Control Method of Energy Storage System to Improve Output Power of PCS

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***Abstract*— This paper proposes an improvement method of a power generation amount of Photovoltaic (PV) system using energy storage system. Power conditioning systems (PCS) of the PV system stops its operation when the generated power of the solar panel is low as in cloudy weather. Even if the solar radiation recovers, the PCS restarts after an interval time. Therefore, the conventional PV system can't fully extract the power of photovoltaic power generation. In the proposed structure, the energy storage system is connected between the PV and the PCS.**

This paper discusses conditions for power generation improvement of the PV system using energy storage system. Experiments using solar radiation data on sunny and cloudy days were carried out. On cloudy days PCS output improved by 5.38%. But on sunny days it decreased by 0.58%. The validity of the improvement condition was confirmed by experimental results.

***Keywords*— *Photovoltaic generation, Power conditioning system, Energy storage system*.**

I. Introduction

In recent years, solar power generation systems such as mega-solar system have rapidly introduced in grid system [1]. Solar power generation system is composed of photovoltaic module (PV) and a power conditioning system (PCS) that outputs generated power of PV to the grid. The PCS may stop when PV power decreases due to a drop in solar radiation. Furthermore, even if the solar radiation recovers, the PCS restarts after an interval of up to 5 minute. Therefore, the conventional PV system can't fully extract the power of photovoltaic power generation [2][3]. For the problem, the authors propose a method using an energy storage system. When the PV power decreases, the PCS powered by the energy storage system. Therefore, the PCS can operate continuous. So, PV power can be acquired continuously.

Generally, when connecting the energy storage system to the photovoltaic power generation system, it is connected to the grid or between the DC/DC converter and the inverter inside the PCS. Often the energy storage system connected to the grid side is used to compensate for fluctuations in PV power. However, this structure can't supply power to the PCS. On the other hand, When the energy storage system is connected between the boost converter and the inverter inside the PCS, it may be possible to supply power to the PCS. However, it is necessary to remodel the PCS circuit because the connection point is inside the PCS. Therefore, when installing to PCS, PCS in operation must be stopped. Moreover, after remodeling the PCS, it is necessary to reacquire authentication about the grid connection. Therefore, between the DC/DC converter and the inverter is not suitable as the connection point of the energy storage system.

This paper proposes a structure that connects the energy storage system in parallel with PV. Power can be supplied to the PCS, no remodeling of PCS is required. Therefore, it is suitable as the connection point of the energy storage system. However, the proposed structure with the energy storage system adds loss because loss occurs in the power converter due to the charge and discharge operation of the energy storage system. Even if the PV power amount increases due to the continuation of the PCS operation, the PCS output power amount may decrease as compared with the conventional configuration when the loss due to the charge and discharge operation of the energy storage system is large.

This paper proposes the system structure and the control method of the energy storage system. In addition, consider the conditions necessary for improving the output power amount of the PCS of the proposed structure. First, the structure and operation of the system are introduced. Next, the control method of the energy storage system used in the proposed structure is explained. After, the proposed structure and the conventional structure are compared by the experimental results. In addition, the improvement conditions of the PCS output power amount in the proposed structure are confirmed by the experimental results.

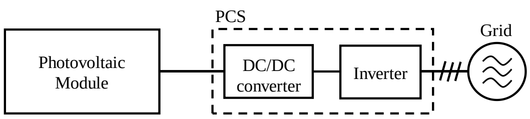
II. Proposed Structure

Fig. 1(a) shows the structure of the conventional photovoltaic power generation system. It consists of the PV and the PCS. The PCS is composed of a DC/DC converter and an inverter. The DC/DC converter performs MPPT control in order to operate the PV at maximum power. The Inverter converts DC power into

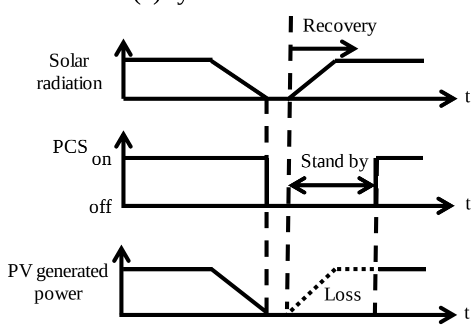
AC power and outputs in to the grid. Fig. 1(b) shows operation of the conventional structure. The PCS stops when solar radiation falls and the PV power decreases. After that the PCS waits even if the solar radiation recovers. Therefore, the conventional PV system can't fully extract the PV power.

