IOP Conf. Series: Earth and Environmental Science **192** (2018) 012037 doi:10.1088/1755-1315/192/1/012037

# The Research on P2G Gas-Electric Hybrid Optimal Economic Dispatch Strategy

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**Abstract.** In many forms of the multi-energy complementary system, the regional multi-energy complementary distributed energy distribution system including distributed photovoltaic power generation (PV) and power-to-gas (P2G) equipment is a typical form. The P2G system uses non-peak excess power to produce hydrogen gas. Hydrogen can be stored directly for use as fuel, or it can be converted to natural gas for storage, enabling conversion of electrical energy to chemical energy. In this paper, the energy conversion and interconnection between electric energy and gas realizes the coordinated operation of distribution network and natural gas network, reduces the distribution pressure of distribution network, and improves the economic efficiency of energy utilization. First, the principle of P2G technology is introduced, and then the mathematical models of source device, conversion device and energy storage device are constructed separately. On this basis, an economic optimization-based micro-network system optimization scheduling model is established to investigate the economic benefits of gas-electric hybrid. Finally, the micro-grid system of the two scenarios is compared in the example, and the results prove that P2G has a good promotion effect on the economic benefits of the park.

## 1. Introduction

In the international background of the world's energy crisis and environmental pollution problems, innovative ideas such as energy Internet and integrated energy systems are constantly emerging. Transforming energy consumption patterns and achieving efficient and clean use of energy have become the common goal of people all over the world. The initial definition of the energy Internet [1] is based on the power system, based on the Internet and other cutting-edge information technologies, with distributed renewable energy as the primary primary energy source. It is a complex multi-network system formed by tight coupling with other systems such as natural gas networks and transportation networks. One of the structural characteristics of the energy Internet is that natural gas has the advantages of high efficiency, clean and environmental protection, which is compared with other primary energy sources. With the development of natural gas extraction technology, the cost of natural gas has declined, and the penetration rate in the power generation industry has tended to increase. On the other hand, the emergence of P2G technology can convert the surplus of renewable energy into methane and then inject it into the natural gas network for transportation or storage. Therefore, the degree of coupling between the power system and the natural gas system is deepened. It is forming a closed-loop system in which energy can flow in both directions. The planning method for power systems alone cannot meet the rules and operational requirements of the energy Internet. ‘Gas-electric hybrid’ in this paper refers to the coordinated operation of distribution network and natural gas network through energy conversion and interconnection between electric energy and natural gas [2]-[4].

In this paper, the combination of electro-gas technology and micro-grid system is used to study the regional multi-energy complementary distributed energy distribution system with distributed photovoltaic power generation (PV) and gas-electric hybrid (P2G). It helps to improve the economic benefits of energy Internet planning and helps to eliminate the intermittent and random renewable energy. Based on the microgrid energy hub model [5], the user-side microgrid system architecture in two different scenarios is established, and the pre-scheduling scheduling model is established on this basis. Comparing and demonstrating the power grid purchasing power and gas turbine output capacity of the microgrid system in two scenarios, the example shows that the P2G gas and electricity hybrid has positively promoted the economic benefits of the park.

## 2. Introduction to P2G technology

The emergence of P2G technology has deepened the gas-electric coupling and formed a closed-loop operation of the power system and the natural gas system. In other words, the P2G technology produces $H_2$ and $O_2$ by electrolysis of $H_2O$, and then catalyzes the production of $CH_4$ by $H_2$ and $CO_2$. CH4 is the most important component of natural gas. P2G-converted CH4 can be directly injected into the natural gas network for transportation and storage. In addition, P2G is also beneficial to enhance the system's ability to accept intermittent renewable energy generation. By January 2016, there are about 50 P2G demonstration stations in Europe, most of which are located in Germany. The installed capacity of P2G ranges from a few kW to several MW [6], [7]. Compared with the capacity of modern interconnected power systems, the installed capacity of P2G projects at this stage is still very limited. The design capacity of future P2G projects will gradually increase with the advancement of technology. It will have an increasingly obvious impact on the coordinated planning and operation of power systems and natural gas systems.

