Development of Optimum Operation Algorithm of Smart Energy House with Storage Battery Prediction Control Based on Load Leveling

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***Abstract*:** *In recently years, a development of smart house combine with renewable energy system was growing rapidly. At the same time, besides load level of smart house with storage battery only a few studies on the conversion, the operation method of battery as a backup power supply still unclear also. Furthermore, based the result of previous study on focusing to the economics efficiency, which investigated by the optimization operation method of storage battery for reducing the electricity charge per day, makes the aim of this study planned to operate the battery control system through the load leveling of detached house for a day. The system consists of a storage battery, bidirectional inverter, photovoltaic power generation, and electric demand load, which connected to the commercial power grid. In order to improve the equipment utilization rate, when the electric power load is unable to cover by the electric power from photovoltaic power generation, it will be automatically supply from the commercial power supply, while the surplus power generated by photovoltaic will be sold to the commercial power supply, which carried out by using Genetic Algorithm (GA) analysis method. Therefore, through the developing of optimization operation algorithm of storage battery by investigating day-to-day disparity of single-family house at Sapporo with electricity rates in January (winter), April (middle) and July (summer), the load levelling to minimize the day gaps as the proposed study can be achieved. In consequence comparing to the previous study, the day gaps of electric power that represent of January, April, and July was decreased around 68.2% (6.71 kWh), 79.9% (7.43 kWh), 75.1% (6.44 kWh) respectively. Whereas the electricity charges becoming increase as an expected for 32.2% (1.97 EUR), 32.7% (2.09 EUR), 50% (0.97 EUR) respectively. Therefore, from above results, the proposed system was expected to contribute to the load levelling of commercial power grid, which considered to lead the improvement of equipment utilization rate and to change the electricity price menu.*

Keywords: Renewable energy, Smart house system, Storage battery, Bidirectional inverter, Genetic algorithm

1. Introduction

Currently in Japan, the output rate of thermal power generation increases, there is concern that the increase in CO_2 emissions and the accompanying depletion of fossil fuels. In recent years, promoting the introduction of renewable energy and energy conservation technology that contribute to reducing environmental impact. Therefore, we focused on the smart house system. In this research, we aim at load leveling of the electric grid from the viewpoint of improving facility utilization rate. In the conventional research, the point of examination was focused on the optimization operation method of storage battery by reducing the electricity rate of the day, which considered to the smart-house economic efficiency. Refer to another researchers about smart house, the analysis result of (Kazushige Kazuichi, 2012) [1], concluded on the utilizing renewable energy of the smart house application, while (Masahide Nakamura, 2011) [2] has been reported of the smart house network system. Furthermore, the development of a photovoltaic power generation system with a small influence of weather conditions due to the introduction of a large-scale storage battery has been reported by (Noriaki Tokuda, Makoto Ryuji, Yoshiaki Kobashi, 2008) [3]. However, there are a few studies on smart house power load leveling with storage batteries, and how to operate the storage battery is still unclear. Therefore, the proposed study, plan to operate the storage battery control system based on the electric load levelling of the detached house for a day. This system consist of storage batteries, bidirectional inverters, photovoltaic power generation and electric power load connected to the commercial power grid. In the case, where the electric demand load is unable to cover by the electric power supply of photovoltaic power generation, it will automatically supply from the purchasing power of commercial power grid system, while the surplus electricity is getting from photovoltaic, it will also be sold to the commercial power grid. Besides a charge-discharge control system of the storage battery in order to reducing the day gap by using numeric analysis of genetic algorithm (GA) through levelling the electric demand load of smart house, the investigation of photovoltaic capacity will also clarify in this study.

2. System configuration

Fig. 1 described the energy in the system configuration of smart house. In the proposed system, electric demand load connected to the commercial power grid, storage battery, bidirectional inverter, and photovoltaic power generation. As shown in Fig. 1, a bidirectional inverter was used to control charge-discharge of the battery. By assumption of general household, the storage battery capacity was decided for 5[kWh] with 90% charge-discharge efficiency. Energy demand load is totally covered by output power of photovoltaic power and storage battery at noon, and purchase from commercial power grid when photovoltaic power unable to meet demand load. The generated surplus power by photovoltaic will also supply to the commercial power grid.

