Regular Paper

An Evaluation on a Power Interchange Method for Realizing Net-Zero Energy House for Multiple Small Communities

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Abstract - We have developed a simulator to achieve net-zero energy through power sharing among multiple households and communities. In multi-household transactions, when the capacity of one household's electricity storage system is depleted and power supply becomes necessary, power can be purchased from other households to meet demand without having to purchase power from the grid, thus enabling power operations that do not rely on grid power. In transactions in which the scale of transactions was extended to multiple communities, a certain increase in the renewable energy consumption rate was confirmed even in communities with low storage battery capacity and photovoltaic power generation capacity through the inter-community exchange of electricity by scattering large-scale facility households with different electricity consumption styles. The seasonal changes in the self-consumption rate showed that securing electricity in the fall and winter is necessary to maintain a high self-consumption rate and renewable energy consumption rate. In the Hokuriku region, where consumption increases in winter, it is considered necessary to introduce new renewable energy generation facilities in addition to photovoltaic power generation to achieve net-zero power consumption per community. In this simulation, only data from the Hokuriku region was used for electricity consumption and solar power generation. By replacing these data, the feasibility of net-zero energy can be verified for all regions, showing that a wide variety of simulations in social systems is possible.

Keywords: Smart Community, Electric Power Management, Net Zero Energy House, Renewable Energy, Simulation

1 INTRODUCTION

The introduction of renewable energies in Japan has rapidly increased with the introduction of the feed-in tariff (FIT) program, which began in November 2009, requiring electric power companies to purchase electricity generated from renewable energies (solar, wind, hydro, geothermal, and biomass) for a certain period at a price set by the government. For residential PV (residential photovoltaic power generation) of less than 10 kW, surplus power after self-consumption is eligible for purchase for 10 years. The system will gradually expire from November 2019. According to the Agency for Natural Resources and Energy, the total number of residential PV systems that will expire under the FIT will be 730,000 (2.82 million kW) in 2020 and 1.65 million (6.7 million kW) in 2023 [1].

The price of electricity sold during the FIT period was 48 yen/kWh in FY 2009. After the end of the FIT, the price will be about 8 yen/kWh, and compared to the purchase price of about 20 yen/kWh, it is considered more economical to consume the electricity generated on site. For this reason, attention is focused on self-consumption houses that generate electricity during the daytime when the sun is rising, store the surplus in storage batteries without selling it to the grid, and discharge the stored electricity at night.

A house that focuses on self-consumption is similar to a net zero energy house (henceforth ZEH). ZEH is a house that aims for zero primary energy consumption with the three characteristics of self-consumption, thermal insulation, and energy saving [2]. The use of air conditioners is reduced by improving the insulation performance of the house, and the entire house is made energy efficient by high-efficiency equipment and HEMS (Home Energy Management System). Since the electricity consumption is low, a combination of PV power generation and storage batteries is expected to be effective.

Storage batteries play an important role in realizing ZEH. The price of storage batteries is on a downward trend, but the price decline will slow down when the cost of raw materials for lithium-ion batteries is taken into account. Instead of installing storage batteries for home use, storage batteries installed in EVs could be used as storage batteries for home use. If EVs are the vehicles used on a daily basis, this is V2H (Vehicle to Home) which links EVs and homes [3]. The storage batteries of EVs that have reached the end of their service life could be used as a substitute for household storage batteries. In terms of used EVs, EVs that went on sale around 2010 have reached the end of their service life and are beginning to appear on the market.

Furthermore, the unstable global situation is causing electricity prices to skyrocket. According to the Agency for Natural Resources and Energy, the Japanese electricity market, which was at about 8 yen/kWh until September 2021, recorded about 26.2 yen/kWh in March 2022 [4]. Against this background, a shift to distributed energy systems using renewable energy sources that do not depend on existing centralized energy systems is being promoted [5]. The operation of distributed energy systems is expected to realize "net zero energy," i.e., zero primary energy consumption.

Smart grids and microgrids are effective power transmission systems for building distributed energy systems. A smart grid is a power transmission system that enables control of the electricity flow not only on the supply side but also on the demand side, and this system makes it possible for consumers to buy and sell electricity from the supply side or between consumers. A microgrid is an electric power network in which a smart grid is deployed within a certain region and energy is produced and consumed locally within the community without relying on external supplies. Microgrid operations that do not rely on electricity sales from suppliers can be expected to secure electricity and heat in the event of a disaster and to reduce electricity costs.

In addition, the need to transmit electricity over long distances in rural areas, including mountainous regions of Japan, has raised concerns about the rising cost of infrastructure maintenance. By operating a microgrid and building an independent power infrastructure zone using renewable energy generation within the surrounding area, it is possible to operate power without relying on an external power supply even when the area is remote from urban areas, eliminating the need to manage the infrastructure of a centralized energy system. As a result, infrastructure maintenance costs can be significantly reduced [6].

In this study, we have first developed a simulator that assumes the installation of a PV power generation and storage system in a house for the realization of ZEH and evaluate the economic feasibility by changes in the amount and cost of the system installation. Next, assuming a small-scale community in a mountainous area, we demonstrate the feasibility of independent power operation and economical power management only in the community and its surrounding area when a microgrid is actually constructed, and discuss the evaluation results using the simulator.