P2G technology refers to the process of converting $H_2O$ and $CO_2$ into $H_2$ or $CH_4$ by using electric energy. It is mainly divided into two types: electric to $H_2$ and electric to $CH_4$ [8]. Considering that the natural gas network has very limited ability to absorb $H_2$ [9], the P2G referred to in this paper refers to the electric transfer $CH_4$ that can be directly connected to the natural gas network.

The realization process of P2G mainly consists of two steps of electrolyzing water and hydrogen methanation [10], [11].

Step 1: Electrolyzing water is to use electricity to electrolyze water to produce H2 and O2. The chemical equation [12] is shown as formula (2-1). At present, the energy conversion efficiency of this step can reach 75%-85% [13].

$$H_2O \overset{e}{\Leftrightarrow} H_2 + \frac{1}{2}O_2 \tag{2-1}$$

Step 2: Hydrogen methanation. It is also known as Sabatier catalytic reaction [9]. The H2 produced in the first step is chemically reacted with CO2 which is under high temperature and pressurized environment to produce H2O and CH4.The chemical reaction equation [14] is shown as formula (2-2). At present, the energy conversion efficiency of this step can reach 75%-80% [15].

$$CO_2 + 4H_2 \overset{c}{\Leftrightarrow} CH_4 + 2H_2O \tag{2-2}$$

The P2G energy conversion efficiency can reach 49%~65% [9]. The P2G plant station contributes to the surplus power generation of intermittent renewable energy. On the one hand, it balances the power generation of renewable energy. On the other hand, it realizes the flow of energy from the power system to the natural gas system, and promotes the power system and the natural gas system positively.

## 3. Microgrid mathematical model with P2G energy storage

The purpose of energy optimization management of the campus microgrid system is to find the optimal electric and gas power distribution method from the online unit of the system to meet specific operational objectives while satisfying the system constraints. This paper focuses on the optimization effect of the current scheduling strategy in energy management. It analyzes the structure of the park system, clarifies the objective function, optimizes variables and constraints, establishes an energy optimization management model, and constructs a numerical example for verification. It's focused on the impact of the economic strategy on P2G energy storage.

This section first classifies the various units within the system to establish a reasonable and accurate mathematical model. Generally, it includes a variety of energy kinds (electricity, gas, cold, heat, etc.). From the structure, it can be divided into energy input, conversion, output and other links. From the function, it can be divided into source equipment, conversion equipment and energy storage equipment. The microgrid system containing P2G energy storage studied in this paper can be represented by Figure 1.

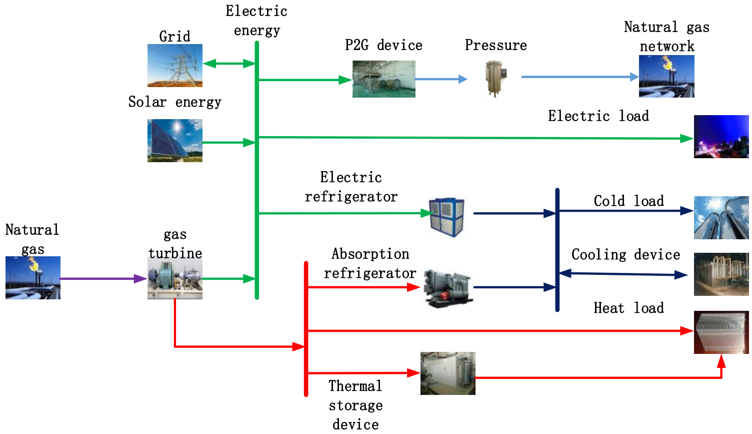



**Fig.1.** Typical structure of the park

As is shown in the figure 1, the source device refers to a device capable of generating heat, electricity, cold, and the like in the form of primary energy, and mainly includes a gas turbine, a power grid, a photovoltaic panel, and the like. A conversion device refers to a device capable of converting one form of energy generated by a source device or other device into another form of energy, mainly including a P2G conversion device, an electric refrigerant, an absorption refrigerating machine, and the like. The energy storage device refers to a device capable of storing energy, and mainly includes a gas storage device, a heat storage device, a cold storage device, and a power storage device.