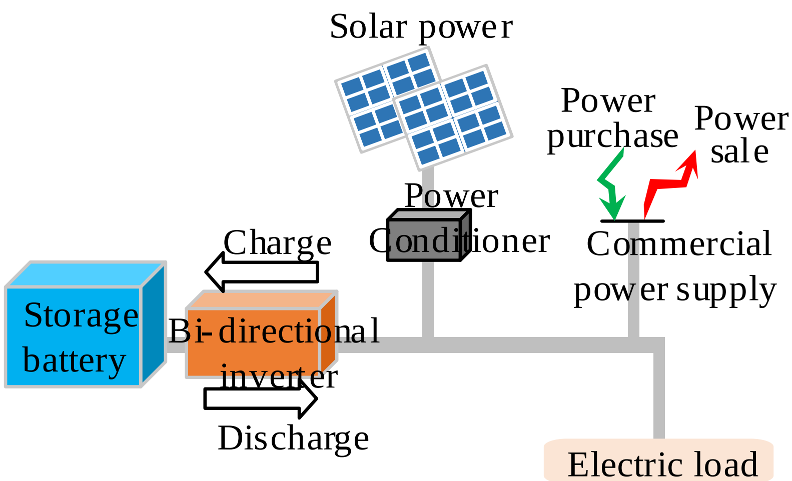

Fig. 1: Analysis system for smart energy house

3. Analysis contents

Load levelling can reduce cost of facility by improving the facility utilization rate through reducing the demand gap for each time zone or season. Therefore, the aim of this paper, besides levelling an electric demand load of smart house, the control system of charging and discharging of storage battery was also optimize through minimizing day gaps by using numerical analysis of genetic algorithm (GA). The investigation between day gap of smart house and the electricity rate of the day will compare with the result of previous research. The changing capacity of photovoltaic will also investigate in this study.

4. Analysis method

4.1. Power balance

Equation (1) shown the power balance equation of this system. The left sides of Eq. (1) means total output power by photovoltaic $P_{pv,t}$ [kW], the supply power $P_{cs,t}$[kW] from the grid, and battery output $P_{bt,dc,t}$ [kWh] The right side is the total electric power load P_{load} [kW] and the power consumption $P_{bt,ch,t}$[kWh] at the time of charging storage battery. The sampling time t was set for an hour.

$$P_{pv,t} + P_{cs,t} + P_{bt,dc,t} = P_{load} + P_{bt,ch,t} \tag{1}$$

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4.2. Objective function

Equation (2) is an expression representing the day gaps of smart houses. P_{cs_max} [kWh] represents the maximum amount of power purchased throughout the day, and P_{cs_min} [kWh] represents the minimum amount of power purchased. By minimizing P_{cs_gap} [kWh], the reducing day gaps and achieving power load level.

$$P_{cs\_gap} = P_{cs\_\max} - P_{cs\_\min} \tag{2}$$

4.3. Optimization by Genetic Algorithm(GA)

In this paper, a chromosome of the charging rate of the storage battery, the discharge rate of the storage battery, and the relative rate charging to the surplus power of the storage battery at each sampling time was generated and determined by using GA, in order to analyse the operation of storage battery through minimizing the day gaps.

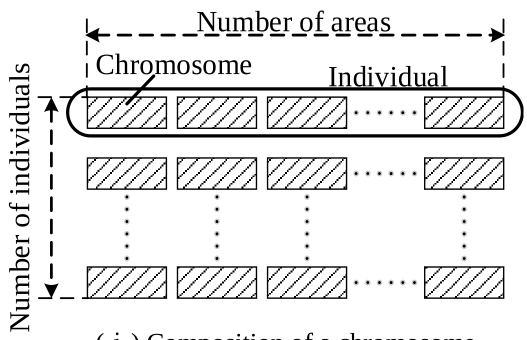
4.3.1 Chromosome Mdel

Figure (2) shows the chromosome model of GA that used to analyse in this study. While in Fig. 2(i) expressing the chromosomes of battery charging rate, discharging rate, and the charging rate which consider to the surplus power. In addition, the chromosome in Fig. 4(ii) composed of 2-bit genes of 0 and 1. Thus, the optimum solution of minimizing the objective function was obtained as follows Eq. (2).

