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DEVELOPMENT OF A GRID INDEPENDENT ENERGY SYSTEM USING ENERGY SUPPLY AND DEMAND PREDICTION
(Part 1) Concept and problem identification from operational data

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ABSTRACT

In this research, we aim to develop an energy self-sufficient system by applying model predictive control. The objective of this research is to construct a model which can predict both the amount of energy load and renewable energy generation in a building. We will aim to verify the validity and effects of both the models and the predictive control, at the Takasago Innovation Center. In this paper, the yearly power balance and transition of power generation and battery power in the building is estimated by operational data. As a result, for self-sufficiency of electricity, it was shown that it's necessary to suppress the Photovoltaic output from an early stage by predicting energy balance, and to optimize the operation plan of combined heat and power system.

1. INTRODUCTION

As the Japanese government declared to aim for a carbon neutral society by 2050, attention for ZEBs (Net Zero Energy Buildings) is higher than ever. But along with the diffusion of renewable energy sources, the conventional power grid has become so strained that reverse power flow is being limited in some areas [1]. Furthermore, due to the rise of natural disasters such as typhoons and earthquakes, the importance of a grid independent, energy self-sufficient system is increasing.

To achieve an energy self-sufficient system by renewable energy sources, we need enough energy to satisfy the load and appropriate allocation of power by batteries etc. However, in areas where reverse power flow is restricted, it is necessary to either suppress the amount of power generation or, convert the surplus power to other energy sources such as thermal energy, when the battery storage reaches full charge. Whichever method we choose, it is required to optimally control the system with respect to the ever-changing energy consumption and the amount of power generated from renewable energy sources, represented by solar power generation (PV).

Therefore, in this study, we adopt model predictive control (MPC), using models of energy consumption, renewable energy power generation and the energy system. Furthermore, we aim to implement the MPC in 高砂熱学工業イノベーションセンター (Takasago Innovation Centers: TICs) energy management system (EMS) [2] and, verify the validity of both the models and the MPC. In constructing prediction models, we plan to study the latest method of GCN (Graph Convolutional Network) [3], in addition to the conventional ANN (Artificial Neural Network) and Bayesian neural network.

Specifically, we plan to carry out our research through the following steps.

0) Step 0 Concept and problem identification (This report)
1) Step 1: Constructing models

We will select model construction methods that predicts energy consumption, power generation such as PVs for a certain period, and verify its accuracy. At this step, both the target accuracy and period of each prediction models are set through energy simulations. The next report (Part 2) is included in this step.

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2) Step 2: Verification of MPC

We will verify the validity and effect of MPC, in which the models developed in step 1 is implemented.

3) Step 3: Implementation of MPC into the TIC EMS

We will implement the prediction model and MPC constructed in steps 1 and 2, into the TIC EMS, and demonstrate their validity and effectiveness.

In this report, the outlines of the following are illustrated: the building of TIC, its power source and storage equipment, the conventional operation plan. the actual values of energy consumption and supply, the actual values of received power from the grid (August 2020 to April 2021). In addition, after showing the calculation results of annual power balance and stored energy, operational issues are described.

In the next report (Part 2), on the construction of the prediction models (step 1), the outline of GCN and the case study results on the prediction of solar radiation using this method is described.

2. OVERVIEW OF TIC

2.1 Building overview

As previously reported [3], TIC was established in April 2020. It is divided into an office, a laboratory, an equipment exhibition building, a presentation room, and a planting / R&D area (Fig. 1). In the estimation with BEST, it is expected to achieve ZEB for the office building, and Nearly ZEB for the entire building.

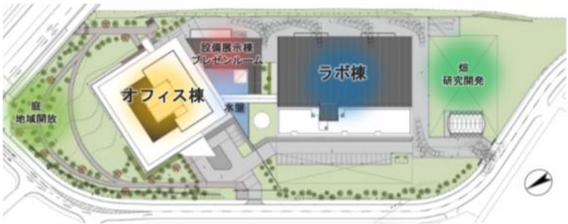

Fig. 1 Overview if TIC

2.2 System overview of energy sources

TIC has an energy system based on power supply from PV, power and thermal energy supply from biomass gasification generators (CHP: Combined Heat & Power) and redistributed surplus power by storage batteries [4] (Fig. 2). By the way, since the building is located where reverse power flow is restricted, batteries were added in March 2021, where the capacity of Li-ion battery was significantly increased, and Sodium-sulfur battery (NAS) was additionally installed. Table 1 shows the specifications of related equipment.