For the problem, power is supplied to the PCS when the solar radiation falls by using the energy storage system. Fig. 2 shows photovoltaic generation system structures with energy storage system. Generally, the energy storage system is connected the grid or between the DC/DC converter and the inverter inside the PCS in a photovoltaic generation system. The energy storage system connected to the grid is used to compensate for fluctuations in the PV power [4][5]. However, this structure can't supply power to the PCS. Also, the energy storage system becomes large because not only the DC/DC converter but also the inverter is necessary. On the other hand, when adding the energy storage system between the DC/DC converter and the inverter inside the PCS [6]~[8], the structure has advantages. Because it does not require an inverter. However, remodeling of the PCS is necessary because the connection point is inside the PCS. The PCS must be stopped to connect the energy storage system and the certification on the grid connection of PCS must be gotten again because PCS remodeling is necessary.

Therefore, this paper proposes a structure that connects the energy storage system in parallel with PV. Fig. 3(a) shows the proposed system structure. It doesn't require remodeling of the PCS because the energy storage system is connected to the input terminal of the PCS. Furthermore, the capacity of the energy storage device can be made smaller than that of the power leveling system. Because the energy storage system operates only when the solar radiation falls and supplies power to the PCS. Fig. 3(b) shows the operation of the proposed structure. When PV power drops, the energy storage system supplies power to the PCS. The PCS stop is prevented. And PV power is improved because the PCS can continuously acquire generated power.

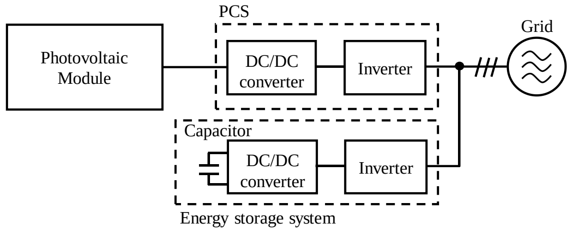


(a)System structure

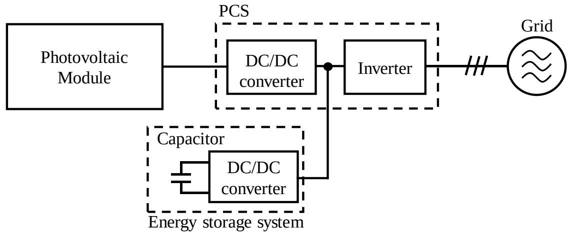


(b)System operation

Fig. 1. Conventional structure.

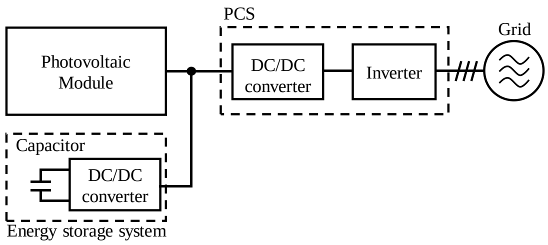


(a)Connection to Grid

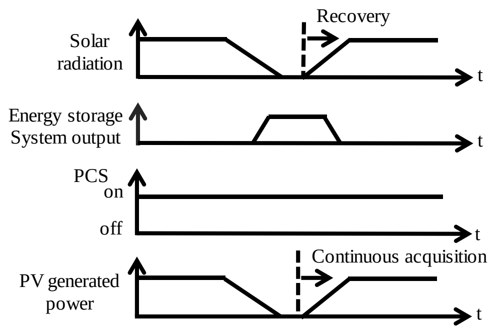


(b)Connection between DC/DC converter and inverter

Fig. 2. Connection points of energy storage system.



(a)System structure



(b)System operation

Fig. 3. Proposed structure.

