# 太陽光発電，ガス複合発電，蓄電池を複合したスマートグリッドの時間変動を考慮したダイナミックシミュレーション

# *Dynamic simulation on a micro-grid system consisting of photovoltaic power, gas combined heat-and-power and battery*

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*Abstract*—**In this study, dynamic analysis of a micro smart grid network system with solar and heat management in a smart grid network system has been investigated. The micro grid network system has been evaluated with considering demanded power changing at different time and weather and the benefits has been estimated.**

***Keywords: micro smart grid; heat; solar; energy balance***

## I. Introduction

Renewable energy and conservation has become one of the hottest research topics during these days. Researches about looking for ways to increase energy efficiency and ensure a sustainable energy supply are benefited to realize the energy sustainable society in the future [1]. And now, there's a new way to leverage technology that's generating interest and action — the smart grid. The smart grid is a type of electrical grid which attempts to predict and intelligently respond to the behavior and actions of all electric power users connected to it – suppliers, consumers and those that do both – in order to efficiently deliver reliable, economic, and sustainable electricity services. The smart grid will help: improve the reliability, capacity and capability of the electricity network; ensure a safe, cost-effective and environmentally sustainable energy supply; enable faster response and resolution to outages; create a resilient, open and dynamic information network [2-4].

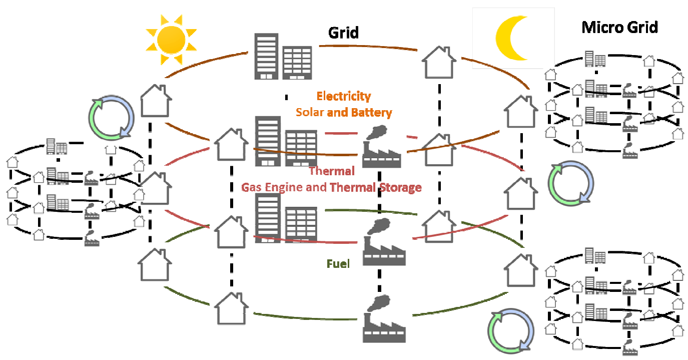



Fig.1 Optimization of heat and electricity supply in a smart grid network

In recent years, a lot of researches relating to the smart grid system with distribution management systems have been carried out [1-6]. Meysam et al [1] illustrated the smart grid and micro-grid development in the recent decades, and showed that the challenges for the successful realization of smart grid includes the integration of renewable energy resources, real time demand response and management of intermittent energy sources. Colson et al [2] proposed a comprehensive real-time micro-grid power management and control with distributed agents, and the system and formulations presented demonstrate the viability and capability of decentralized agent based control for micro-grids. Kevin et al [4] analyzed the cost effective of smart grid network combing power and communication network. Yun et al [6] introduced the development of smart distribution management system for real-time predictive operation in distribution systems, the system is consist of device level for the real time data acquisition and the server level for the data related to the voltage, current, faults, power quality and load profiles of the network.

Each respective element technology in smart grid system (such as solar photovoltaics, gas engine, and various forms of distributed generation, thermal storage, secondary battery, and many more) are being developing. Furthermore, the authors are interested in optimizing the heat and electricity in the smart grid network, it is necessary to investigate the solar and heat management in a micro grid.

In this study, in order to contribute to a green innovation and optimize the heat and electricity in the smart grid network, we tried to develop a simulation model of a micro smart grid system that can predict the needed function of respective element technology according to demand of end user at different weather conditions, it is necessary to investigate the feasibility of this micro smart grid system. We proposed a combined complex smart grid (as shown in Fig. 1) consisting of lots of micro grids including gas engine (heat), solar power plant, thermal storage, end users (such as LED, secondary battery, factory, etc.). The number of installed and the size of each facility of the smart grid and place the installation has been optimized by modeling simulation and the benefits due to energy balance calculation has been estimated.

