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Optimal operation of integrated energy system combined cooling heating and power based on the improved raccoon algorithm

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***Abstract*-In view of the low economic benefit caused by the shortage of integrated energy system, an economic optimization method of integrated energy system (CCHP) is proposed. Aiming at economic optimization and calculate the carbon emissions of the system. The system model and constraints of the units including gas turbine and gas boiler are constructed, and the raccoon algorithm is improved to improve the optimization search ability. The simulation results show that the improved algorithm can solve the problem of low economic benefit.**

Keywords-CCHP, Improve the raccoon algorithm, Economic benefits

I. INTRODUCTION

The existing integrated energy system [1] is often planned and operated independently, without considering its economic [2] and environmental protection [3], resulting in high cost and serious pollution. Nowadays, more research is being done on how to jointly optimize the [4] with independent energy supply systems while reducing environmental pollution and increasing economic performance.

Literature [5] utilizes the improved multi-objective grey Wolf algorithm for model solution, but the method is too many iterations and inefficient. Literature [6] improves the PSO algorithm for multi-objective optimization, but the algorithm has insufficient accuracy. In conclusion, a new method is needed to realize the efficient solution of the optimal accuracy problem of the integrated energy system. Therefore, this paper proposes CCHP system optimization based on the improved raccoon algorithm [7].

II. INTEGRATED ENERGY SYSTEM MODELING

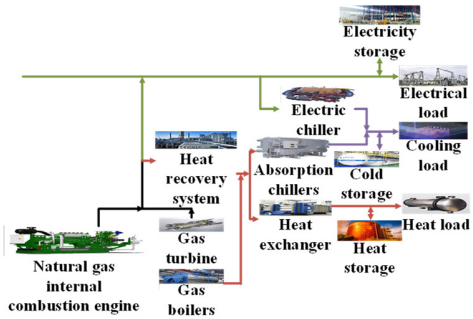

Fig. 1. Network architecture diagram of CCHP

The integrated energy system is the most commonly used regional integrated energy system, and its network architecture is shown in Figure 1.

The mathematical model and constraints of natural gas internal combustion engine are:

$$P_{GE.e} = \eta_{GE}^{e} P_{GE.g} \tag{1}$$

$$\begin{cases} P_{GE.eh} = \dfrac{P_{GE.e}\left(1-\eta_{GE.e}-\eta_{GE.L}\right)}{\eta_{GE.e}} \\ P_{GE.h} = P_{GE.eh}\,\eta_r Co \end{cases} \tag{2}$$

$$P_{GE.\min} \le P_{GE} \le P_{GE.\max} \tag{3}$$

where $P_{GE.e}, P_{GE.eh}, P_{GE.g}$ represent Power generation power, thermal power and actual output thermal power; The η_{GE}^{e} represents generating efficiency ; η_r is the thermal loss rate; η_r is the flue gas recovery rate, usually 0.9; Co is the heating coefficient, usually 1.2; $P_{GE.\min}, P_{GE.\max}$ are the lower and upper limits of thermal power.

Mathematical model and constraints of gas turbine are:

$$C_{GT} = \begin{cases} \left(-0.824 \cdot P_{cap} + 6713.6\right) P_{cap} & P_{cap} < 4000 \\ \left(-0.168 \cdot P_{cap} + 4113.92\right) P & P_{cap} \ge 4000 \end{cases} \tag{4}$$

$$P_{GT.e} = 0.2188 + 2.21\times10^{-5} \cdot P_{cap} - 1.02\times10^{-9} \cdot {P_{cap}}^{2} \tag{5}$$

$$P_{GT.h} = -0.025 \cdot \ln\left(P_{cap}\right) + 0.64 \tag{6}$$

$$P_{GT.\min} \le P_{GT} \le P_{GT.\max} \tag{7}$$

where P_{cap} represents its rated capacity; C_{GT} represents it had invested in the money; $P_{GT.e}, P_{GT.h}, P_{GT.\min}, P_{GT.\max}$ is the power generation, heat production rate and its lower and upper limits of power.

