Study of introduce power storage device in PV system

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***Abstract*—This paper reports the results of an experimental study on the installation locations of photovoltaic system (PVS) and energy storage systems.**

Currently, the installation location of energy storage devices varies depending on the system configuration; for instance, the location depends on when such devices are installed in parallel with the renewable energy generation system or when they are integrated with the grid-connected system of the PVS.

Therefore, in this study, experiments were conducted on the installation method of energy storage devices and the number of photovoltaic panels installed to effectively utilize the PVS.

Keywords—Battery; renewable energy; photovoltaic systems.

I. Introduction

In recent years, various efforts have been made to realize a low-carbon society, with renewable energy as the main power source.

In Japan, the "Growth Strategy Action Plan" announced on June 18, 2021, aims to decarbonize the country and is also accelerating the selection of suppliers in the global supply chain. In addition, the development of power systems such as smart grids, smart communities, and microgrids is being promoted. The development of smart grids, smart communities, microgrids and other power systems is underway. With the spread of these smart grids and microgrid-like power systems, power generation systems based on renewable energy, etc., are attracting attention[1][2][3].

However, given that renewable energy depends on the natural environment, the power generated power is unstable. This calls for the introduction of energy storage devices. However, the location of energy storage devices in the current situation differs depending on the system configuration; for instance, it depends on when such devices are installed in parallel with renewable energy generation equipment or when they are integrated with the grid-connected system (PCS) of the photovoltaic power generation system (PVS) [4] [5] [6] [7] [8][9].

Therefore, in this study, experiments were conducted on the installation method of energy storage devices and the number of photovoltaic (PV) panels installed in order to effectively utilize the PVS.

II. Experimental set-up

In this study, experiments were conducted using PVS, PCS, rectifiers, and energy storage devices.

The specifications of these devices are shown in Table 1.

Figure 1 shows the configuration of the system used in this study. Experiments were conducted 1) when the energy storage devices were not connected to the system from the PV panels to the PCS, as shown in Fig. 1(a); 2) when the energy storage devices were connected to the DC side between the PV and PCS, as shown in Fig. 1(b); and 3) when the energy storage devices were connected to the AC side between the PCS and the system, as shown in Fig. 1(c).

Figure 2 shows the experimental model. In this experiment, the maximum power consumption of the PV system was 12.5 kW, the rated capacity of the PCS was 10 kW, and the capacity of the storage device was 15 kWh with lead storage batteries. In addition, the storage device was charged with power when the PV output exceeded 10 kW. This was due to the limitations of the experimental facility, but in an actual grid, the power consumption of the PVS, rated capacity of the PCS, and capacity of the storage device would need to be approximately 10 times greater. First, a comparison was made between the case where the PV capacity was loaded in excess of the rated capacity of the PCS (overloading) and the case where the PV capacity was matched to the rated capacity of the PCS in the circuit shown in Figure 1(a). Then, a comparison was made for different overloading capacities when the energy storage devices were placed on the DC and AC sides of the grid.

III. Result and Discussion

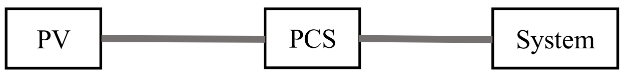
The results of the conducted experiments described in the previous section are presented next.

A. PV loading comparison results

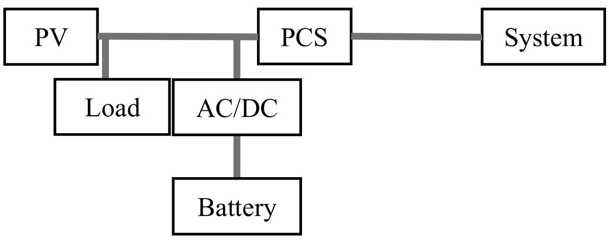
Figure 3 shows a comparison of the case in which the PV panels matched the capacity of the PCS and the case in which the panels were overloaded. In this figure, the vertical axis represents the power, and the horizontal axis represents

