ADVANCED ISLANDING OPERATION METHOD INTEGRATING MULTIPLE POWER SUPPLIES INCLUDING PHOTOVOLTAIC POWER GENERATION

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ABSTRACT

This study focuses on stand-alone power operation in a house during a blackout. The purpose of this type of operation, known as islanding, is to balance the power supply with load demand fluctuation, and to ensure its long-term sustainability. Therefore, we used multiple forms of power supply such as a battery energy storage system (BESS), PV generator, and a home energy management system (HEMS) to control the load of appliances. The four types of power generation equipment (the PV system, BESS, electric vehicle (EV), and fuel cell (FC)) have different characteristics in terms of their output power, capacity, and response time, etc. In consideration of these output properties and the response time of the power generation equipment, we implemented control to enable the islanding operation to continue, which was verified to be effective even in a limited power supply situation.

INTRODUCTION

Immediately after the Great East Japan Earthquake in 2011, many residents around metropolitan areas in Japan experienced inconvenience because of scheduled blackouts during which electricity was not available a few hours a day for one month. Consequently, at residential sites, renewable energy (RE) equipment, such as photovoltaic (PV) panels as well as energy storage systems, such as batteries and electric vehicles (EVs) were introduced rapidly. The use of this equipment is expected to lead to the development of an islanding operation technique that would make it possible to use some appliances in the house on the occasion of a blackout. However, these sources have different output properties, especially the PV output, which fluctuates depending on the weather. For each of these power systems, this study examines effective control methods capable of absorbing the fluctuation, by considering each characteristic in the limited power supply situation, yet ensuring consumer convenience.

SYSTEM CONFIGURATION

In Japan, a single-phase three-wire 100-V /200-V distribution system is normally used for transmitting power to low-voltage (LV) customer sites. Fig. 1 shows the distribution panels (DPs) in the experimental smart house. The characteristics of installing each form of power generation in the smart house are listed in Table 1. When the house is affected by a blackout, the switch (SW) in the important load distribution panel is converted to BESS islanding output (islanding mode). The BESS, which behaves as a voltage type inverter, provides a 2-kW output—single-phase with three lines of 100/200 V—during the islanding operation. Besides the PV system, an FC and EV are connected with the distribution panel as a current type inverter.

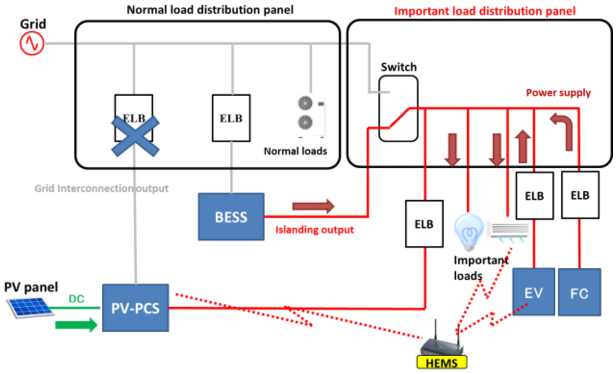

Fig.1. Distribution panel in a smart house.

Table 1. Characteristics of each generator.

Equipment	BESS	PV	Fuel Cell	Electric Vehicle (V2H)
Output	1ϕ3W 100/200V Capacity: 5.5kWh Discharge: 2kW (1kW/each)	1ϕ2W 200V Rated output: 4.0kW	1ϕ2W 200V Output: 0.75kW (0.00kW～0.75kW)	1ϕ2W 200V Output: 0.7kW (0.35kW～0.7kW)
Input	Charge: 2kW (0kW～1kW)		－	Charge: 2.4kW (1.2kW～2.4kW)
Control mode	・ECHONET-Lite (Charge & Discharge)	・ECHONET-Lite ・Curtail output to 50% (> 109V) ・Stop output (>115V)	・ECHONET-Lite (Start)	・ECHONET-Lite (Charge & Discharge)
Load following	instantaneous	－	instantaneous	instantaneous
Isolated operation	1ϕ3W 100/200V Capacity: 5.5kWh Discharge: 2kW (1kW/each)	Independent outlet 1ϕ2W 100V (Max.1.5kW)	1ϕ3W 200V Output: 0.75kW (0.00kW～0.75kW)	1ϕ3W 200V Output: 0.7kW (0.35kW～0.7kW)