*3.1 Mathematical model of the source device*

*3.1.1 Gas turbine*

$$\begin{cases} P_{GT} = V_{HG} \cdot q_{HG} \cdot \eta_{GT} \\ Q_{GT}^{s} + Q_{GT}^{w} = V_{HG} \cdot q_{HG} \cdot (1 - \eta_{GT} - \eta_{GT}^{loss}) \\ \eta_{GT}^{s} = Q_{GT}^{s}/P_{GT} \\ \eta_{GT}^{w} = Q_{GT}^{w}/P_{GT} \\ P_{GT}^{min} \le P_{GT} \le P_{GT}^{max} \end{cases} \quad (3\text{-}1)$$

Where $P_{GT}$, $Q_{GT}^{s}$ and $Q_{GT}^{w}$ represent the output of electric power, flue gas heat power and hot water heat power. $V_{HG}$ and $q_{HG}$ represent the consumption and calorific value of natural gas, respectively.$\eta_{GT}$,$\eta_{GT}^{loss}$,$\eta_{GT}^{s}$ and $\eta_{GT}^{w}$ represent power generation efficiency, energy loss rate, flue gas thermoelectric ratio, and hot water thermoelectric ratio.$P_{GT}^{min}$ and $P_{GT}^{max}$ represent the lower and upper limits of the output power.

*3.1.2 Solar power generation equipment*

Photovoltaic power generation equipment does not need to consider operational regulation, and the power generation can be used preferentially.

$$P_{PV}^{min} \le P_{PV} \le P_{PV}^{max} \quad (3\text{-}2)$$

$P_{PV}^{min}$ and $P_{PV}^{max}$ are the lower and upper limits of the power generated are respectively.

*3.2 Mathematical model of the conversion device*

*3.2.1 P2G device*

P2G device converts electrical energy into natural gas.

$$\begin{cases} P_{P2G}^{g} = \eta_{P2G} \cdot P_{P2G}^{c} \\ 0 \le P_{P2G}^{c} \le P_{P2G}^{rated} \end{cases} \quad (3\text{-}3)$$

$P_{P2G}^{c}$ *and* $P_{P2G}^{g}$ represent input and output power.$\eta_{P2G}$ is the efficiency factor of P2G device.$P_{P2G}^{rated}$ indicates the rated power of P2G device.

*3.2.2 Electric refrigerator*

Electric refrigerator is a device that converts electrical energy into cold energy.

$$\begin{cases} C_{EC} = P_{EC} \cdot COP_{EC} \\ C_{EC}^{min} \le C_{EC} \le C_{EC}^{max} \end{cases} \tag{3-4}$$

$P_{EC}$ and $C_{EC}$ are the input electrical power and the output cooling power.$COP_{EC}$ is refrigeration coefficient.$C_{EC}^{min}$ and $C_{EC}^{max}$ are the lower and upper limits of the output cooling power respectively.

*3.2.3 Absorption type heating and cooling machine*

The machine is used as a cold and heat energy conversion device.

$$\begin{cases} Q_{CH/C}^{out} = Q_{CH/C}^{in} \cdot \eta_{CH/C} \\ Q_{CH/C}^{min} \le Q_{CH/C}^{out} \le Q_{CH/C}^{max} \\ C_{CH/C}^{out} = Q_{CH/C}^{in} \cdot COP_{CH/C} \\ C_{CH/C}^{min} \le C_{CH/C}^{out} \le C_{CH/C}^{max} \end{cases} \tag{3-5}$$

