Optimal Configuration of Multi-energy Complementary Distributed Energy System

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Abstract. In order to achieve energy saving and emission reduction, a multi-energy complementary distributed energy system was designed, which integrated distributed energy systems, fan and PV. Based on particle swarm optimization, a multi-objective optimization model of energy, economy and environment was constructed with the separation production as the reference object. The gas turbine runs on the principle of no waste of energy, and electric refrigeration ratio, the gas turbine capacity, fan and PV capacity of the system are optimized. Taking Hongqiao industrial park in Taixing, Jiangsu Province as an example, the optimal design scheme of comprehensive operation index was obtained. The results show that the system has obvious advantages in energy saving and emission reduction, compared with other operation modes, when the system operated on the principle of no waste of energy.

1. Introduction

In order to achieve the goal of energy saving and emission reduction, and the sustainable social development, the combination of renewable energy and traditional distributed energy system (DES) has become a current research hotspot. The traditional DES is combined with renewable energy such as biomass energy, solar energy and wind energy. For one thing, it can reduce the gas consumption and electricity purchase of the combined power supply system, for another, it can make up for the shortcomings of renewable energy discontinuity and instability [1,2]. A micronet mathematical model of CCHP including the wind energy and other new energy sources has been established in document [3], and also considers the influence on the operation of micronet economy caused by the net playing with residual electricity and the costs of operation and maintenance, etc.; The combination of solar energy and traditional DES in document [4] has optimized the design of the capacity of internal combustion engine, and also provides a reference for the comprehensive utilization of solar energy; the optimal allocation of DES is determined by considering of the different load of thermoelectric ratio and cold electricity ratio in document [5].

1.1. MCDES System Introduction

The Multi-energy Complementary Distributed Energy System (MCDES) is consisted by photovoltaic, draught fan and traditional DES, the system energy flow chart as shown in figure1.
Figure 1. Energy flow chart of multi-energy complementary distributed energy system

In figure 1, the gas turbines use natural gas as fuel to provide electricity to consumers, and the insufficient power can be provided by draught fans, photovoltaic and external power grids, and the heat energy carried by the high temperature exhaust gas will be recovered by HRSG, and this part of heat energy can be transited to absorption refrigerator and temperature-decreased pressure reducer to meet the users’ demands for cold and heat load respectively, the insufficient heat and cold load needs can be supplemented by gas fired boilers, meanwhile, the insufficient cooling load can also be provided by electric refrigerator.

1.2. The Operation Strategy Analysis of MCDES
(1) The gas turbine adopts a mixed mode of without energy waste, when the Load thermoelectric ratio \( \frac{Q_1}{E_1} \) is larger than the gas turbine thermoelectric ratio \( \frac{Q_r}{E_{pgu}} \) to use the electricity fixing heat, and the insufficient heat is provided by gas fired boilers, as shown in the B point in the figure; when the load thermoelectric ratio \( \frac{Q_1}{E_1} \) is less than the gas turbine thermoelectric ratio \( \frac{Q_r}{E_{pgu}} \) to use the heat fixing electricity, as shown in the A point in the figure, and the insufficient heat is provided by external power grid. The gas turbine will not produce superfluous electricity or heat energy by this operational mode, then can avoid the waste of energy, the system performance characteristics of gas turbine and HRSG as shown in figure 2.

\[
\begin{align*}
E_1 (t) & = E (t) + E_{ec} (t) \\
Q_r (t) & = Q_{ha} (t) + Q_{hb} (t) \\
Q_r & = \frac{\eta_{rec}}{\eta_{pgu}} \left( 1 - \frac{E_{ec}}{E_{pgu}} \right)
\end{align*}
\]

\( E_1 (t) \) is the electrical load at t time; \( E_{ec}(t) \) is t time electric refrigeration mechanism cold electricity consumption; \( E_{ha}(t) \) and \( E_{hp}(t) \) are t time fans and PV output respectively; \( Q_r \), \( E_{pgu} \) means the gas turbines consume a certain amount of electricity and heat generated by natural gas; \( \eta_{pgu} \), \( \eta_{rec} \) are the efficiency of the gas turbine and the waste heat boiler respectively.
Figure 2. System characteristic curve of gas turbine and waste heat boiler

(2) When the principle of using electricity fixing heat is adopted and the total load $E_1$ is less than or equal to the fan and PV output, the electrical load is satisfied by fans and photovoltaic, the cooling load is all met by the electric refrigerator, the heat load is satisfied by gas boiler, decoupling component system; The residual electric load is satisfied successively by gas turbine and power grid when the total load $E_1$ is larger than the fan and PV output. When the system adopts the principle of using heat fixing electricity, the electrical load is met by the gas turbine first, and then met by fan and PV, if there is still electrical load needed to buy from the power grid.

2. Mathematical model of complementary power generation of MCDES

2.1. Optimization Variable
The gas turbine capacity $F_{\text{max}}$, the proportion of refrigerating supplied by an electric refrigerator to the total cooling load $\lambda$, draught fan, PV capacity are the optimize variables for this article. The capacity of waste heat boiler can be determined according to the exhaust gas flow and exhaust temperature of gas turbine after the confirmation of gas turbine capacity; while for gas-fired boilers, when the capacity of gas turbine and waste heat boiler is determined, the capacity can be determined according to the maximum cooling and heating load of the system.