ROLE AND OUTPUT PRIORITY OF EACH GENERATOR

Because a PV generator uses renewable energy and is expected to supply power during the time of an islanding operation, but its output fluctuates according to the weather, it is necessary to use other generators to balance the supply and demand to continue the islanding operation. Thus, the FC is enabled to supply electric power using gas and boiling hot water. Because the BESS and EV contain rechargeable batteries, they necessitate repeated electric discharging / charging. Based on the characteristics of each generator, the prioritization of power supply during an islanding operation is shown in Fig. 2. The desirable operation of each apparatus is described by the following proposals

Purpose of islanding operation

- ✓ Capable of performing islanding operation (supply and demand adjustment possibility)
- ✓ Capable of maintaining stable independent operating conditions for a long time

Way of thinking for the realization

- ✓ Giving priority to other energy sources (PV, FC) over rechargeable batteries (EV, BESS)
- ✓ Giving priority to generators that are not able to control its output

BESS: Working as a voltage source and maintaining a fully charged state or minimum electric discharge

PV: Generating the maximum output by P_MAX control basically and given top priority of supplying the household appliances, and the surplus energy share to charge BESS or EV as much as possible

FC: The generation time is adjustable. Performing the maximum generation and supplying the household appliances, and providing hot water supply preparations. Surplus energy charges BESS or EV as much as possible.

EV(vehicle to home (V2H)): Main purpose is providing mobility, with power supply being a secondary purpose. Controlling its charge/discharge in order to supply the part of the power supply that is expressed "as much as possible" and the shortage on the supply described above.

Household appliance: Using minimum electricity and aiming at effective electricity usage by using electricity generated by the PV panels and the fuel cell.

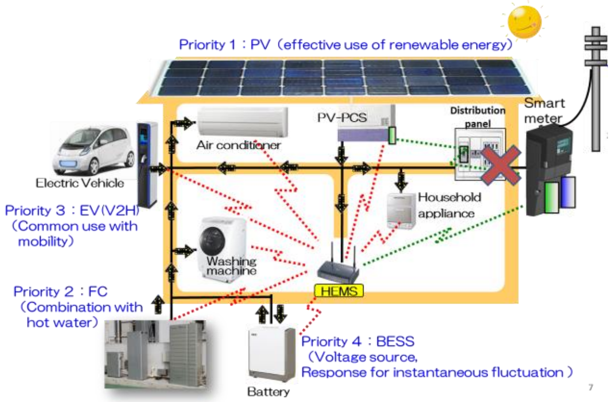

Fig.2 Priority of each power source

PRIORITY OF THE OUTPUT OF EACH GENERATOR

The priority assigned to the output of each generator is decided at the position of the current transformer (CT) to prevent reverse tide + control for FC, V2H and the characteristic of each inverter. When CT for the FC, V2H control is installed at position ①in Fig. 3, FC,V2H cannot output when PV outputs and BESS charges. This is because CT (RPR: Reverse Power Relays) detects the reverse power flow and stops the output. In this case, PV is the priority generator (max. 4 kW) > EV (0.35 - 0.7 kW) > FC (0.05 -0.75 kW) > BESS (0 - 2 kW). When CT is installed at ②, the priority of the output of FC, EV increases because they can provide output regardless of the charged or discharged status of the battery.

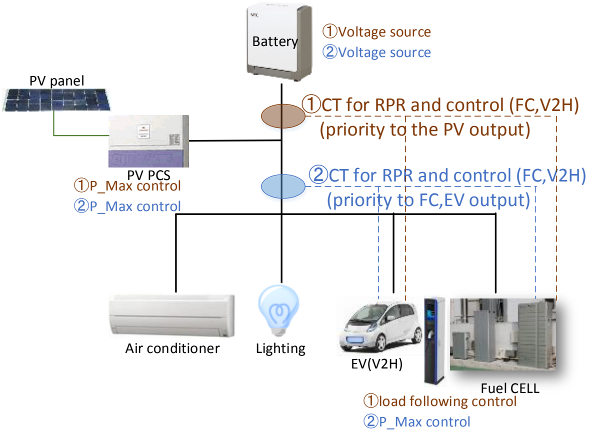

Fig.3 Position of CT of FC and EV in DP

In the case of an islanding operation, the load and PV output become fluctuating components. We investigated the possible continuing range of the islanding operation, by performing islanding operation tests in which we changed the ratio to increase the load and PV output from 0.5kW to 2kW. As an example, the output properties of each generator are shown in Fig.4 when the PV and load are increased by 1kW. Fig.4 shows the case for CT position ①. In this case, PV outputs according to the command level and the battery charges if the PV output becomes redundant. When the battery reaches a charged state, FC and EV cannot output.