$Q_{CH/C}^{in}$,$Q_{CH/C}^{out}$ and $C_{CH/C}^{out}$ are the input thermal power, the output thermal power, and the output cooling power.$\eta_{CH/C}$ and $COP_{CH/C}$ represent heating efficiency and cooling coefficient.$Q_{CH/C}^{min}$ and $Q_{CH/C}^{max}$ represent the lower and upper limits of the output thermal power.$C_{CH/C}^{min}$ and $C_{CH/C}^{max}$ are the lower and upper limits of the output cooling power。

*3.3 Mathematical model of energy storage equipment*

*3.3.1 Power storage device*

A power storage device has the ability to store electrical energy for a long time and to release electrical energy.

$$\begin{cases} 0 \le P_{ES,C} \le \gamma_{ES,C} \cdot Cap_{ES} \\ 0 \le P_{ES,D} \le \gamma_{ES,D} \cdot Cap_{ES} \\ W_{ES}^{min} \le W_{ES} \le W_{ES}^{max} \\ W_{ES}^{t} = W_{ES}^{t-1}(1-\sigma_{ES}) + (P_{ES,C} \cdot \eta_{ES,C} - \frac{P_{ES,D}}{\eta_{ES,D}})\Delta t \end{cases} \tag{3-6}$$

*3.3.2 Heat storage device*

A heat storage device has the ability to store thermal energy for a long time and to release thermal energy.

$$\begin{cases} 0 \le Q_{HS,C} \le \gamma_{HS,C} \cdot Cap_{HS} \\ 0 \le Q_{ES,D} \le \gamma_{ES,D} \cdot Cap_{HS} \\ W_{HS}^{min} \le W_{HS} \le W_{HS}^{max} \\ W_{HS}^{t} = W_{HS}^{t-1}(1-\sigma_{HS}) + (Q_{HS,C} \cdot \eta_{HS,C} - \frac{Q_{HS,D}}{\eta_{HS,D}})\Delta t \end{cases} \tag{3-7}$$

*3.3.3 Cool storage device*

A cold storage device has the ability to store refrigeration for a long time and to release the amount of refrigeration.

$$\begin{cases} 0 \le Q_{CS,C} \le \gamma_{CS,C} \cdot Cap_{CS} \\ 0 \le Q_{CS,D} \le \gamma_{CS,D} \cdot Cap_{CS} \\ W_{CS}^{min} \le W_{CS} \le W_{CS}^{max} \\ W_{CS}^{t} = W_{CS}^{t-1}(1-\sigma_{CS}) + (C_{CS,C} \cdot COP_{CS,C} - \frac{C_{CS,D}}{COP_{CS,D}})\Delta t \end{cases} \tag{3-8}$$

*3.3.4 Gas storage device*

The gas storage device can store natural gas and release natural gas for a long time.

$$\begin{cases} W_1 = W_0 + (Q_c\eta_c - Q_d/\eta_d)\Delta t \\ W_{min} \le W \le W_{max} \\ 0 \le Q_c \le Q_{c,max} \\ 0 \le Q_d \le Q_{d,max} \end{cases} \tag{3-9}$$

## 4. Energy optimization management of P2G multi-source energy storage microgrid

The daytime scheduling strategy of the campus system refers to the completion of the scheduling plan before the scheduling date, and then the scheduling plan is executed during the scheduling day without change.

*4.1 Objective function*

Considering the economics of the operation of the park system, the goal of daytime scheduling should minimize the cost of running the schedule. The operation scheduling cost does not consider the cost of purchasing, maintenance, overhaul, etc. of the equipment, and only includes the cost of purchasing electricity and gas. At the same time, regardless of whether the system sells electricity to the grid, the objective function is

$$\min C = C_e + C_g \tag{4-1}$$

$C$ represents the total cost of the operation schedule.$C_e$ and $C_g$ represent the purchase cost of electricity and natural gas respectively. It can be calculated by the equation (4-2).