Table 1. specifications of experimental equipment

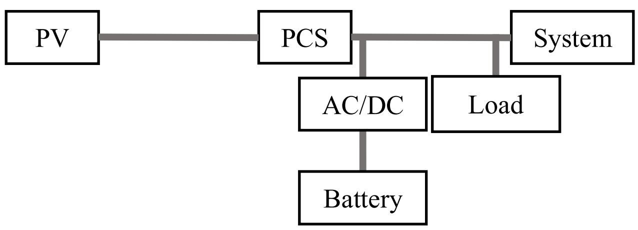
Name of equipment	Performance
Photovoltaic power generation system (PVS)	Output capacity:10[kW] Input voltage:AC 200±20[V] Output voltage:DC 0～400[V]
Grid-connected system (PCS)	Maximum allowable input voltage:750[V] Rated output voltage:3W202[V] Rated frequency:50/60[Hz] Rated output:9.9[kW] Rated input voltage:400[V] Rated input current:28.3[A]
Rectifier	Output capacity:105[kW] Input voltage:AC 240[V] Output voltage:DC 383[V]
Lead-acid battery	Rated capacity:15.6[kWh] Nominal Voltage:312[V] Connection:26serial



(a) Pattern without energy storage device



(b) Pattern with an energy storage device is installed on the DC side



(c) Pattern with an energy storage device is installed on the AC side

Fig. 1． Model system (example of the configuration of a solar power generation system and storage batteries)

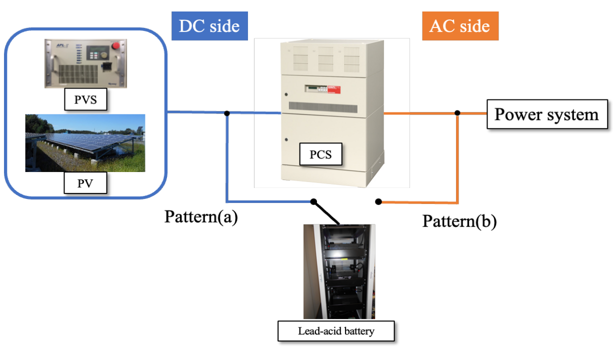


Fig.2． the appearance of the experiment

the time; the PV output power and PCS rated output are listed. The results show that overloading improves power generation during periods of low solar radiation. In addition, the amount of power generation lost is limited owing to the limited number of days throughout the year in which the output reaches its maximum.

B. Results without energy storage devices

Next, the results for the case in which the energy storage devices are placed on the DC and AC sides of the grid are presented. Figure 4 depicts the results for a PV output of 10 kW in the case shown in Fig. 1(a). Figure 5 shows the results for the case shown in Fig. 1(a) at a PV output of 15 kW. Figure 6 shows the results for the case shown in Fig. 1(a) at a PV output of 20 kW. In these figures, the vertical axis represents power and the horizontal axis represents time; the PV and PCS output powers are listed.
At all output times, the PV output exceeded the PCS rating. The PV output of 11 kW in Figs. 5 and 6 was due to the fact that the output could only match the capacity of the PCS.

C. Results on the DC side of the energy storage device

Figure 7 displays the results for a PV output of 10 kW in the case shown in Fig. 1(b). In this figure, the vertical axis represents power; the horizontal axis represents time; and the PV power, PCS power, battery power, and DC load power are listed. This figure shows that the storage device was charged before PCS activation and that the battery supplied the shortfall in PV output power even after PCS activation.

Figure 8 depicts the results for a PV output of 15 kW in the case shown in Fig. 1(b). In this figure, the vertical axis represents power; the horizontal axis represents time; and the PV output power, PCS output power, system power, battery power, and load power are listed. This figure shows, as in Fig. 7, that the shortfall decreases owing to the increase in PV output power.

Figure 9 displays the results for a PV output of 20 kW in the case shown in Fig. 1(b). In this figure, the vertical axis represents power; the horizontal axis represents time; and the PV output power, PCS output power, system power, battery power, and load power are listed. The figure shows that the PV output power further increased, and the surplus of output power was charged into the storage device.

D. Results on the AC side of the energy storage device

Figure 10 depicts the results for a PV output of 10 kW in the case shown in Fig. 1(c). This figure displays the PV output power, PCS output power, system power, battery power, and load power. The figure shows that before PCS activation, AC power was fed to the load from the system side, and after PCS activation, the remainder of the load and battery charge flowed to the system.

Figure 11 displays the results for a PV output of 15 kW in the case shown in Fig. 1(c). Figure 12 depicts the results for the case shown in Fig. 1(c) at a PV output of 20 kW. In these figures, as in Figs. 5 and 6, the PV output only matches the capacity of the PCS.

