Power-Supporting Operation of Energy Storage for Energy-Independent Housing Complex

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***Abstract*—This paper proposes an energy storage operation method that reduces power-consuming time by avoiding net power consumption in an energy-independent housing complex composed of multiple houses and photovoltaic power generation. The energy storage charges energy generated from the photovoltaic power generation in the housing complex during the day and compensates for power consumption at night using the stored energy. The function of the energy storage was verified through simulation developed in Python. In addition, through a real 56 kW photovoltaic power plant and an energy storage with a power capacity of 25 kW and a battery capacity of 114 kWh, about 21 hours of positive grid power per day was achieved on average during an operating period of 35 days.**

Index Terms*—energy-independent, housing complex, energy storage, photovoltaic power generation, renewable energy*

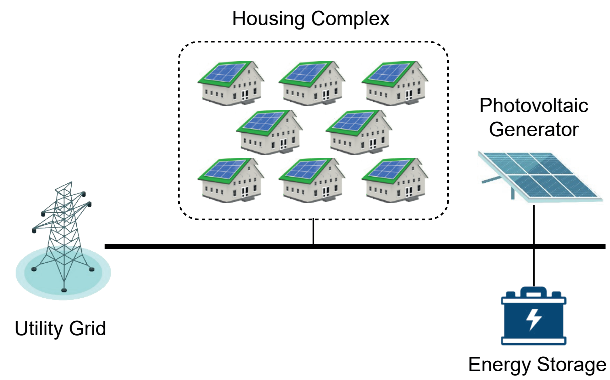

Fig. 1. System architecture of energy-independent housing complex.

I. Introduction

Renewable power generation is a method of obtaining energy from the surrounding environment and is gradually replacing conventional fossil fuel-based energy production. Several countries in Europe are aiming to increase the share of renewable energy production up to 100% [1]. Representative photovoltaic power generation produces electricity from sunlight. It can be installed in a variety of capacities, from small-scale homes to large-scale photovoltaic power plants. The number of zero-energy buildings and housing complexes that are independent of energy by installing photovoltaic power generation is continuously increasing [2].

Studies have been conducted to generate as much power as possible from the photovoltaic power generation [3], [4]. However, in zero-energy buildings with it, power generation is concentrated only during the day, while the load consumes power steadily, thus there is an imbalance in supply and demand. To solve this, demand management methods have been studied [5]. However, a more fundamental approach is needed at a scale beyond a single building. On the other hand, energy storage is one of the distributed resources that can store surplus energy and use it when necessary, and is widely used as a means to compensate for the intermittency of renewable power generation [6], [7]. Studies have been conducted to optimize the power and battery capacities [8]. The impact of renewable power generation on the power grid can be reduced by using the energy storage appropriately.

This paper aims to minimize the time that an energy-independent housing complex depends on grid power supply. The energy storage is used to charge the surplus power, and to compensate for the power consumption by multiple houses during the time when photovoltaic power is not generated. As a result, the net power consumption becomes zero or negative, in other words, power generation to the grid becomes positive. This method contributes to the power independence of energy-independent housing complexes.

II. Energy-independent housing complex

A plurality of houses constituting a housing complex are connected together to a distribution network of an electric power grid to receive power. Individual houses can be equipped with their own photovoltaic power generation for energy independence. However, the energy independence of the entire housing complex is not guaranteed because the capacity of each photovoltaic power generation and the size of the power consumption of the load are different. For energy independence of the housing complex, as shown in Fig. 1, shared photovoltaic power generation is installed with the required capacity in the same distribution network to which the housing complex is connected.

The energy storage can be connected to the power grid along with the photovoltaic power generation to regulate the flow of electricity supplied to the housing complex. As the photovoltaic power generation is concentrated during the day, the energy storage absorbs power when power generation is

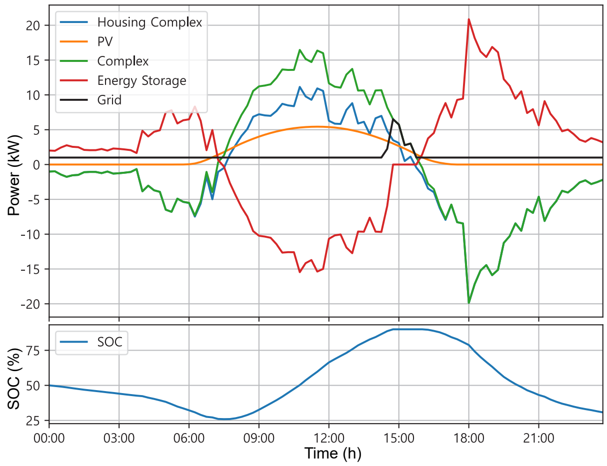

Fig. 2. Simulated power waveform of housing complex with energy storage.

high, and it supplies power when power demand is high. Accordingly, it is possible to obtain power independence as well as energy independence of the housing complex.