2 RELATED WORK

Ishikawa and Matsuo [7] conducted a simulation using storage battery capacity, connection and charge/discharge control methods, and water heater boil-up time as parameters to evaluate the primary energy savings and economic efficiency of installing storage batteries in PV equipment in post-FIT homes. The best results were obtained by shifting the boiling time of the heat-pump water heater without installing the storage battery system, which resulted in an annual profit of 0.37 million yen and a reduction in primary energy consumption of 14 MJ (3.9 kWh). The paper also argues that if 3 kWh of storage batteries are installed at a unit price of 8 yen/kWh, one of the following conditions must be met: the storage battery installation cost must be less than 150,000 yen, the durability period must be extended to 28 years, or the electricity price must rise to 186% of the current price.

Yabe et al. [8] evaluated the economic efficiency of storage batteries by determining the changes in the self-consumption rate and the annual cost before and after the introduction of storage batteries for each consumer based on electricity demand data and actual solar power generation data for residences and businesses with solar power generation throughout Japan. The study concluded that a 5kWh storage battery at 60,000 yen/kWh can be installed in a house, and that the investment can be recovered in about 15 years. The payback period is about 11 years when electricity rates with late-night starting times are selected and varies depending on the demand characteristics and other factors. For commercial customers, the payback period is about 8 years when a 60,000 yen/kWh storage battery with the PV power generation output for 30 minutes is installed.

Goto et al. [9] proposed a framework and a solution method for the problem of determining the supply-demand operation plan of a microgrid by calculating the operating reserve based on the forecast error trends of power demand and PV power output. The validity of the proposed framework is verified through numerical simulations. The demand-supply operation planning problem is formulated as a demand-supply operation planning problem for a general microgrid. In addition, they defined a demand-supply operation planning problem that considers uncertainty by using the probability distribution of the net demand forecast. In the simulation, the operational cost for the forecasted value of net demand resulted in worse solution results compared to the conventional method. On the other hand, the solution succeeded in reducing the expected value of operational cost by approximately 20% compared to the conventional method.

Komiyama et al. [10] evaluated the optimal combination of power generation facilities, considering the introduction of renewable energy and inter-regional power transmission. Wind power generation facilities in Japan are concentrated in regions such as Hokkaido and Tohoku, and there is a need to develop inter-regional power transmission lines. Therefore, an optimal power generation model was developed as a linear programming model that considers the transmission of power using inter-regional transmission lines. As a result, it was shown that wind power can be supplied to the Tokyo metropolitan area, where solar power is the main source of renewable energy supply, by expanding the regional power grid. It was also shown that the introduction of more PV power generation facilities in the Kyushu and Shikoku regions, which have long hours of sunlight, should be promoted.

3 DEVELOPMENT OF ZEH ECONOMIC EVALUATION SIMULATOR

3.1 ZEH Model

This section discusses a house in which a PV power generation system and an energy storage system are installed. Electricity is supplied to the house from the amount of electricity generated by the PV power generation system. If consumption exceeds the amount of electricity generated, the storage batteries are discharged to make up for the power shortfall. If the amount of electricity generated and discharged from the storage batteries is still insufficient, the remaining shortage is met by purchasing electricity from the grid. Surplus power from solar power generation is charged into storage batteries, and surplus power that cannot be charged due to full battery is sold to the grid. These power transfers are controlled through HEMS.

We will also consider the use of electricity consumption forecasting and PV power generation forecasting. Smart meters measure residential electricity consumption, and PV equipment sensors measure power generation and solar radiation. The power consumption forecast, PV power generation forecast, and remaining storage battery capacity can be used to predict future excesses and deficiencies in power, enabling power control to minimize power costs.

The assumed ZEH is shown in Fig. 1. In this study, the power transfer in Fig. 1 is first simulated.

3.2 Overview of ZEH Economic Evaluation Simulator

The data used in the simulation, such as the amount of electricity consumption and solar power generation, are recorded in CSV and DB formats. When parameters such as the amount of installed PV and energy storage systems and installation costs are entered into the simulator and executed, the data is read and the power transfer simulation is started.

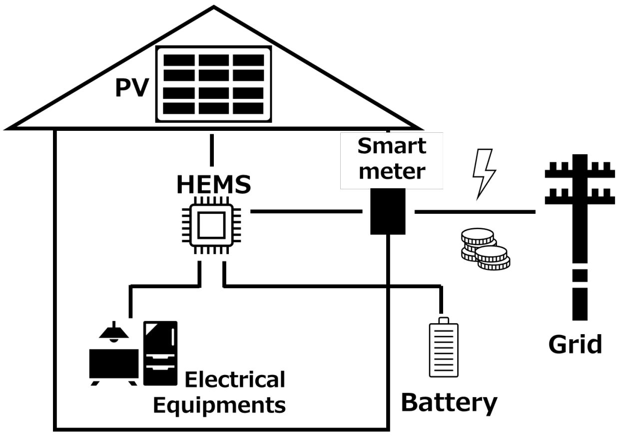

Figure 1: ZEH Model

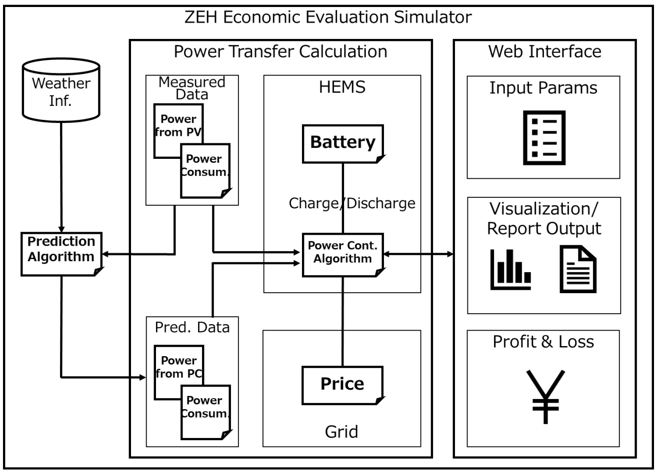

Figure 2: ZEH Economic Evaluation Simulator System Structure

Power transfer calculations are performed in every 30-minute period over a year. After the simulation is complete, a graph is plotted showing the power transfer and profit/loss. The resulting data can be downloaded in CSV format.