The mathematical model and constraints of gas boiler are:

$$\eta_{Boi} = \eta_{Boi.r}\left(0.0951 + 1.525\beta_{Boi} - 0.624\beta_{Boi}^{2}\right) \tag{8}$$

$$F_{Boi} = V_{Boi}^{CH_4} LHV_{CH_4} \eta_{Boi} \tag{9}$$

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$$F_{B\text{oi.min}} \le F_{B\text{oi}} \le F_{B\text{oi.max}} \tag{10}$$

where $F_{B\text{oi}}$ is the gas consumption; $Q_{B\text{oi}}$ is the thermal power; $\eta_{B\text{oi}}$ is the coefficient of efficiency ; $\eta_{B\text{oi.r}}$ is the operational efficiency; $\beta_{B\text{oi}}$ is the load rate; $V_{B\text{oi}}^{CH_4}$ is gas consumption; The actual operating efficiency is 0.85; $F_{B\text{oi.min}}, F_{B\text{oi.max}}$ are the lower and upper limits of thermal power.

The mathematical model and constraint of electric refrigerator and absorption refrigerator are:

$$\begin{cases} Q_{EC} = COP_{EC} P_{EC} \\ Q_{EC.\min} \le Q_{EC} \le Q_{EC.\max} \end{cases} \tag{11}$$

$$\begin{cases} Q_{AC} = COP_{AC} P_{AC} \\ Q_{AC.\min} \le Q_{AC} \le Q_{AC.\max} \end{cases} \tag{12}$$

where Q_{EC}, Q_{AC} is the output power; COP_{EC}, COP_{AC} is the cold energy efficiency coefficient; P_{EC}, P_{AC} is the input electric power; $Q_{EC.\min}$, $Q_{EC.\max}, Q_{AC.\min}$, $Q_{AC.\max}$ are the lower and upper limits of the power.

The mathematical model and constraints of electricity storage, heat and cold equipment are:

$$\begin{cases} E_{ES}^{t} = (1-\mu_e) E_{ES}^{t-1} + \eta_{in}^{e} P_{in}^{e}(t) - P_{out}^{e}(t)/\eta_{out}^{e} \\ E_{ES.\min} \le E_{ES}^{t} \le E_{ES.\max} \end{cases} \tag{13}$$

$$\begin{cases} E_{HS}^{t} = (1-\mu_h) E_{HS}^{t-1} + \eta_{in}^{h} P_{in}^{h}(t) - P_{out}^{h}(t)/\eta_{out}^{h} \\ E_{HS.\min} \le E_{HS}^{t} \le E_{HS.\max} \end{cases} \tag{14}$$

$$\begin{cases} E_{CS}^{t} = (1-\mu_c) E_{CS}^{t-1} + \eta_{in}^{c} P_{in}^{c}(t) - P_{out}^{c}(t)/\eta_{out}^{c} \\ E_{CS.\min} \le E_{CS}^{t} \le E_{CS.\max} \end{cases} \tag{15}$$

where E_{ES}^{t} is the remaining capacity in the period t; μ_e, μ_h, μ_c is the self-discharge rate, heat, and cold energy storage loss rate; $P_{in}^{e}(t), P_{out}^{e}(t), P_{in}^{h}(t), P_{out}^{h}(t), P_{in}^{c}(t), P_{out}^{c}(t)$ is the input and output power, heat and cold power; $\eta_{in}^{e}, \eta_{out}^{e}, \eta_{in}^{h}, \eta_{out}^{h}, \eta_{in}^{c}, \eta_{out}^{c}$ are the input and output conversion efficiency; $E_{ES.\min}, E_{ES.\max}, E_{HS.\min}$ $, E_{HS.\max}, E_{CS.\min},$

$E_{CS.\max}$ are the upper and lower capacity limits.

