Control method of energy storage system to increase output power from power conditioning systems (PCS)

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

This paper also proposes control method of the energy storage system. The effectiveness of the proposed system is verified by experimental results. The electric power amount of photovoltaic module in the case of applying the conventional discharge control method and the proposed discharge control method was compared. When using the conventional discharge control method, electric power amounted to 7.4 Wh. On the other hand, when the proposed discharge control method was used, electric power amounted to 8.5 Wh. The electricity amount of photovoltaic module improved by 14.9%.

Keywords—Photovoltaic generation, power conditioning system, energy storage system.

I. INTRODUCTION

In recent years, photovoltaic power generation systems such as mega-solar system have rapidly introduced in grid system [1]. photovoltaic 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 minutes. Therefore, the conventional PV system can't fully extract the power of PV 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. And, PV power can be acquired continuously.

Generally, when connecting the energy storage system to the PV 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 DC/DC 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.

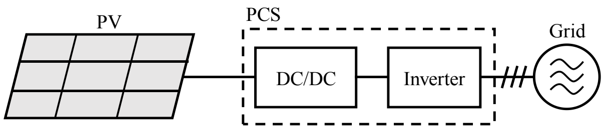
This paper proposes a structure that connects the energy storage system in parallel with PV. Power can be supplied to the PCS no remodeling of PCS is required. Therefore, it is suitable as the connection point of the energy storage system. However, the proposed structure with the energy storage system adds loss because loss occurs in the power converter due to the charge and discharge operation of the energy storage system. If the amount of power generated by PV increases due to the continuation of PCS operation, if the amount of improvement is larger than the loss due to charge and discharge operation of the energy storage system, the proposed configuration is advantageous as compared with the conventional configuration. Further, the control method at the time of discharging of the conventional energy storage system has a drawback that PV is unable to be optimally operated since the power characteristic is fixed. Therefore, in this paper, we propose a new discharge control method of energy storage system. By the proposed method, it is possible to achieve both power supply from the energy storage system to PCS and optimum operation of PV.

First, the configuration and behavior of each system is introduced. Next, the control method of the energy storage system used in the proposed configuration will be explained. Experiment was carried out, and the experimental results of the control method of the energy storage system will be explained below. Experimental verification and experimental results are shown, and the usefulness is shown.

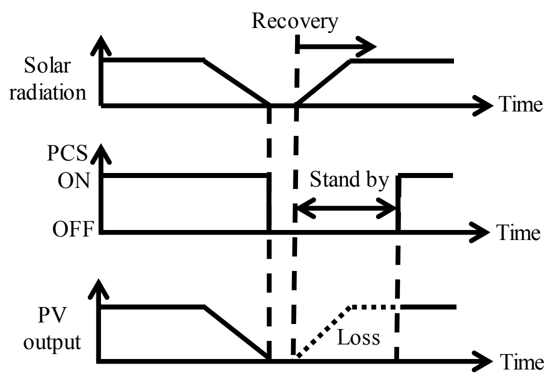
II. Proposed Structure

Fig. 1(a) shows the structure of the conventional PV 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 PV power 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 PV power 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.



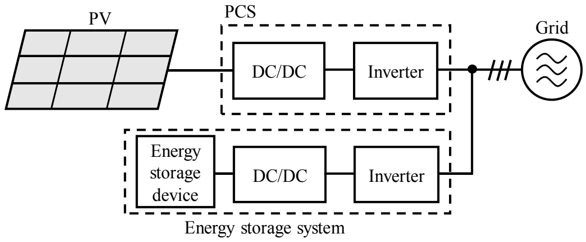
(a) System structure



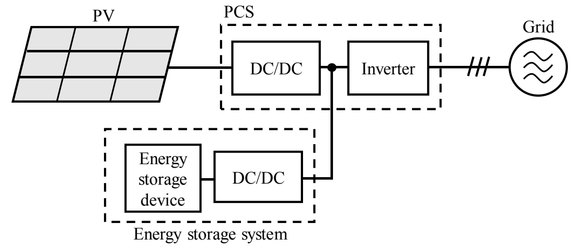
(b) System operation

Fig. 1. Conventional structure.