The function and configuration of the simulator developed in this study are shown in Fig. 2.

3.3 Solar Power Generation Data

An energy management experiment system for distributed energy is being conducted at the Hakusanroku Campus of the Kanazawa Institute of Technology, and energy-related data is being collected as part of the experiment [11]. Measured solar-generated electricity in 2020 is used for the power transfer simulation. Since the data is measured at 2-second intervals, we calculated the amount of electricity by using the average value of electricity generated every 30 minutes.

3.4 Electricity Consumption Data

The electricity consumption of eight detached houses in the Hokuriku region (Niigata Prefecture) is used to create electricity consumption data from the energy consumption data published by the Architectural Institute of Japan [12]. The electricity consumption of the eight houses was averaged and aggregated by time and classified into three categories. Using the consumption of eight houses as the basic data used in the simulation may lead to a deterioration in accuracy. In the future, if it becomes possible to obtain or measure more data, the accuracy of the simulation can be expected.

Electricity consumption and housing assignments are shown in Table 1.

The classified data are averaged and aggregated by week, day of the week, and time, and scaled with the maximum value set to 1, and used in the simulation. The simulation reproduces electricity consumption according to households by adjusting the size according to a parameter called the average monthly electricity consumption rate. The electricity charges follow the metered B electricity rates of Hokuriku Electric Power Company.

3.5 Power Transfer Simulation

Figure 3 shows an overview of the simulation algorithm. First, a simulator using real data is developed, and later a simulation that takes the electricity supply-demand forecast into account and a simulation in which storage batteries are replaced by EVs are implemented.

Table 1: Three distinguished power consumption models

Model	House ID
Night/Midnight: Concentrated use at night or late at night when the user is away during the day, late-night hot water supply	1,2,6
Evening: Always at home and often used in the evening	4,5
Morning/Evening: Always at home and often used in the morning and evening	3,7,8

4 SETTING UP A ZEH SIMULATION

4.1 Electricity Consumption

Each power consumption model is used in the simulation with the power consumption sized as an average monthly power consumption charge of 10,000 yen. For the adjusted power consumption, Fig. 4 shows the monthly power consumption and Fig. 5 shows the average daily power consumption.

Annual electricity consumption was 5621 kWh. The annual electricity consumption per household in Hokuriku is 6333 kWh, which is about 11% lower than the annual consumption per household in the same area. In all cases, electricity consumption is high in winter and low in spring and fall.

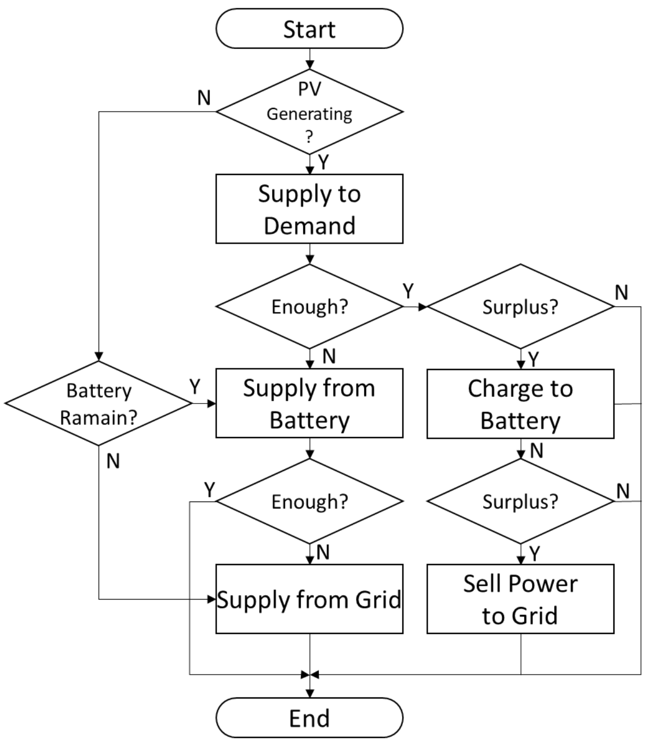

Figure 3: ZEH Economic Evaluation Simulator Algorithm Outline

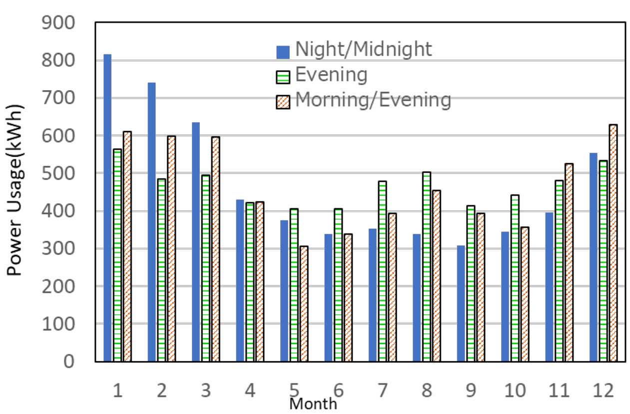

Figure 4: Monthly total power consumption amount

4.2 Setting up PV Power Generation and Energy Storage Systems

We simulate combinations of PV outputs of 5, 10, 15, and 20 kW and storage capacities of 0, 5, 10, and 40 kWh, respectively. The storage capacity of 40 kWh is based on the case where an EV is used as a storage battery. Degradation of the power generation and storage system is not considered in this paper. Table 2 shows the settings of the installed system.

