Research on Coordinated Optimization of Integrated Intelligent Energy Supply

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Abstract. The coordination and optimization of integrated intelligent energy resources is an advanced energy supply strategy. And it is also a key issue for the development of integrated intelligent energy resources. Meanwhile, the characteristics of energy supply equipment and equipment, load characteristics and user needs should be taken into account. In this paper, an integrated intelligent energy system of some enterprise is taken as an example to research the coordinated optimization of integrated intelligent energy supply. The energy supply facilities in the park include CCHP system, photovoltaic power generation system, water storage system and municipal power supply, cooling and heating. How to coordinate and optimize these energy supplies according to the characteristics of each energy supply unit, load time domain, electricity and gas price information will be the main content of this paper. In this paper, a coordinated energy supply strategy is proposed. And a whole system model is established. At last, the advantage of the strategy and the model is verified through simulation.

1. Introduction

At present, some basic theoretical studies have been completed in developed countries such as Europe, America and Japan. And the results of integrated energy utilization have been preliminarily verified by laboratory tests and field demonstration projects[1~3]. In China, with the development of industrial parks, the popularization of new energy generation and the upgrade of new investment mode, the new demands come out. Developing comprehensive intelligent energy system and making full use of the advantages of various energy sources to achieve coordinated energy supply have become the best choice. At present, there are some demonstration projects in China, which have achieved some demonstration results in distributed gas turbines and energy cascade utilization[4~6]. Combined with the on-going energy system reform in China, it will gradually changes the difficulty situation, such as the single operation mode of power grid, heat network and gas network, the coordination between different business departments, inconsistent planning and inefficient operation. It can be expected that the coordinated energy supply of integrated intelligent energy resources will become the benefit of future energy network operation companies.

As an advanced energy supply strategy, the coordination and optimization of integrated intelligent energy resources is also a key issue in the development of integrated intelligent energy. The multiple energy sources can be utilized comprehensively through the coordination of various distributed energy supply units. Thus, it can effectively improve the full absorption of intermittent energy, the stability and economy of the system.
In order to coordinate and optimize energy supply, the characteristics of energy supply equipment, load and user needs should be taken into account. In this paper, the integrated intelligent energy system of an enterprise park is taken as an example to study the coordinated optimization of integrated intelligent energy supply. The energy supply facilities in the park include CCHP system, photovoltaic power generation system, water storage system and municipal power supply, cooling and heating. How to coordinate and optimize these energy supplies according to the characteristics of each energy supply unit, the characteristics of load time domain, electricity and gas price information will be the main content of this paper.

2. System and energy supply strategy analysis
The system energy supply diagram is shown in figure 1.

![System Energy Supply Diagram](image)

Figure 1. The system energy supply diagram

From the diagram, it can be seen that the electric load of the system is supplied by the gas turbine generator set of the triple-generation system and the power grid. The cold and heat load is supplied by the lithium bromide unit of the triple-generation system, the water storage system and the conventional electric refrigerator. According to the need, the power external characteristic model and cost model of these energy supply units are established. And the cost of purchasing electricity and gas are considered in the cost model, while the cost of equipment maintenance, depreciation and other operating cost and the cost of pollutant discharge treatment are not considered.

The summer load of this park is taken as an example. All the basic data is as shown in figure 2.

![Basic Data Analysis Chart](image)

Figure 2. The basic data analysis chart

According to the above analysis, the following strategy analysis is made.
(1) solar energy is the cleanest energy, and the installed capacity is small, so power generation is preferred. According to the load size and the predicted power generation size of photovoltaic, the maximum power can also be used for photovoltaic power generation when there is no energy storage in the system.

(2) in order to ensure the maximum efficiency of the gas generator, the cooling capacity made by the waste heat of the combined cooling heating and power (CCHP) system is preferred for the cooling load.

(3) for the insufficient part of CCHP supply, grid power supply shall be used.