III. CONTROL METHOD

When the electric power generated by PV decreases, the electric power is supplied from the energy storage system to the PCS. The discharge power of the DC/DC converter is controlled by a power-voltage reference curve in Fig. 4. The power-voltage reference curve is obtained to make limiting the discharge power possible. The PCS has a MPPT control [9]. If the discharge control has the power-voltage relationship of the PV system, it is possible to cause the operating point to follow the peak of power generation using the MPPT control. Therefore, the discharge power can be limited.

When the electric power generated by PV is sufficient, a part of the generated electric power is used for charging the energy storage device. The principle diagram is shown in Fig. 5. The charging power is controlled to be constant, when charging the energy storage device. This method doesn't disturb the MPPT control of the PCS. The power inputted to the PCS is obtained by subtracting the generated power with the constant charging power set to the storage devices, when the charging power is kept constant. Therefore, the power characteristic of PV matches the maximum power point of the power characteristics of PCS, and the charge can be done without disturbing the MPPT control.

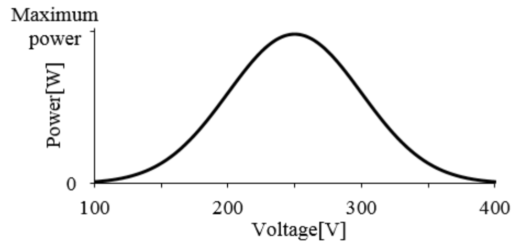


Fig. 4. Power characteristic of discharging power.

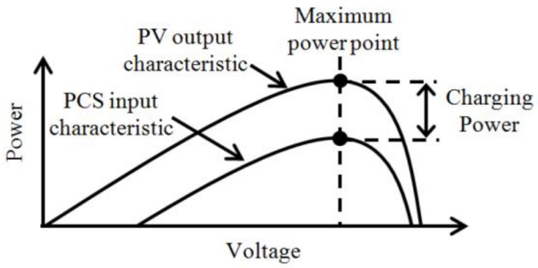


Fig. 5. Power characteristic of charging power.

IV. Experimental Structure

Fig. 6 shows experimental structure. PV output power, energy storage system output power and PCS output power are measured by a power meter in the experiment. The PV is simulated by programmable power supply with rated 5 kW. Solar radiation data and PV parameters are used to simulate the PV. The PV parameters are shown in Table 1. Solar radiation data for 20 minutes on sunny and cloudy days is used. Rated power of the PCS is 5 kW. When the input voltage of 300 V or more is continued for 10 seconds, it starts up and starts the MPPT control. The PCS stops when the input power becomes less than 500W. The energy storage system is simulated by bidirectional chopper, DC power supply and electronic load device.

The energy storage system monitors the PV power and performs charge and discharge operations. Fig. 7 shows the control block of charge and discharge operations. Charging is done when the PV power reaches 1500 W or more. The maximum value of charging power is 300 W. The current command value is calculated from the command value of the charging power, and the current is controlled by using the PI controller.

Discharge is carried out when the PV power becomes 500 W or less. The discharge power command value is called from the lookup table using the PV voltage. The current command value is calculated from the discharge power command value of the discharge power, and the current is controlled by using the PI controller. During charging, bidirectional chopper is used as a step-down chopper that switches S_{2_chop}. During the discharge, bidirectional chopper is used as a step-up chopper that switches S_{1_chop}. The current is monitored by the microcomputer, and the voltage used for capacitor simulation is calculated. The voltage of the DC power supply is set to the calculated capacitor voltage. The capacitor is assumed to be 3 F. The energy storage system performs initial charge until the capacitor reaches 50 V. After, charge and discharge between 50 V and 150 V. The rated power of bidirectional chopper is 500 W. It is 1/10 of the PCS.

