Series-Parallel DC-DC Converter for Power Supply System Using Renewable Energy as Distributed Power Sources

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***Abstract*— The purpose of this paper is to discuss about a configuration of power supply systems, with can provide power from renewable energy sources to a load effectively. A series-parallel power supply is proposed as a highly efficient power supply from a 1200 V dc bus to the load in a dc power supply system.**

Keywords—renewable energy, distributed power supply, ac power supply system, dc power supply system, series-parallel power supply

I. Introduction

Utilization of renewable energy has been drawing increasing attention toward for a low carbon society because it does not emit carbon dioxide. Recently, renewable energy system which have a relatively small scale and is in close to the power consumption area instead of renewable energy systems which have huge capacity for centralized power generation. Such systems are called distributed power supply. It is essential to improve an efficiency of power supplies and power supply systems for utilizing renewable energy that is prone to unevenness in power generation due to weather. More power can be obtained from the renewable energy when the efficiencies of power supplies and power supply systems are improved. It can contribute realizing the low carbon society.

Most of the power obtained from renewable energy, including photovoltaics (PV) is dc. A dc power supply system, in such a condition, has high affinity and reduce a number of power supplies. It brings an improvement of the efficiency of the power supply system [1]. However, the improvement is slight when a bus voltage is low, for instance 380 V [1], [2]. This tends to be more conspicuous as the power to be handled increases. A higher bus voltage is needed such as 1200 V to solve this issue.

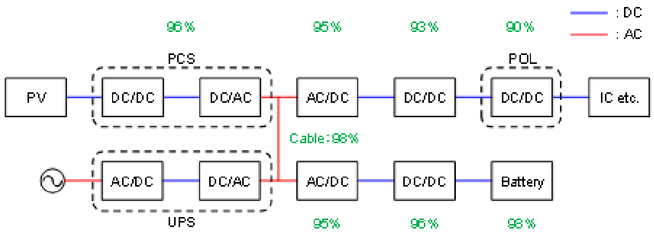
On the other hand, a voltage stress on power devices becomes high in the dc power supply system with a higher bus voltage. Although IGBTs and SiC MOSFETs can endure such a voltage stress, they need higher cost and more time to develop them. Therefore, a series-parallel power supply, which consists of power supplies using low voltage MOSFET, is a reasonable solution for this issue [3]-[13]. To support the bus voltage of the 1000 V class, it is better to add more stages to divide the input voltage.

This paper presents, firstly, discussion of a power conversion efficiency from renewable energy sources (e.g. photovoltaics) to the load, focusing on the power supply system and its construction. After that, the series-parallel power supply, that consists of four full-bridge dc-dc converters, is proposed to realize a high efficiency of power suppling from the dc bus to the load in the dc power supply system with 1200 V dc bus.

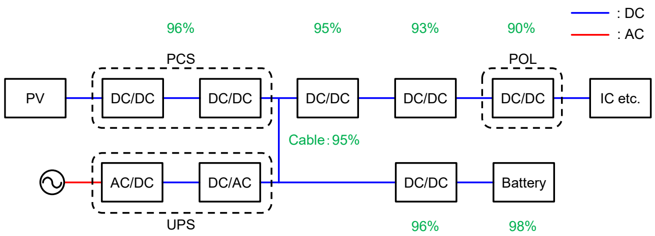
II. Construction of Power Supply Systems and Their Power Conversion Efficiency

Figure 1 shows power supply systems utilizing the PV as a distributed power supply: the ac power supply system, the dc power supply system with 380 V dc bus, and the dc power supply system with 1200 V dc bus. These power supply system is referred from [2], [15]-[18] and is classified into these three power supply systems including the dc power supply system with 1200 V dc bus.

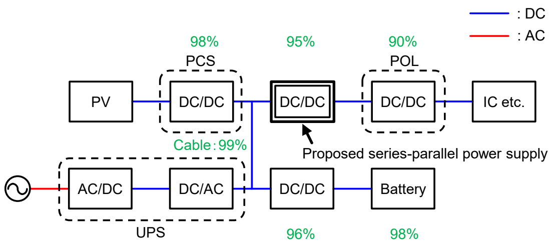
Power conversion efficiency of each power supply in power supply systems, which are an ac power supply system, a dc power supply system with 380 V dc bus, and a new dc power supply system with 1200 V dc bus, is decided according to literatures [2], [14]. These efficiencies are the best efficiencies, so in this comparison, values obtained by subtracting about 2% from these values are used so that they are as close to practical values as possible. The efficiency of



(a) Ac power supply system.



(b) Dc power supply system with 380 V dc bus.



(c) Dc power supply system with 1200 V dc bus.

Fig. 1. Power supply systems utilizing PV as distributed power supply.

the proposed series-parallel power supply in the new dc power supply system with 1200 V dc bus is set to 95%, which is the target efficiency value of this power supply. When the proposed series-parallel power supply is in a light load condition, it is adaptively controlled to secure a high efficiency. Namely, this power supply keeps a high efficiency not depending on a load condition.