III. Simulation

In order to verify the operation of the energy storage according to the demand and supply of power in the housing complex, five houses, a shared photovoltaic power generation, and an energy storage including charging and discharging functions were modeled in Python. The energy storage has a power capacity of 25 kW and a battery capacity of 114 kW. Power consumption data of less than 1 kW on average and power generation data of 3 kW for individual houses, and data of less than 10 kW for shared photovoltaic power generation are given. All data are in units of 5 minutes, and the energy storage power was also recorded in the same units.

Fig. 2 shows that for power independence of the energy-independent housing complex during one day, the energy storage charges the generated power of the housing complex with the shared photovoltaic power generation, and discharges it to compensate for the consumed power of the housing complex. The complex power, the sum of all photovoltaic power generation and power consumption, is positive during the day and negative at night. The housing complex almost always send 1 kW to the power grid.

IV. Implementation

Ten houses equipped with individual power generation were determined as one housing complex. Shared photovoltaic power generation and energy storage were installed and connected to the power distribution network to which the housing complex is connected, as shown in Fig. 3. Photovoltaic power generation is 56 kW, PCS is 25 kW, and battery is 114 kWh. Considering the size of the housing complex, the magnitude of photovoltaic power generation was recorded after reducing to 20% or 30%. All power data collected from the power meters was recorded in a database at 5-minute intervals. The operation server receives the latest power data from the database and the status information of the energy storage, determines the energy storage power for the housing complex, and directs the output to the storage.

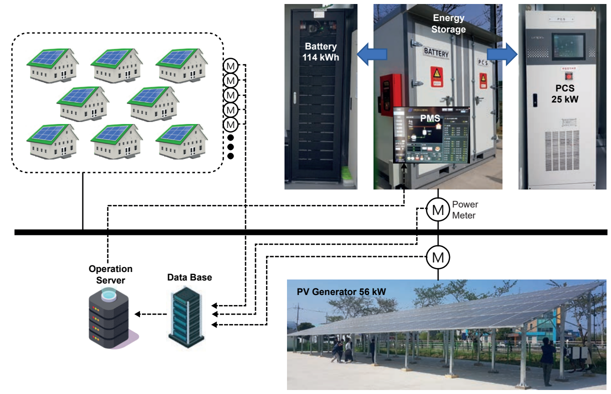

Fig. 3. Implementation of shared photovoltaic power generation and energy storage.

TABLE I
Analysis of consumption and generation of power and energy.

	Consumption by load			Generation by PV		
	Power (kW)		Energy (kWh)	Power (kW)		Energy (kWh)
	avg	max		avg	max	
H1	0.57	1.3	13.6	0.73	2.68	17.44
H2	0.49	0.98	11.72	0.67	2.51	17.19
H3	0.41	1.18	9.83	0.57	1.96	13.77
H4	0.51	1.42	12.33	0.72	2.7	17.26
H5	0.54	0.87	12.97	0.72	2.66	17.31

V. Experimental Results

A. House power profiles

Individual houses belonging to the housing complex have different power consumption patterns. Fig. 4 shows the average of power data collected at the same time in 5-minute increments over 15 days from the power meters installed in the five houses. As shown in Fig. 4(a), power consumption in Houses 1, 2, and 4 is temporarily high in the morning and evening, and House 5 shows a pattern in which power consumption is maintained from daytime to evening. On the other hand, as shown in Fig. 4(b), the pattern of power generation is similar because all houses have the same capacity.

Table I presents an analysis of consumption and generation of power and energy in houses. The average power consumption is around 0.5 kW in all houses, and the maximum power consumption is more than twice the average in most cases. Because the weather was good for 15 days of data collection, the maximum power generation at noon except House 3 had a high value of about 2.6 kW. Therefore, this housing complex has a pattern in which surplus power is generated during the daytime and the power consumption is high during the night time. On the other hand, because the 16.6 kWh of energy generation is greater than the 12.1 kWh of energy consumption, the housing complex is energy-independent from the power grid.

