Operation optimization of multi-energy flow integrated energy system based on multi-objective

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Abstract. In order to solve the problem that most of the existing combined cooling, heating and power integrated energy systems only consider the investment cost of the system unit or the system environmental pollution affecting the overall optimization of the system, with the goal of system economy and environmental protection, the construction of gas turbines, gas boilers, The optimization model of the combined cooling, heating and power system of electric refrigerators and other units and the establishment of constraint conditions; according to the requirements of the cooling, heating, and electric loads in the dispatch cycle, as well as the energy supply efficiency of each equipment of the system, the starting and stopping power and other operating parameters are in the interval. Based on the respective data, a multi-energy flow regional integrated energy system economic dispatch optimization operation strategy optimized within the dispatch period is proposed. The results show that the operation strategy can take into account the economy and environmental protection of the system at the same time, make the system operation more optimized.

1 Introduction

Existing energy systems are often planned and operated separately, resulting in low energy utilization and high pollution [1]. Nowadays, people are more researching how to coordinate and optimize each independent energy supply system to reduce its environmental pollution while increasing energy efficiency and economic performance [2]. The large-scale access of various energy sources has led to the fact that the energy system is often unable to balance economy and environmental protection, and the ability to optimize operation is insufficient. Therefore, how to optimize the integrated energy system and take into account the economy and environmental protection of system operation has become a problem that needs to be solved [3]. Ref. [4] used linear models to configure the optimal capacity of power, natural gas, and thermal systems to improve the energy utilization efficiency of the system; Ref. [5] considered carbon emissions and the consumption of renewable energy, and proposed a new hybrid power flow calculation method to ensure the economic and stable operation of the combined heat and power microgrid.

$$C_{CCHP} = R(C_{inf.GT}P_{cap.GT} + C_{inf.GB}P_{cap.GB} + C_{inf.GE}P_{cap.GE} + C_{inf.EC}Q_{cap.EC}) + C_{inf.AC}Q_{cap.AC} \quad (2)$$

In formula (2): R is the capital recovery rate; $P_{cap.GT}$, $P_{cap.GB}$, $P_{cap.GE}$ are the rated electric power of gas turbines, gas boilers, and natural gas internal

The objective function is established with the optimal system economy and environmental protection, and the constraint conditions are established, and the optimization model of the combined cooling, heating and power (CCHP) system is established; finally, the results are analyzed and studied in combination with the calculation example. The system's operating results under a single goal and taking into account multiple goals at the same time provide a reference for the later collaborative optimization of IES.

2 collaborative optimization objective function of IES

The goal is to minimize the economic cost and optimal environmental protection of the integrated energy system. The economic cost of the system is mainly divided into unit investment cost C_{CCHP} , electricity purchase cost C_e and natural gas purchase cost C_g . The objective function is

$$C_J = C_{CCHP} + C_e + C_g \quad (1)$$

combustion engines respectively; $Q_{cap.EC}$ and $Q_{cap.AC}$ are electric refrigerators, The rated cold power of

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absorption chillers; $C_{inf.GT}$, $C_{inf.GB}$, $C_{inf.GE}$, $C_{inf.EC}$, $C_{inf.AC}$ are gas turbines, gas boilers, natural gas internal combustion engines, electric refrigerators and absorption chillers within the rated power, respectively operating costs.

$$C_e = \sum_{t=1}^T c_{e,t} P_{e,t} \quad (3)$$

In formula (3): T is one operating cycle of the system; C_e is the unit price of electricity purchased by the system during t period, and P_e is the purchase power of the system during t period.

$$C_g = \sum_{t=1}^T c_g P_{g,t} \quad (4)$$

In formula (4): C_g is the unit price of natural gas purchased by the system during the period t ; $P_{g,t}$ is the gas purchased power of the system during the period.

During system operation, the combustion of natural gas produces carbon dioxide gas. Therefore, when the system is running, the emission: the objective function of the environmental protection cost C_H of carbon dioxide is

$$C_H = W_{CO_2} [\varepsilon_e P_{EC}^{IN} + \varepsilon_g (P_{GT.g} + P_{GB.g} + P_{GE.g})] \quad (5)$$

In formula (5): W_{CO_2} is the unit price of CO_2 emission; ε_e is the emission coefficient of carbon dioxide per unit of electric power; ε_g is the carbon dioxide emission coefficient of unit volume of natural gas. The overall system optimization function C_Z is

$$C_Z = \min(C_J + C_H) \quad (6)$$

3 Integrated energy system modeling and constraints

3.1. Integrated energy system modeling and constraints

The CCHP is the most commonly used in IES. The mathematical model and constraints of the gas turbine are

$$\begin{cases} P_{GT.e} = \eta_{GT}^e P_{GT.g} \\ P_{GT.h} = \eta_{GT}^h P_{GT.g} \end{cases} \quad (7)$$

Where: $P_{GT.e}$ is the power generation of gas turbine; $P_{GT.h}$ is the heat generation power; η_{GT}^e is the power

generation efficiency; η_{GT}^h is the heat generation efficiency; $P_{GT.g}$ is the gas consumption power.