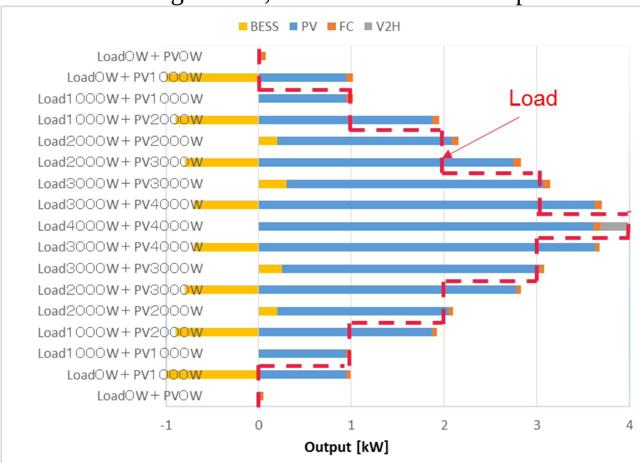

Fig.4 Operation of each generation source upon increasing PV and load (CT position ①).

Fig.5 shows the case of CT (EV) position ②. The PV outputs according to the command level, but EV outputs fully (0.7 kW) unlike the case in Fig. 4. FC and EV supply the load deficit. Fig. 6 shows the range over which an islanding operation changes the amount of load and PV output. A battery whose output range is (-1 kW - 2 kW), which enables it to function during a steep change, is used and the part surrounded by a red dotted line is the range that is available for the islanding operation.

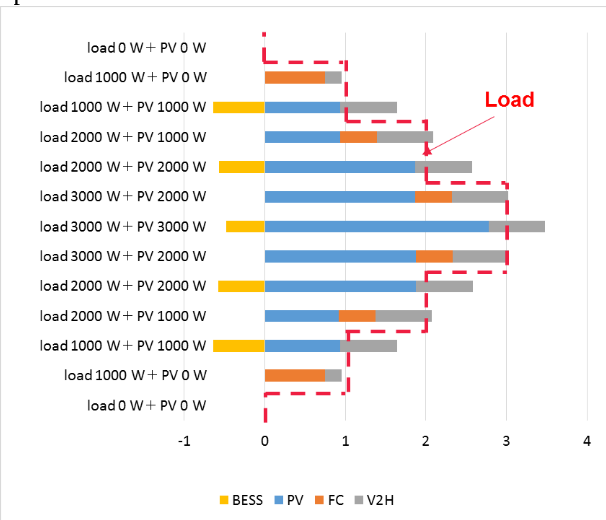

Fig.5 Operation of each generation source upon increasing PV and load (CT position ②).

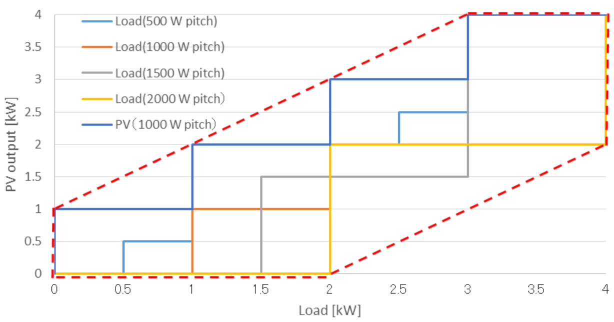

Fig.6 Possible range of islanding operation.