## II. MODELING

At the first stage, model of a micro smart grid system with real time change and management of solar and heat was carried out to establish the evaluation and calculation method of fuel and electricity amount and the benefit effects.

### A. *Model and approach*

Model of a micro smart grid system is shown in Fig. 2, which is consisted of photovoltaics from isolation, a gas engine fueled by methane, and a secondary battery for electricity storage. The image of a micro smart grid model is shown in Fig.2. In the simulation, the following conditions are assumed.

- If solar power is not enough, replenish from the gas engine which has a maximum output of 35kW grid-power;
- The excess of solar power is stored and used at night;
- If the total power supply is not enough at high consumption, more gas engine is set in parallel;
- The difference of solar radiation in sunny, cloudy day is considered.

Specifications of equipments used in simulation are shown in Table 1. The specifications of the gas engine are shown in Table 2.Solar power is calculated by the following equation. Amount of solar radiation is the information of JMA weather statistics.

Table 1 Specifications of equipments

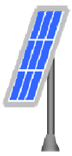
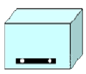
| | | |
|---|---|---|
| Solar panel  | Product | Sanyo Electric HIT-B200J01 |
| | Module conversion efficiency | 17% |
| | Size | 1.319m×0.894m(14kg) |
| | Numbers | 16 pieces (3.2kW total equivalent) |
| | Temperature correction factor (loss) | 12%(June～August) |
| | Other losses | 5% |
| Power conditioner  | Product | Sanyo Electric SSI-TL27A2 |
| | DC-AC conversion efficiency | 94.5% |
| | Power consumption | 5% of the solar power consumption |
| | Standby power at night | 3W |
| Secondary battery  | Product | Energy Farm Light EF-2 |
| | Capacity | 2500Wh |
| | Charge efficiency | 90% |
| | Discharge efficiency | 90% |

Table 2 Specifications of gas engine

| | |
|---|---|
| Fuel type | Methane |
| Power output | 35kW |
| Power generation efficiency | 34% |
| Exhaust heat recycle efficiency | 51% |
| Overall thermal efficiency | 85% |

Solar power = solar radiation ×area of solar panels× number × DC-AC conversion efficiency× module conversion efficiency× (1-temperature correction factor) × (1-other losses) / 3600 (1)

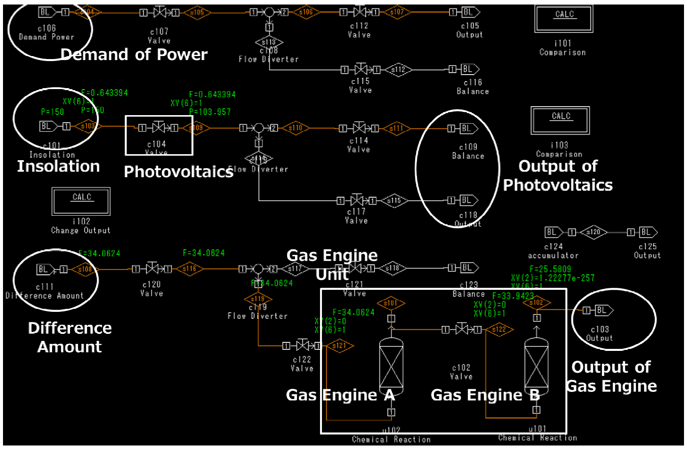



Fig. 2 Model of a micro smart grid system

The approach of the micro smart grid system is illustrated as follows. A non-steady state mode is used by Visual Modeler because insolation for photovoltaics is non-steady parameter. Units in the micro grid system are added by C program language in the analysis system as show in Fig.2.

Every energy forms including electricity from photovoltaics and gas engine, methane fuel, thermal heat from gas engine are all transformed as hydrogen energy as shown in Fig.3.