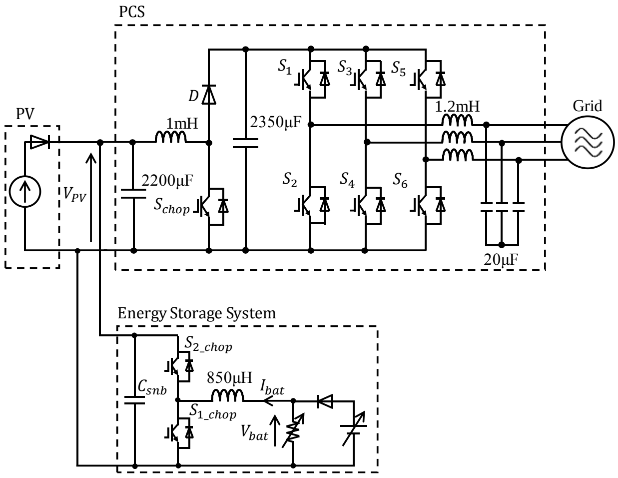
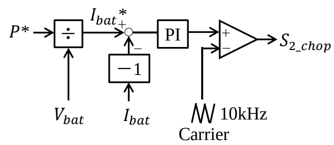
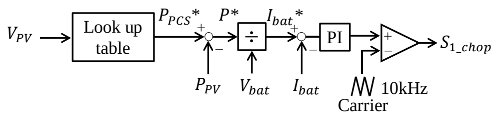


Fig. 6. Experimental structure.



(a)On charge



(b)On discharge

Fig. 7. Control brock.

Table 1. PV parameter.

Open circuit voltage	400V
Short circuit current	20A
Maximum power voltage	300V
Maximum power current	16.7A

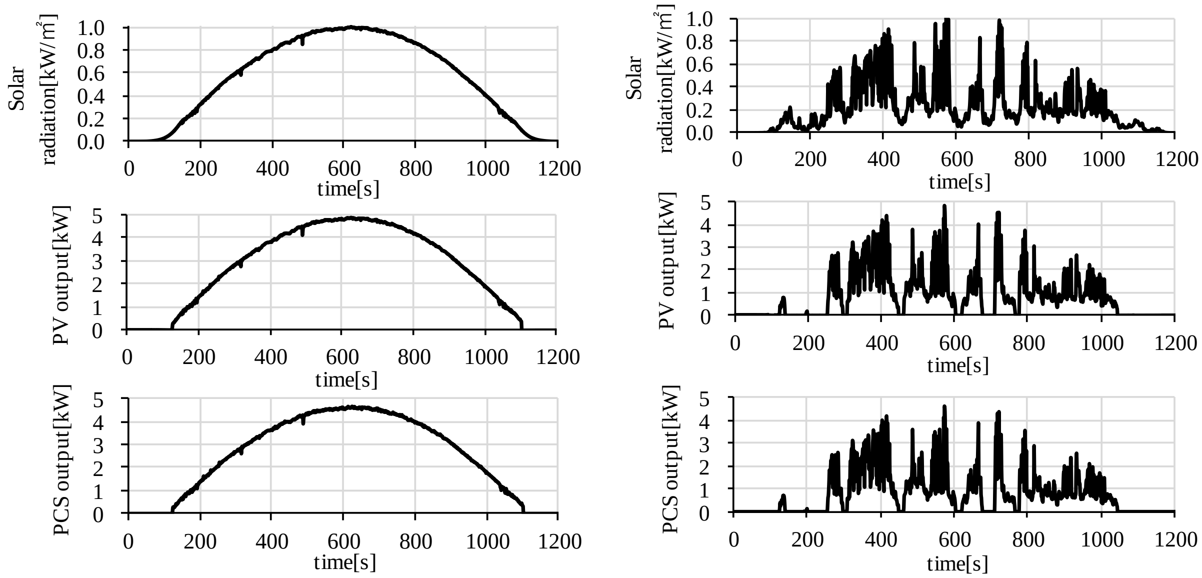
V. Experimental Results

Fig. 8 shows experimental results on sunny day and cloudy day in the structure of only PV and PCS. On sunny days it is confirmed that PCS doesn't stop until sunset. On the other hand, the stop of the PCS is confirmed on cloudy day. This is because PV power declined when the solar radiation falls. After the PCS stops, there is a standby time so PV generated electricity is not acquired.