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.

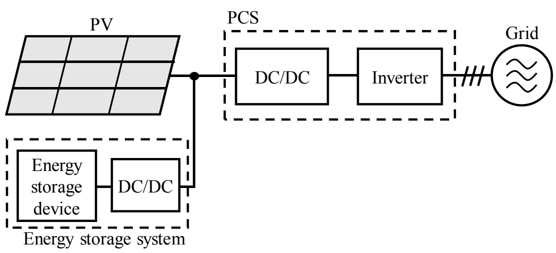


(a) Connection to Grid

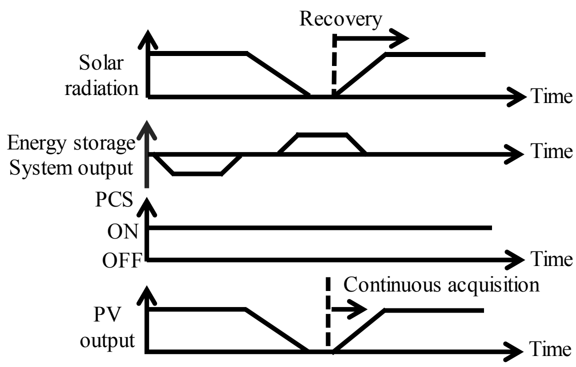


(b) Connection between DC/DC converter and inverter

Fig. 2. Connection points of energy storage system.



(a) System structure



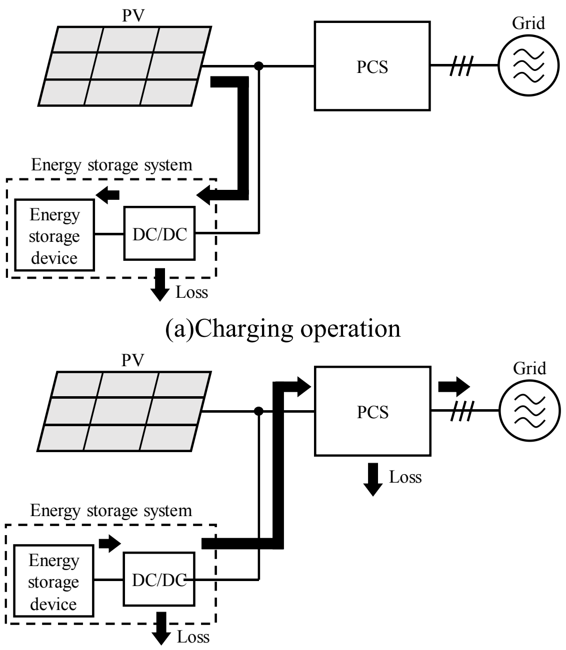
(b) System operation

Fig. 3. Proposed structure.

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 power 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. 4 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 energy storage device during charging. At this time, loss occurs in the DC/DC converter. During discharging, the power is output from the energy storage device. Then, it is output from energy storage system after power conversion by the DC/DC converter. Therefore, 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. Also at this time loss is generated by the PCS.

From the above, the condition under which the proposed configuration is advantageous is that the amount of PV generated power improved by continuous operation of the PCS exceeds the loss generated by the charge and discharge operation.



(b)Discharging operation

Fig. 4. Energy flow during charging and discharging of the energy storage system.