4.3 System Pricing Assumptions

The installation cost of the PV system is assumed to be 336,000 yen/kW, the main unit cost of the stationary storage battery 140,000 yen/kWh, and the main unit cost of the V2H system 493,000 yen [13]. The cost of the EV itself is not included. The construction cost of the energy storage system is assumed to be 336,000 yen per installation. Table 3 shows the unit installation costs of stationary storage batteries, PV power generation, and energy storage systems, and Table 4

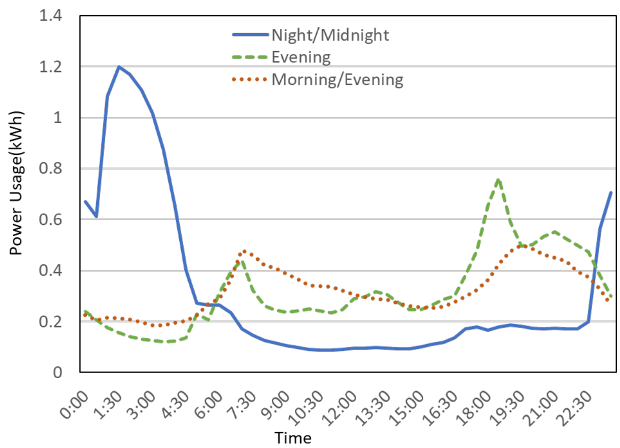

Figure 5: Average daily power consumption

Table 2: System parameters

Parameter	Value
Power conversion efficiency	95%
Maximum charge/discharge efficiency	95%
Maximum charge and discharge power	3kW

Table 3: System costs per unit

System	Cost
solar power (generation)	336,000 yen/kW
Stationary storage battery	140,000 yen/kWh
V2H(EV)	493,000 yen/unit
Energy storage system installation cost	336,000 yen per case

Table 4: System installed costs in this paper

PV (generation)		Battery system	
Spec.	Price(M Yen)	Spec.	Price(M Yen)
5kW	1. 68	0 kWh	0
10kW	3.36	5 kWh	1.036
15 kW	5.04	10kWh	1.736
20kW	6.72	40kWh (EV)	0.829

shows the system installation costs in this paper.

The cost of using an EV for the energy storage system is 493,000 yen for V2H plus 336,000 yen for construction, regardless of the capacity.

Since electricity consumption tends to be low during the day and increases from evening to night, we adapted Hokuriku Electric Power Company's Kutsurogi-night 12 [14] as the electricity rate plan for our simulation. Kutsurogi Night 12 is a rate plan with low electricity prices during the nighttime (20:00~8:00). This report considers only the basic charge (1,650 yen/month) and the electricity volume charge, and does not include the renewable energy surcharge and the unit price of fuel adjustment. The unit price of electricity sold is assumed to be 8 yen.

5 ZEH ECONOMIC EVALUATION SIMULATION RESULTS

5.1 Profits and Losses on Electricity Sales for the Year

The difference between the simulated profit/loss on electricity sales and the conventional electricity rate (120,000 yen) was calculated and used as the profit/loss for one year. Basic charges and system installation costs are not included.

Figure 6 shows the one-year power trading profits and losses for the evening model.

The maximum profit was 178,000 yen in the model with 20 kW of PV power generation, 10 kWh of storage capacity, and consumption in the evening. Although profit increases with increasing PV output, it cannot be said that profit increases with increasing storage capacity.

5.2 15-Year Profit/Loss Including Initial Cost

A minimum loss of 26,000 yen was recorded for the concentrated nighttime model with only 5 kW of PV power generation, and a maximum loss of 6,365,000 yen was recorded for the concentrated morning and evening model with 20 kW of PV power generation and 10 kWh of storage batteries. No profit was obtained, including the initial cost.

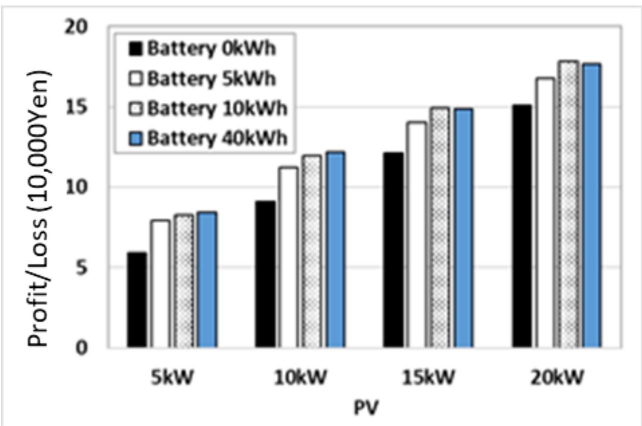

Figure 6: Profits and losses from electric power trading (Evening model)

The 15-year gains and losses for the nighttime concentration model are shown in Fig. 7.

Under the conditions of this paper, it would be more economical not to install the system. If the unit cost of installing a PV power generation system is 330,000 yen, the Night/Midnight model with 5 kW of PV power generation can reduce electricity rates by 0.4 million yen from the conventional electricity rate plus the basic rate.

