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Resilience Evaluation of Positive Energy Building in Japan

Chiho Jimba[1*], Yutaro Akimoto[1], Keiichi Okajima[1]

1 Graduate School of Systems and Information Engineering, University of Tsukuba, Japan

(*Corresponding Author: s2320543@u.tsukuba.ac.jp)

ABSTRACT

Global warming has been a glowing problem. At the same time, natural disaster such as earthquake and rainstorms are becoming more frequent. Therefore, decarbonization and increase of resilience are needed to all energy systems. Practically, PEB and PED has been positively introducing in the world. To show resilient systems, this study conducted several pattern of case studies which can evaluate the resilience quantitatively. Through this case study, it revealed that three-day evaluation is more effective than one-day evaluation.

Keywords: energy system, PV, Battery, resilience, quantitative evaluation, time series

NONMENCLATURE

Abbreviations	
PEB	Positive Energy Building
PED	Positive Energy District
IEEJ	The Institute of Electrical Engineers of Japan
SOC	State of Charge
Symbols	
R_{1N}	Resilience indicator (Number of power outages)
R_3	Resilience indicator (Redundancy)
R_4	Resilience indicator (Surplus power)
R_5	Resilience indicator (Insufficient supply)

1. INTRODUCTION

There are several studies about the environmental or economical evaluations about energy systems. Tilman et al. evaluated the optimal installed capacity of PV and battery storage systems and their impact on the power grid, as well as their economic efficiency [1]. Teppei et al. conducted an economic evaluation of the installation of PV and battery storage systems [2]. However, resilience evaluation is needed to prevent severe damages due to disasters. Despite the importance of resilience evaluation, there are not enough research about them. Therefore, resilience evaluation is needed. Especially with multiple resilience indicators because resilience evaluation using only a single indicator cannot clarify the multiple impacts of energy systems.

Our previous study conducted the research about resilience evaluation using five resilience indicators with reference to the IEEJ [3][4]. It revealed that energy resilience is differ if the power interruption occurs at the different times. Also, resilience indicators show best or worst value in different times among all five resilience indicators. However, the previous study has just evaluated a single day and cannot show the resilience of more than a single day. Generally, power outages caused by actual disaster rarely finish in a day and several days evaluation is needed. Therefore, this study conducts several days evaluation which can show the difference in the resilience indicators between a single day evaluation and several days evaluation. Three-day evaluation can also show the importance of each resilience indicators. The three-day demand and supply data are from projected data of three consecutive days in real PEB in Japan. PV and battery system have installed in this facility. This study focuses on the comparison of a single day evaluation and three-day evaluation.

2. MATERIAL AND METHODS

2.1 Resilience indicators

In this study, four resilience indicators are used as shown in Table 1. The resilience indicators Redundancy R_3, Surplus power R_4 are same as previous indicators [4]. This study newly set the resilience indicator $R_{1\mathrm{N}}$ as the Number of power outage times. Based on Insufficient supply ratio R_5 in the previous resilience indicator, this study dealing with the resilience indicator R_5 as the amount of insufficient supply.

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Table 1. Resilience indicators

Parameter	Resilience indicators
R_{1N}	Number of power outages
R_3	Redundancy
R_4	Surplus power
R_5	Insufficient supply

2.2 Calculation of resilience indicators

The time of outage from the grid set in the simulation is the "time of supply interruption" and is denoted by T_{OUT}. The time of power outage due to supply shortage is defined as t_0, t_1, t_2, …. The time when the supply exceeds the demand for electricity and power is restored is denoted as t_0', t_1', t_2'… in that order. The end time of the simulation is T_{END}.

In this study, "Tolerance [4]" is defined as the ability to avoid power outages and denoted by the Number of power outages R_{1N}. In Figure 1, Number of power outages R_{1N} becomes 4 because the total number of outage times t_0, t_1, t_2, t_3 is 4. "Redundancy" is defined as the time [min] during power can be supplied from power outage restoration after the time of supply interruption. Figure 1 shows the concept of Redundancy in this study. As shown in equation (1), the Redundancy R_3 is the sum of the times from power outage when $E_{consume} - D \geq 0$. $E_{consume}$ is the electricity which can be used for consuming. D is electricity demand.

$$R_3 = t_0 - T_{OUT} + (t_1 - t_0') + (t_2 - t_1') + \cdots + (t_n - t_{n-1}') \quad (1)$$

