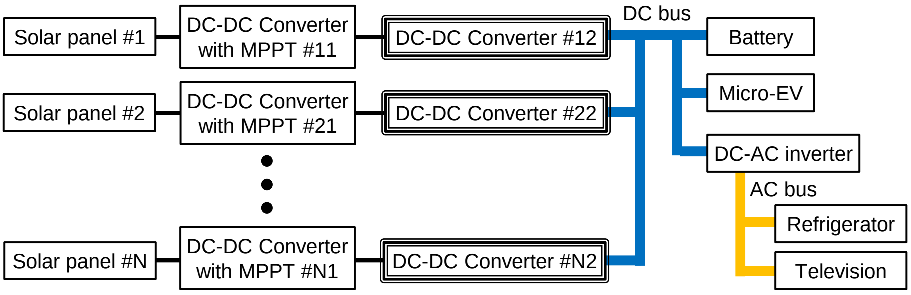

Fig. 1. Distributed power system

Solar radiation energy, which is renewable energy, is taken out from the solar cells as electric power by a dc-dc converter with the maximum power point tracking control [21-25], and sent to the dc bus through a converter for connecting to the dc bus. Plural power sources combining the PV and the two converters are connected to the dc bus, and the electric power is sent to the ac load in the house through the dc-ac inverter, and the battery compensate the power. When excluding the power consumed in the house through the dc-ac inverter, the circuit of dc-dc converter for the PV is configured to serve also as a charging circuit for the battery including the EV battery. In other words, this can be regarded as a system to charge the batteries from parallel different energy sources.

Generally, the battery is charged with a single converter [26]. However, when charging a battery with large-capacity, charging may be performed by parallel operation of multiple converters, and in that case, it is common to use a balance circuit that controls the charging output balance between the respective parallel-connected converters.

From the viewpoint of efficiency of the converters of the entire system, it is more efficient to distribute the load and operate the small capacity converters in parallel than single operation of the large capacity converter. This is because each converter can be operated at an efficient operating point. Moreover, the manufacturing cost can be suppressed by mass-producing the small capacity converters.

On the other hand, in parallel operation, it is necessary to communicate with each converter for balance control, and control becomes complicated. In particular, when connecting converters that are far apart, the connection network requires a large cost.

In the PV system, it is common to install a converter for each unit of solar panel, since the PV panels are placed in a relatively distant place because of conditions of the irradiation and installation space, etc. Consequently, the converters connected to the dc bus are in parallel, but because they are located at a distance, it is difficult to collect the information of those currents and to balance the currents.

And, above all, the generated power differs for each solar panel, so control becomes extremely complicated in conventional parallel operation control and it is hard to realize.

In order that the distributed power system which is desirable to be able to use various renewable energy become widely used for households, independent and autonomous operation of each power source is an important factor. However, there have been very few detailed reports on the current balance of the converters considering the parallel charging of the EV battery, which will increase in the future.

This paper presents the behaviour of the power control of dc-dc converters directly connected to the dc bus with battery and the power behaviour of whole system.

First, the system model and the behaviour of the voltage of the battery are shown. Then it is demonstrated that the characteristics of the converter and the charging mechanism of the total system. As a result, in the last short period of the battery charging period, an imbalance occurs in which the current flows to the dc bus only from the higher voltage of the parallel-connected conditioner, but it will not be a problem in the circuit operation.

On the other hand, in the constant current mode which occupies most of the charging period, it is found that the current flow out at the designated value with good balance from each parallel connected converter. As a result, it was found that when multiple conditioners are connected to the dc bus in such a renewable energy system for household, it is possible to realize autonomous charging with good balance even without the current balance control.

2. Charging Characteristics of EV Battery

Because the lithium ion battery may ignite / smoke if the charging is made with wrong operation, the charging voltage and the charging current are specified for each battery. The charging of the lithium ion battery is generally performed by the constant current / constant voltage charging method. The Constant Current / Constant Voltage Charging Method is called CCCV charging method. First, charging is performed with a constant current, and when the battery voltage reaches a specified value, in order to prevent overcharging the mode moves to constant voltage charging.

Figure 2 shows typical charging characteristics of a constant current / constant voltage charging system of a lithium ion battery. Charge is started at the charging current of I_{oBatt_1}. Constant current charging is performed from the battery voltage E_{oBatt_0} at the charging start time t_0 until the time t_1 at which the battery voltage reaches E_{oBatt_1} after the battery voltage gradually rises. After the battery voltage reaches E_{oBatt_1}, constant voltage charging is performed at the charging voltage E_{oBatt_1}. As charging progresses at a constant voltage, the charging current gradually decreases and it is judged that the battery is fully charged at the time t_2 when the charging current reaches to the lower limit value I_{oBatt_1}, then the charge stops.