The power balance constraints of the system are as follows:

$$\begin{cases} P_{GE.e} + P_{GT.e} + P_{Elc} - P_{EC} = P_e \\ P_{GE.h} + P_{GT.e} + P_{GT.h} + Q_{B\text{oi}} - Q_{AC} = Q_h \\ Q_{AC} + Q_{EC} = Q_C \end{cases} \tag{16}$$

In the formula, P_e, Q_h, Q_c are respectively electric load, thermal load and cold load.

III. Objective Function of Cooperative Optimization of CCHP

A. Objective function

In order to evaluate the indexes of the cooling and power supply system and achieve the goal of minimum economic cost, this paper introduces the reference system and takes the economic index as the objective function.

System economic cost is mainly divided into operating cost and environmental cost.Operating cost includes power purchase cost, gas purchase cost and unit operation and maintenance cost.

$$\begin{cases} C_J = C_e + C_g + C_{ope} \\ C_e = \sum_{t=1}^{T} r_{e,t} P_{e,t} \\ C_g = \sum_{t=1}^{T} r_{g,t} P_{g,t} \\ C_{ope} = C_{ope,GT} P_{GT} + C_{ope,GB} P_{GB} + C_{ope,EC} P_{EC} + C_{ope,AC} P_{AC} + C_{ope,Boi} P_{Boi} \end{cases} \tag{17}$$

where C_g, C_e, C_g, C_{ope} is the total cost, power purchase, gas purchase cost and operation and maintenance cost; $r_{e,\ t}, r_{g,\ t}$ is the electricity purchase, gas unit price; $P_{e,t}, P_{g,t}$ is the purchase electricity, buy gas power.

B. Carbon emission calculation

$$C_{wang} = \min \sum_{i=1}^{24} \left\{ \sum_{k=1}^{n} \left(W_{MT,K} \cdot P_{MT} + W_{g,k} P_{g,p} \right) \cdot C_k \right\}_i \tag{18}$$

C_{wang}, C_k is the the total treatment cost of pollution gas generated in 24 hours; k indicates the type of polluting gases; $W_{MT,K}$, $W_{g,k}$ represents the micro gas turbine, large power grid produces the emission coefficient of pollution gas k; $P_{g,p}$ represents the power purchased from the large grid.

Overall optimization function is $C_t = \min\left(C_J + C_{Wang}\right)$.

IV. System Optimization Scheduling of Raccoon Algorithm

Raccoon optimization is a novel optimization algorithm proposed by Dehghani in 2023. By simulating the process of hunting and killing, we update the raccoon position and find the optimal solution iteratively [8].

A. Improved Raccoon Optimization Algorithm (ICOA)

1) Circle mapping population initialization

The standard COA adopts a random initialization strategy, which leads to reduce the overall diversity of the group, and also causes the algorithm to fall into the local extreme value, thus reducing the global optimization ability in the later stage. Chaos mapping is a nonlinear, unpredictable random sequence that improves the diversity and randomness of groups. Based on this, the population is initialized using Circle chaotic mapping to improve the search accuracy. Circle The chaotic map is represented as follows:

$$\begin{cases} x_{i,i+1} = \mathrm{mod}\left\{ d_1 x_{i,j} + d_2 - \left[(d_3 / d_1) \sin(d_1 \pi x_{i,j}) \right], 1 \right\} \\ x_i = x_i (ub - lb) + lb \end{cases} \tag{19}$$

where $x_{i,\ j+1}$ is the j+1 dimensional position of the i raccoon; mod () is the modulo function; d1, d2 and d3 are constants, can change the chaos mapping effect. In this paper, they are 1,

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0.2 and 0.25 respectively. x_i is the position of the i raccoon; u_b、l_b is the upper and lower limit of the search space.