III. Proposed Control Method

A control method at the time of charge and discharge of the energy storage system will be described. Fig. 5 shows the principle of control during charging. Charging is done when PV generated electric power is sufficient. However, when PV generated electric power is sufficient, the PCS is performing MPPT control. Therefore, in order to operate the PV optimally, it is necessary to charge without disturbing the MPPT control. Part of PV generated electricity is charged to the energy storage device with constant power. This method does not disturb the MPPT control of PCS. Since the charging power is constant, the power obtained by subtracting the charging power from the power characteristic of PV is input to the PCS. The maximum power point voltage of the power characteristic of PV and the power characteristic of PCS coincide. When the input voltage of the PCS follows the peak of the power characteristic input to the PCS by MPPT control, the peak voltage is the same as PV. Therefore, PV can operate at the maximum power point, and it can be ridden without disturbing MPPT control.

Fig. 6 shows the principle of control during discharging. At the time of discharging, the energy storage system is operated as if only PV is connected to the PCS. Prepare the power characteristic input to the PCS, the energy storage system monitors the input voltage of the PCS, and obtains the power command value by referring to the power characteristic from the voltage. The PV power is subtracted from the power command value to generate the discharge power command value of the energy storage system. By giving power-voltage characteristics to the discharge power, the PCS operates so as to follow the characteristic peak by MPPT control. Therefore, the discharge power can be limited. However, the maximum power point voltage of PV continues to change constantly due to temperature and solar radiation. If the characteristic prepared in advance peak voltage does not match the maximum power point voltage of PV, it becomes a problem that PV is unable to operate at the maximum power point. This is because the mismatch between the voltage when the PCS follows the peak of the discharge power characteristic and the maximum power point voltage of the PV. The input voltage of the PCS follows the peak of the input power-voltage characteristic by MPPT control. Therefore, when move the power-voltage characteristic, the peak voltage also moves. Therefore, the input voltage of the PCS can be changed. The energy storage system detects the PV current and voltage with the sensor and monitors the generated power. And, by moving the power characteristics in the direction in which the PV generated electric power increases, it is possible to achieve both the optimum operation of PV and the electric power supply to the PCS. PV generated power is always fluctuating according to the period of MPPT control of PCS. When the energy storage system monitors the PV power and moves the power characteristics in the direction in which the PV generated power increases, there is concern that the power fluctuation caused by the MPPT control disturbs the determination of the movement direction of the power characteristic. Therefore, when determining the direction of movement of the power characteristics, a low-pass filter that can sufficiently suppress the power fluctuation due to the MPPT control of PCS is used for PV generated power.

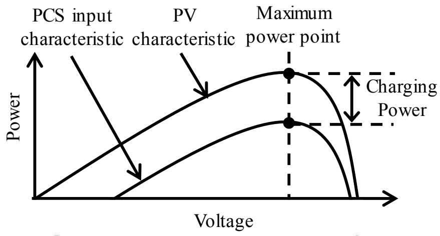
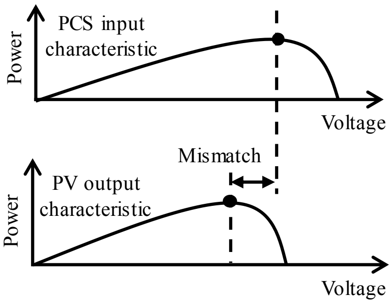
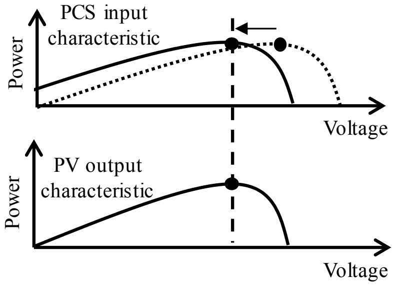


Fig. 5. Power characteristics at charging operation.



(a)Conventional method



(b)Proposed method

Fig. 6. Power characteristics at discharging operation.

IV. EXPERIMENTAL RESULTS

Fig. 7 shows experimental structure. PV output power and energy storage system output power are measured by a power meter in the experiment. The PV is simulated by programmable power supply with rated 1.5 kW. Solar radiation data and PV parameters are used to simulate the PV. The PV parameters are shown in Table 1. Rated power of the PCS is 5 kW. The energy storage system is simulated by bidirectional chopper and DC power supply. The energy storage system detects current and voltage of the PV by using sensor and monitors the PV power and performs discharge operations. Fig. 8 shows the control block of discharge operations. Discharge is carried out when the PV power becomes 300 W or less.