Following assumptions are set about photovoltaics (PV) in the power supply system. Power generation time is 4 hours per day. For this duration, power is directly fed from the PV to the load. For the remaining 20 hours, the load is supplied with power from batteries charged by the PV. An overall efficiency is calculated by averaging based on this time ratio.

Figure 2 shows a comparison of the efficiencies of each power supply system for practically supposed cases. Case A describes the best efficiencies, which is achieved in a special application such as a data center. Case B considers a capability of decreasing of the efficiency for Case A in a practical use so that efficiencies of all components are decreased 2%. The light load condition or low performance of two stages of the power supply close to the load are supposed in Case C, Case D, and Case E. The efficiencies of these two power supplies are decreased 5% in Case C, 10% in Case D, and 15% in Case E, respectively. For general industrial applications, the two stages of power supply in front of the load have a relatively

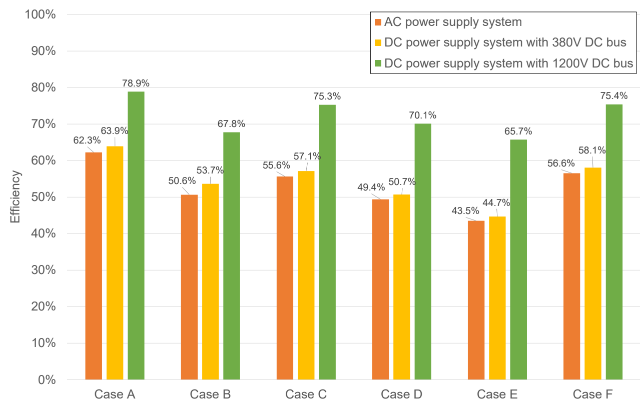


Fig. 2. Efficiencies of each power supply system from PV to load.

small capacity and severe cost constraints. Therefore, it is appropriate to consider Case C to Case E for such a case. When the power supply system is in the light load condition, the two stages of power supply decrease their efficiencies drastically. Case D and Case E becomes suitable. In these cases, of the dc power supply system with 1200 V dc bus indicates 17% to 22% higher efficiency.

The efficiencies of the power supply systems are calculated again based on time ratio of the light and heavy load conditions, and they are compared. This is shown in Fig. 2 as Case F. The time ratio of the light and heavy load conditions is assumed 2:8. The efficiencies of the two stages of power supply in front of the load are assumed to decreasing to 70% in the light load condition. In this operating condition, the efficiencies of these two stages of power supply are calculated as 88% and 86%. As a result, this condition is close to Case C, and the dc power supply system with 1200 V dc bus still shows about 17% to 19% higher efficiency than that of the other power supply systems. Thus, the dc power supply system with 1200 V dc bus can utilize power from renewable energy sources more effective than the others.

The dc power supply system with 1200 V dc bus omits the power supply stages as compared to the others so that its efficiency can be improved, resulting up to 22% higher efficiency than that of the others. In addition, the proposed series-parallel power supply achieves a high efficiency even in the light load condition because it is adaptively controlled depending on the load condition to improve its efficiency.

III. Proposed Series-Parallel Power Supply

The proposed series-parallel power supply is illustrated in Figure 3. V_{in} and V_{out} represent its input voltage and output voltage, respectively. This power supply consists of four full bridge dc-dc converters. V_{inx}, V_{outx} and I_{outx} also represent an input voltage, output voltage, and output current for each full bridge dc-dc converter. They have, per unit, a rated input voltage of 500 V, target output voltage of 48 V, and rated power of 1.5 kW. Inputs of four full bridge dc-dc converters are connected in series and their outputs are connected in parallel. Total power is 6 kW and a total rated input voltage is 2000 V. The specification of the proposed series-parallel power supply can be adjusted by the number of the full bridge dc-dc converters according to applications. In the proposed series-parallel power supply, the number of operating units is controlled depending on the load condition, causing improvement of its efficiency.