E. From results A to D

These results indicate that when the PV output power exceeds the rated capacity of the PCS, the battery is charged if it is installed on the DC side. However, the battery is not charged if it is installed on the AC side. This leads to the conclusion that it is better to install batteries on

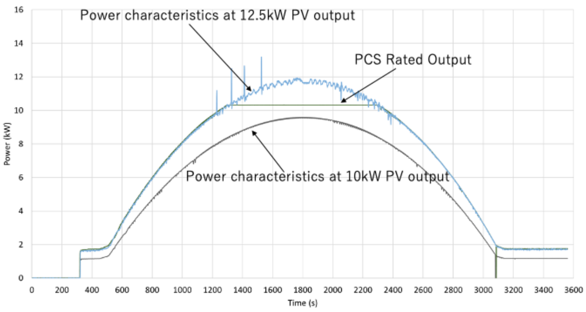


Fig.3. Results of PV Panel Loading Comparison

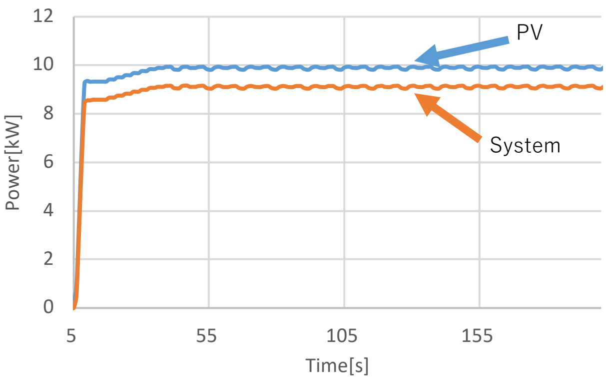


Fig.4. Results of 10 kW without energy storage device (Pattern A)

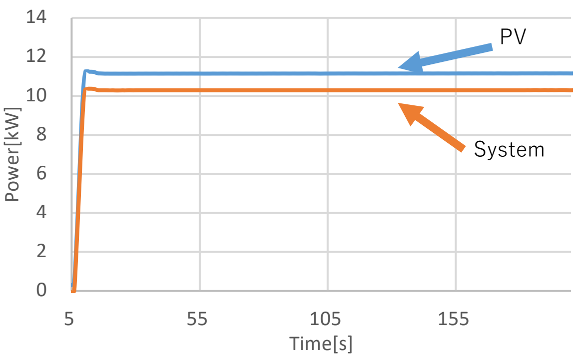


Fig.5. Results of 15 kW without energy storage device (Pattern A)

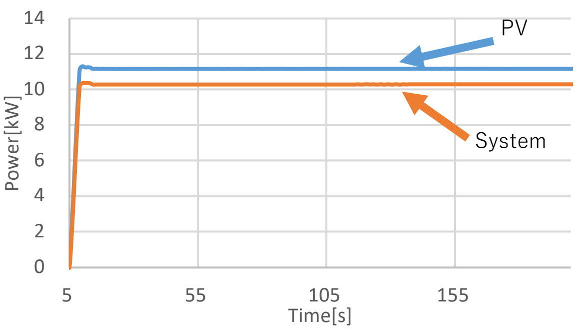


Fig.6. Results of 20 kW without energy storage device (Pattern A)

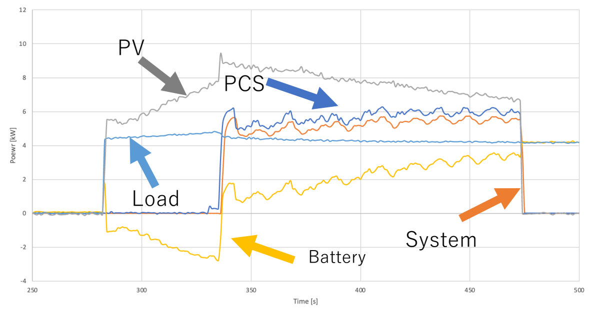


Fig.7. PV capacity 10kW, with energy storage device installed on DC side Result (Pattern B)

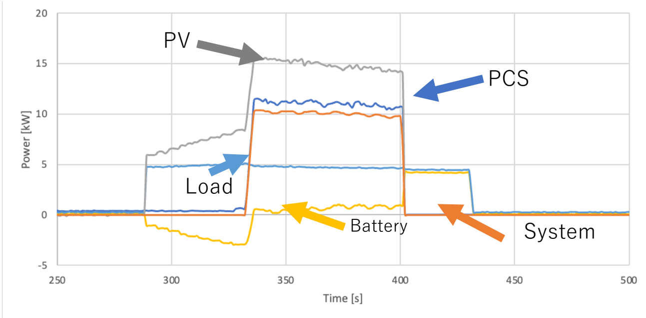


Fig.8. PV capacity 15kW, with energy storage device installed on DC side Result (Pattern B)