The discharge power characteristic is stored in a lookup table in the control microcomputer of the energy storage system. The power command value is referred to from PV voltage. And subtracts the power of PV from the referenced power command value to generate a discharge power command value of the energy storage system. Dividing the power command value by the voltage, calculate the current command value, and perform PI control.

In this experiment, the movement of the power characteristic of the proposed discharge control method is performed by monitoring the PV generated power and using the hill climbing method. Using the hill climbing method, increase or decrease the voltage value in the direction in which the PV power increases. When referring to the lookup table, the reference position of the power characteristic is shifted by adding increment / decrement. Relatively move the peak voltage of the power characteristic.

Since PV generated power continues to fluctuate due to MPPT control of PCS, fluctuating components are eliminated by using a low pass filter in order to prevent fluctuation disturbing the hill climbing method operation. The cutoff frequency of the low-pass filter is 1 Hz since the period of the MPPT control of the PCS is 0.1 second. Also, the movement period of the power characteristic is 2 second. Therefore, the MPPT control of the PCS can sufficiently follow up.

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 rated power of bidirectional chopper is 500 W. It is 1/10 of the PCS.

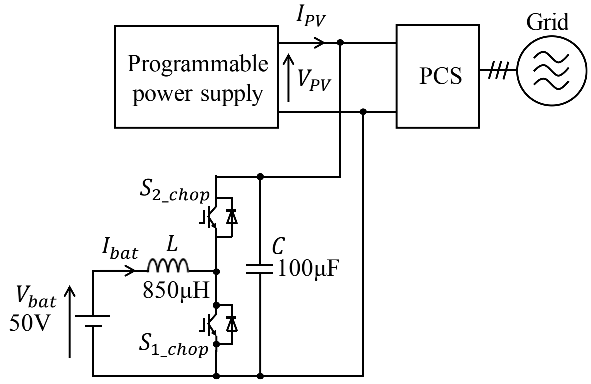


Fig. 7. Experimental structure.

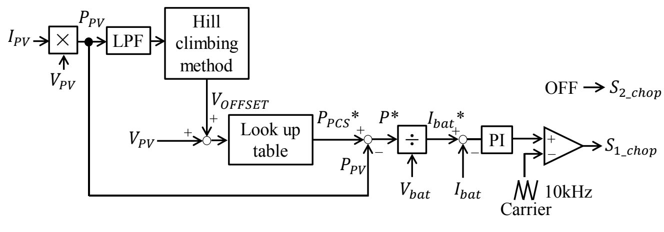


Fig. 8. Control brock in discharging.

Table 1. PV parameter.

Open circuit voltage	200V
Short circuit current	10A
Maximum power voltage	160V
Maximum power current	9A

Table 2. Experimental parameter

MPPT control cycle of PCS	0.1s
Steps of MPPT control of PCS	2.0V
Update cycle of hill climbing method of energy storage system	2.0s
Steps of hill climbing method Of energy storage system	5.0V

Fig. 9 shows the experimental result during the discharge operation of the proposed method. The peak voltage of discharge power characteristics and the input voltage of PCS during discharge control are shown. When applying the proposed method, it can be seen that the input voltage of the PCS continues to fluctuate greatly. This is because the energy storage system monitors the PV generated power and moves the power characteristic in the direction in which the generated power increases. Because the peak voltage of the characteristic