Fig.9 shows experimental results on sunny day and cloudy day in the proposed structure that energy storage system was added to the PV and the PCS.

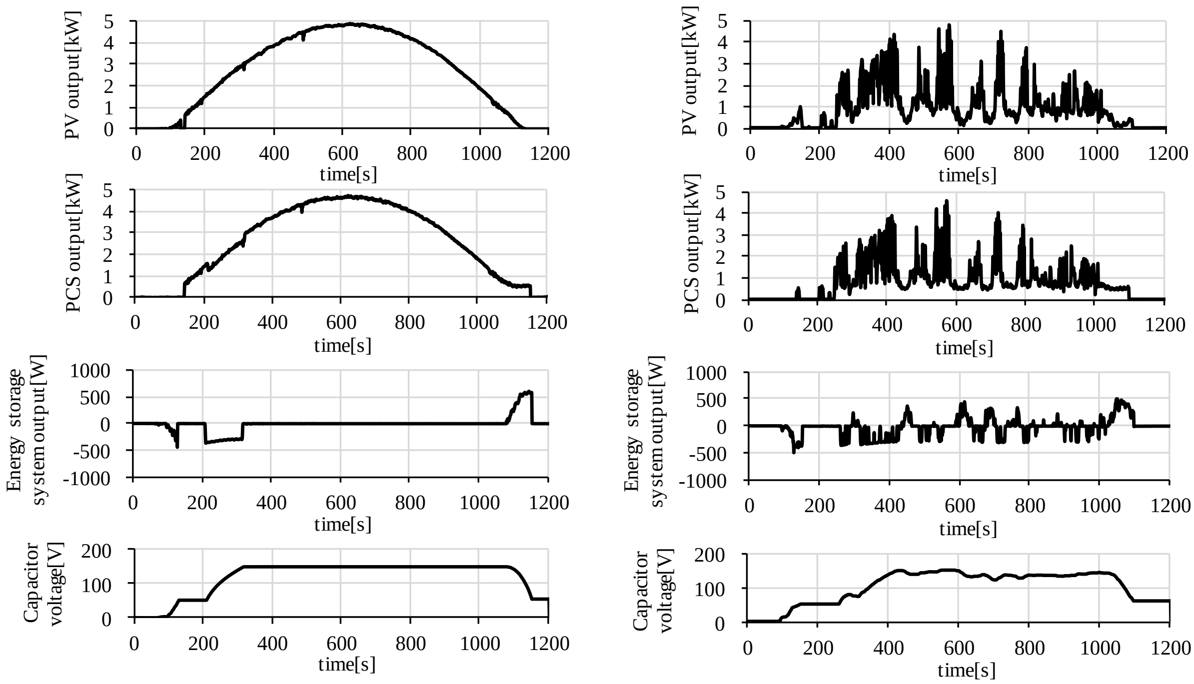
On the proposed structure, the PCS is started after the initial charging operation of the energy storage system. On the sunny day, it is confirmed that the charging operation is performed after the PV power reaches 1500 W or more. The voltage of the capacitor rises with the charging operation. Charging stops after the capacitor voltage reaches 150 V. At the sunset, PV output power will decrease, so the energy storage system discharges. The power storage system discharges until the capacitor voltage decreases to 50 V.

On the cloudy day, it is confirmed that the energy storage system is discharging when PV power decreases after charging. Therefore, the PCS continued operation. And PV power was continuously acquired. As sunset, the capacitor is discharged until the voltage reaches 50 V as well as on the sunny day.



(a)Sunny day (b)Cloudy day

Fig. 8. Experimental results of conventional structure.



(a)Sunny day (b)Cloudy day

Fig. 9. Experimental results of proposed structure.

Fig. 10 shows PV generated energy in each weather. PV power generation amount increased by 0.30 % on sunny days. On cloudy days PV power generation amount increased by 10.82 %. On both days, the amount of power acquired from the PV is improved, because the energy storage system performs the initial charging operation. And on sunny days, the amount of power acquired from the PV is improved, because the PCS continues to operate due to the discharging operation when the PV power decreases due to sunset. Furthermore, the amount of power acquired from the PV is improved, because the PCS continues to operate due to the discharge operation when the solar radiations falls.