2.2. Objective Function
(1) Annual energy saving rate

$$PES = \frac{F_1 - F_3}{F_1}$$

$PES$ is the Annual energy saving rate; $F_1$, $F_3$ are the annual energy consumption of Sub supply system and MCDES respectively.

(2) Annual operating cost savings rate

$$TCS = \frac{AC_1 - AC_3}{AC_1}$$

$TCS$ is the Annual operating cost savings rate; $AC_1$, $AC_3$ are the annual operating cost of Sub supply system and MCDES respectively.

(3) Annual greenhouse gas emission reduction rate

$$CDER = \frac{CDE_1 - CDE_3}{CDE_1}$$

$CDER$ is the Annual greenhouse gas emission reduction rate; $CDE_1$, $CDE_3$ are the Annual greenhouse gas emissions of Annual greenhouse gas emissions.

(4) Objective Function
In this paper, the weighted sum of the three optimization objective functions, which represent energy, economy and environment respectively, is taken as the total objective function, as follows:
\[
\text{max } IP = \omega_1 PES + \omega_2 TCS + \omega_3 CDER
\]

\( IP \) is the Comprehensive operation index; \( \omega_1, \ \omega_2, \ \omega_3 \) are the weight factors of objective functions respectively, \( \omega_1 = \omega_2 = \omega_3 = 1/3 \).

3. Optimal allocation based on particle swarm optimization
Particle Swarm Optimization (PSO) has a very high search ability, requires fewer parameters, and is simple to operate. It is widely used in many research fields. Flow chart as shown in figure 3.

![Flow chart of algorithm in mixed operation mode of gas turbine](image-url)

Figure 3. Flow chart of algorithm in mixed operation mode of gas turbine

4. Example analysis

4.1. Example System
This article chooses Jiangsu Taixing Hongqiao Industrial Park as the research object to optimize the analysis. Selecting the WTG3 wind turbine, the important parameters are as follows: The capacity of single draught fan is 2.5MW, the in wind speed is 3m/s, the rated wind speed is 9.5m/s, the out wind speed is 20m/s, which can install 20 pieces maximum. It can install the 310WP PV modules 40MW maximum. Jiangsu's industrial natural gas price is RMB2.95/m³; The purchase price is RMB1.0697/kwh; Particle swarm optimization parameters: The maximum number of iterations is 200; The population size is 100. Typical daily cooling and heating load of the park is shown in figure 4.
4.2. Analysis of optimization results

After optimization calculation, the gas turbine capacity $F_{\text{max}} = 103 \text{MW}$, the ratio of electric refrigeration $\lambda = 0.8$, the number of fans = 10 and the photovoltaic capacity = 19MW of the MCDES system are obtained. The performance optimization curves are shown in figure 5 and 6.

The annual energy consumption , annual operating cost and annual CO$_2$ emission of the MCDES system when IP achieves the optimal value under different operation modes are shown in table 1.

| Evaluation indexes of under different operation strategies |
|----------------------------------------------------------|
| Annual energy consumption /10^5MW·h | Annual operating cost /10^8yuan | Annual CO$_2$ emission /10^5kg | Turbine capacity $F_{\text{max}}$/MW | Electric refrigeration ratio $\lambda$ | Number of fans /platforms | PV Capacity/MW | Comprehensive operation index IP |
| Fix electricity by heat | 7.21 | 4.23 | 1.75 | 52 | 1 | 20 | 40 | 0.3013 |
| Fix heat by electricity | 5.43 | 3.16 | 1.45 | 79 | 1 | 20 | 26 | 0.3892 |
No waste of energy | 4.82 | 2.42 | 1.25 | 103 | 0.8 | 10 | 19 | 0.4677

5. Peroration
In this paper, a multi-energy complementary system is designed. Taking Jiangsu Tiaxing Hongqiao Industrial Park as an example, the following conclusions are drawn:

Compared with the other two operation modes, the MCDES can effectively reduce the annual energy consumption, annual CO₂ emissions, and is with obvious advantages in energy saving and emission reduction, and at the meanwhile it also can improve the overall performance of the system.

References
[1] Gu, W., Wu, Z., Wang, R. (2012) Multi-objective operation of heat and power microgrid considering pollutant emission. Automation of Electric Power System, 36: 177-185.
[2] Fumo, N., Mago, P.J., Chamra, L.M. (2009) Emission operational strategy for combined cooling, heating, and power systems. Applied Energy, 86: 2344-2350.
[3] Liu, C., Wang, Y.T., Wang, L.C., et al. (2015) Research on the economical operation of the micro-grid with CCHP. Electrical Measurement & Instrumentation, 52: 31-37.
[4] Wu, H.B., Wang, D.X., Liu, X.Y. (2015) Strategies evaluation and optimal allocation of combined cooling heating and power system with solar. Automation of Electric Power Systems, 39: 46-51.
[5] Hu, R., Ma, J., Li, Z.K., et al. (2017) Optimal allocation and applicability analysis of distributed combined cooling-heating-power system. Power System Technology, 41: 418-425.