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# Optimal Operation for Integrated Residential Distributed Energy Resources Considering Internal Reserve

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**Abstract**

In recent years, an increasing number of distributed energy resources (DERs) in residential sector began to have an impact on electrical system operation. Especially, through massive introduction of photovoltaic power generation like rooftop solar, it became difficult to balance supply and demand of electricity in some area of Japan. To deal with this problem, this paper proposes integrated system of residential DERs which secure the supply reserve internally. Mixed Integer Linear Programming (MILP) model of integrated system is developed, and verified by case studies. The results of case study shows that the operation which secures internal reserve of 20% of PV generation can be performed by about 2% increase of the total cost.


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*Keywords:* Distributed Energy Resources; Home Battery; Fuel Cell CHP; Photovoltaics; Energy Management System;

## 1. Introduction

Recently, people's increasing awareness of energy conservation and low carbon society promotes installation of distributed energy resources (DERs) in residential sector such as rooftop PV, micro-CHP, and home battery. While acquiring electricity sales income from PV reverse flow, DERs in residential sector has no responsibility to the grid operation under current Japanese system. As the Government of Japan has set the goal of introducing further renewable energy to improve self-sufficiency rate and reduce CO2 emission [1], increasing variable power generation such as rooftop PV has begun to have serious influences on the grid system. To deal with this situation, various grid

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operation methods such as wide area operation using inter-connection lines [2], microgrid concept, and virtual power plant concept have been studied. These concepts utilize distributed resources actively and integratedly to ensure stable grid operation from different perspectives and ranges. Especially, the utilization of the residential DERs to compensate the deviation of variable output are studied in [3].In this paper, based on the virtual power plant concept, the integrated operation method of residential DERs are considered. This integrated system is modeled by mixed integer linear programming (MILP) optimization model. To deal with the problem of variable output of PV, the novel concept of internal reserve by fuel cell is introduced in the model.

This paper is divided in five sections. The configuration of proposed system and MILP model of the system are shown in Section 2. The data used in case study are shown in Section 3. The result and discussion of the case study is shown on Section 4. Section 5 is comprised by conclusion and future work.

**Nomenclature**

| | |
|---|---|
| $t$ | Time |
| $p$ | House Number |
| $CS_{cost}$ | Consumers' Total Cost [JPY/day] |
| $E_{cost}$ | Consumers' Total Electricity Cost [JPY/day] |
| $G_{cost}$ | Consumers' Total Gas Cost [JPY/day] |
| $PV_{sold}$ | Total Revenue from PV Generation Selling [JPY/day] |
| $E_{dm}(t,p)$ | Electricity Demand of House p and Time t [kWh/30min] |
| $H_{dm}(t,p)$ | Hot Water Demand of House p and Time t [kWh/30min] |
| $E^{gr}{}_{dm}(t,p)$ | Electricity Supply from Grid [kWh/30min] |
| $E^{fc}{}_{dm}(t,p)$ | Electricity Supply from Fuel Cell [kWh/30min] |
| $E^{bt}{}_{dm}(t,p)$ | Electricity Supply from Home Battery [kWh/30min] |
| $E^{pv}{}_{dm}(t,p)$ | Electricity Supply from PV [kWh/30min] |
| $H^{tn}{}_{dm}(t,p)$ | Hot Water Supply from Heat Tank [kJ/30min] |
| $H^{bh}{}_{dm}(t,p)$ | Hot Water Supply from Backup Heater [kJ/30min] |
| $Reserve_{up}(t)$ | Internal Reserve [kW] |
| ReserveRate | Internal Reserve Rate Regarding PV Generation [%] |
| $PV_{gen}(t)$ | Total PV Generation of Time t [kW] |
| $BINFC_{tot}(t)$ | The number of Fuel Cell in Operation |
| $FC_{gen,max}$ | Maximum Generation Capacity of Fuel Cell [kW] |
| $FC_{gen}(t)$ | Total Fuel Cell Generation of Time t [kW] |

## 2. Integrated System of Residential DERs

### *2.1. System overview*

In the proposed system, the cluster of houses equipped with fuel cell CHP, rooftop PV, home battery, and Home Energy Management System (HEMS) is considered. The overview of the system is shown on Fig.1(a), and the model of energy flow in each houses in the cluster is shown on Fig.1(b). This cluster is integratedly operated by Aggregator Energy Management System (AEMS) by exchanging information between AEMS and each HEMS. The aggregator also participates in Electricity Market and surplus power from rooftop PV can be bidden on the market. If the bidding electricity can't be matched due to fluctuations of PV generation, there is a risk that the aggregator will pay a penalty to the market. In order to mitigate such risk, a method of securing reserve within a cluster using fuel cell CHP is studied in this model. Additionally, the effect of the premium for the PV selling in electricity market is considered looking to the future investment promotion system like Feed-in-Premium (FIP).