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Energy optimization and scheduling of natural gas cogeneration industrial park considering photovoltaics

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Abstract. Combined heat and power (CHP) has important application value for realizing sustainable energy development and building a green and low-carbon society, but the complex internal energy structure and equipment coupling relationship also brings challenges to its operation optimization. In this paper, the energy optimization scheduling is studied on the natural gas cogeneration industrial park microgrid, and a multi period dynamic optimization scheduling model for the natural gas cogeneration industrial park microgrid with the goal of minimizing operating costs is established. The network operation characteristics constraints of the cooling network, heating network, power supply network, and gas supply network is considered, as well as the impact of various types of energy storage devices on microgrid scheduling. Based on the scenario method, a industrial park microgrid energy optimization scheduling model considering random fluctuations in photovoltaic output is established. Measures such as quickly adjusting the energy storage and discharge power of the energy storage device are taken to balance the uncertain fluctuations in photovoltaic output. Taking a natural gas cogeneration industrial park microgrid as an example, the correctness and effectiveness of the proposed optimization scheduling model are verified. The calculation results show that the obtained microgrid operation scheduling scheme can effectively save energy consumption and reduce microgrid operation costs; The collaborative operation of multiple types of energy storage devices can more effectively reduce the operating costs of microgrids and is conducive to smoothing out the uncertain fluctuations of photovoltaic power generation.

Keywords: combined heat and power, thermoelectrolytic coupling, multi-energy complementarity.

1. Introduction

In order to support the low-carbon transformation of China's industry, build a sustainable and environment-friendly society, and ensure the smooth achievement of the dual carbon goals, it is very important to systematically study the carbon emissions of industrial parks, conduct zero-carbon deductions and plan carbon reduction paths, so as to guide the construction of clean and efficient industrial parks from the theoretical level. The balance of electricity, gas, cold and heat in the operation of the microgrid of the whole natural gas combined cooling, heating and power industrial park involves the coordinated operation of various energy supply equipment such as power supply, gas supply, cooling and heating Therefore, it is of great practical significance for the development, popularization and application of microgrid technology and the efficient utilization of renewable energy in natural gas cogeneration parks to reasonably describe the mathematical models of various energy supply equipment in the microgrid, establish their energy optimization scheduling models, and study the optimal operation mode of the microgrid after the access of distributed renewable energy.

Based on a variety of emission reduction schemes, the key to analyzing the carbon emissions of industrial parks is to construct a comprehensive economic model that can effectively solve the carbon neutrality problem of industrial parks. The research body of Ref. [1] is a type of electricity-gas integrated energy system, which studies the effect of reducing carbon emissions by using carbon capture technology, and proposes a more economical low-carbon operation strategy. In Ref. [2], the coupling relationship between the coal chemical system and the wind power-hydrogen energy storage system was studied, and the coal chemical system was continuously operated with the rated output under the limitation of maximum wind power consumption, and a local WP-HES&CCMFCS twolayer control model was constructed, which provided an idea of maximizing the consumption of clean energy in a fixed system environment. Ref. [10] provides an optimization strategy for the allocation of wind, solar, fuel and storage in the park, which is more economical than that of a single gas turbine trigeneration. In Ref. [4], a carbon emission assessment model was established to evaluate and measure the carbon emissions of the park. Compared with the baseline scenario and the zero-carbon scenario, the carbon reduction of different carbon reduction measures such as building energy conservation, renewable energy utilization, water conservation and non-traditional water utilization, green travel, and garbage disposal in green space was analyzed, but the carbon emission analysis only focused on the annual data and did not penetrate to a more detailed time granularity.

2. Industrial Park CHP microgrid base model

In this paper, the CHP microgrid system is mainly composed of a fan, a photovoltaic, a gas turbine, a waste heat boiler, a gas boiler, a storage battery, and a regenerative electric boiler, in which the gas turbine and the waste heat boiler constitute the cogeneration unit, and the battery and regenerative electric boiler are used as electric energy storage and thermal energy storage devices respectively.

2.1. Combined heat and power unit model

The combined heat and power unit consists of a gas turbine and a waste heat boiler, the heat generated by the combustion of natural gas drives the gas turbine to generate electricity, and the exhaust high-temperature flue gas is recovered by the waste heat boiler and converted into heat energy that can directly supply the heat load. The corresponding models are as follows.

$$\begin{cases} P_{GT,t} = \eta_{GT} H_{GT,t}^{max} \\ H_{GT,t} = \alpha_{GT} P_{GT,t}^{max} \end{cases} \tag{1}$$

$$\begin{cases} P_{GT,t}^{min} \leq P_{GT,t} \leq P_{GT,t}^{max} \\ \Delta P_{GT,t}^{min} \leq \Delta P_{GT,t} \leq \Delta P_{GT,t}^{max} \end{cases} \tag{2}$$

where $P_{GT,t}$ and $H_{GT,t}$ are the discharge power of the cogeneration unit and exothermic power respectively. $H_{GT,t}^{max}$ is the thermal power of natural gas consumed by a cogeneration unit. η_{GT} and α_{GT} are the number of thermoelectric components, respectively. $P_{GT,t}^{min}$ and $P_{GT,t}^{max}$ are the upper and lower limits of the discharge power of the thermal power unit respectively. $\Delta P_{GT,t}^{min}$ and $\Delta P_{GT,t}^{max}$ are the ramp-up rate of power generation and the upper and lower limits of the ramp-up rate of thermal power units.