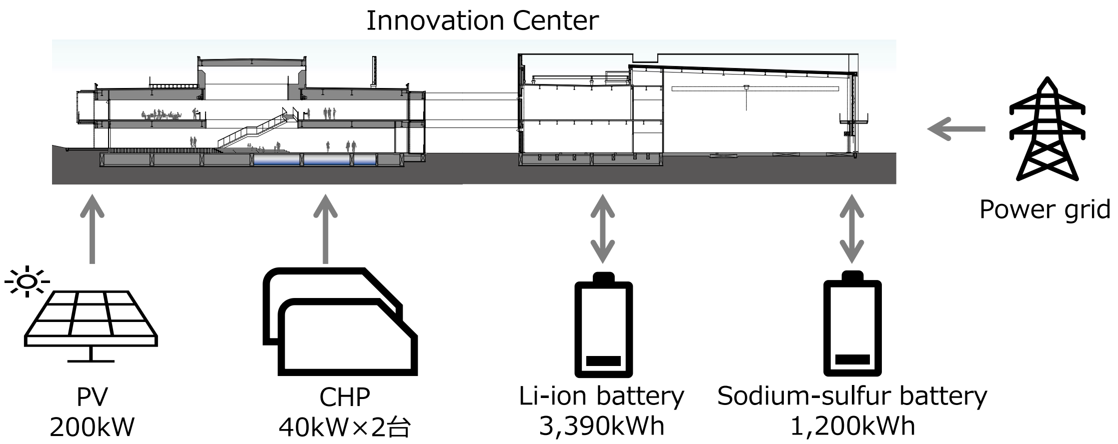

Fig. 2 TIC energy system

Table 1 Equipment specifics

Name	Item	Specifics
PV	Maximum Output	200.64kW (285W×704 panels)
CHP	Type	CHP (Fuel:Wood chips of pellets)
	Electricity Output	45 kW × 2
	Heat Output	100 kW × 2
Battery (Li-ion)	Type	Lithium-ion battery
	Capacity	430 kWh
		2,965 kWh (Newly-established)
	Maximum Output	± 429 kWh
	Overall Efficiency	89.5%
	Auxillary	3 kW
Battery (NAS)	Type	Sodium-sulfur Battery (NAS)
	Capacity	1,277 kWh (Newly-established)
	Maximum Output	±200 kWh
	Overall Efficiency	80% (Heater excluded)
	Heater Input	6 kW
	Auxiliary	4 kW

3. ENERGY OPERATIONAL PLAN

3.1 Operation of CHP

Base operation of CHP is planned with the goal of operating 7,800 hours a year for both units [5].

3.2 Operation of storage batteries

(1) Li-ion battery

At the time of establishment, the rated capacity of the Li-ion battery was 430kWh, but it was expanded in March 2021 to a total of 3,390kWh. From the viewpoint of preventing deterioration, the lower limit is set to about 50kWh before expansion, and about 300kWh after expansion, and it is set so that discharge cannot be performed beyond that. For charging and discharging of the Li-ion battery, constant power reception control is applied. The controller installed in the product constantly monitors the power receiving point. When the power in the building is surplus (when reverse power flow occurs), the Li-ion battery is charged. When the power is insufficient (when power flows from the grid), the Li-ion battery is discharged. This control method is mainly installed in general power storage systems. Because the current system cannot generate reverse power flow, the set value of power reception from the grid is set to 10 kW, in anticipation of safety. In other words, even while aiming for power self-sufficiency, power will be constantly received around 10kW.

(2) NAS battery

NAS battery was newly installed in March 2021 as a subsidiary storage capacity for the Li-ion battery [2].

3.3 Operation of PV

For the concept of power generation, CHPs which can provide stable power supply are used as base power source, in contrast to the PV which is easily affected by the weather. Therefore, PV is targeted for suppression. Since surplus power cannot be converted into other energy sources with the current equipment, PV output is suppressed when the storage capacity approaches full charge. Specifically, the PV suppression rate (control level) increases when the amount of electricity stored exceeds a certain percentage of the preset maximum storage capacity. Fig. 3 shows the control diagram, and Table 2 shows the current setting values. In this study, we will proceed with the PV as the target for suppression for the time being.