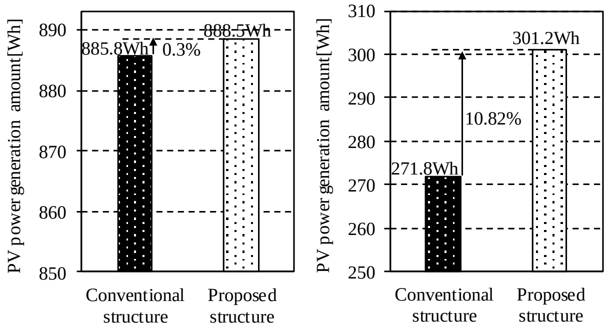
Fig. 11 shows PCS output power amount in each weather. PCS output power amount decreased by 0.58 % on the sunny day, and improved by 5.38 % on the cloudy day. PCS output power amount improved on cloudy day but decreased on sunny day. This reason is considered.

The condition is considered which the output power amount of the PCS of the proposed structure become larger than that of the conventional structure. In the conventional structure, PV power can’t be acquired until the PCS restarts. So loss is generated. On the other hand, PV power can be acquired which is the loss caused by the standby of the PCS in the conventional structure when the operation of the PCS is continued by the discharging operation of the energy storage system on the proposed structure. The power obtained by continuing the operation of the PCS is output to the grid after power conversion by the PCS. Therefore, it is improved by the amount outputted to the grid within the PV generation amount improved by continuous operation of the PCS.

However, a part of PV power is charged and discharged by the energy storage system in the proposed structure. Therefore, loss is generated by the converter of the energy storage system. Fig. 12 shows the energy flow during charging and discharging of the energy storage system. The power input to the energy storage system is converted by the DC/DC converter and charged in the capacitor during charging. At this time, loss occurs in the DC/DC converter. During discharging, the power is output from the capacitor. Then, it is output from energy storage system after power conversion by the DC/DC converter. So, loss is generated by the DC/DC converter. Furthermore, the power output from the energy storage system output to the grid after converted by the PCS. So, also at this time loss is generated by the PCS.

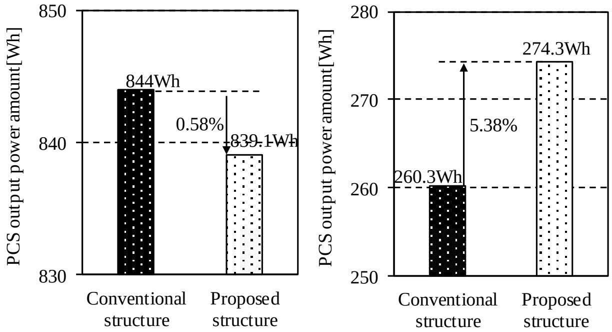
For the above, loss occurs in the DC/DC converter during charging operation and in the DC/DC converter and PCS during discharging operation when part of PV power is charged and discharged by the energy storage system in the proposed structure.

Therefore, if the amount outputted to the grid within PV power generation amount improved by continuous operation of the PCS is larger than loss caused when the charged energy of the energy storage system is output to the grid after the charge and discharge operation and the conversion by the PCS, then the PCS output power amount is improved as compared with the conventional structure, when the PCS stop is avoided in the proposed structure.



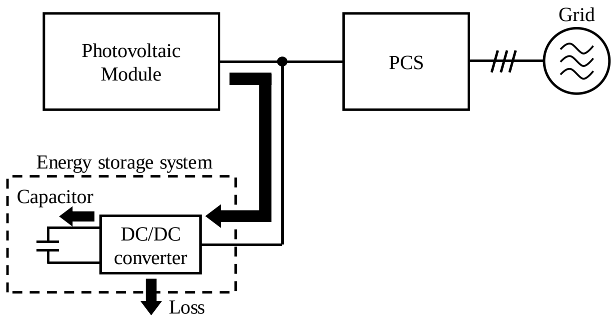
(a)Sunny day (b)Cloudy day

Fig. 10. PV power generation amount.

