1. Introduction

In order to improve the efficiency of energy utilization, reduce environmental pollution and realize the sustainable development of energy, the construction of integrated energy system has attracted wide attention in the world. The integrated energy system relies on information transmission technology, energy conversion technology and energy storage technology to couple various energy networks such as power grid, heat supply network and natural gas network to realize multi energy collaborative supply and energy comprehensive cascade utilization [1].

The park level integrated energy system refers to the energy supply system close to the load terminal and high proportion of industrial load, also referred to as the park integrated energy system. The typical distributed heating and cooling system (DHC) and distributed combined cooling heating and power system (CCHP) are all park level integrated energy systems. It is one of the best ways to solve the energy shortage and environmental problems through the principle of multi energy complementarity and cascade utilization of energy. At present, there are many successful cases in Europe and other western countries. The park integrated energy system is a small unit integrated energy system, which has the advantages of convenient management and operation, and can realize the local consumption of new energy. It is the mainstream direction of the development of integrated energy system.

The park level integrated energy system is a regional energy system. Its main feature is that the energy demand is no longer a single power demand. It is a integrated energy system integrating the main body of power supply, gas supply, heat supply and the corresponding energy storage. It can realize the self-production and self-marketing of various types of energy to a certain extent. From the form of energy, the park level integrated energy system mainly includes electric power subsystem, thermal...
subsystem, natural gas subsystem and energy storage subsystem. The main bodies are coupled by energy conversion elements to form the electricity-heat-gas micro energy network.

2. Mathematical Model for Optimal Operation of Integrated Energy System

The integrated energy system of the park is generally dominated by electric energy and natural gas energy, and the external energy supply network is composed of tie line and natural gas pipe network. The system includes all kinds of energy conversion equipment and energy storage equipment to meet the three load requirements of electricity, heat and gas on the user side [2].

The park level electricity-heat-gas integrated energy system is mainly composed of four main bodies: electric power, thermal power, natural gas and energy storage. With the help of energy hub, the power system, natural gas system and thermal power system in the energy supply area are organically integrated to realize multi energy complementary. The configuration of electricity-heat-gas integrated energy system is shown in Figure 1.

The electric power subsystem transmits the electric energy from the wind turbine, photovoltaic, fuel cell, CCHP unit and other equipment to the load side for users to use. Taking gas-fired internal combustion engine as the core, through the consumption of natural gas, electricity is produced to directly supply part of the power load. At the same time, it is connected with the large power grid to realize the power exchange with the external power grid. The active access of photovoltaic generating units increases the environmental protection and economic benefits of the system. When the power load demand is large, the system can interact with the power grid.

The thermal subsystem takes hot water as the carrier of heat energy. It uses CCHP units, gas boilers and other equipment at the source end to heat the water, and uses the water supply network to deliver it to the load end for users, and then returns to the source end for reheating through the return water network [3]. When the power supply is sufficient and the heat supply is insufficient, it can be supplemented by the electric boiler.

The natural gas subsystem is composed of gas source, gas transmission and distribution network, compressor and load, which is mainly responsible for providing fuel for the equipment burning natural gas [4]. In order to ensure the flexibility of dispatching, the source end of the park level integrated energy system is usually equipped with several kinds of power sources and heat sources. The selection and cooperation of various types of equipment directly determines the performance indexes of the system. In addition, the flue gas generated during the combustion of natural gas can be mostly received by the
flue gas absorption heat pump, which is converted into heat and cold energy and directly supplied to
users [5].

Energy storage subsystem, as the link of integration of other kinds of energy subjects, can effectively
improve the optimal allocation of energy system in the space-time category, and is the "heart" of
integrated energy system. A single energy storage configuration usually has a certain degree of
functional constraints. Therefore, it is necessary to make full use of the complementarity of various
energy storage technologies and optimize the configuration of hybrid energy storage to meet the energy
storage needs of different levels in the integrated energy system, so as to improve the energy utilization
efficiency of the integrated energy system and the reliability of the overall energy storage system.

3. Mathematical Model for Optimal Operation of Integrated Energy Systems

The model mainly considers gas turbines, energy storage and other equipment to meet the user's load
demand for electricity, heat and gas. It takes the minimum operation cost as the objective function to
realize the economic operation of the system. Specifically, the user's load demand for electricity is met
by wind power, photovoltaic, and gas units. The heat load demand is met by gas boilers, and the gas
load demand is met by P2G.

3.1. System Constraints

The output constraints of each equipment are as follows.

3.1.1. Photovoltaic power generation system.

\[ P_{pv,t} = AI\eta_{pv} \]  

(1)

In the formula, \( A \) is the photovoltaic installation capacity. \( I \) is the sunshine intensity. \( \eta_{pv} \) is the
photoelectric conversion efficiency.

3.1.2. Gas units.

\[ P_{DG,j}^{\text{min}} \leq P_{DG,j} \leq P_{DG,j}^{\text{max}} \]  

(2)

In the formula, \( P_{DG,j} \) is the gas unit power. \( P_{DG,j}^{\text{max}} \) is the upper limit of gas unit power. \( P_{DG,j}^{\text{min}} \) is
the lower limit of gas unit power.

3.1.3. P2G.

\[ P_{P2G,t} = P_{\text{gas},t}^{P2G} \times \eta_{P2G} \]  

(3)

In the formula, \( P_{P2G,t} \) is the power of P2G gas generation. \( P_{\text{gas},t}^{P2G} \) is the electrical power of P2G
input. \( \eta_{P2G} \) is the efficiency of P2G equipment.