$$\begin{cases} C_e = \sum_{t=1}^{n} c_e^t P_G^t \Delta t \\ C_g = c_g^t \sum_{t=1}^{n} (P_{CU}^t + P_{CH/C}^t + P_{GB}^t) \Delta t \end{cases} \tag{4-2}$$

*n* indicates the number of points in the schedule.$c_e^t$ and $c_g^t$ are the price of electricity and natural gas at the t-th scheduling time point.$P_G^t$,$P_{CU}^t$, $P_{CH/C}^t$ and $P_{GB}^t$ respectively indicate the purchase power of the grid during the t-th scheduling time, the gas power consumed by the cogeneration unit, the gas power consumed by the heating and cooling unit, and the gas power consumed by the gas boiler. $\Delta t$ indicates the interval duration between two adjacent scheduling time points.

*4.2 Restrictions*

Each component of the system should meet its respective output power constraints：

$$\begin{cases} P_{imin} \le P_i \le P_{imax} \\ Q_{imin} \le Q_i \le Q_{imax} \\ C_{imin} \le C_i \le C_{imax} \end{cases} \tag{4-3}$$

$P_i$ , $Q_i$ and $C_i$ respectively indicate the electric power, thermal power and cooling power output of a certain component.The subscript min indicates the lower limit of the output power, and the subscript max indicates the upper limit of the output power.

For energy storage equipment, the following constraints should also be met.

*4.2.1 Charge/discharge power constraints*

$$\begin{cases} P_{min}^C \le P_{ES,C} \le P_{max}^C \\ Q_{min}^C \le Q_{HS,C} \le Q_{max}^C \\ C_{min}^C \le C_{CS,C} \le C_{max}^C \end{cases}, \begin{cases} P_{min}^D \le P_{ES,D} \le P_{max}^D \\ Q_{min}^D \le Q_{HS,D} \le Q_{max}^D \\ C_{min}^D \le C_{CS,D} \le C_{max}^D \end{cases} \tag{4-4}$$

*4.2.2 Energy storage constraints*

$$W_{imin} \le W_i \le W_{imax} \tag{4-5}$$

*4.2.3 Energy storage mechanism constraints*

$$W(t+1) = (1-\sigma)W(t) + (P_c\eta_c - P_D/\eta_D)\Delta t \tag{4-6}$$

$W(t)$ and $W(t+1)$ represent the energy storage at the current time and the next time respectively.σ is energy self-loss rate.$P_c$ and $P_D$ represent charge/discharge power.$\eta_c$ and $\eta_D$ indicate the efficiency at the time of charge/discharge.

*4.2.4 Working state constraints*

Let 0-1 variable X(1, t) denote the energy storage state of the energy storage device at time t. $X(1,t)$=1 indicates that the device is in energy storage state,and $X(1,t)$=0 indicates the device is not in storage state. Similarly, let 0-1 variable $X(2,t)$ denote the discharging energy state at time t.As is known,the energy storage and discharge states cannot exist at the same time

$$X(1,t) + X(2,t) \le 1 \tag{4-7}$$

## 5. Case analysis

The example system constructed in this paper is shown as Figure 2. The system source equipment includes a utility grid, a photovoltaic device, a gas turbine, and the conversion device includes an electric gas transfer device, an electric refrigerator, an absorption type warm and cold machine, a heat pump, an energy storage device, a storage battery, and a storage battery, and the load includes an electric load, a heat load, and a cold load. In order to compare the differences in electric power of microgrid systems in different scenarios, this paper compares and analyzes the economic dispatch results of two different structures.