2) Levy flight strategy

In the second stage of COA, it is easy to fall into the local optima later on, so the Levy flight strategy [9] is introduced to improve the situation. Levy flight is a random walk strategy that balances local development and global search capabilities. The COA Development Phase raccoon location update is described as:

$$S = \frac{\theta}{|\omega|^{1/\beta}} \tag{20}$$

$$\theta \sim N\left(0, \sigma_u^2\right), \quad \omega \sim N\left(0, \sigma_v^2\right) \tag{21}$$

$$\sigma_u = \left(\frac{\tau(1+\beta)\sin(\pi\beta/2)}{2^{(\beta-1)/2}\tau\left[(1+\beta)/2\right]\beta} \right)^{1/\beta} \qquad \sigma_v = 1 \tag{22}$$

where: L is the flight step length; Beta is 1.5; Γ (.). Is the Gamma function; μ and ν are normally distributed.

3) Reverse learning strategy

According to the latest research results, the reverse solution is more likely to be close to the global optimal value than the current optimal solution. Specifically, this strategy is applied to the position updating process of individuals in the raccoon algorithm, as a means for the algorithm to jump out of the local optimal state [10]. The following is a mathematical expression description of the reverse learning strategy:

$$\bar{x}_{i,j} = \left(ub_j + lb_j\right)/2 + \left(ub_j + lb_j\right)/2k - x_{i,j}/k \tag{23}$$

B. Improved raccoon algorithm specific implementation steps

1) Initialize the population and set algorithm parameters including population size, individual upper and lower bounds, maximum number of iterations, etc

2) All individual raccoon information was randomly initialized, and raccoon population fitness values were calculated to determine the optimal raccoon location x_{best} .

3) Update the exploratory stage raccoon location based on the executed raccoon hunting and attack strategies; update the development stage raccoon location based on the executed raccoon escape predator strategy.

4) Based on the executed reverse learning strategy.

5) Fitness values were calculated based on the new raccoon position, and the best raccoon locations were compared and saved x_{best} .

6) Repeat Step 3-Step 6 until the algorithm termination condition is met.

7) Output x_{best} to find the optimal solution.

V. Example Analysis

10:00-14:00,18:00-20:00,7:00-9:00, purchase and sale price is 0.71 and 0.65 yuan; 15:00-17:00,21:00-22:00, purchase and sale price is 0.47 and 0.39 yuan;00:00-6:00, purchase and sale price is 0.31 and 0.21 yuan.

The ICOA algorithm was compared with the other algorithms and tested with the Rastrigrin function. The results obtained are shown in Figure 2. The number of ICOA and COA populations was set to 30, the number of iterations was 500, and the other used algorithm default values.

As can be seen from Figure 2, ICOA obtains the theoretical optimal value for 20 times in different dimensions, and the optimization accuracy is better than other algorithms. It has higher optimization accuracy and better global search ability. It shows that the optimization performance of ICOA can be effectively improved based on three improvement strategies of Circle mapping, Levy flight and reverse learning.

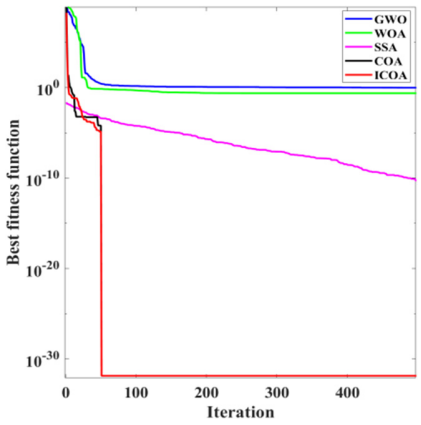

Fig .2. Evolution of the average optimal fitness of the test function

Figure 3-Figure 5 shows the power optimization results of 0-24 hours a day in the electric heat setting and economic optimal operation mode.