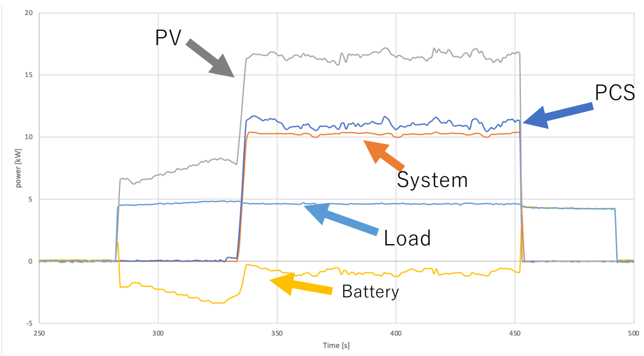


Fig.9. PV capacity 20kW, with energy storage device installed on DC side Result (Pattern B)

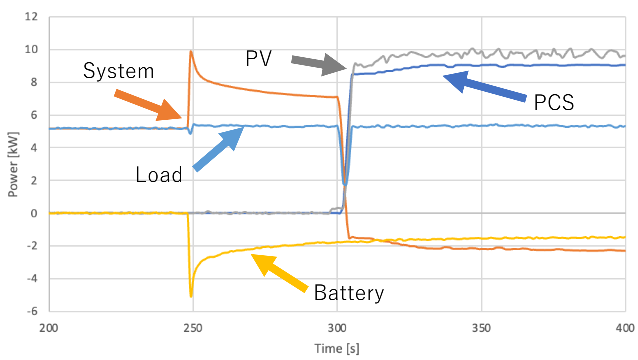


Fig.10. PV capacity 10kW, with energy storage device installed on AC side Result (Pattern C)

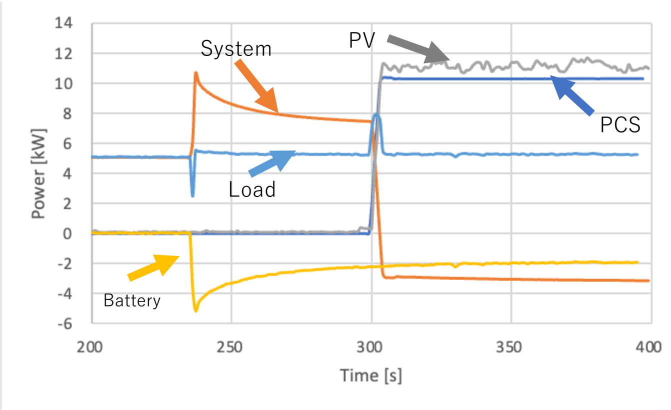


Fig.11. PV capacity 15kW, with energy storage device installed on AC side Result (Pattern C)

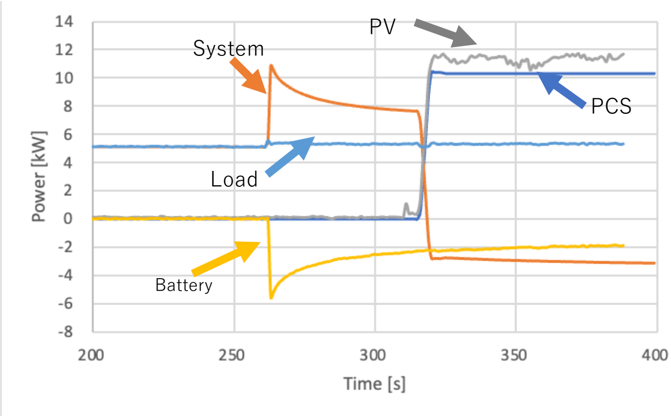


Fig.12. PV capacity 20kW, with energy storage device installed on AC side Result (Pattern C)

the DC side for the power exceeding the rated capacity of the PCS to be used as effectively as possible.

IV. Conclusion

The global use of renewable energy is expected to increase in the future. Energy storage devices are indispensable for the efficient use of this energy. Therefore, we compared the loading capacities of PV systems and examined the optimal locations for installing energy storage devices. Based on these results, connecting PV panels that exceed the rated output power of the PCS can improve the amount of electricity generated during low sunlight hours, such as in the morning and evening. In addition, by installing an energy storage device on the DC side rather than on the PCS, the surplus exceeding the rated capacity of the PCS can be recharged.

This shows that overloading the system can improve power generation during low sunlight hours, and charging the surplus that exceeds the rated capacity of the PCS to the storage device enables efficient operation. In the future, we will continue our research to make more effective use of the DC power.

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