The mathematical model and constraints of the gas boiler are

$$P_{GB.h} = \eta_{GB}^h P_{GB.g} \quad (8)$$

Where: $P_{GB.h}$ is the heating power of the gas boiler; $P_{GB.g}$ is the gas consumption power; η_{GB}^h is the heat generation efficiency.

The mathematical model of a natural gas internal combustion engine is

$$\begin{cases} P_{GE.e} = \eta_{GE}^e P_{GE.g} \\ P_{GE.h} = \eta_{GE}^h P_{GE.g} \end{cases} \quad (9)$$

Where: $P_{GE.e}$ is the power generated by natural gas internal combustion engine; $P_{GE.h}$ is the heat generation power; η_{GE}^e is the power generation efficiency; η_{GE}^h is the heat generation efficiency; $P_{GE.g}$ is gas consumption power. The mathematical model of the electric refrigerator is

$$Q_{EC}^{OUT} = COP_{EC} P_{EC}^{IN} \quad (10)$$

In formula (14): COP_{EC} is the output cooling power of the electric refrigerator; P_{EC}^{IN} inputs the electric power; COP_{EC} is the cooling coefficient of the electric refrigerator.

The mathematical model of the absorption chiller is

$$Q_{AC} = COP_{AC} Q_{AC}^h \quad (11)$$

In formula (15): Q_{AC} is the output cooling power of the absorption chiller; COP_{AC} is the cooling coefficient; Q_{AC}^h is the input heating power.

The power balance constraint relation of electric energy, natural gas, heat energy and cold energy in this system is

$$\begin{cases} P_{e,t} + P_{GT.e} + P_{GE.e} - P_{EC}^{IN} = L_e \\ P_{GT.h} + P_{GB.h} + P_{GE.h} + Q_{AC} = L_h \\ P_{g,t} + P_{GT.g} + P_{GB.g} + P_{GE.g} Q_{AC}^s = L_g \\ P_{EC}^{OUT} + P_{AC} = L_c \end{cases} \quad (12)$$

Where: L_e is the electrical load delivered by the system to the user side; L_h is the heat load delivered by the

system to the user side; L_g is the gas load delivered by the system to the user side; L_c is the cooling load delivered by the system to the user side.

4 Case analysis

In order to verify the economics of the regional integrated energy system dispatching strategy for cooling, heating and power, and the correctness of the established system model, the summer daily load data of an office building in a park is used as the load data of the system to carry out the system Optimal scheduling, using 0-1 mixed integer linear programming method to solve the dynamic economic model.

The rated capacity of each equipment in the calculation example system in this paper is as follows: (1)

Figure1. Forecast value of cold, heat and electric load

The micro gas turbine is a micro gas turbine with a rated capacity of 200 kW; (2) The heat exchanger rated power is 180 kW; (3) The rated heating power of the electric boiler is 150kW; (4) The rated cooling capacity of the absorption chiller is 200kW; (5) The rated power of the electric chiller is 200kW.

The system includes a gas turbine generator, a natural gas internal combustion engine and a set of power storage equipment. The price of natural gas in the system is 3.12 yuan/m³, and the daily load curves and electricity prices of various energy sources are shown in Figures 1 and 2. Based on the improved algorithm, the combined cooling, heating and power system model is optimized and solved with the best economic efficiency, the best environmental protection, and the comprehensive consideration of system economy and environmental protection. The solution results are shown in Table 1.

Figure 2. Electricity price chart

Table 1. Electricity price (Unit: ten thousand yuan)

Optimization goal	C_J	C_H	C_Z
Minimal operating cost	1103.23	60.32	1163.55
Minimal environmental cost	1131.63	57.04	1188.67
Minimal overall cost	1103.79	57.58	1161.47

The system model fully meets the needs of cold, heat, and electricity loads. The specific conditions of the optimized scheduling operation are as follows:

1) During periods of low electricity prices, since the overall economic benefits of CCHP with micro-gas turbines are not as good as the economic benefits of purchasing electricity from the grid, energy is mainly supplied by the grid.

2) During the period of flat electricity price, the economic benefits of CCHP supply with micro-gas turbines are equivalent to the economic benefits of power grid purchase.

3) At peak power prices, the economic benefits of CCHP with micro-gas turbines are better than those of power grid purchases.

5 Conclusion

In this paper, an optimization model of CCHP is established, and the objective function and constraint

conditions are constructed with the lowest operating cost and the lowest environmental cost caused by CO₂ emissions. The model solution results prove that the improved solution can take into account the economic and environmental aspects of the system.

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