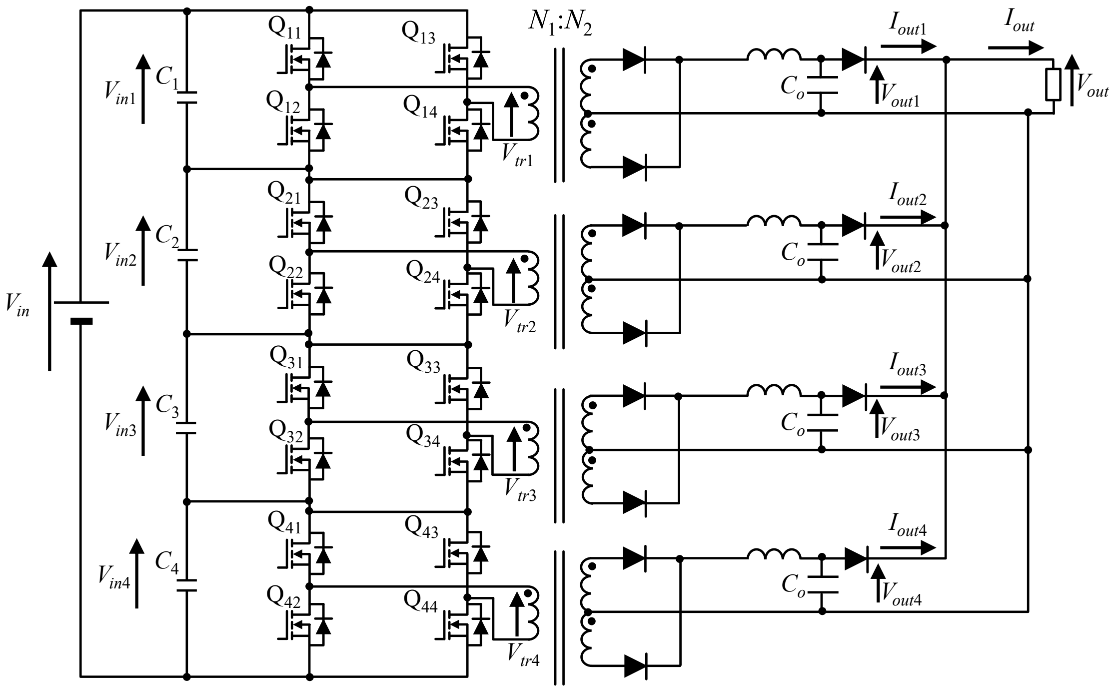


Fig. 3. Proposed series-parallel power supply.

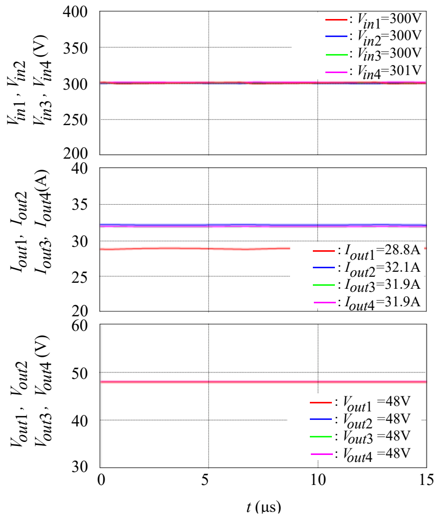


Fig. 4. Operating waveform of proposed series-parallel power supply in simulation.

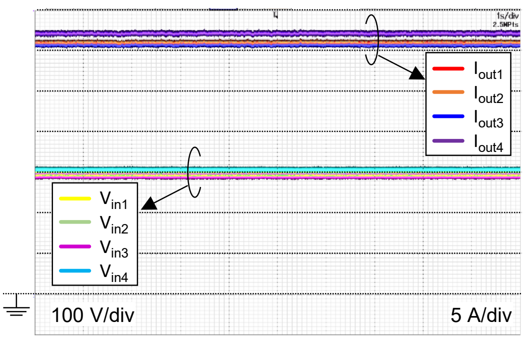


Fig. 5. Operating waveform of proposed series-parallel power supply in experiment.

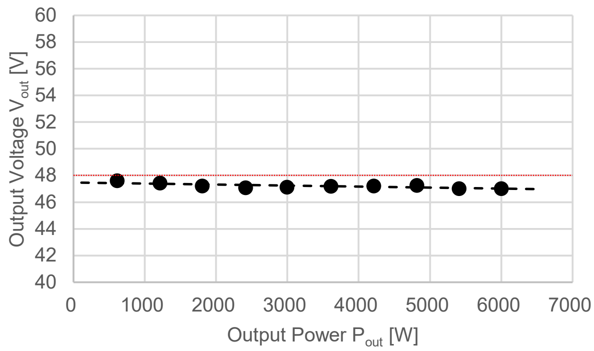


Fig. 6. Experimental result of regulation characteristics of proposed series-parallel power supply.

Figure 4 is a simulation result of the proposed series-parallel power supply when the input voltage V_{in} is 1200 V and output power P_{out} is 6 kW. The input voltage and output current are shared evenly for each unit. As a result, it is revealed that the proposed series-parallel power supply can be operated in principle. Corresponding to this simulation result, an experimental result is shown in Fig. 5. The operating waveform is similar to the simulation result. Moreover, the output voltage V_{out} of the proposed series-parallel power supply is well regulated within plus-minus 1% of the target voltage 48 V as shown in Fig. 6 although V_{out} slightly decreases due to blocking diodes at each output of full bridge dc-dc converter.

IV. Conclusion

In this paper, the configurations of the power supply systems that can effectively use renewable energy as a distributed power supply are discussed, and they are compared from the viewpoint of efficiency. As a result, it is confirmed that the efficiency of the dc power supply system with 1200 V dc bus is up to 22% superior to the AC power supply system and the dc power supply system with 380 V dc bus.

Furthermore, the series-parallel power supply compatible with the dc power supply system with 1200 V dc bus is proposed and its basic operation is verified through the simulation and experiment.

ACKNOWLEDGMENT

This paper is based on results obtained from a project, JPNP14004, commissioned by the New Energy and Industrial Technology Development Organization (NEDO).

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