5.3 Profit/Loss at the Time of Electricity Price Hikes

In the future, the unit price of electricity is expected to increase due to the rising price of fossil fuels.

In this section, we present simulation results assuming electricity unit prices soar up to 10, 30, 50, and 100%. Below are the combinations of systems that resulted in profits when losses were less than without the systems installed.

A 10% spike in the price of electricity would be profitable when only 5 kW of PV power is installed, a 30% spike would be profitable when 5 kW of PV power and an EV is substituted as a storage battery, a 50% spike would be profitable when 5 kW of PV power and 5 kWh of storage batteries are combined, a 100% spike would be profitable when only 10 kW of PV power is installed, and a 100% spike would be profitable when 5 kW of PV power and 10 kWh of storage batteries are combined. Table 5 shows the system combinations that are profitable in the Night/Midnight model due to the increase in the unit price of electricity.

Assuming that the price per unit of electricity spiked to 100%, installing only 5kW of PV power generation would be the most effective.

When we compare PV 5kW + storage battery 5kWh and PV 5kW + EV 40kWh at the price rises to 50%, the latter is 207,000 yen cheaper to install, but even after subtracting 207,000 yen from the latter's profit, the latter's profit is still 18,000 yen higher. This confirms the effectiveness of the introduction of a large-capacity energy storage system or EV.

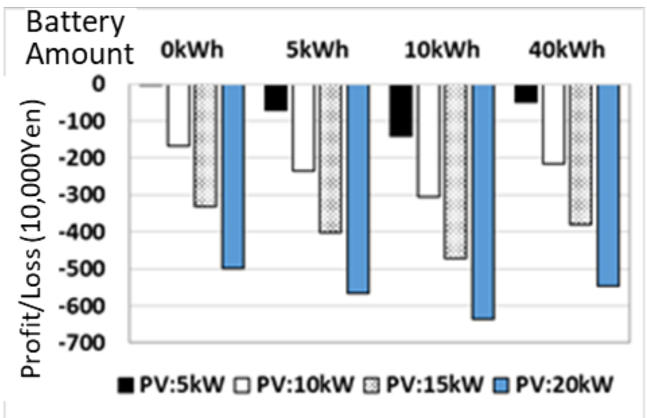

Figure 7: 15-year profits and losses (Night/Midnight model)

6 ELECTRICITY DISTRIBUTION TO MULTIPLE HOUSEHOLDS

6.1 Multi-Households Model

In this chapter, we assume a situation such as a community with several households equipped with PV power generation equipment and energy storage systems in the neighborhood by using electricity exchange among them to identify how electricity sharing resolve the electricity shortage. The multi-households model can also be used to simulate diverse and realistic electricity transactions by changing the electricity consumption patterns and the scale of the PV power generation and storage systems for each household. Figure 8 shows the electricity exchange model for multi-households' electricity exchange transactions.

6.2 Overview of Multi-Households Electricity Sharing Simulator

We simulate the flexible distribution of electricity among multiple households by running multiple simulators simultaneously and having each household disclose its electricity status and trade electricity through communication. In addition, we consider the power sharing network among multiple households as a single community and evaluate large-scale power sharing among communities with different power consumption patterns and power generation patterns.

Table 5: Rate of increase in unit price of electricity and profitable system combination

Price increase rate	System Configuration	Installation Cost (million Yen)	Profit/Loss (Yen)
10%	PV5kW	0.168	147,000
30%	PV5kW	0.168	493,000
	PV5kW+BT40kWh (EV	2.509	31,000
50%	PV5kW	1.68	839,000
	PV5kW+BT40kWh (EV	2.509	384,000
	PV5kW+BT5kWh	2.716	164,000
100%.	PV5kW	1.680	1,703,000
	PV5kW+BT40kWh (EV	2.509	1,269,000
	PV5kW+BT5kWh	2.716	1,040,000
	PV5kW+BT10kWh	3.416	355,000
	PV10kW	3.360	54,000

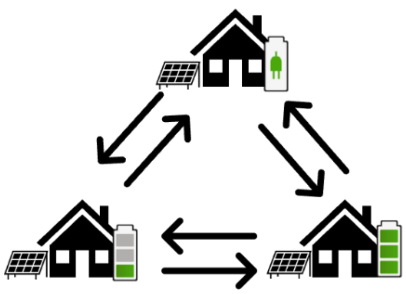

Figure 8: Multi-Households Electricity Sharing Model

In addition to the functions of the ZEH economic evaluation simulator, the following functions in Table 6 are implemented to simulate electricity sharing among multiple households.

Details are explained in Section 6.4.

6.3 Electricity Calculation Method for Electricity Sharing

When conducting electricity sharing among multiple households, the amount of electricity that each household wishes to trade is determined, and simulations are conducted in a form that more closely resembles realistic transactions. As we explain in Section 3.4, the energy consumption used in the simulation is classified into three patterns. These power patterns were mixed in the community, and the simulator is operated. In addition, a minimum power configuration that assumes facilities that do not consume power but only generate, store, and supply power is also included.

6.4 Multi-Households Electricity Sharing Algorithm

Figure 9 shows the algorithm outline of the multi-households' electricity sharing algorithm. The left process shows the requester and the right one is the responder.