3.1.4. Boilers.

\[ P_{EB,t} = P_{\text{ele},t}^{EB} \eta_{eg} \]  

(4)

In the formula, \( P_{EB,t} \) is the heat output power of the electric boiler. \( P_{\text{ele},t}^{EB} \) is the electric power of
the electric boiler. \( \eta_{eg} \) is the heat transfer efficiency of the electric boiler.

3.1.5. Energy Storage Systems. Due to the difficulty of electricity storage, this paper uses P2G
equipment to convert the surplus electricity produced into gas and store the gas in the gas storage device.

\[ P_{GS,j} = P_{GS,j-1} + P_{\text{gas},t}^{Gj} \eta_{gst} \frac{P_{\text{gas},t}^{Gj}}{\eta_{gst}} \]  

(5)
In the formula, $P_{GS,t}$ is the gas retention power of the gas storage tank at time $t$. $P_{gas} \text{sto}_t$ is the storage power of the gas storage tank. $\eta_{gas}$ is the gas retention efficiency. $P_{gas} \text{rl}_t$ is the release power of the gas storage tank. $\eta_{rl}$ is the gas release efficiency.

### 3.2. Power Balance

The park mainly uses power generation equipment. Part of the output of gas turbines and photovoltaic equipment is supplied to users in the park, while the other part is supplied to power-to-heat and power-to-gas equipment to generate heat and gas resources to supply users. The power balance is as follows:

$$P_{pv,t} + P_{DG,t} = P_{P2G,t} + P_{GS,t} + P_{EB,t} + P_{all,t}$$  \hspace{1cm} (6)

In the formula, $P_{aE,t}$ represents the electricity load power of the demand side.

### 3.3. Objective Function

$$\min D = k_{pv}P_{pv} + k_{DG}P_{DG} + k_{P2G}P_{P2G} + k_{EB}P_{EB} + k_{GS}P_{GS} + C_{ele} + C_{gas}$$  \hspace{1cm} (7)

In the formula, $k_{pv}$ is the unit cost of photovoltaic units. $k_{DG}$ is the unit cost of the gas unit. $k_{P2G}$ is the unit cost of the P2G equipment. $k_{EB}$ is the unit cost of the electric boiler. $k_{GS}$ is the unit cost of the gas storage tank. $C_{ele}$ is the electricity purchasing cost. $C_{gas}$ is the electricity purchasing cost.

### 4. Example Analysis

This paper selects an integrated energy system in a park to conduct a calculation example analysis. The user's electrical load in the system is shown in Figure 2. It can be seen that 8:00-20:00 in the system is the peak period of electricity load.

![Figure 2. Load curves of electricity, gas and heat.](image)

The fixed cost of the system consists of one-time investment in various equipment. The unit investment of each equipment in the market and its rated power are shown in Table 1.

| Equipment                                      | Unit investment (yuan/kW) |
|-----------------------------------------------|--------------------------|
| Photovoltaics                                 | 12000                    |
| Gas turbines                                  | 8112                     |
| Electric hydrogen production equipment         | 800                      |
| Electric boilers                              | 1047                     |
| Gas boilers                                   | 782                      |

Table 1. Construction cost of each equipment unit.
The purchase and sale price of electricity between the integrated energy system and the main grid is divided into four segments according to the local industrial tariff. The sharp period is 11:00-14:00, 16:00-18:00, and the purchase price is 1.05 yuan/kWh. The peak period is 10:00-11:00, 14:00-16:00, 18:00-21:00, and the purchase price is 0.95 yuan/kWh. The flat period is 07:00—10:00, 21:00—24:00, and the purchase price is 0.65 yuan/kWh. The valley period is 00:00—07:00, and the purchase price is 0.38 yuan/kWh.

By using the model in Section 3, the output of each equipment in different periods under the lowest total system cost can be obtained, as shown in Figure 3.

![Figure 3. Output diagram of each equipment in different periods.](image)

It can be seen from the figure that the unit cost of gas turbine is more economical, and the system uses gas turbine most, which is far higher than photovoltaics. The peak and valley periods of hydrogen generated by electric hydrogen production equipment correspond to the trend of gas load curve in the park, and the peak and valley periods of electric boiler heat production correspond to the heat load in the park. The typical daily maximum output of each equipment is shown in Table 2.

| Equipment                          | Maximum output (MW) |
|-----------------------------------|---------------------|
| Photovoltaics                     | 10.374              |
| Gas turbines                      | 28.773              |
| Electric hydrogen production      | 14.214              |
| Electric boilers                  | 13.42               |
| Gas storage tanks                 | 10.432              |

According to the maximum output in the table, the capacity of the integrated energy system in the park can be set. In order to ensure the stability of energy supply in the peak period and the lowest cost in the park, the output margin is set as 1%.
According to the unit cost of each equipment, the total planning cost of the integrated energy system is 352800 yuan. Gas turbines have the highest cost of 183,800 yuan, followed by the photovoltaic cost, which is 125,700 yuan. The costs of electric hydrogen production equipment, electric boilers and gas storage tanks are 11500 yuan, 20600 yuan and 11200 yuan respectively.

5. Conclusions
This paper first analyzes the characteristics of each electric power subsystem, thermal subsystem, natural gas subsystem and energy storage subsystem in the park level integrated energy system. Secondly, with the minimum operating cost as the objective function and considering the output constraints of each system, the optimal operation model of the integrated energy system is proposed. Finally, a park level integrated energy system is selected for calculation and analysis. The output of each equipment in different periods is studied under the lowest total cost of the system, and the planning cost of the integrated energy system is obtained according to the unit cost of each equipment.

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