Generally, the lithium ion batteries that store the electricity generated by PV power generation or the like and used for the energy management is operated within a range of SOC from 20% to 50% ± 10%. On the other hand, in EV applications, it is operated in the range of SOC from 10% to 90% from the reason of the travel distance of the car. Therefore, E_{oBatt_0} and E_{oBatt_1} are set for each battery so that SOC is 10% at the time t_0 and SOC is 90% at the time t_1. In addition, when the lithium-ion battery is charged to near 100% of SOC, the deterioration of the battery progresses and the battery capacity decreases. Therefore, generally, constant voltage charging at the time between t_1 to t_2 is protected so as not to be performed by the BMS (Battery Management System).

Hereinafter, the period when the converter performs the constant current operation is referred to as State 1, and the period when the constant voltage operation is performed is referred to as State 2.

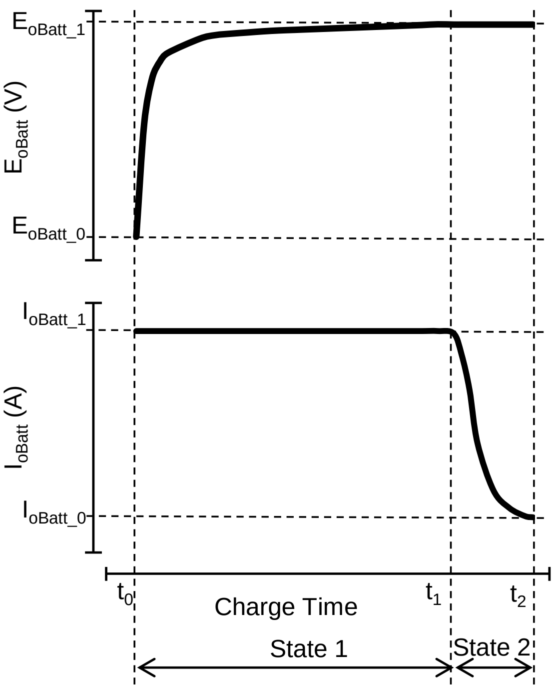

Fig. 2. Charging characteristics

3. The Operation Mechanism during Parallel Charging to EV Battery by Multiple Conditioners

In Fig.1, a combination of a dc-dc converter with MPPT connected to a PV panel and a dc-dc converter connected to a dc bus is called a conditioner. In this section, it is clarified that the behaviour of the current and the voltage during charging battery by using multiple dc-dc converters connected to the dc bus.

Figure 3 shows a block diagram of the dc-dc converter circuit, and Fig.4 shows the block diagram of system used in this experiment. In the experiment, a stabilized dc power supply is used for emulating a dc-dc converter with MPPT for PV. And two dc-dc converters #12 and #22 are connected in parallel and connected to a resistance load as shown in Fig.4.

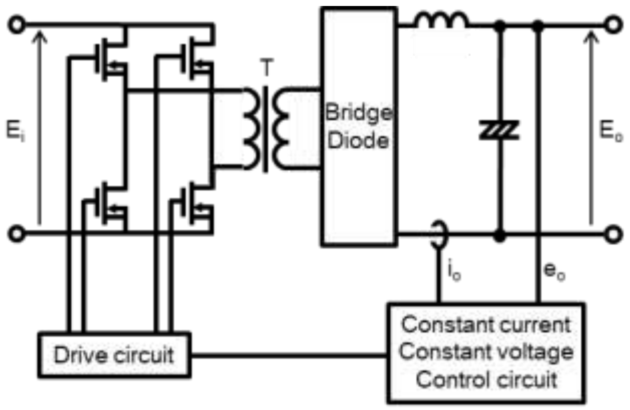

Fig. 3. Block diagram of dc-dc converter

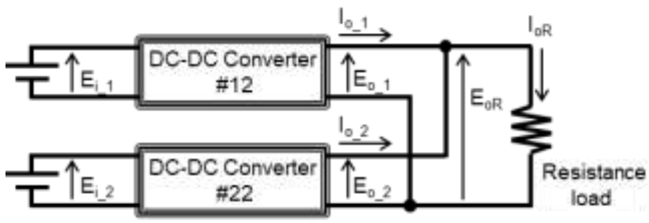

Fig. 4. Test circuit with resistance load

Figure 5 shows the output characteristics of each dc-dc converter #12 and # 22. Dc-dc converter performs CCCV operation, that is, Constant Current Constant Voltage operation, the constant current operation at 80A is performed until the output voltage becomes 85V, and when the output voltage reaches 85V, the operation of converter moves to constant voltage output at 85V. Each converter has an error of about 2% in their voltage / current detection. It is confirmed that the dc-dc converter #12 used in this experiment is operated at the constant voltage of 85V and the constant current of 80A, the dc-dc converter #22 is operated at the constant voltage of 84V and the constant current of 82A.