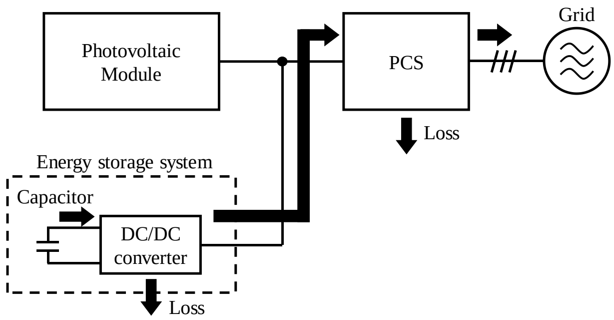


(a)Sunny day (b)Cloudy day

Fig. 11. PCS output power amount.



(a)Charging operation



(b)Discharging operation

Fig. 12. Energy flow during charging and discharging of the energy storage system.

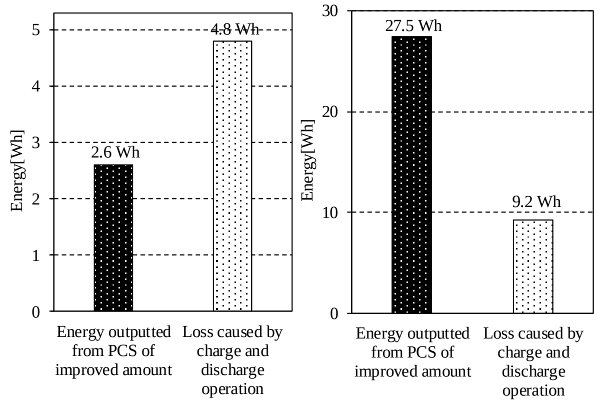
Fig. 13 shows the amount outputted to the grid within PV power generation amount improved by continuous operation of the PCS and loss caused by charging and discharging of the energy storage system. The amount is 2.6 Wh that outputted to the grid of the PV generation amount improved by continuous operation of the PCS on the sunny day. And loss of 4.8 Wh is generated when the charged energy of the energy storage system is output from the PCS. Therefore, on the sunny day, the PV output power amount improved but the PCS output power amount decreased of the proposed structure, because the loss due to charge and discharge exceeds.

On the other hand, the amount is 27.5 Wh that outputted to the grid of the PV generation amount improved by continuous operation of the PCS on the cloudy day. And loss of 9.2 Wh is generated when the charged energy of the energy storage system is output from the PCS. Therefore, on the cloudy day, the PV output power amount improved and the PCS output power amount improved too, because the loss due to charge and discharge is less than improved amount.

VI. Conclusion

This paper proposes an energy storage system that improves the total PV output power. The main purpose of adding the energy storage system is to continue the operation of the PCS. Since the energy storage system is connected between the PV and the PCS, it has the advantage that it can be added to the existing system. The proposed system consists of DC/DC converter and capacitor. The power rating of the DC/DC converter is sufficiently smaller than that of the PCS. This paper discusses control method of DC/DC converter for improving power output from the PCS. When the solar power generation is large, the DC/DC converter charges the capacitor. When the PV power decreases, the PCS is powered by the energy storage system.

Experiments using solar radiation data on cloudy day and sunny day were carried out. As results of the experiment, it was confirmed that PV output power amount increased by 10.82 % and PCS output power amount increased 5.38 % on cloudy day. On sunny day, PV output power amount increased by 0.3 %, but it was confirmed that PCS output power amount decreased by 0.58 %. Reason about this cause was considered. A part of the PV power is charged and discharged by the energy storage system in the proposed structure, so that loss occurs in the DC / DC converter of the energy storage system. The output power amount of the PCS can't exceed power amount of the conventional structure, when the loss generated by the charge and discharge operation of the energy storage system is larger than the amount output from the PCS of the PV output improvement amount. This was confirmed by comparing the amount outputted to the grid of the PV generation amount improved and the loss generated by the charge and discharge operation.



(a)Sunny day (b)Cloudy day

Fig. 13. Energy about improved amount and loss caused by charge and discharge operation.

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