Effect of introducing hybrid power system for housing

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Abstract
In recent years, the introduction of photovoltaics (PVs) has been expanding in houses, but the instability of power supply and demand balance due to fluctuations in the amount of power generation has become a problem. Therefore, in this study, we proposed a system that combines PV, fuel cell (FC) and battery (BT), and conducted a case study of annual energy simulation in a house. As a result, the introduction of the proposed system increased the electricity self-sufficiency rate, reduced CO₂ emissions and running costs, so the effectiveness of this system was shown.

Key Innovations
• We proposed a housing system that combines PV, FC (PEFC), and BT.
• Since FC is used, the simulation is performed considering not only the power supply but also the hot water supply.
• We propose various control methods using three energy resources.

Research Implications
By combining BT and FC with PV, which is being widely introduced in houses, it is possible to secure a stable power source even during times when there is no PV power generation or during a power outage.

Introduction
In recent years, the introduction of renewable energy has been increasing worldwide toward decarbonization. In Japan, 5th Energy Basic Plan has set the goal of making renewable energy the country’s main source of power, and the introduction of PVs in housing is expanding. However, it is difficult to provide a stable power supply with PVs alone because the amount of power generated changes according to the weather and time of day. Therefore, the combination of PVs with other energy resources is attracting attention. For example, BTs can store surplus PV power and discharge it as needed, leading to an increase in the self-consumption of power generated by PV. In addition, because FCs can generate electricity at any time, they can be operated in accordance with the power generation status of PVs. Furthermore, FCs are recommended by the government, and above all, polymer electrolyte FCs (PEFCs) are easy to start and stop and have a high exhaust-heat recovery rate. (Arai, 2019)

Therefore, in this research, we propose a hybrid system that combines a PV, FC, and BT and conduct a case study involving a simulation of the annual energy production/consumption of a house to clarify the effect of introducing this system from the viewpoint of energy savings and economic efficiency.

Methods
In this analysis, the equipment is operated using hourly housing load data and the amount of PV power generation when the number of people in the household is between 1 and 4. Figure 1 and Table 1 show the control flow and the specifications of each device, respectively. When there is a net demand for power, the PV and FC systems are used to supply power. When there is a supply deficit, power is supplied by BT or external power. In addition, hot water is supplied from the FC when it has a sufficient amount of hot water whereas a backup boiler operates when the

![Figure 1: Control flow.](image)

Table 1: Equipment specification.

<table>
<thead>
<tr>
<th>Device</th>
<th>Power generation capacity (kW)</th>
<th>Storage capacity (kWh)</th>
<th>Input capacity (kW)</th>
<th>Output capacity (kW)</th>
<th>Charge/discharge loss</th>
<th>Charging start time</th>
<th>Discharging start time</th>
</tr>
</thead>
<tbody>
<tr>
<td>PV</td>
<td>3.53 (if surplus)</td>
<td>5.6 (90% of them are used)</td>
<td>1.5</td>
<td>2.0</td>
<td>15%</td>
<td>10:00</td>
<td>17:00</td>
</tr>
<tr>
<td>BT</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FC</td>
<td>0.7 (PEFC)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

![Table 2: Analysis Case.](image)

Case | PV | FC | BT
---|----|----|----
Case1-1 | Grid | - | -
Case1-2 | FC-Grid | FC | -
Case2-1 | FC-PV-BT | FC | -
Case2-2 | FC-BT | FC | -
amount of hot water stored in the FC is insufficient. Case 0 is the base case in which no equipment is installed. In Case 1, a PV and FC are used. Case 2 is the proposed system; FC power supply is prioritized in Case 2-1, and PV power supply is prioritized in Case 2-2.

Results

Energy saving

Figure 2: Annual primary energy consumption.

Figure 2 shows the annual primary energy consumption for a household of 4 people. The introduction of the system resulted in a significant reduction in consumption of external power and a reduction in overall energy consumption. In addition, the surplus power from the PV increased due to the synergistic effect of introducing the FC, while PV self-consumption increased with the introduction of BT. Table 3 shows the annual CO₂ emissions and electricity self-sufficiency rate. The electricity self-sufficiency rate increased, resulting in a reduction in CO₂ emissions.

Table 3: CO₂ emissions and electricity self-sufficiency rate.

<table>
<thead>
<tr>
<th></th>
<th>Case1-1</th>
<th>Case1-2</th>
<th>Case2-1</th>
<th>Case2-2</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂ emissions</td>
<td>2.12</td>
<td>1.92</td>
<td>1.95</td>
<td>1.74</td>
</tr>
<tr>
<td>[t-CO₂/kWh]</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electricity self-sufficiency rate [%]</td>
<td>38</td>
<td>84</td>
<td>95</td>
<td>95</td>
</tr>
</tbody>
</table>

Economic evaluation

Figure 3: Annual running cost.

Figure 3 shows the annual running cost for a household of 4 people. As with annual primary energy consumption, annual running costs were reduced by introducing the proposed system. Furthermore, it was suggested that the net running cost could be further reduced by utilizing the feed-in tariff (FIT) system for PVs. In addition, Payback time for the equipment used in the analysis was calculated for each case and varying number of people per household. Figure 4 shows Payback time results. In Case 1, it was suggested that the initial investment could be recovered during the service life of the equipment by utilizing the FIT system. In Cases 2-1 and 2-2, the initial cost of BT was high, so it would take a considerable number of years to recover the cost, but Payback time could be shortened by utilizing the FIT system.

Conclusions

In this study, we conducted a simulated case study of annual energy production/consumption in a house. The results obtained are summarized below.

- The introduction of the proposed system improved the electricity self-sufficiency and PV self-consumption rates and reduced primary energy consumption, CO₂ emissions, and running costs.
- Payback time was significantly shortened by using the FIT system.

From the above results, the effectiveness of the proposed system was demonstrated from the viewpoint of energy savings and economic efficiency. In the future, we plan to clarify the control method for the system.

Acknowledgements

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References