(4) there are many peak price periods in the daytime and valley price in the early morning. In the peak price period, the system load demand is large, while in the valley price period, the system load demand is small. Using the peak valley difference of electricity price, we can refrigerate and store the cold in the valley price period and releases the cold in the peak price period. The CCHP system also participates in the coordination of energy supply in the peak price period.

3. Coordinated optimization model

3.1. Objective Function

Taken the minimum economic cost as the goal, considering the power and gas purchase cost, not considering the operation cost such as equipment maintenance, depreciation and pollutant emission treatment cost, objective function of the coordinated optimization energy supply is established as follow.

\[
\min \quad C_{\text{total}}(t) = C_{\text{grid}}(t) + C_{\text{gas}}(t)
\]

Where,

\[
C_{\text{grid}}(t) = r_{\text{elc}}(t) \cdot E_{\text{grid}}(t)
\]

\[
C_{\text{gas}}(t) = r_{\text{gas}}(t) / n_{\text{gas}} \cdot F_G(t)
\]

\[
E_{\text{grid}}(t) = E_{\text{czl}}(t) + E_{\text{elc}}(t)
\]

In this formula, \(C_{\text{total}}(t)\) is the total cost. \(C_{\text{grid}}(t)\) is the purchasing electricity cost. \(C_{\text{gas}}(t)\) is the purchasing gas cost. \(r_{\text{elc}}(t)\) is the electricity price. \(E_{\text{grid}}(t)\) is the quantity of purchasing electricity. \(r_{\text{gas}}(t)\) is the gas price, \(n_{\text{gas}}\) is the gas heat value. \(F_G(t)\) is the gas consumption of gas turbine. \(E_{\text{czl}}(t)\) is electric energy required by conventional electric refrigerator. \(E_{\text{elc}}(t)\) is the electricity of electric load demand.

3.2. Constraint Condition

3.2.1. Electric load balance. The electric power provided by the supply side of the system is balanced with the electric load power of the system, as follow.

\[
P_G(t) + P_{\text{PV}}(t) + P_{\text{grid}}(t) = P_{\text{elcload}}(t) + P_{\text{czl}}(t)
\]

In this formula, \(P_G(t)\) is the electrical power provided by the CCHP, \(P_{\text{PV}}(t)\) is the photovoltaic power, \(P_{\text{grid}}(t)\) is the electrical power provided by the grid, \(P_{\text{elcload}}(t)\) is the electrical load of the system, \(P_{\text{czl}}(t)\) is the input power of the conventional electric refrigerator.

3.2.2. Cooling load balance. The cooling power provided by the supply side of the system is balanced with the cooling load of the system, as follow.

\[
P_{\text{xlz}}(t) + P_{\text{czl}}(t) + P_{\text{xlg}}(t) = P_{\text{iload}}(t)
\]
In the formula, $P_{xz1}(t)$ is the cooling power provided by the lithium bromide waste heat unit of CCHP. $P_{czl}(t)$ is the cooling power provided by the conventional electric refrigerator. $P_{xlgl}(t)$ is the cooling power provided by the energy storage tank. $P_{load}(t)$ is the cooling load of the system.

3.2.3. Output restriction of each energy supply unit.

(1) Gas generator.
The generating power shall be greater than the minimum cut-off power and less than the rated power, as follow.

$$P_{Gmin} \leq P_G(t) \leq P_{G0} \quad (7)$$

Where, $P_{Gmin}$ is the minimum cut-off power and $P_{G0}$ is the rated power of gas generator.

(2) Lithium Bromide Unit
The cooling power generated shall be less than the rated power.

$$0 \leq P_{xz1}(t) \leq P_{xz10} \quad (8)$$

Where, $P_{xz10}$ is the rated power of lithium bromide waste heat unit.

(3) Energy storage tank
The cooling capacity in the energy storage tank shall meet the following conditions

$$Q_{sdgmin} \leq Q_{xlgl}(t) \leq Q_{sdgmax} \quad (9)$$

Where, $Q_{sdgmin}$ is the minimum storage capacity of the energy storage tank, and $Q_{sdgmax}$ is the maximum.