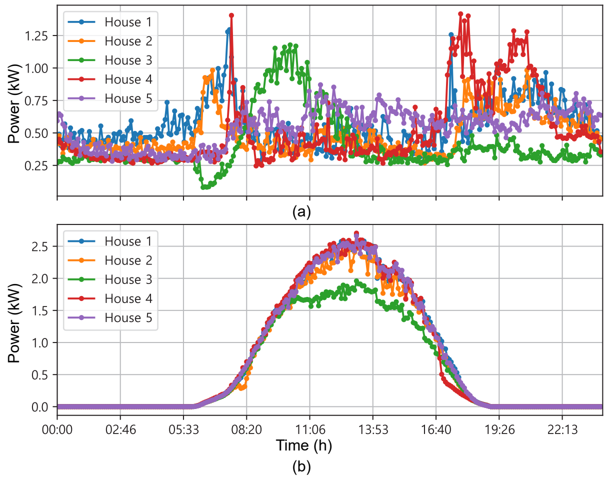

Fig. 4. Average power consumption and generation profile of houses.

B. Energy storage operation

Based on power consumption data of 10 houses of the housing complex and power generation data by individual and shared photovoltaic power generation, energy storage was operated for 35 days to compensate for the power consumption in the housing complex and to increase the time of positive grid power. The SOC of the energy storage was limited to a minimum of 10 and a maximum of 80. Fig. 5 shows the results of a day operation. From the point when the power generation exceeds the power consumption, the energy storage started to charge, but it could not charge anymore due to overcharging after 4 hours.

Excluding two hours from 19 to 21, when the energy storage was intentionally shut down, the housing complex sent power to the grid for 22 hours instead of being supplied. Excluding the overcharging period, a constant power of 1 kW was maintained for about 14 hours. As shown in Fig. 6, for the 35 days, the housing complex sent positive power to the grid for 21.1 hours on average per day. Except for a few days when the weather is cloudy, it corresponds to 22 hours.

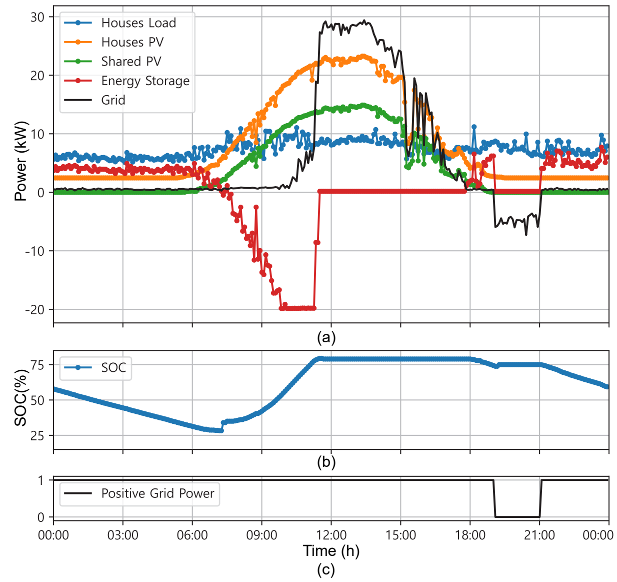

Fig. 5. Measured power from housing complex with PV and storage.

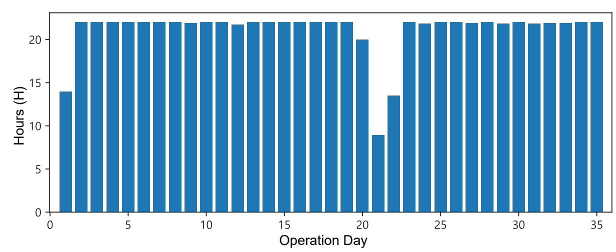

Fig. 6. Achieved time of positive grid power for 35 days.

VI. Conclusion

This paper proposes the operation of energy storage that compensates for the power consumption of the housing complex. Actual photovoltaic power generation and energy storage were installed near the housing complex and operated for 35 days, achieving 21 hours of positive grid power per day. Through the proposed method, it is hoped that many energy-independent housing complexes will become power-independent.

Acknowledgment

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