2.2. Gas boiler model

Gas boiler can convert the chemical energy contained in natural gas into heat energy with a constant conversion efficiency, and its model is as follows:

$$H_{GB,t} = \eta_{GB} H_{GB,t}^{gas} \tag{3}$$

where $H_{GB,t}$ is the exothermic power of gas boilers. η_{GB} is the gas boilers gas-heat conversion rate. $H_{GB,t}^{gas}$ is the thermal power of natural gas consumed by a gas boiler.

2.3. Photovoltaic output constraints:

$$0 \leq P_{PV,p,t} \leq \gamma_{PV,p,t} Q_{PV,p} \tag{4}$$

where $\gamma_{PV,p,t}$ is the standardized output prediction curves for photovoltaic power plants, respectively.

2.4. Energy storage operation constraints:

$$0 \le P_{ES,e,t}^{Dis} \le Q_{ES,e} \tag{5}$$

$$0 \le P_{ES,e,t}^{Cha} \le Q_{ES,e} \tag{6}$$

$$S_{e,t} = S_{e,t-1} + \eta_e^{Cha} P_{ES,e,t}^{Cha} - \frac{P_{ES,e,t}^{Dis}}{\eta_e^{Dis}} \tag{7}$$

$$0 \le S_{e,t} \le H_e Q_{ES,e} \tag{8}$$

$$S_{e,0} = S_{e,N_T} = \lambda_{ES,e}^{min} H_e Q_{ES,e} \tag{9}$$

where: $S_{e,t}$ the state of charge of the energy storage device at the t moment, η_e^{Cha} and η_e^{Dis} are the charging and discharging efficiency of the energy storage device, H_e is the energy storage time of the e energy storage device, and $\lambda_{ES,e}^{min}$ is the initial energy storage level of the e energy storage device. Eq. (5) and Eq. (6) are the discharge and charging power constraints of the energy storage device, respectively, Eq. (7) is the power conservation constraint of the energy storage device, Eq. (8) is the power limit constraint of the energy storage device, and Eq. (9) means that the state of charge of the energy storage device is consistent with the state of charge at the initial moment and the last moment.

3. Optimal scheduling of industrial park microgrid energy considering random fluctuation of photovoltaics

The output of photovoltaic power plants is affected by weather factors such as light intensity and temperature; therefore, it is necessary to consider the random fluctuation characteristics on the basis of photovoltaic prediction, simulate the uncertain fluctuation of the output of photovoltaic power station.

Electricity and heat load demand and renewable energy output are shown in Figure A1 of the Appendix. Select different scenarios for comparison, as shown in Table A1. The cost of contaminants is shown in Appendix Table A2. Information on electricity and natural gas prices is shown in Table 1. The natural gas prices in Table 1 are the result of unit conversion. Natural gas is denominated in m3 in China, and the price of natural gas is 3.3 RMB/m3, the calorific value is 9.706 kW·h /m3, the converted natural gas price is 0.340 RMB/(kW·h).

Table 1. Prices of electricity and natural gas

time	Period	Electricity purchase price	Electricity sold price	Gas price
Peak	08:00-21:00	1.046	0.523	0.340
Valley	21:00-8:00	0.446	0.223	0.340

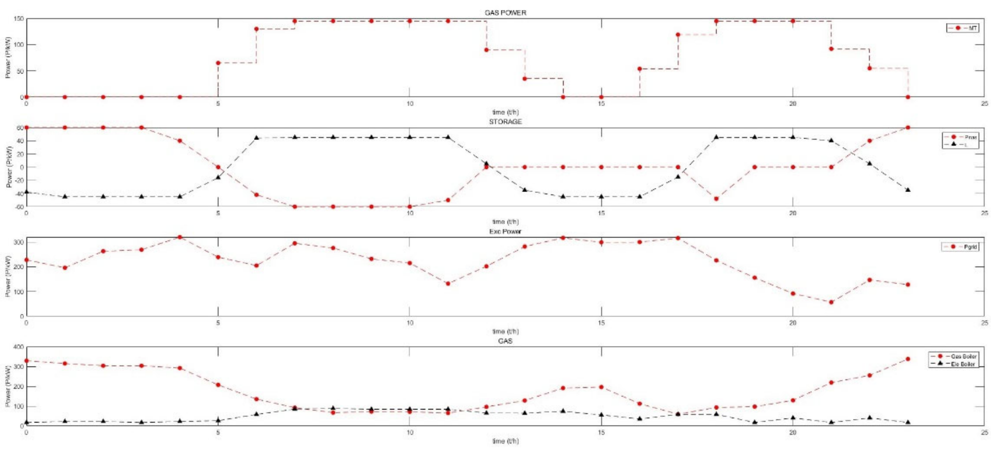

Figure 1. Power flow in time series

In the valley period of electricity load at night, the active power injected into the microgrid of the distribution network is maintained at the minimum value, and the remaining power supply load of the industrial park is provided by the gas generator set all, and the battery is used to store electricity at night; and the electricity load is significantly increased during the day, and the residual power supply load is purchased from the distribution network only under the condition that the output of the gas generator is the maximum active power and the photovoltaic power generation is fully absorbed; and in the peak period of the two electricity loads, the battery is used to discharge, which plays the role of peak shaving, so the power purchase from the distribution network is reduced, and the operation cost of the microgrid is saved.

4. Summary

On the basis of considering the detailed network characteristics constraints of the cooling network, heating network, power supply network and gas supply network, a multi-time energy optimization scheduling model of the microgrid of the natural gas combined cooling, heating and power industrial park was established with the goal of minimum operating cost, and the influence of multiple energy storage devices of power storage, cold storage and heat storage, as well as access to the photovoltaic power station on the operation and scheduling of the industrial park microgrid was considered.

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