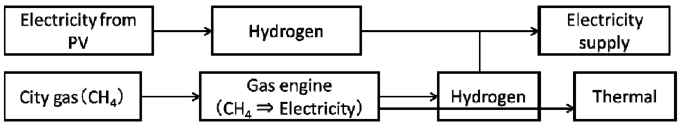



Fig. 3 Every energy forms standard as hydrogen energy

The calculation flow of the micro smart grid system is shown in Fig.4. The insolation is non-steady and changes with time at every 5 seconds, as the electricity from photovoltaics also changes with time corresponding. If the electricity supply is not enough, the gas engine works and began to supply electricity. If the electricity is excessed, it is storage as electricity or thermal storage.

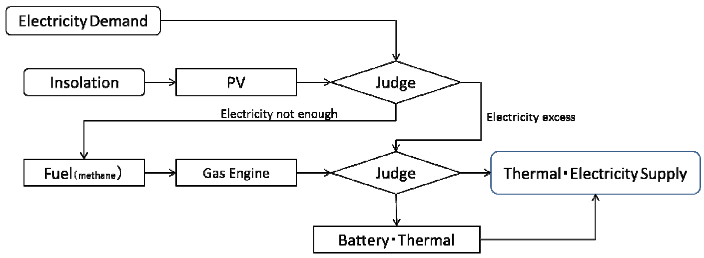



Fig. 4 Calculation flow of the micro grid system

### B. *Results and discussion*

Based on the above conditions, the thermal or battery recycle effect of the grid power consumption has been calculated. The results of sunny day and cloudy day are shown in Fig. 5 and 6.

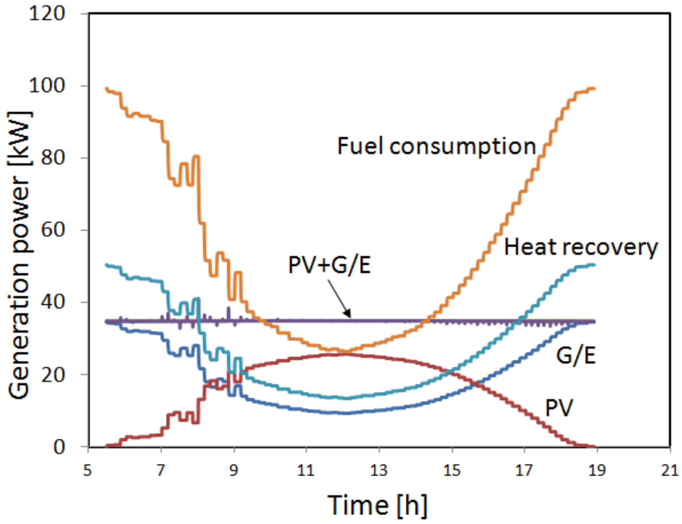



Fig. 5 Simulation results (sunny day)

The horizontal axis of the graph is real time of a day; the vertical axis of the graph is electricity power. The black line is the demanded fuel in the micro smart grid system; the red line is electricity from gas engine; the blue line is the recycled thermal energy; the green line is electricity from solar power; the purple line is the sum electricity amount of solar power and gas engine; the brown line the demanded power. When there is no solar power output from the middle of the night until the morning, replenish from secondary battery or the gas engine. If solar power exceeds the power consumption during the day, the excess is stored with secondary battery and used at night.

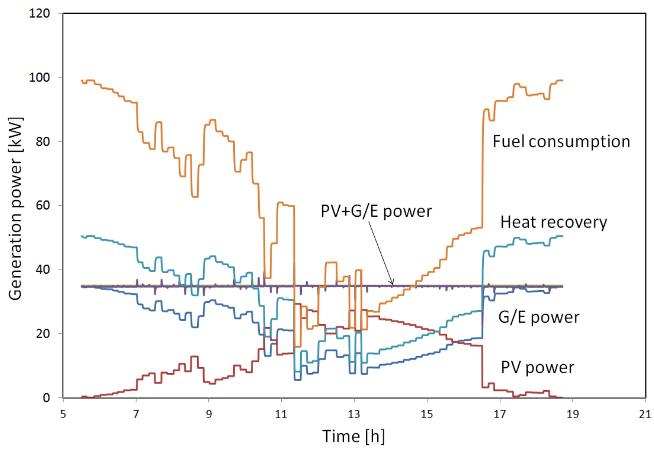



Fig. 6 Simulation results (cloudy day)