INFLUENCE OF PV OUTPUT FLUCTUATION

The output of BESS changed up to 2 kW, which could support an instant change in output, thereby confirming that an islanding operation would be sustainable. Based on this result, the sustainability of the islanding operation was investigated for the use of a constant load with an inverter, and for changing the output of PV. The influence of the PV output fluctuation on an islanding operation was evaluated by using the three PV output profiles (one fine-weather day, two cloudy days) shown in Fig. 7. Pattern1 is that of a fine day and stable in its output with little fluctuation, but multiplication of the PV output is the highest of the three. Pattern 2 is that of a cloudy day with a large fluctuation band of the PV output because of the solar shadow, and sudden fluctuations in the PV output. Pattern 3 is also that of a cloudy day with high-frequency changes in the output, which occurs in a stable band, but, with a large number of changes in its output.

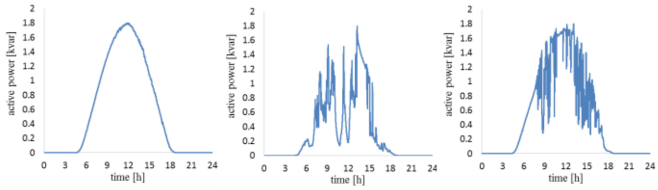

Fig.7 PV output profiles: sunny day (left) and cloudy days (middle and right).

Fig. 8 and Fig. 9 show examples of the test result; the PV output (pattern2 and pattern 3) of the cloudy day using a simulated load of 1-kV and 2.5-kW uniformity load with an inverter. In this test, the load quantity was constant, but the PV output fluctuated greatly; thus, FC, EV(V2H), and BESS supplied the shortage.

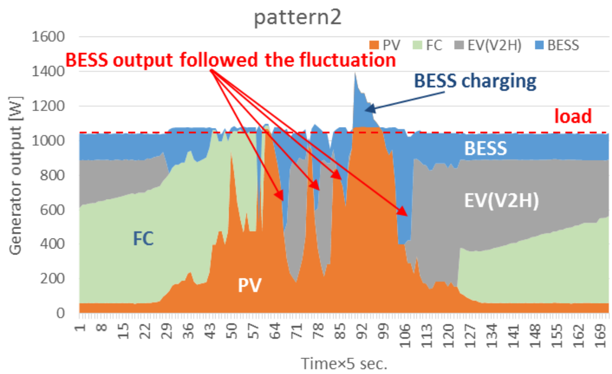

Fig.8. Output profile (pattern2) with 1 kW constant load.

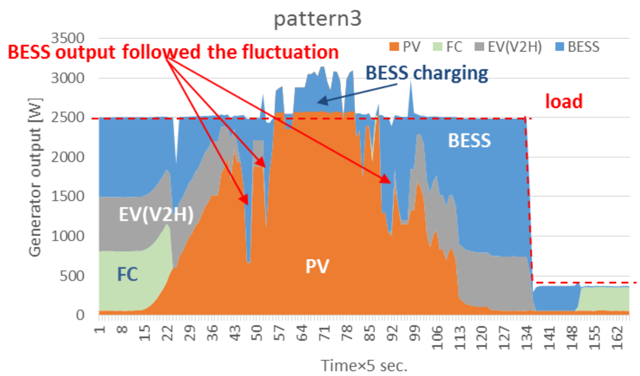

Fig.9. Output profile (pattern3) with 2.5 kW constant load.

INFLUENCE OF PV OUTPUT AND LOAD FLUCTUATION

The output priority of each generation is: PV (Max. 3 kW) > FC (0.05 - 0.75 kW) > EV (0.35 - 0.7 kW) > BESS (-1 - 2 kW). BESS was able to quickly compensate for the fluctuation in PV, after which the output of FC and EV reserved the state of charge (SOC) of BESS. When the PV output exceeded the load amount (2.5 kW), and the excess quantity that was generated became redundant, BESS smoothly switched over from discharge mode to charge mode to maintain the supply-demand balance. In this case, the PV output changed up to 2 kW, but the BESS output followed the fluctuation and could continue the islanding operation.

Next, the effect of changing the quantity of load apparatus and load amount was investigated, in addition to the change in the PV output. Using the household appliances according to the times provided in Table 2, and sweeping the PV output patterns shown in Fig. 7, the output of each generator and each load are shown in Fig. 10.

Table 2. Time schedule of load apparatus changes.