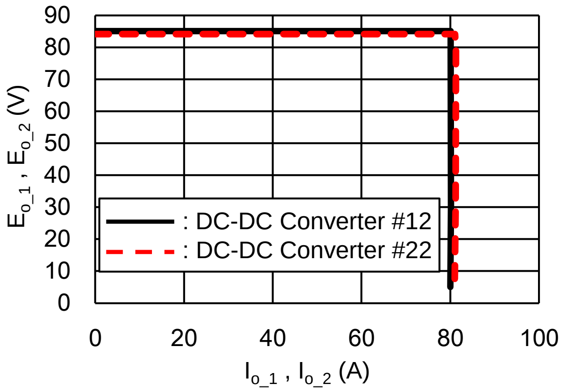

Fig. 5. Characteristics of dc-dc converters #12 and #22 at $E_{i\_1} = E_{i\_2} = 240V$

Figure 6 shows the result of measuring the total efficiency of dc-dc converters taking varying the load resistance while converter #12 and #22 are combined in parallel and operated at 160A of output current I_{oR}. For the input voltages E_{i_1} and E_{i_2}, the efficiency is measured at the voltage 240V, 270V and 380V supposing fluctuations in the output voltage from the dc-dc converter with MPPT. For micro EV, it is popular to use a 48V or 72V battery.

In the case of 48V micro EV, the output voltage range of the converter during charging is 55V to 65V, and the maximum power efficiency of the measurement result is 91.3% in the range. In any of the input voltages of 240V, 270V, and 380V, the power efficiency of the measurement result is 91% or more in the range of the output voltage of 55V to 65V.

In the case of 72V micro EV, the output voltage range is supposed to be 70V to 85V, the maximum power efficiency is 93.2% in the range. In any of the input voltages of 240V, 270V, and 380V, the power efficiency of the measurement result is 92.6% or more in the range.

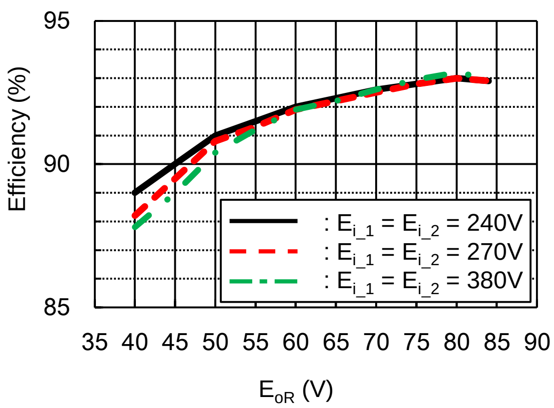

Fig. 6. Power efficiency against change of output voltage in parallel operation at $I_{oR} = 160A$

Figure 7 shows an experimental circuit in which a battery is connected instead of a resistance load. Table 1 shows the specifications of the battery cell used in this experiment.

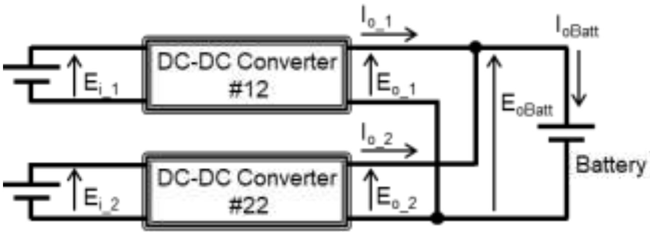

Fig.7. Test circuit with battery

Table 1. Specification of battery cell.