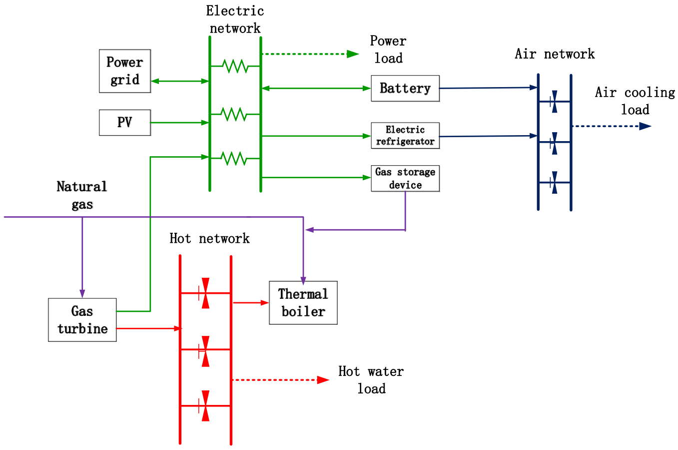



**Fig.2.** Study structure diagram

In the first scenario, the microgrid system does not contain energy storage equipment and P2G equipment, and only contains coupling elements between different energy sources. In the second scenario, the microgrid system adds P2G equipment and gas storage equipment to improve the coupling characteristics of the power network and the natural gas network. The model device types of the two microgrid systems are shown in Table 1.

**Table.1.** Components of two microgrid systems

| Device | Scene 1 | Scene 2 |
|---|---|---|
| Gas Turbine | ✓ | ✓ |
| PV | ✓ | ✓ |
| Hot and cold machine | ✓ | ✓ |
| Electric refrigerator | ✓ | ✓ |
| P2G | × | ✓ |
| Electric energy storage | ✓ | ✓ |
| Thermal energy storage | ✓ | ✓ |
| Cold energy storage | ✓ | ✓ |
| Gas storage | × | ✓ |

As is shown,it is the main calculation data used in this example. The daily scheduling period takes 1 hour.In the system,the daily load and PV output prediction curve are shown in Figure 3.The time-of-use price and natural gas price are shown in Figure 4.

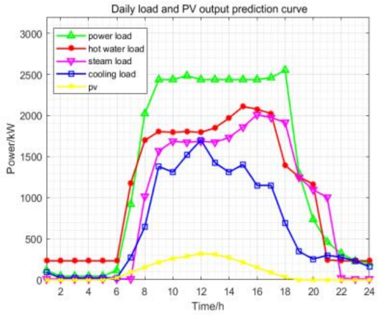



**Fig.3.** Daily load and PV output prediction curve

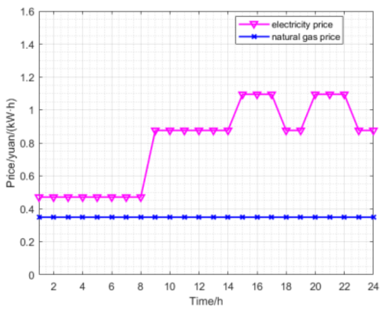
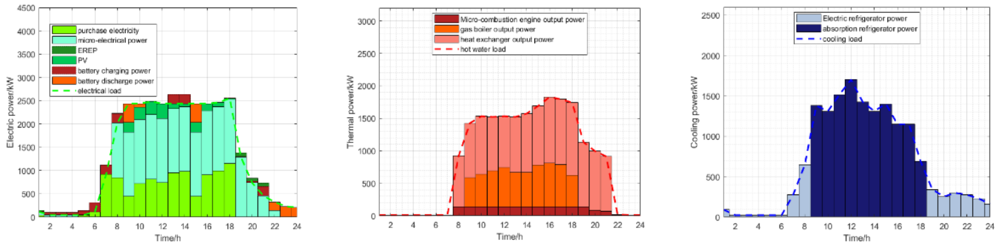



**Fig.4.** Time-sharing tariff

Don't consider the influence of the electrical gas conversion characteristics on the daily dispatching strategy. According to the system parameters, the MATLAB program is programmed, and the CPLEX solver in the YALMIP toolbox can be called to obtain the optimal scheduling results of cold, heat and electric power.