"Surplus power" of the system is the difference between the demand and the supplied energy [kWh] in the interval where the supply exceeds the demand in a certain time range after a supply interruption time. It is shown in Figure 1, where area that total amount of

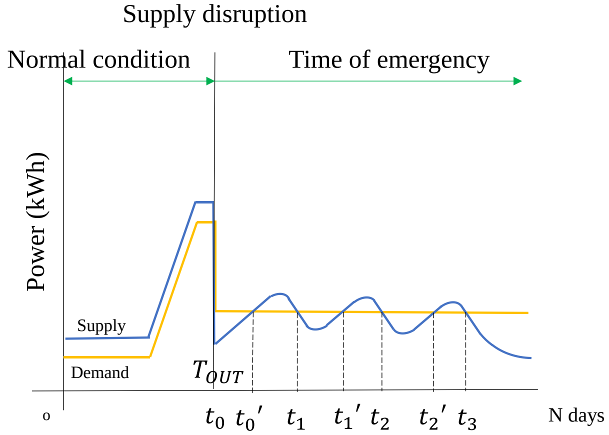

Fig. 1. Conceptual diagram of resilience indicators

supply exceeds demand. As shown in equation (2), the Surplus power R_4 is the sum of the electricity quantities in the interval $E_{consume} - D \geq 0$ after the supply interruption time.

$$R_4 = \int_{T_{OUT}}^{t_0} (E_{consume} - D)\mathrm{dt} + \int_{t_0'}^{t_1} (E_{consume} - D)\mathrm{dt} + \cdots + \int_{t_{n-1}'}^{t_n} (E_{consume} - D)\mathrm{dt} \quad (2)$$

Finally, "Insufficient supply" has defined as an indicator that has an opposite relationship to the "Surplus power" R_4. It is shown in Figure 1, where area that demand exceeds total amount of supply. As shown in equation (3), Supply shortage R_5 is the difference between electricity demand and supply during the power outage.

$$R_5 = \int_{t_0}^{t_0'} (D - E_{consume})\mathrm{dt} + \int_{t_1}^{t_1'} (D - E_{consume})\mathrm{dt} + \cdots + \int_{t_n}^{t_n'} (D - E_{consume})\mathrm{dt} \quad (3)$$

3. CASE STUDY

3.1 Case study facility

This study proposes a method for quantitative evaluation of resilience based on the demand of an actual building in Japan and operational data of PV and storage batteries. PEB is an energy-efficient building that produces more energy than it uses via renewable sources, with high self-consumption rate and high energy flexibility, over a time span of one year. In this study, the PEB in Oita city is used and designed as a temporary shelter in the event of an actual disaster.

3.2 System configuration

Figure 2 shows the demand data and measured power generation at the subject facility from September 14th to 16th, 2022. The PEB is equipped with PV and storage batteries. The storage battery is a lithium-ion battery with a capacity of 64.8 kWh. Weather was not clear sunny day for three days, but 14th and 15th were not so cloudy days and PV generate power at daytime. Compare two days, 14th generate more power than 15th. For 16th, because there was short time of sunny weather, it can be seen the Power generation shortly going up at about 12:00. In this study, supply interruption