Cathode Active Material	LMO with LNO
Anode Active Material	Graphite
Capacity	32.5 Ah
Nominal Voltage	3.75 V
Weight	787 g
Energy Density	157 Wh/kg

Figure 8 shows the charging characteristics of the lithium ion battery obtained by experiment in the circuit of Fig.7. Figure 9 shows the output current characteristics of the dc-dc converters #12 and #22 at the same time as Fig.8. According to the characteristics of the battery used in the experiment, the battery voltage E_{oBatt_1} at 10% of SOC is 70V and the battery voltage E_{oBatt_2} at 90% of SOC is 85V. In State 1, the output currents I_{o_1} and I_{o_2} of the dc-dc converters #12 and #22 are set to 80A so that the battery charging current I_{oBatt} would be 160A. When I_{oBatt} becomes 0A, charging is stopped. In the experiment, each converter performs constant current charging at 80A in the State 1 period when the SOC is 10% to 90%. Then as the State 2 period the constant voltage charging (trickle charge) at 85V is performed until the SOC closes to100%. The time of State 1 is 40 minutes and the time of State 2 is 10 minutes.

As shown in Fig.9, in State 1, the output current of two dc-dc converters are balanced at approximately 80A respectively without balance control. In State 2, the lower voltage one of the dc-dc converter #12 and #22 shifted to the constant voltage operation first, the other one shifted to the constant voltage operation with a delay. As shown in Fig. 6, the maximum power efficiency is 93.2%, and constant current charging is performed with high efficiency of 92.6% or more in the entire range of State 1. In the constant voltage charging period as State 2, the charging current between the converters is unbalanced, however, because it is within the rated operating range of converter, it does not cause a problem.

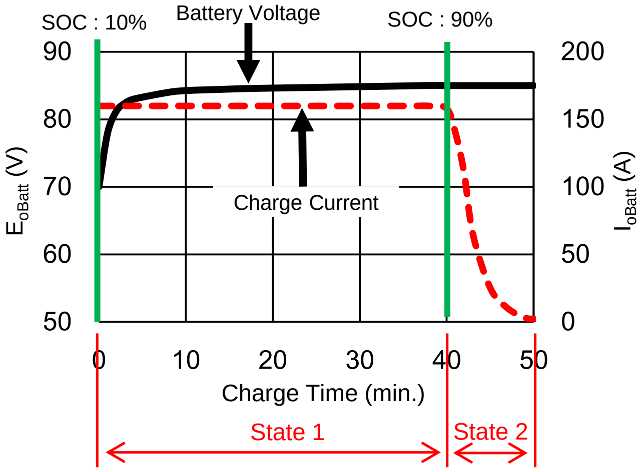

Fig. 8. Charging characteristics of battery

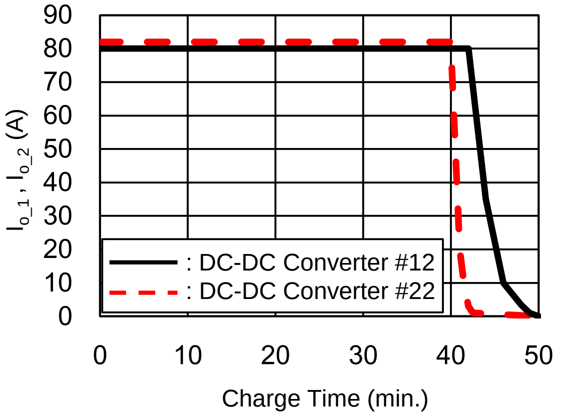

Fig. 9. Output current of dc-dc converter #12, #22

When charging a battery for EV with multiple converters connected in parallel, even if there is a difference in output current due to measurement accuracy variations of control system between the respective converters, stable parallel charging is performed in state 1. This is because each converter is operating at constant current in State 1. Therefore, it is important that a conditioner of renewable energy connected to a distributed power system for households that charges the battery for EV is capable of constant current operation as well as constant voltage operation.

4. Conclusion

(1) Since the converter operates in the voltage mode in a period, an imbalance operation occurs in which the current flows to the dc bus only from the conditioner with higher voltage of the parallel-connected conditioner. However, in the constant current mode which occupies most of the charging period, it is revealed that the current flow out at the designated value with good balance from each parallel connected converter.

(2) When connecting multiple conditioners to the dc bus, it is demonstrated that autonomously balanced charging can be performed without current balance control.

(3) When operating small capacity converters connected to the dc bus in parallel operation, charging operation of each converter is performed at the good operating point for efficiency. The maximum efficiency of converter is 93.2% for 72V battery.

Even in the case of three or more converters, it can be easily extrapolated that those autonomous converters perform stable and balanced parallel charging at constant current in State 1 without mutual balance control.

In the current distributed power systems, the centralized control by an energy management system that controls the power of the converters and the batteries connected to the local bus is the mainstream. However the results of this paper indicates that it is very important to expand use of the combination of dc bus and autonomous converters to utilize various renewable energy sources in the EV society coming in the near future.

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