Table 6: Additional Function

implementation function	
Household-to-household communication capability	Reproduction of power trading
Algorithm for determining the amount of electricity during power sharing	Process for determining content at the time of transaction

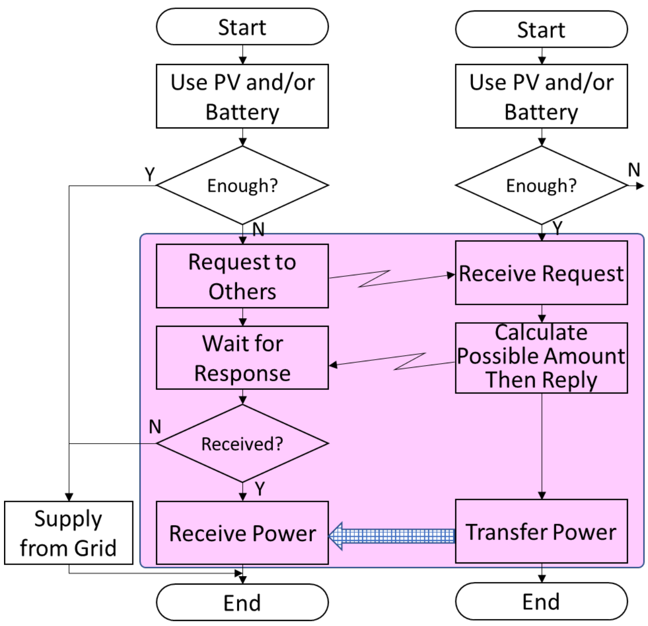

Figure 9: Multi-Households Power Sharing Simulator Algorithm Outline

Households whose remaining battery capacity has been reduced below a certain level due to electricity consumption are approached by other households to sell their electricity. The households with sufficient remaining battery capacity present their tradable electricity to the electricity-deficient households. Prospective buyers adopt the optimal power trading details based on the offers from the responding households and charge their batteries until a certain capacity is met or the trading partner ceases to exist. If the battery cannot be recharged, electricity is purchased from the power company to meet the remaining demand.

7 SIMULATION OF ELECTRICITY DISTRIBUTION AMONG MULTI-HOUSEHOLDS

7.1 Two Cases for Simulation

First, we set up a household model case for one-to-one electricity sharing among households in a community and conducted simulations according to this setting.

Table 7 shows the electricity consumption plans and household equipment configurations used in the simulations. The reason why we choose Morning/Evening and Night/Midnight households is that their average daily power consumption is complementary.

In the first case, we simulate the storage battery capacity and PV generation capacity settings that could realistically be installed by an average household at this moment.

In the second case, we assume a scenario in which the benefits of installing large-scale facilities increase due to the future low cost of energy storage and power generation equipment and soaring electricity prices and set the scale of facilities to be installed by Household-2 to a large scale.

7.2 Multi-households' Simulation Results and Evaluation

First, simulations are conducted for the first facility case. The simulator is operated from July 6 to July 13, when the supply to other households by PV power generation could be verified, to confirm that sharing is achieved. Figure 10 shows the electricity demand-supply ratio for Household-1.

On days when PV power generation is high during the day, electricity is supplied from the storage battery in Household 2, indicating that peak-time electricity demand could be met through sharing. However, on many days, the grid power supply is still relied on.

Table 8 shows the amount of electricity purchased and the consumption rate of PV power generation compared to the case without electricity sharing.

The results show that the consumption rate of PV power consumption decrease, and the amount of electricity purchased from the grid increases because of the electricity sharing. These results indicate that even small-scale facilities can consume a portion of the demand through electricity sharing during the season when PV power generation can be expected.

The simulation is then performed in the Case 2 setup, with the following electricity demand-supply ratios for Household 1 for July 6~July 13 as shown in Fig. 11.

Table 7: Case1 Parameters

Case 1	Household-1	Household-2
Electricity Consumption Plan	Morning/Evening	Night/Midnight
Storage battery capacity (kWh)	5	5
PV power generation equipment (kW)	5	5
Case 2	Household-1	Household-2
Electricity Consumption Plan	Night/Midnight	Morning/Evening
Storage battery capacity (kWh)	5	15
PV power generation equipment (kW)	5	15

Table 8: Case 1, Electricity Purchased and PV power Consumption Rate for Household 1

	One household	Two households Sharing
PV power consumption rate (%)	54.8	52.0
purchased from the grid amount (kWh)	46.3	50.0

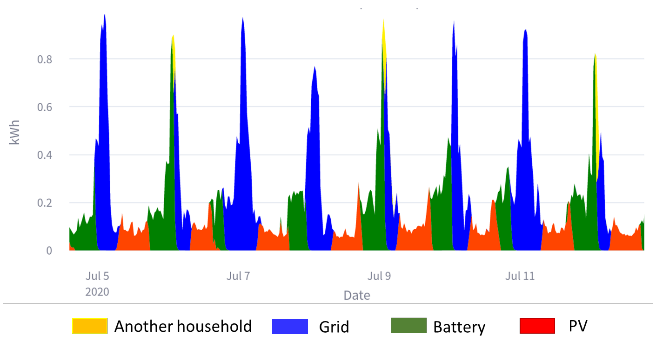

Figure 10: Case1: Household-1 Summer Electricity Supply Ratio

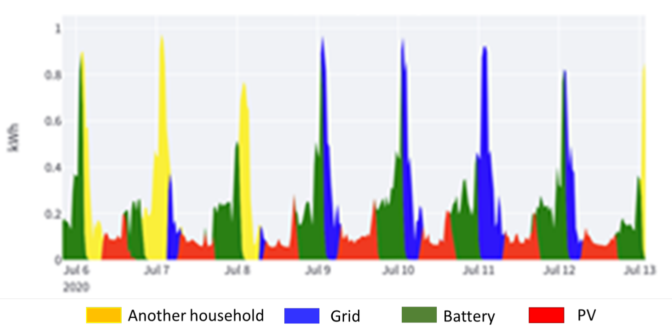

Figure11: Case2, Household1 summer electricity supply ratio

Compared to Fig. 10, the period during which the nighttime peak demand can be met only by storage battery discharge and discharge from household-2 is longer. By differentiating the amount of system installation among households, the sharing amount of electricity supply by households that could afford it increased, resulting in a change in the electricity supply ratio. Table 9 shows the changes in the amount of electricity purchased and the PV power consumption rate compared to the case without electricity sharing.