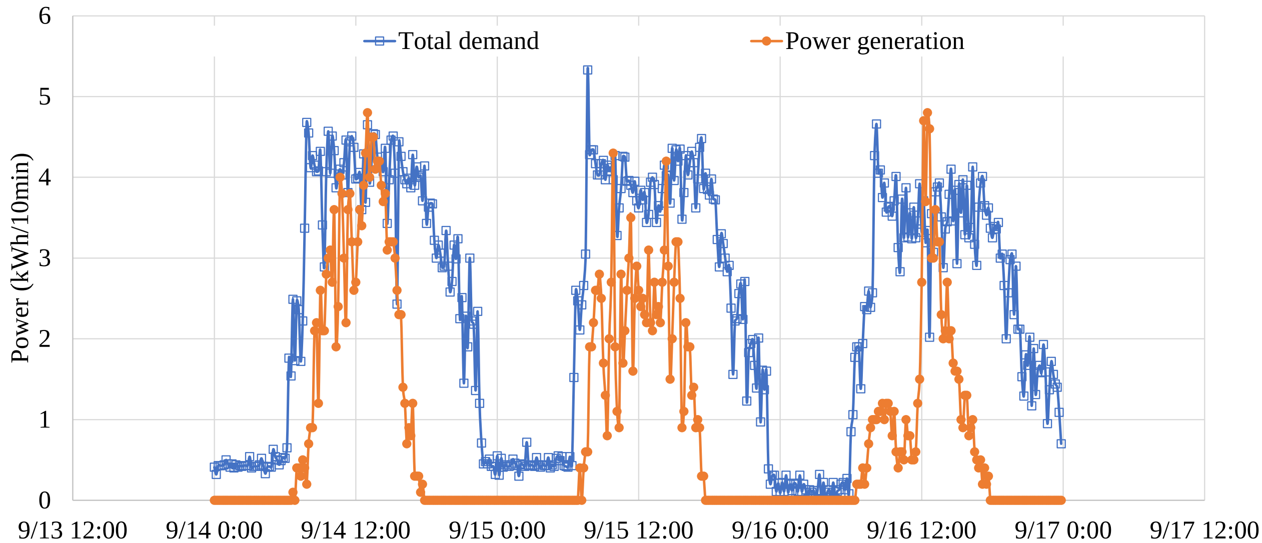

Fig. 2. Power data at the subject facility (9/14-9/16)

time was set at 1:00 a.m. on September 14th. Before the supply interruption time, Total demand and Power from grid has decided based on the projected data by the case study facility. After the supply interruption time, demand changes to the emergency pattern, and Power from grid becomes 0. Battery discharge in the system exceeds the SOC only at the time of emergency.

4. RESULTS AND DISCUSSION

4.1 Simulation of three-day evaluation (September 14th - September 16th)

This study conducted three-day evaluation from September 14th to 16th. Interruption time is 1:00 a.m. on September 14th. Power generation, power from grid and total demand shows in Figure 3. From Figure 3, battery remaining capacity is quite small at second and third day resulted in less than 20 percent. In this situation, because there are not enough power during the simulation, Number of power outages $R_{1\mathrm{N}}$ resulted in 8. Redundancy R_3 was 1690 minutes, Surplus power R_4 was 0, and Insufficient supply R_5 was 332.01 kWh/10min. Because we conducted three days evaluation, we could clarify the battery remaining capacity more after than a first day of the interruption time. Furthermore, Figure 4 shows the insufficient amount of electricity with each time. Insufficient amount of electricity becomes bigger and the time that cannot satisfy the demand is 1150 minutes in third day. On that day, only 290 minutes can be satisfied with electricity.

4.2 Comparison of all resilience indicators

When conduct simulation with three days, each of the one-day simulation, we set supply interruption time at 1:00 a.m. From Table 2, total sum of interruption time is 10 among all one-day simulation. However, number of power outage time of three-day simulation was 8. The sum of interruption times was not same to the simple calculation. The reason is because of the remaining battery capacity and supply interruption time. When simulating one day, the interruption time was set at 1:00 a.m. of each day. On the other hand, when simulating three-day, supply interruption time was set in the first day of 1:00 a.m. and the battery remaining capacity continues to the next day of initial remaining capacity. Therefore, when battery remaining capacity insufficient in first day, that states would affect second and third day. Actually, this study also affected that battery remaining capacity was already 0 at 12:00 a.m. of 16th.

Simulation of 16th in Table2 shows the necessity of the resilience indicator, Number of power outages $R_{1\mathrm{N}}$ and Insufficient supply R_5. Normally, the Number of power outages $R_{1\mathrm{N}}$ become large when the Insufficient supply R_5 also large. However, when simulated only in 16th, although the Insufficient supply R_5 was the largest among all of one-day simulations, Number of power outages $R_{1\mathrm{N}}$ was the smallest of all. The reason is the time cannot satisfy with demand was very long and almost beyond most of the day. It also can be seen as Redundancy R_3 was only 520 minutes. This situation can be explained that only short sunny hour satisfied demand and otherwise the state was out of power resulted in the minimum power outage times.