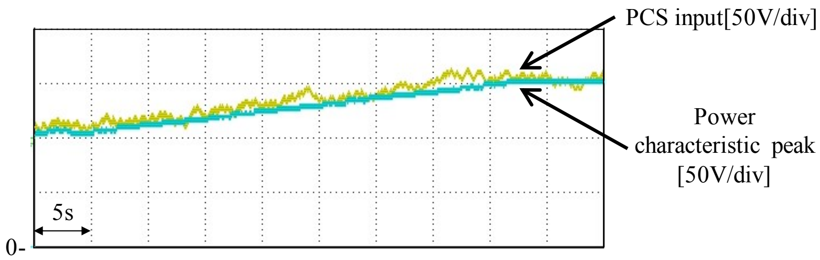
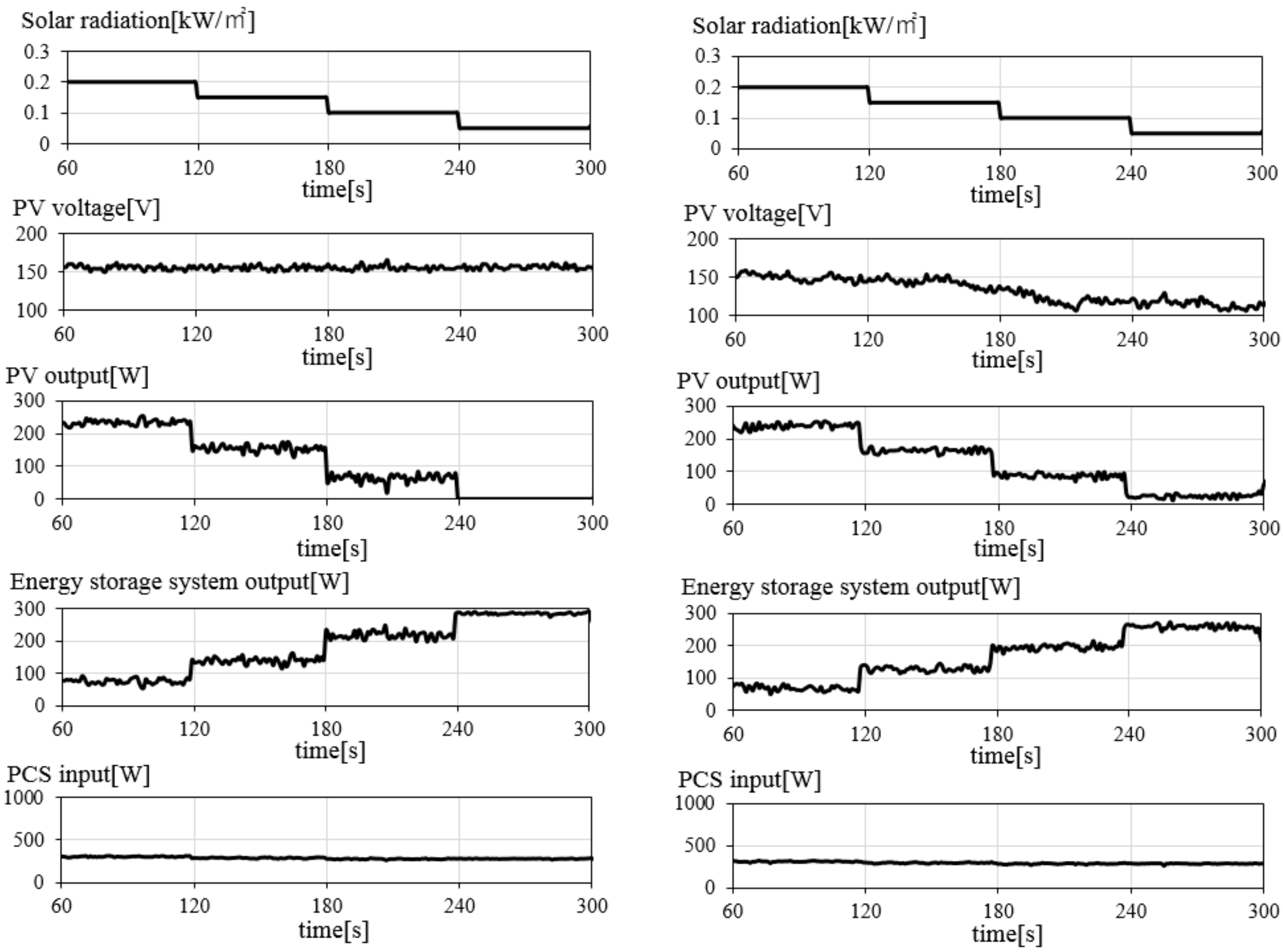
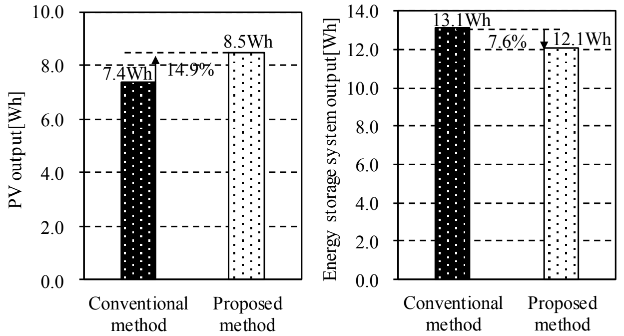