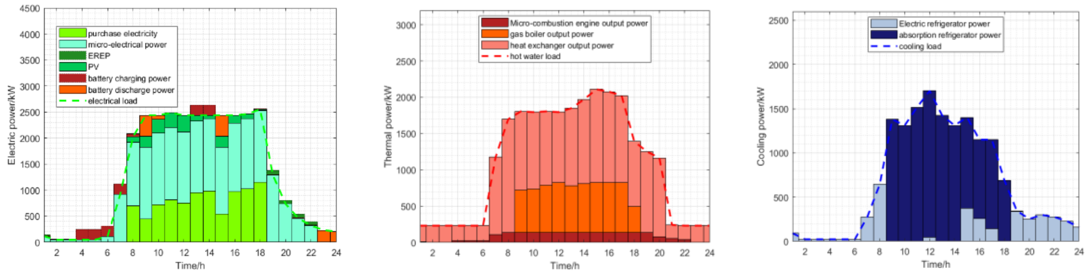



（a）Electric power optimization (b) Hot water power optimization（c）Cooling power optimization

**Fig.5.** Day-time optimization scheduling results without P2G

Without considering P2G equipment and energy storage equipment, the daily operating cost of the system is 40,156 yuan.

When considering the characteristics of electrical gas conversion, the optimal cooling, heat and electricity scheduling results of the system are shown in Figure 6.

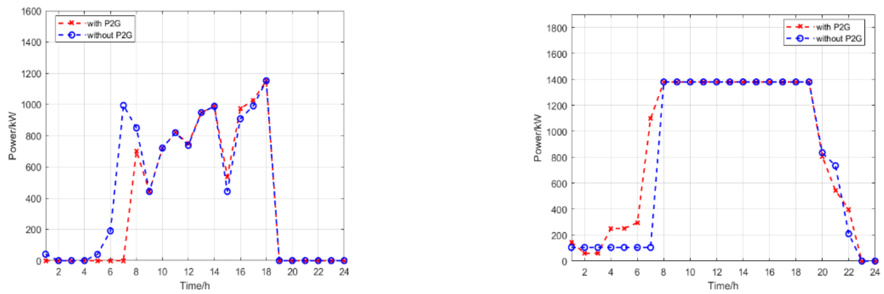



（a）Electric power optimization (b) Hot water power optimization (c)Cooling power optimization

**Fig.6.** Day-time optimization scheduling results with P2G

In the case of considering P2G equipment and energy storage equipment, the daily operating cost of the system is 38,750 yuan.

Considering the electrical gas conversion characteristics, the power purchase power of the grid and the gas power of the gas turbine are compared as follows.




（a）Grid purchase power comparison chart (b) Gas turbine electric power output comparison chart

**Fig.7.** Consider the P2G characteristics output comparison chart

The running cost with P2G is lower than that without P2G. The reason is that when the P2G device is added, the cost of the microgrid system will be reduced without considering the cost of the device.It can be seen from Fig.7.The power purchase power of the grid changes significantly between the 4th and 8th scheduling moments;the output power of the gas turbine changes significantly before the 8th scheduling time point and after the 20th scheduling time point. Therefore, P2G equipment consumes residual solar energy, reduces power purchase power of the grid, and increases gas turbine output.

## 6. Conclusion

This paper combines P2G equipment and micro-grid system to construct a multi-source energy storage micro-network system model in two scenarios. On this basis, the goal of the P2G multi-source energy storage microgrid system is established. In both scenarios, the impact of P2G device access on system cost is analyzed. Finally, through the example verification, P2G can reduce the overall energy purchase cost of the system. In the follow-up work, on the one hand, the model of the microgrid system in this paper is relatively simple, and the equipment cost is not considered, and the system model construction will be further improved; On the other hand, the scheduling strategy is a relatively rough energy management method. In the future, the intraday scheduling strategy will be considered to improve the prediction accuracy.

## 7. Acknowledgements

I really appreciate the help from my tutor and classmates. With their help, I finished the paper.

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