In the optimization of the economic optimal operation mode, the load curve is optimized compared with the electric heat operation mode, and part of the electricity, heat and cooling loads are optimized to the trough periods of electricity, heat and cold.

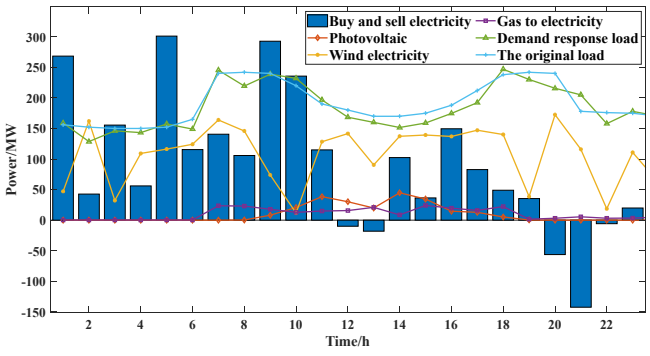

Fig. 3. Power optimization results of the power grid

In the grid operation curve, the power is provided to the grid during the trough period from 0 to 6 and 10 to 16:00 hours and the peak period, and the power is purchased from the grid between 6 to 10 and 16-22 hours. As can be seen from

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Figure 4, through the optimization under the economic optimal operation mode, the load curve is optimized compared with the load curve in the electric thermal operation mode, and part of the load in the peak period is transferred to the trough period of power consumption, which plays a role in "peak shifting and valley filling" of the power load.

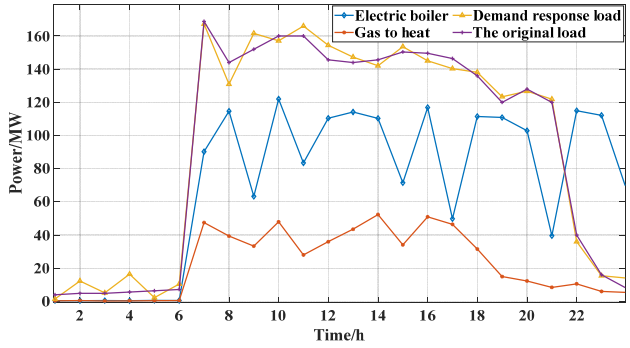

Fig. 4. Power optimization results of hot grids

In the heat network operation curve, in 6 to 20 time for heat peak, from the figure, through the optimization of economic optimal operation mode, the load curve than the electric thermal operation mode load curve overall reduction, and part of the heat load optimization to the heat trough time, can alleviate the heat peak pressure, and in the heat trough for heat storage.

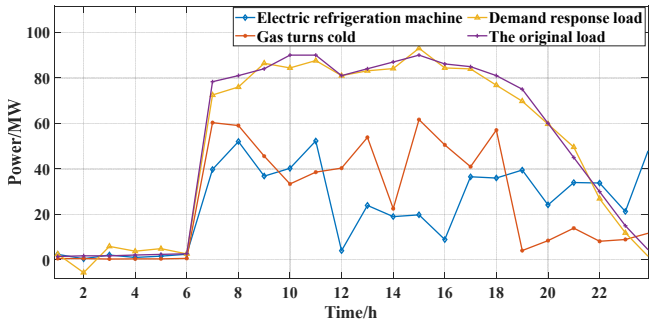

Fig. 5. Power optimization results of cold grids

In the cold network operation curve, in 6 to 18 time for cold peak, from the figure, through the optimization of economic optimal operation mode, the load curve than electric thermal load curve, and the part of cold load optimization to cold low time, can alleviate the hot peak pressure to some extent, and the cold storage in cold trough.

VI. Conclusions

This paper studies the economic operation optimization of CCHP integrated energy system with gas turbine, gas boiler and other equipment, and the minimum economic operation cost and the model by improving the raccoon algorithm. The simulation results show that the proposed algorithm can reduce the economic operation cost of system and guide the optimal scheduling of CCHP.

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