Optimization and Computer Numerical Simulation of Integrated Energy System through Electric Power Design

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Abstract. Firstly, the energy supply structure and internal equipment model of integrated energy system (IES) are analyzed. Taking P2G equipment as renewable energy consumption and CO2 absorption equipment, and considering renewable energy consumption rate and carbon emission index, the optimal scheduling model of IES is established. By setting three scenarios, this paper focuses on the impact of P2G equipment and power storage equipment on IES renewable energy consumption and energy saving and emission reduction benefits, and comprehensively evaluates the two types of equipment from renewable energy consumption and economic benefits. The results of an example show the effectiveness of the proposed model.

Keywords: Integrated energy system, Renewable energy consumption, carbon emission.

1. Introduction
Energy is the first element of social development. Solving the contradictions between social development and residents’ energy needs, as well as environmental issues and energy development, has become a hot issue discussed in recent years[1]. The integrated energy system couples a variety of different types of energy. Through various coupling devices inside the system, different energy sources can be replaced and complemented, which not only improves the utilization rate of primary energy, but also promotes the consumption of renewable energy[2].

At present, the research on the optimized operation of the integrated energy system has achieved certain result. A standardized matrix modeling method and optimization method for an integrated energy system is proposed in literature [3]. An optimized operation model of an integrated energy system considering integrated demand response is proposed in Literature [4]. Two-stage optimal operation of integrated energy system considering multiple uncertainties and integrated demand response is proposed in literature [5]. Literature [6] analyzed its impact on the flexibility of system optimization operation and the consumption of intermittent renewable energy by adding P2G equipment. None of the above studies involved the impact of P2G equipment and energy storage equipment on the consumption of renewable energy and carbon emissions in IES, respectively. Therefore, based on the existing research, this paper uses P2G equipment as renewable energy absorption and CO2 absorption equipment, comprehensively considering the renewable energy
absorption rate and carbon emission indicators, and establishes an IES optimal scheduling model. The proposed model is evaluated in terms of renewable energy consumption and economic benefits.

2. Energy supply architecture and internal equipment model of IES

2.1. Typical energy supply architecture of IES

The power flow diagram of IES used in this paper is shown in Figure 1. The energy sources of IES are mainly from the superior power grid and gas companies. The new energy power generation equipment of IES mainly includes photovoltaic and wind power generation. As an electric heat gas coupling device, gas turbine generates electricity by consuming gas and supplies it to the load side. The shortage of heat energy can be made up by gas boiler (GB) and electric boiler (EB). Electric hydrogen generation equipment (P2G) converts electric energy into natural gas, coupling power grid and gas grid[7]. P2G equipment has a good performance for the system to absorb renewable energy, significantly reducing the wind and light waste[8].

![Figure 1. Typical energy supply structure diagram of IES and its energy flow framework](image-url)

2.2. Main equipment modeling

(1) P2G equipment

\[
P_{P2G,i} = P_{PV,i}^{out} + P_{wind,i}^{out} + P_{P2G,i}^{in}
\]

\[
G_{P2G,i} = \frac{\eta_{P2G} P_{P2G,i}}{\lambda_{P2G}}
\]

(2) Energy storage equipment

\[
S_{i,j} = S_{i,j-1} (1 - \sigma_{i}) + (P_{i,j}^{in} - \frac{P_{i,j}^{in}}{\eta_{i,j}^h}) \Delta t
\]

\[
0 \leq P_{i,j}^{in} \leq \lambda_{i,\text{max}}^h S_{i,j,\text{max}}
\]

\[
0 \leq P_{i,j}^{in} \leq \lambda_{i,\text{max}}^d S_{i,j,\text{max}}
\]

\[
\alpha_{i,j}^d S_{i,j,\text{max}} \leq S_{i,j} \leq \alpha_{i,j}^d S_{i,j,\text{max}}
\]

3. Optimal scheduling model and solution

3.1. Objective function

The goal of the IES optimized operation model is to minimize operating costs, including energy consumption costs, penalty costs for abandoning renewable energy, operation and maintenance costs, and CO2 emissions costs. The expression is as follows:
The cost functions are shown in formula (4)-(7).

\[
F_{u,j} = \rho_{u,j} P_{u,j} + \rho_{p,g} G_{p,g}
\]

\[
F_{e,j} = c_e(P_{p,e} - P_{p,v,j}) + (P_{w,p} - P_{w,p,j})
\]

\[
F_{c,j} = \kappa_{c,t} P_{c,t} + \kappa_{c,c} Q_{c,c} + \kappa_{c,e} Q_{c,e} + \kappa_{c,ie} Q_{c,ie} + \kappa_{c,es} Q_{c,es} + \kappa_{c,es} Q_{c,es} + \kappa_{c,es} Q_{c,es}
\]

\[
C_{c,t} = \mu_{c,g} (P_{c,t} + Q_{c,t}) + \mu_{c,g} Q_{c,g} + \mu_{c,g} P_{c,g} - \nu_{c,p2g} P_{c,p2g}
\]