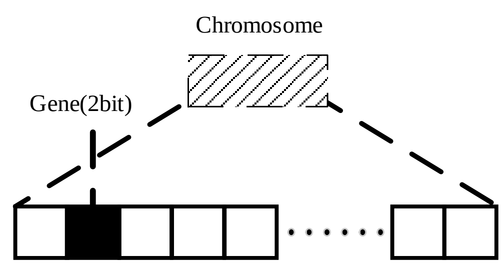
4.3.2 Analysis Flow

Figure 3 describes the analysis flow of this paper, and proceed following this procedure.

(a) Weather data of Sapporo city (solar radiation) [4], initial data of power demand as follows [5] and analysis conditions such as GA parameters as an input.
(b) Calculate an electric power which obtained by solar power generation from initial data.
(c) Randomly prepare the population of the initial generation by the number determined by the GA parameter.
(j) Calculate the power balance using Eq. (1).
(k) Calculate charge-discharge value of storage battery according to the chromosome data.
(n) Calculate the fitness of chromosome model by using the objective function, Eq. (3), and arrange them in order to increase the fitness of chromosome.
(o) Determine a chromosome model with high fitness, select and cull.
(p) Mutation and crossover probability given to the chromosome model based on the probability given in advance, and performed of genetic manipulation.
(r) Determine the highest ranked of chromosome model as the optimal solution.
(s) The operating method of storage battery of the day that minimizes the day gaps is decided.



(i) Composition of a chromosome



(ii) Composition of a gene

Fig. 2 Chromosome model

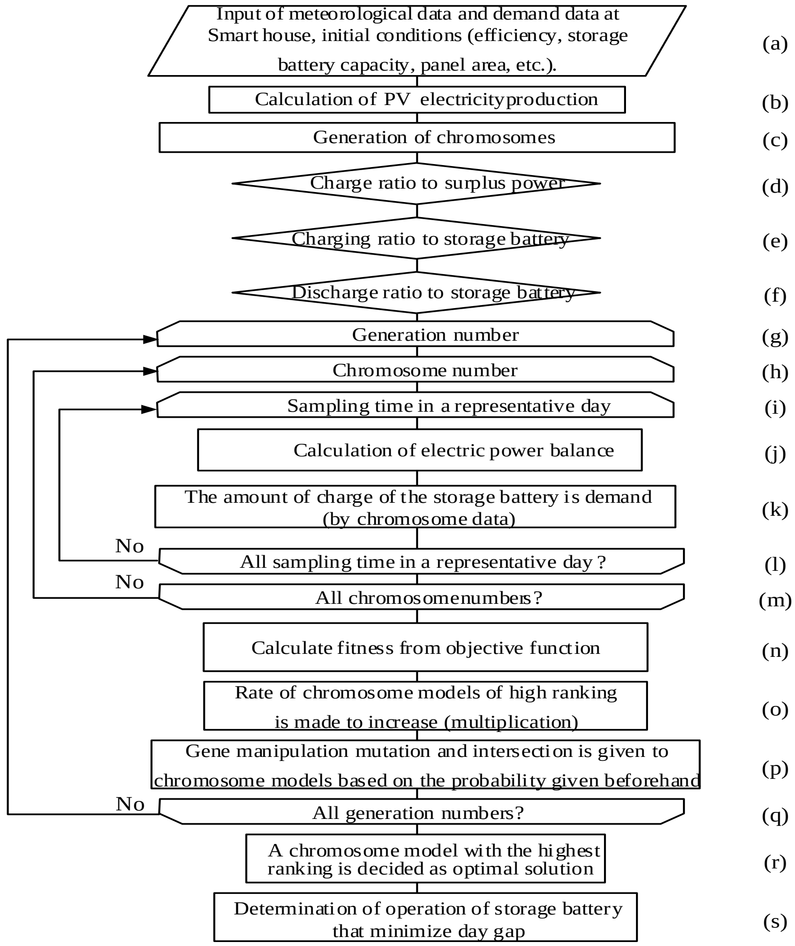


Fig. 3 Analysis flow

5. Analysis conditions

5.1. Power demand

Figure 4 shows the electricity demand for one day of household in Sapporo. In this paper, the average electric demand load data that was get from annual report of Hokkaido Electric Power Company vol.2015, for January (winter), April (middle), July (summer) that was used to analyse in this study.

5.2. Solar radiation data

Figure 5 shows the amount of solar radiation in Sapporo City published by Meteorological Agency in 2015, for January (winter), April (middle) and July (summer), was set in the middle of the month of 15th as the representative day.