The PV power consumption rate increase by about 20% compared to when only one household is operating. The amount of electricity purchased from the grid also decrease. It was found that increasing the scale of the installed system in some households have a significant impact on the PV power consumption rate in other households.

8 SIMULATION OF MULTI-COMMUNITY ELECTRIC POWER SHARING

8.1 Overview of Electricity Transactions between Communities

We assume that there are communities with multiple households in the vicinity to trade electricity. Since the electricity storage pattern by PV power generation differs from community to community (Fig. 12), a stable electricity supply in winter, which is difficult to achieve in a simulation of only one community, can be expected.

8.2 Smart Marginalized Communities

In this study, we define "Smart Marginalized Community" as a community in a smart grid system that achieves net-zero energy in mountainous areas and does not rely on external power supply.

In this simulation, we are working to achieve a form of energy self-sufficiency by producing electricity and heat for their own consumption, called net-zero energy. This study aims to "achieve complete net-zero energy by means of renewable energy (mostly PV energy) and energy storage systems that do not rely on external power," and hypothesizes that it is possible to achieve these goals and realize smart marginal community. We then verify the configuration of the smallest marginal community that can satisfy the conditions and the combination of power generation and storage systems.

The optimal configuration and changes in the degree of net-zero energy realization is also examined when considering the realization of net-zero energy in regions with different demand and generation conditions.

Table 9: Case 2: Electricity Purchased and PV Power Consumption Rate for Household-1

	One household	Two households Sharing
PV power consumption rate (%)	54.8	73.0
purchased from the grid amount (kWh)	46.3	27.6

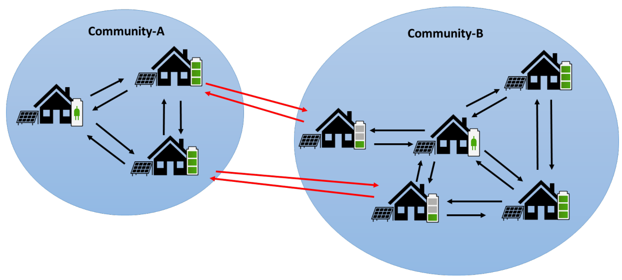

Figure 12: Model of inter-community electricity sharing

8.3 Model Case in Two Communities

A model case is then set up for two neighboring communities to share electricity with each other, and simulations are conducted according to this set-up. Table 10 and 11 show the electricity consumption plans and household facility configurations used in the simulations.

8.4 Multi-Community Simulation Results and Evaluation

The simulator is operated for one year. Figure 13 and Fig. 14 show the percentage of electricity demand supplied by Household-1 and the amount of electricity supplied by Facility 1 during the period from July 1 to July 31.

The results in Fig. 13 show that household 1 receives a large amount of electricity from Facility 1 and also receives electricity from Facility 2. Table 12 shows the amount of electricity purchased and the consumption rate of renewable

Table 10: Case 3: Community-1 Parameters

Community-1			
Case 3	Household-1	Household-2	Equipment-1
Electricity Consumption Plan	Night/Midnight	Morning / Evening	a little
Battery capacity (kWh)	5	5	15
Solar power generation (kW)	5	5	15

Table 11: Case 3: Community-2 Parameters

Community-2			
Case 3	Household-3	Household-4	Equipment-2
Electricity Consumption Plan	Night/Midnight	Morning / Evening	a little
Battery capacity (kWh)	5	5	15
PV generation (kW)	5	5	15

energy by Household 1 compared to the case without electricity supply.

The consumption rate of renewable energy is significantly increased, and the amount of electricity purchased from the grid is also reduced through the sharing power supply system. In addition to the intra-community transactions, the power acquired through transactions with power generation facilities in other communities is considered to have enabled more stable operation that is not dependent on grid power.

Figure 15 shows the relation between the amount of equipment and the amount of electricity transactions. From Fig. 15, we can recognize that increase in battery capacity can reduce both the amount of electricity discarded and the amount of electricity purchased from the grid.

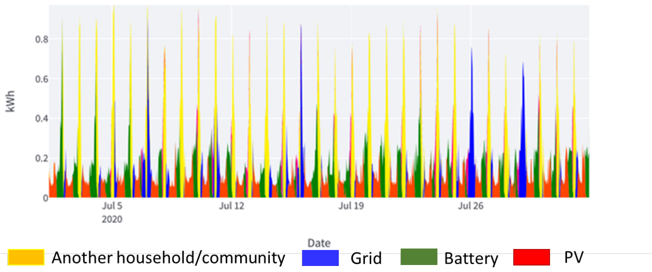

Figure 13: Household1 Summer Electricity Supply Ratio

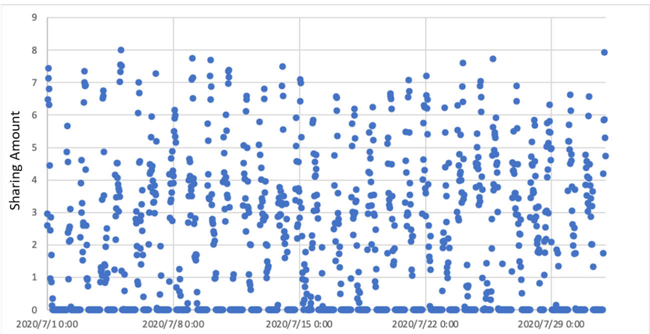

Figure 14: Amount of Electricity Sharing for Equipment-1

Table 12: Case 1, Electricity Purchased and Renewable Energy Consumption Rate for Household 1