3.2. Constraint condition

The operation constraints of IES include energy balance constraints, equipment operation constraints and energy purchase constraints to ensure the energy supply and safe operation of the system. The energy balance constraints are shown in formula (8)-(10).

\[
P_{e,t} + P_{e,t} + P_{e,t} + P_{e,t} = P_{e,t} + P_{e,t} + P_{e,t} + L_{e,t}
\]

\[
Q_{e,t} + Q_{e,t} + Q_{e,t} = L_{e,t} + Q_{e,t}
\]

\[
G_{e,t} + G_{e,t} = G_{e,t} + G_{e,t} + L_{e,t}
\]

Formula (11) is the constraint of equipment operation.

\[
\begin{cases}
P_{e,t} < P_{e,t} < P_{e,t} \\
Q_{e,t} < Q_{e,t} < Q_{e,t}
\end{cases}
\]

4. Analysis of simulation example

4.1. Example scene parameters

This paper selects a residential area as the research object for analysis. IES unit operation parameters in reference [9], energy storage equipment parameters in reference [10]. The time of use price is adopted in this paper, and the price of each period is shown in Table 1. The price of natural gas is 3.17 S/m³. The specific day ahead multi energy load forecasting curve and typical daily renewable energy forecasting values are shown in Figure 2(a)-(b) respectively.

This paper mainly compares the impact of P2G equipment and power storage equipment on the IES system. Therefore, it is divided into three scenarios to explore the optimization effect of P2G equipment and power storage equipment on the system. The scenario classification is shown in Table 2 below, and the results are as follows \times Indicates that there is no such device, \checkmark indicates that the device is included.
Table 1. Electricity price information

| Time division       | Price ($/kWh) |
|---------------------|---------------|
| Peak 8:00-11:00,18:00-23:00 | 0.8118        |
| Parity 7:00-8:00,11:00-18:00 | 0.5713        |
| Valley 23:00-7:00    | 0.3438        |

Table 2. Scenarios setting

| Scenarios | Renewable energy | ES | P2G |
|-----------|------------------|----|-----|
| 1         | √                | ×  | ×   |
| 2         | √                | √  | ×   |
| 3         | √                | ×  | √   |

4.2. Comparative analysis of different scenes

The consumption rate of renewable energy under the three scenarios is shown in Figure 3(a). It can be seen from the figure that scenario 1 consumes the least amount of renewable energy, and the total daily consumption of renewable energy can reach 7174.2kWh. In scenario 2, the consumption of renewable energy is increased. However, due to the small capacity of energy storage and the state of energy storage is related to the state of the previous time, the consumption rate of renewable energy is decreased in some periods of the night. Compared with the scenario of adding energy storage and equal capacity P2G equipment, renewable energy can be fully absorbed in a scheduling cycle.

Figure 2(a). Customer load forecasting curve

Figure 2(b). Renewable energy forecast curve

Figure 3(a). Comparison of renewable energy consumption rate in different periods

Figure 3(b). Cost comparison under different scenarios
The operating costs in different scenarios are shown in Figure 3(b). It can be seen from the figure that the operation cost of scenario 1 is the highest, which is 25813.7$. When the power storage equipment is added, the operation cost is 1131$ lower than that of scenario 1. The new equipment increases the operation and maintenance cost, but improves the utilization rate of wind and light, and reduces the abandonment cost of renewable energy sources. When only P2G equipment is added, the operation and maintenance cost of the system decreases by 7771.14$. Although the operation and maintenance cost increases slightly, the energy cost and the cost of abandoning renewable energy are greatly reduced, and the carbon emission is reduced.

![Figure 4(a). Optimized operation results of electric](image)

![Figure 4(b). Optimized result of thermal operation](image)

The optimization results of the system are shown in Figure 4(a)-(b). In the results of power optimization operation, most of the power demand is supplied by renewable energy, which makes the GT output of gas turbine always at a low level and does not need to purchase power from outside. P2G equipment has high power in 1-6 period, 9-14 period and 23-24 period, so as to absorb renewable energy to the maximum extent and absorb a large amount of CO₂, which improves economic and environmental benefits. In the results of heat energy optimization, EB has been in a high operating state. Due to the less heat load, the energy storage equipment only stores heat in the 10th, 16th and 17th periods to absorb the remaining heat, and releases heat in the 11th, 13th and 18th and 19th periods to make up for the lack of heat supply, but the operating level is relatively low.

5. Conclusions
Firstly, this paper analyzes the energy supply structure and internal equipment model of IES. Taking P2G equipment as renewable energy consumption and CO₂ absorption equipment, considering renewable energy consumption rate and carbon emission index, the optimal scheduling model of IES is established. Through the comparative analysis of three scenarios including no P2G and energy storage, only P2G equipment and only energy storage, it can be concluded that under the same power, P2G equipment has better renewable energy consumption capacity and better emission reduction effect than energy storage equipment.

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