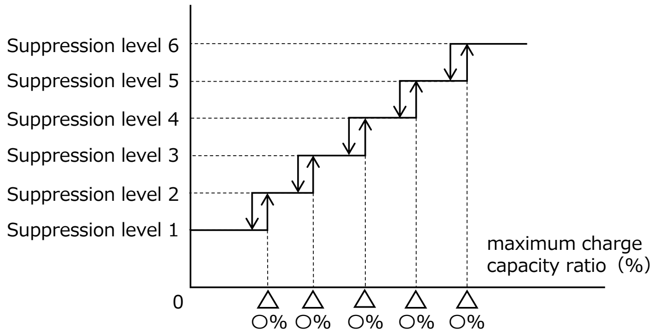

Fig. 3 PV output and suppression control

Table 2 Set values of PV suppression control

Battery charged amount (%) (Maximum capacity SP ratio)	Suppression level	PV output(%) (PV maximum output ratio)
79	Level 2	100
84	Level 3	100
89	Level 4	90
94	Level 5	60
99	Level 6	0

4. ACTUAL POWER GENERATION AND POWER CONSUMPTION

To show the validity of inputs for the annual estimation described in chapter 5, this chapter explains the measured data, such as the power generated from CHPs and PVs, the power received from the grid, and the amount of power consumption from August 2020 to April 2021.

4.1 Actual power generated from CHPs

When both CHPs operated stably, the actual generated power was approximately 74kWh per hour on average, against the rated 80kWh (40kWh x 2), confirming that the power generation was almost as rated.

4.2 Actual power generated from PV

During the measurement period (August 2020 to April 2021), the daily average of power generation from PV was approximately 538kWh, about 94% of the estimated value at the time of design (572kWh/day). The 6% difference can be considered that power generation from PV was suppressed when the Li-ion battery approached the maximum storage amount, as described in Section 3.3.

4.3 Actual received power from grid

The hourly average of received power from the grid was approximately 25 kWh, over 1.5 times the assumed value (10 kWh). This can be considered that received power increased when the power storage reached the bottom limit, due to lack of storage capacity.

4.4 Actual power consumption

The daily average of power consumption during the measurement period (August 2020 to April 2021) was approximately 1,720kWh for the whole building, and about 866kWh for the office. For the whole building, target power consumption at the time of design was about 4,590kWh, so it was quite less than the target. During the measurement period, it can be considered that the occupancy rate of the laboratory was significantly lower than the normal operation state. For the office, it was approximately 1.5 times the initial target (556kWh). For this, 2 causes are considered: 1. Power for special equipment for exhibition is included, 2. Operation rate of rooftop units where higher than expected [2].

5. CALCULATION OF ANNUAL POWER BALANCE AND TARGET SETTING

In this chapter, the target value for annual suppression amount of PV output is shown, based on annual power balance calculation for 2021. Annual power balance calculation is based on simple models such as power consumption model of TIC, power supply models of CHP and PV, which are based on current operating conditions previously explained. In addition, the issues in PV suppression and CHP operation is shown, based on calculation results of annual stored electricity and power received from the grid.

5.1 Annual power consumption

The time average was calculated from measured values, divided into four categories: winter (December-March), summer (June-September), intermediate period (April-May, October-November), and holidays. For holidays however, data from March to April 2021 was used, when power usage of the laboratory was near normal operation.

5.2 Annual power generation from PV

Since there is no actual measurement data of both PV output and solar radiation from May to July, and since some of the actual measurement data includes the result of suppression control, the annual solar radiation presented by the Meteorological Agency (Observatory: Tateno) and a simple estimation formula [6] were used to estimate the annual PV output.

5.3 Annual power generation from CHP

CHP is assumed to operate for 7800 hours a year, generating 74 kWh per hour, as shown in 4.1. In addition to the year-end and New Year holidays, the year-end and New Year holidays, the long holidays in May, and the “Obon” period, maintenance days were set on weekends between these consecutive holidays, for a total of 960 hours.

5.4 Charged power of storage battery

Storage capacity is set to 4,100kWh, which is the sum of 2,900kWh for the Li-ion battery (about 85% of the rated capacity), and 1,200kWh for the NAS battery. As for the Li-ion battery, a margin of about 15% is set, from the viewpoint of preventing deterioration and as a subsidiary capacity.

5.5 Power for auxiliary equipment

For CHP auxiliary equipment such as chip dryer, circulation pump etc., the average value 8.2kWh was used. For storage battery auxiliary equipment, the specification value (Table 1) was used.

5.6 Annual power balance

Table 3 shows the calculation results of the power balance in 2021. By subtracting total power consumption from the total power supply (PV, CHP and received power from the grid), the annual surplus power 27,039 kWh is calculated. But if we set the storage capacity to 4100kWh, it can be considered that a maximum of 4100 kWh of surplus power is capable of charge.

Thus, it can be considered that the surplus power minus the charging capacity is necessary to be suppressed in total (approximately 23,000kWh). Therefore, for 2021, the target of maximum output suppression of PV was set to 23,000 kWh. By the way, “maximum output suppression” is defined as suppressed PV output, which would have been generated if it was not suppressed.