Fig. 9. Experimental result of movement and tracking of power characteristics in proposed method.



(a)Conventional method (b)Proposed method

Fig. 10. Experimental results in discharging.



(a)PV output (b)Energy storage system output

Fig. 11. Results of power amount.

moves, the PCS operates so as to follow near the peak by MPPT control. From the above, it can be confirmed that by moving the discharge power characteristic, it is possible to move the input voltage of the PCS.

Fig. 10 shows the waveform of each part when the conventional discharge control method and the proposed method are applied. When the conventional method is applied, it can be confirmed that the PCS input voltage is almost constant because the discharge power characteristic is single. On the other hand, experimental results applying the proposed method can confirm that the PV voltage is changing. This is because the electric power characteristic is moved while monitoring the PV generated electric power.

Next, PV generated electric energy is compared. When the conventional method was applied, the PV generated electric energy amount in the period shown in the figure was 7.4 Wh. On the other hand, when applying the proposed method, the PV generated electric energy amount in the period shown in the figure was 8.5 Wh. It is confirmed that it improved by 14.9 %. When the conventional method is applied, since the discharge power characteristic during the discharge period is single, the voltage that the PCS follows with the MPPT becomes almost constant. Then, a mismatch between the peak voltage of the discharge power characteristic and the peak voltage of the power characteristic of PV occurs. On the other hand, when applying the proposed method, the energy storage system monitors the PV generated power and moves the discharge power characteristics in the direction in which the PV generated power increases. Since the input voltage of the PCS can be moved and it can be operated at the maximum power point of PV, PV power generation amount has increased. Also, when comparing the discharge electric energy amount in the period of the figure, when applying the conventional method, it became 13.1 Wh. When applying the proposed method, it was 12.1 Wh. It was confirmed that the reduction was 7.6%. When the proposed method is applied, the amount of electric power that can be acquired from PV increases. Therefore, it is possible to reduce the amount of discharge electric power required for continuing operation of the PCS. From the above, the effectiveness of the proposed method was confirmed.

V. 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 energy storage device. 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 PV. During charging, keep charging power constant so do not disturb PCS MPPT. At the time of discharging, since discharge power characteristics are prepared, discharge power can be limited. Then, by moving the characteristic in the direction to increase PV generated electric power, optimum operation of PV can also be achieved. Then, the experiment was carried out, and the PV generated electric power amount in the case of applying the conventional discharge control method and the proposed discharge control method was compared. When the proposed discharge control method was used, the PV generated electric power amount improved by 14.9%. In addition, the discharge electric energy was reduced by 7.6%.

By using the proposed method, it was confirmed that the PV can be optimally operated and the operation of the PCS can be continued with less electric power. From the above, the effect of the proposed discharge control method was verified.

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