5.3. Introduction capacity of solar power generation

The introduction pattern of solar power generation in this analysis assumed in 4-pattern that is, 4 kW, 4.5 kW, 5.0 kW, 5.5 kW as refer to the maximum demand load capacity of households.

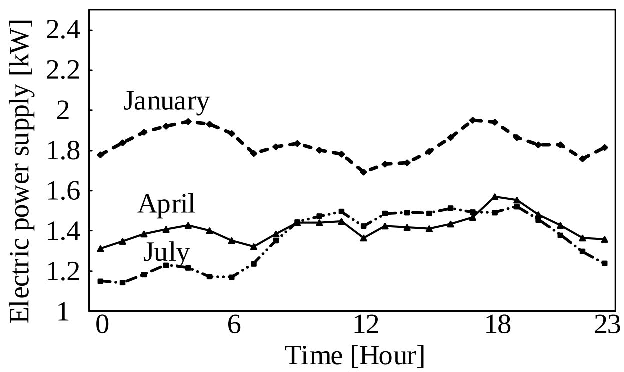


Fig. 4 Electricity demand in one household in Sapporo

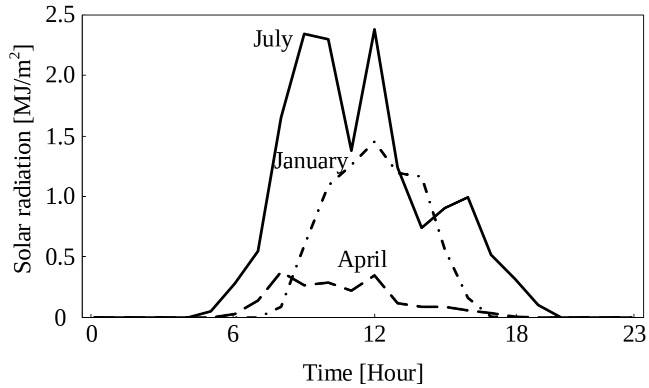


Fig. 5 Solar radiation amount on each month's representative day

5.4. GA parameters and equipment conditions to be used

Table 1 shows the GA parameters, which contains of chromosome and generation number, crossover and mutation probability, and probability of selection itself. The values in the table was determined by using trial and error method, while in Table 2, describes the conversion efficiency of photovoltaic power generation, battery capacity, and charge-discharge efficiency of battery.

TABLE I: GA parameters

Number of chromosomes	1000
Generation number	300
Probability of cross-over	95%
Probability of mutation	1%
Selection	
Individuals with the maximum of adaptive value	15% in all the individuals
Individuals with the 2nd to 5th place of adaptive value	5% in all the individuals

TABLE Ⅱ: Equipment conditions

Solar power	
Conversion efficiency	15.3%
Storage battery capacity	5kWh
Charge and discharge efficiency	90%