5.7 Annual charged power and power received from grid

Annual calculation results of charged power and received power from gird are shown in Fig. 4 and 5, respectively. Through calculation, it was assumed that the charge / discharge efficiency was 0.8 (charge: 0.89, discharge: 0.89). On the other hand, PV suppression control was calculated on the premise of the current control described in 3.3.

As a result, the total suppressed PV output was approximately 36,300kWh, about 1.6 times higher than the target (23,000kWh). On the other hand, it was confirmed that the maximum storage capacity of 4,100kWh was frequently exceeded, especially from April to July. Therefore, it can be considered that while the current

PV suppression control works excessively, it is insufficient to keep the storage capacity below the set value, and that the policy of using MPC mentioned at the beginning is expected to be effective.

As for power received from the grid, there were still some periods in which the expected value (10kWh) was exceeded, although it was significantly reduced after the addition of batteries. Therefore, since the power supply is insufficient during these periods, to aim power self-sufficiency, the following solutions can be considered: 1. Reduce the amount of PV output suppression, 2. Either change CHPs maintenance period, or increase its operating time in some cases.

On the other hand, it should be avoided as much as possible to suppress PV output in the first place and therefore, it is necessary to consider capacity control of CHPs in the future.

Table 3 Estimated yearly power balance

	±	Item	Power
Power supply	+	PV	224,312 kWh
	+	CHP	577,200 kWh
	+	Grid	87,600 kWh
Power load	-	Week days	558,629 kWh
	-	Holidays	125,994 kWh
	-	Auxiliarys	177,450 kWh
Surplus power			27,039 kWh
Battery capacity	-	Li-ion / NAS	4,100 kWh
Suppress target	22,939 kWh (10% of total PV output)		

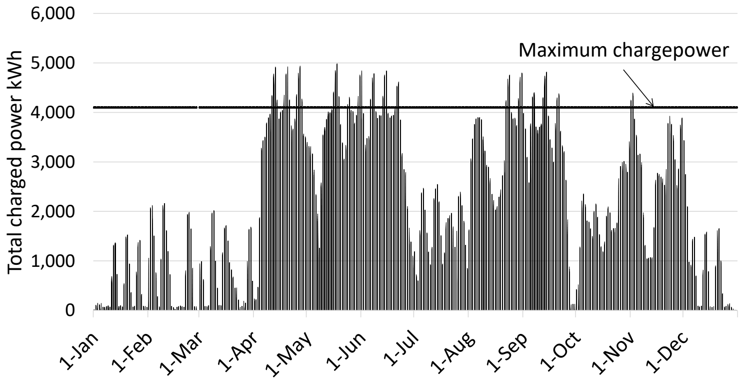

Fig.4 Annual charged power (estimation)

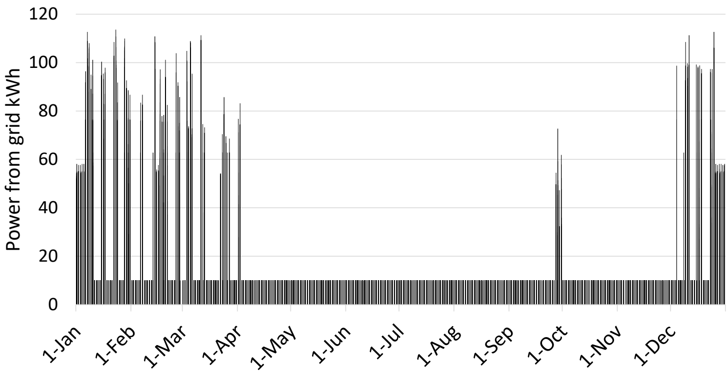

Fig.5 Annual received power from grid (estimation)

6. CONCLUSIONS

This report illustrated the outline of TIC's building, power source equipment, and its energy operation states. In addition, by calculation of annual power balance and storage, it was shown that predictive control of power generation and power consumption is necessary, and that detailed verification of CHP's annual operation plan is also necessary. In the next report (Part 2), on the first step in constructing a prediction model, the outline of GCN (Graph Convolutional Network) and the result of a case study on solar radiation prediction using this method is described.

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要　約

本研究は、建物内の自家発電で得た再生可能エネルギーにより自給自足することを目指した「エネルギー自立型システム」の開発に向け、電気・熱エネルギーの消費量と供給量の予測手法、またこれらを用いたモデル予測制御の妥当性や効果を実証することを目的としている。本稿では、実証を行う高砂熱学イノベーションセンターにおける発電、蓄電設備の概要と現状の運用状況を示し、年間の蓄電量を試算した。その結果、電力を自給自足するにはエネルギー収支を予測し、早い段階から太陽光発電の出力を抑制する必要があることと、熱電併給システムの運用計画を最適化する必要があることを確認した。