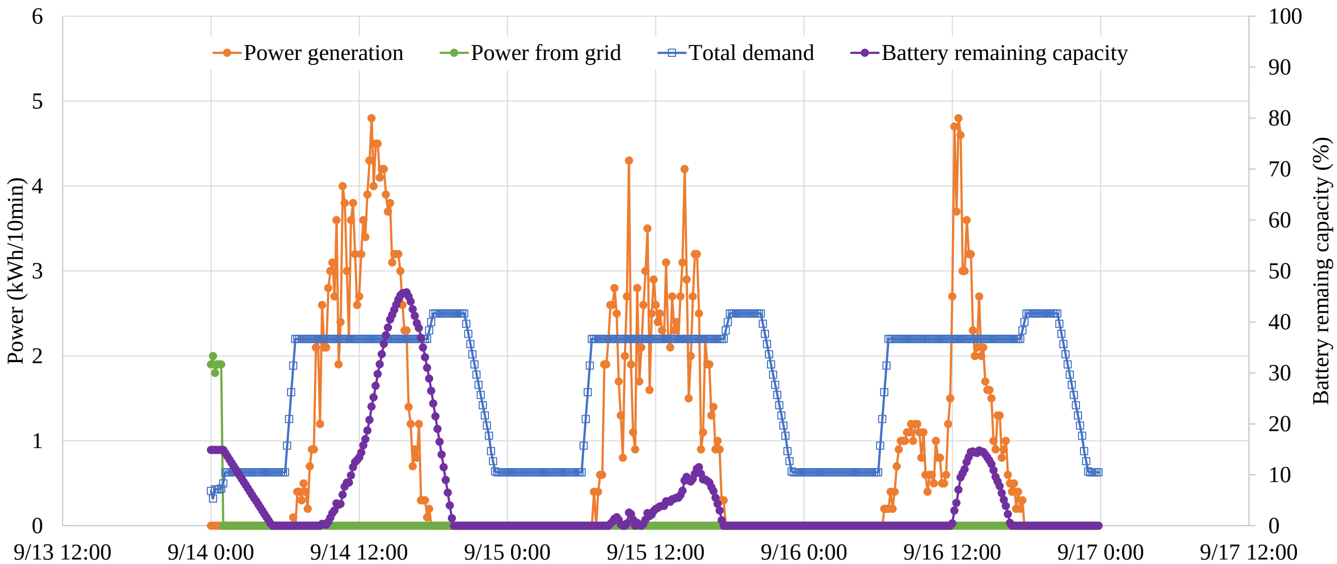

Fig. 3. Result of supply-demand relationship

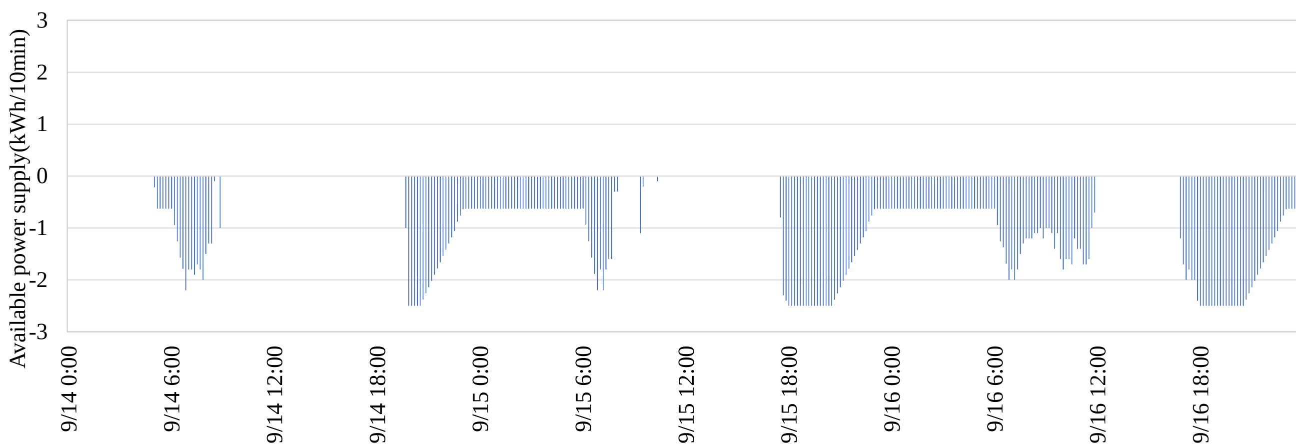

Fig. 4. Available power supply

5. CONCLUSIONS

In this study, we conducted three-day of quantitative resilience evaluation. From this simulation, three-day evaluation is effective because when supply interruption occurs at first day of 1:00 a.m., it became clear that power outage frequently occurs on third day. Furthermore, by using battery remaining capacity continues to the next day of initial capacity, this study able to simulate close to the actual situation.

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