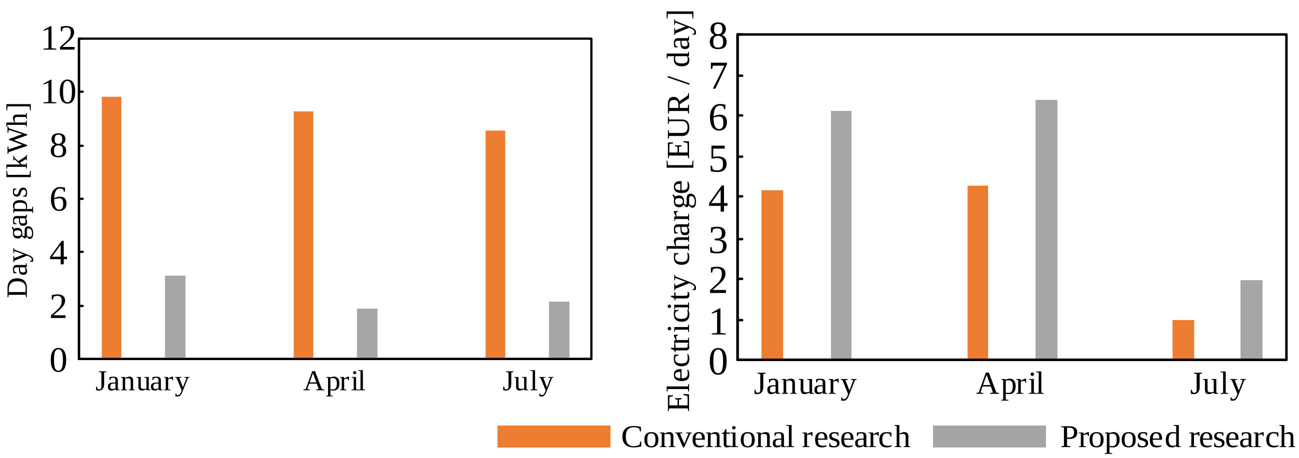
5.5. Day gaps and electricity charges

As refer to the conventional research, which is the economic efficiency of smart house get paid attention and investigate how to operate the storage battery in order to reducing the electricity charges on detached houses for one day. Therefore, due to the objective function in this study is minimizing the electricity charge of the smart house, the same value of electric demand load and weather conditions from the previous analysis will use once again in this study, which the numerical analysis was performed by GA method. Following to the unit price of Hokkaido Electric Power Co. [6], the electricity unit price in this analysis comparing to the conventional research was obtained for 4.16 EUR in January, then 4.31 EUR in April, and July get around 0.97 EUR. While, the day gaps was obtained around 9.84 kWh, 9.3 kWh, and 8.57 kWh, respectively.

6. Analysis result

6.1. Day gaps in each month, and electricity charges

Fig. 6(a) shows the day gap of each month of the 4.5 kW solar cell compared with the previous research, while in Fig. 6(b) described the electricity charge. Table 1 also shows the day gaps of the proposed system and the conventional system and numerical results of the electricity charge. Refer to the Table 1 and Fig. 6(a), it was clear that the day gaps were all decreased in each month, decreased by 68.2%, 79.9%, 75.1% in January, April and July respectively. Therefore, load levelling may consider for each month. On the other hand, due to the electricity fee is the objective function in the previous research, the electricity purchase at night was carried out cheaper than the electricity purchase of this proposed system. By using the same electric fee menu, the electricity rates was increased by 32.2%, 32.7%, 50% in January, April and July respectively.



(a) Day gaps in each month

(b) Electric charges in each month

Fig. 6 Day gaps and Electric charges compared with conventional research

TABLE Ⅲ: Daily gaps and electricity charges of the proposed research and conventional research

	January		April		July	
	Conventional research	Proposed system	Conventional research	Proposed system	Conventional research	Proposed system
Day gaps	9.84 [kWh]	3.13 [kWh]	9.3 [kWh]	1.87 [kWh]	8.57 [kWh]	2.13 [kWh]
Daily electricity charge	4.16 [EUR]	6.14 [EUR]	4.31 [EUR]	6.40 [EUR]	0.97 [EUR]	1.94 [EUR]

6.2. Day gaps and electricity charges of each month when changing capacity of solar power.

A line graph as shown in the Fig. 7 describes the day gaps, then a bar graph describes the electricity rate when introduce the variation capacity of photovoltaic, comparing to the previous study. Through these graphs can be seen that the day gaps was greatly reduced in every month of the analysis. Moreover, from January and April in (a), (b), in the proposed system, even if the capacity of the solar cell was changed, the day gaps remained unchanged. Consequently, it became clear that the capacity and the day gaps in July was larger than the other month due to the electric unit price from commercial power grid has increased. As shown in 6.1 section, the electricity charge was found to be higher than the proposed system at any capacity each month. However, it was also confirmed that the difference became smaller as the capacity of the solar power increased.