Elapsed time	Heater	Hair dryer	Electric kettle	A.C.	INV	Total amount
outlet	100V			200V		
0						0 kW
1						0 kW
2	0.33 kW					0.33 kW
3	0.67 kW					0.67 kW
4	1 kW					1 kW
5	0.67 kW		1.2 kW			1.87 kW
6	1 kW	1.2 kW				2.2 kW
7			1.2 kW			2.2 kW
8		1.2 kW			1 kW	3.2 kW
9					2 kW	4.2 kW
10				1.7 kW		1.7 kW
11						1.7 kW
12						1.7 kW
13						1.7 kW
14						1.7 kW
15						1.7 kW

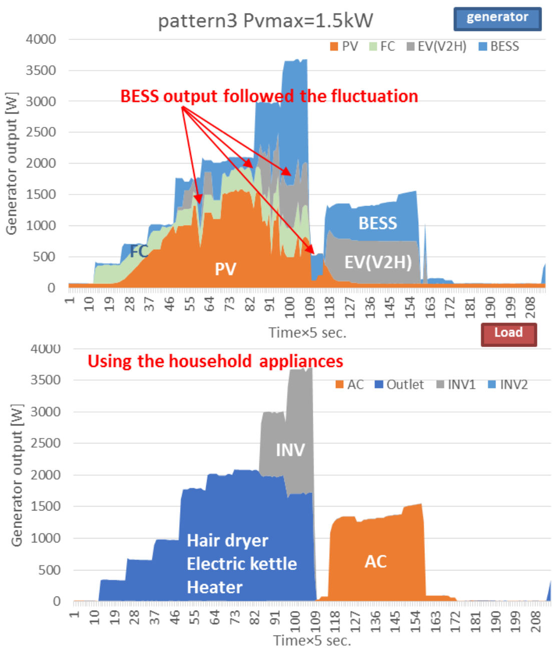

Fig.10. Output profile of generators and loads

HEMS CONTROL

We aimed to expand control of the islanding operation by controlling the load apparatus to maintain the output of the battery in a constant range by using a home energy management system (HEMS). Fig. 11 shows the experimental result. Load consumption increased, and beyond the value of 1 kW, which is the BESS output threshold, HEMS restrains the consumption of household appliances to maintain the BESS output within the threshold. This control can be exercised by reserving the SOC of BESS to ensure continuation of the islanding operation.

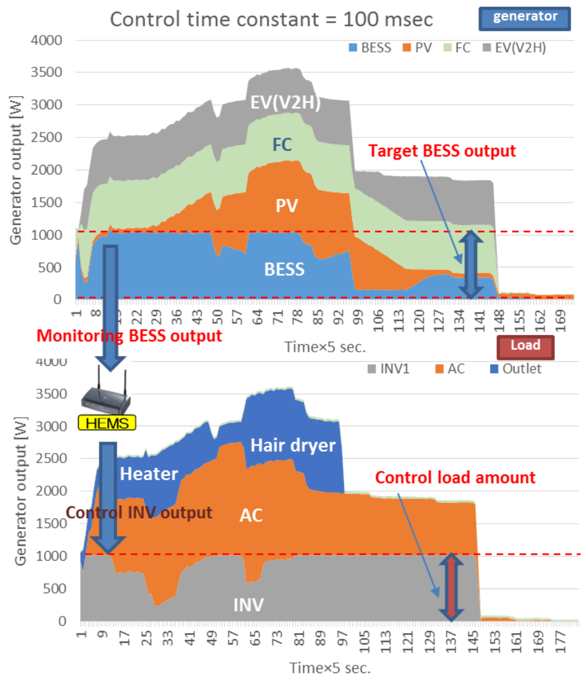

Fig. 11 Experimental result of HEMS control

CONCLUSION

The research presented in this paper focused on the operation of stand-alone power management in a smart house. This requires a continuous islanding operation based on the effective utilization of the PV output. However, because the PV output fluctuates according to the weather, it is necessary to understand the characteristics of the other power generators and to ensure that they are appropriately integrated during situations in which the power supply is limited. Furthermore, it would be possible to use electric household appliances by implementing HEMS.

REFERENCES

[1] J. Yoshinaga, et al, 2015, "Islanding Operation Technology Integrated with Multiple Power Supplies", 23th International Conference on Electricity Distribution, paper 0294