As shown in Fig. 5 and 6, the demanded fuel decreases when the solar power increases because of the higher insolation. It is possible to reduce the fuel consumption with the introduction of solar power and secondary battery. In the case of cloudy, the fuel consumption is changed dramatically because of the non-steady isolation at cloudy day.

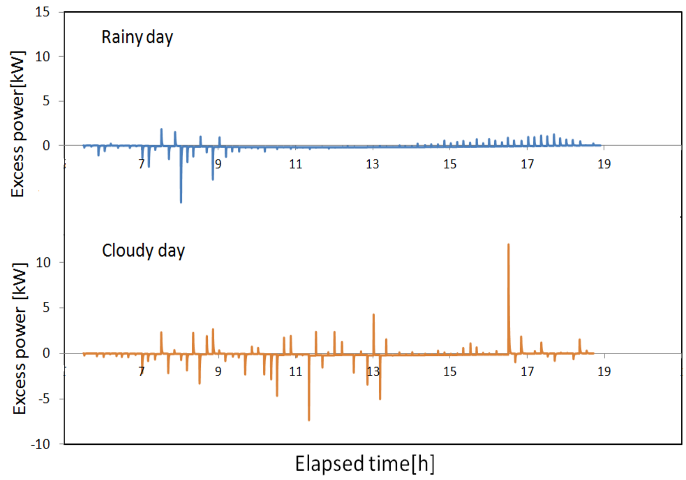



Fig. 7 Excess amount of electricity with time

From the above results, we estimated the amount of recycled thermal energy. The amount of recycled thermal energy is defined as Equation (2):

Recycled thermal energy = Demanded fuel × Heat recycle efficiency (2)

In the sunny day, the amount of recycled thermal energy is about 1.36GJ during the time period of 5:30 to 19:00, which is averaged about 28kW. On the other hand, the amount of recycled thermal energy is about 1.56GJ, corresponding as 32kW in the cloudy day.

In order to feasibility of the micro smart grid system, it is necessary to know the lacked amount of electricity at these weather conditions which is show in Fig. 7. The positive value means the lacked amount of electricity between the demanded electricity and supplied electricity. The negative value means the excess amount of electricity between the supplied electricity and demanded electricity. In case of sunny day, the electricity balance between supplies and demand can be kept, whereas, the lack between supplies and demand at cloudy increases. The lacked amount of electricity between supplies and demand is maximum at 12kW at cloudy, in order to solve this shortfall part, a maximum battery at 200Wh is needed.

## III. Conclusions

In this study, in order to contribute to a green innovation and optimize the heat and electricity in the smart grid network, we tried to develop a simulation model of a micro smart grid system that can predict the needed function of respective element technology according to demand of end user at different weather conditions. A combined complex smart grid was proposed, at the first stage, model of a micro smart grid system with real time change was carried out to establish the evaluation and calculation method of complex smart grid and estimate the benefits effect.

It was able to model the case of a micro smart grid system introducing the equipments of solar power generation and gas engine power generation with thermal storage and secondary battery for electricity storage. The simulation was carried out to estimate the energy consumption and recycled thermal energy by the balance calculation. The benefit effects of sunny day, cloudy day are 1.36GJ and 1.56GJ, equal as 28kW and 32kW respectively.

In case of sunny day, the electricity balance between supplies and demand can be kept. Whereas, the lack between supplies and demand at cloudy increases. The lacked amount of electricity between supplies and demand is maximum at 12kW at cloudy, in order to solve this shortfall part, a maximum battery at 200Wh is needed.

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