	One household	Inter-community Sharing
PV power consumption rate (%)	37.3	54.0
purchased from the grid amount (kWh)	3523	2484

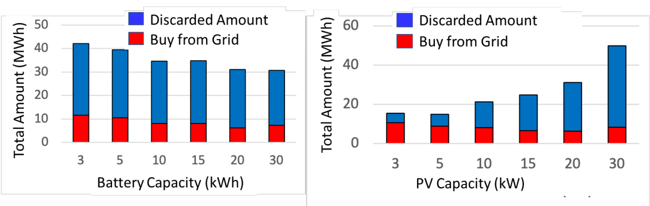

Figure15: Amount of Capacity and Grid Power Transactions

However, the effect gradually decreases when the capacity is increased beyond 20 kWh, and little change in the total amount of electricity was observed between 20 kWh and 30 kWh.

In the verification by changing the PV power generation facilities, the amount of electricity discarded tended to increase as the power generation facilities become larger, resulting in a large increase in the total amount of electricity consumed. However, the amount of electricity purchased from the grid decrease in a negative correlation with the size of the facility, resulting in an electricity consumption of 5 kWh less than the total electricity consumption for a facility with a capacity of 3 kWh. This result suggests that a smart marginal community that does not rely on buying and selling power from the grid can be realized by reducing the size of PV power generation facilities to a size appropriate for the scale of the community and increasing the size of storage batteries.

8.5 Seasonal Changes in PV Power Consumption Rates

In order to investigate the factors that reduce the PV power consumption rate, the PV power consumption rate is calculated for each of the following seasons: winter (January to March), spring (April to June), summer (July to September), and fall (October to December).

We set up three households each at two communities and all households equip 5kW PVs and 20kWh storage batteries. Table 13 shows each household consumption model.

Table 14 shows the seasonal PV power consumption rates.

Table 14 shows that the PV power consumption rate is close to 100% in spring and summer, and that electricity consumption can be achieved without power supply from the grid. However, in the fall season, the consumption rate is in the 70% range, and in the winter season, the consumption rate drops to the 50-60% range. This is due to the decay of PV power generation and the increase in electricity consumption.

The amount of solar power generation decreases during the winter season. In winter, weather conditions tend to

Table 13: Consumption model for seasonal evaluation

Community-1	
Household-1	Night/Midnight
Household-2	Evening
Household-3	Morning/Evening
Community-2	
Household-4	Daytime (every time same)
Household-5	Evening
Household-6	Morning/Evening

Table 14: Seasonal PV power consumption rates

	H-1	H-2	H- 3	H- 4	H- 5	H-6
winter	53.6	63.8	62.5	68.8	62.8	62.8
spring	100.0	100.0	100.0	100.0	100.0	100.0
summer	100.0	100.0	100.0	100.0	99.8	99.8
fall	71.4	77.7	73.8	72.2	77.7	73.8

worsen, and when the PV panels are covered with snow, power cannot be generated. If the inability to generate electricity persists for several days, the grid power supply will have to be relied on if PV power generation and storage batteries are the only means of supplying electricity, resulting in a decrease in PV power consumption. Therefore, in order to further increase the average rate, it is necessary to solve the energy problem, especially heating, during the fall and winter seasons with renewable energy sources that do not rely on PV power.

9 CONCLUSION AND FUTURE WORKS

In this research, we have developed a simulator to evaluate the economic efficiency of ZEH. The simulator is useful for each household to consider the installation of equipment. The simulator can be operated through a web interface, so it can be operated by many people.

If economics is the only consideration when installing PV power generation and storage systems, it is best to refrain from installing PV power generation and storage systems. The introduction of these systems should be based on the assumption that losses will be accepted. However, we have shown that it is possible to profit from the introduction of PV and EVs when electricity prices soar.

In addition, a simulator was improved to investigate the feasibility of net-zero energy by integrating electricity among multiple households or communities.

In a one-on-one simulation assuming intra-community transactions, the amount of electricity purchased decrease, and the PV power rate increase when the storage batteries and capacity of one household are increased, while the demand during peak hours is only partially compensated by the sharing of the other household when the size of the storage batteries and PV generation facilities of both households are small.

In the case of transactions in which the scale of transactions is expanded to multi-communities, by scattering large facility households with different electricity consumption styles, the surplus electricity of large households was passed on to small facility households, and as a result, a high renewable energy rate is confirmed.

One of the challenges for the future is to change the electricity transaction price, which is fixed within and between communities, using an algorithm. In addition, because electricity consumption is high during the winter season, the smart marginal communities could not be realized, so it is necessary to derive constraints on environmental changes, such as improvements to power generation and storage facilities and price decreases.

ACKNOWLEDGEMENT

This work was partially supported by Grants-in-Aid for Scientific Research(C) numbered 21K11856.

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(Received: Novemver 19, 2023)
(Accepted: February 15, 2024)

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