(4) Photovoltaic

$$0 \leq P_{PV}(t) \leq P_{PV0} \quad (10)$$

Where, $P_{PV}(t)$ is the photovoltaic power, and $P_{PV0}$ is the rated power of photovoltaic power.

(5) Conventional generator

$$0 \leq P_{czl}(t) \leq P_{czl0} \quad (11)$$

Where, $P_{czl}(t)$ is the cooling power provided by the conventional refrigerator, and $P_{czl0}$ is the rated power provided by the conventional refrigerator.

4. Simulation
An enterprise park is taken as an example for simulation verification and analysis. The basic information of the park is as follows:

4.1. Supply side. (1) At present, there is a substation in the superior power grid of the park, which is 110kV.

(2) Two 10kV medium voltage buses are used for power distribution, with interconnection switch set in the middle; and four transformers in operation in low-voltage distribution system, which is 10kV / 0.4kV.

(3) CCHP system. A 635kw internal combustion engine and flue gas hot water LiBr unit matched, which the refrigerating capacity is 700kW and the heating capacity is 600kW.

(4) Distributed roof photovoltaic power generation system. The total installed capacity is 300kWp

(5) Energy storage system of water storage tank. There are three 200m$^3$ energy storage tank.

4.2. Demand side. There are three research buildings and one test plant in the park. This paper takes the research building as the main power consumption object.

Based on the previous chapter’s analysis and the proposed energy supply strategy and model, the simulation is carried out in the MATLAB environment.

The traditional system without integrated intelligent energy, integrated energy system with CCHP and photovoltaic and integrated intelligent energy system with CCHP, photovoltaic and energy storage tank are respectively simulated. The simulation results are shown in figure 3, 4 and 5.
It can be seen from the figure that the power supply of the original system only depend on the power grid. In the integrated energy system with CCHP and photovoltaic, the electric load is jointly supplied by CCHP, photovoltaic and the grid, and the cooling load is jointly supplied by CCHP and municipal cooling. In the integrated intelligent energy system of CCHP, photovoltaic and energy storage tank, the electric load is jointly supplied by CCHP, photovoltaic and the grid, and the cooling load is jointly supplied by CCHP, energy storage tank and municipal cooling. Guided by the economy, the energy storage tank stores the cold power at the valley price at night and releases it at the peak price in the day.

Under the three operation schemes, the cost calculation results of the system are shown in table 1.
Table 1. Cost results

| Scheme                          | electricity cost (yuan) | gas cost (yuan) | total energy cost (yuan) | cost saving (yuan) | energy supply equipment          |
|--------------------------------|-------------------------|-----------------|--------------------------|--------------------|----------------------------------|
| original traditional system    | 51544                   | 0               | 51544                    | 0                  | Grid                             |
| integrated intelligent energy system | 36127                 | 6406            | 42533                    | 9011               | Grid, CCHP, PV                   |
| integrated intelligent energy system | 34773                 | 6406            | 41179                    | 10365              | Grid, CCHP, PV, energy storage tank |

It can be seen from table 1 that intelligent energy coordinated optimization of energy supply has obvious advantages in economy. That verifies the correctness and superiority of the optimization energy supply strategy and model proposed in this paper.

5. Conclusion
The coordinated optimization is a key issue for the development of integrated intelligent energy resources. And it is an advanced energy supply strategy. The multiple energy sources can be utilized comprehensively through the coordination of various distributed energy supply units. Thus, it can effectively improve the full absorption of intermittent energy, the stability and economy of the system.

In this paper, an integrated intelligent energy system of some enterprise is taken as an example to research the coordinated optimization of integrated intelligent energy supply. A coordinated energy supply strategy is proposed. And a whole system model is established. The simulation verified the correctness and superiority.

With the development of industrial parks, developing comprehensive intelligent energy system and making full use of the advantages of various energy sources to achieve coordinated energy supply have become the best choice. Thus, coordinated optimization of integrated intelligent energy supply shall be paid more and more attention.

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