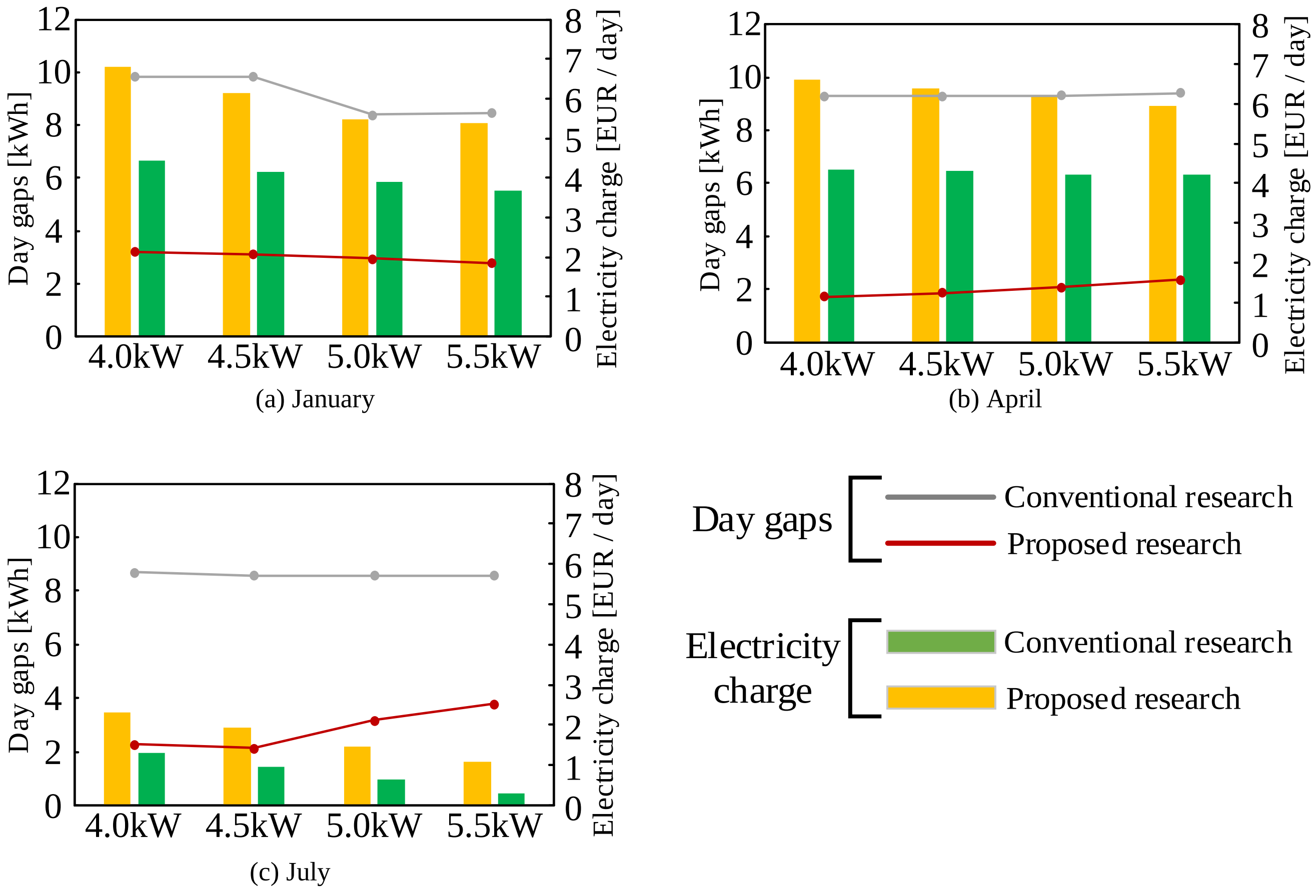


Fig. 7 The variation of solar power capacity, levelling load and electricity charge of each month of the analysis

7. Conclusion

The aim of this study at load leveling of the power grid and investigated charge-discharge control of storage battery for smart house application. The comparison result the previous study obtained that by using GA analysis method, the day gaps was able to minimize. Then following the conclusions of the investigation.

1) In the proposed system, it was revealed that in the 4.5 kW solar power, the day gaps are reduced by 68.2%, 79.9%, 75.1% in January, April and July respectively compared with the conventional system.
2) Even if the solar cell capacity was increased, it became clear that the day gaps got bigger at all capacity of each month compared with the conventional research.

From above analysis result, it can be considered that optimization operation of storage battery by this proposed system contribute to the load levelling of power grid, leading to the improvement facility utilization rate and change of electricity charge menu.

8. Symbol table

$P_{pv,t}$: Power of solar power generation [kW]
$P_{cs,t}$: Commercial power supply [kW]
$P_{bt,ch,t}$: Charge of storage battery [kWh]
$P_{bt,dc,t}$: Discharge of storage battery [kWh]
P_{load} : Power load [kW]
P_{cs_gap} : Day gaps [kWh]
P_{cs_max} : Maximum purchased power [kWh]
P_{cs_min} : Minimum purchased power [kWh]

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