Research on Optimal Design and Control Method of Integrated Energy System Based on Improved Cloud Adaptive Particle Swarm

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Abstract. In order to rationally design the capacity of each energy coupling unit of the integrated energy system, effectively coordinate and optimize the control of the integrated energy system equipment. This paper proposes an improved cloud adaptive particle swarm algorithm design control method. First, three busbars and multi-energy coupling equipment models based on electric, thermal, and gas loads are established, and then the model has better global optimization capabilities and defenses. Then, an improved cloud adaptive particle swarm algorithm with better global optimization capabilities and anti-premature convergence characteristics is used to optimize the annual economic optimization model established to meet the power balance constraints of each bus and energy coupling equipment. Finally, under the conditions of output constraints and system energy purchase constraints, taking a typical park as an example, the simulation verifies the effectiveness of the method proposed in this paper in the optimization design and control operation of the integrated energy system.

1 Introduction

Integrated Energy System (IES), as an effective means to solve current energy problems, has the functions of energy generation, distribution, conversion and dispatch[1-2]. At the same time, IES has improved energy consumption efficiency, and promoted the development of clean energy and the consumption of renewable energy. The design control of IES is a complex non-linear, multi-objective, multi-constrained mixed integer optimization problem. In order to better realize the design and control of the integrated energy system, the system's design and control problem is usually solved through modern intelligent optimization algorithms. Commonly used algorithms are: Genetic algorithm, tabu search algorithm and particle swarm optimization algorithm, etc. Unreasonable integrated energy system's design and control will affect the energy efficiency of the system. In order to give full play to the role of IES, it needs to be reasonably configured as a whole.

Regarding the optimization of IES' design and control, a large number of scholars have conducted research. Literature [3] considered the problem of energy coupling equipment type selection and system capacity allocation, and applied mixed integer linear programming algorithm to optimize the established annual comprehensive economic optimal model. Literature [4] proposed a two-tier multi-objective Planning model, introducing weight coefficients to minimize investment costs, operating costs, and carbon emissions of the system. The upper layer uses whale optimization algorithm for optimization, and the lower layer uses the MATLAB/YALMIP/GUROBI joint solver to obtain the best capacity and economy of the system. Sex. Literature [5] considered the impact of construction timing issues on the planning of the park's integrated energy system, based on a unified bus model, comprehensive investment, operation and maintenance costs, and aimed at the economic optimization of the entire life cycle of the system construction, and proposed a sort of analysis. Stage planning model. Literature [6] introduced a carbon trading mechanism to restrict carbon emissions, consider equipment investment, operation and maintenance costs, and use a two-stage robust model to optimize planning and control. In addition, there is a lack of comprehensive analysis of energy coupling units, and there are fewer types of optional coupling units provided for planning applications. Most of them have determined equipment strategies or application scenarios, and optimized equipment on a given basis. At the same time, the explanation of the degree of coupling between energy coupling units is insufficient, and there is a lack of quantitative comparison with traditional energy sources. It is difficult to accurately evaluate the high energy efficiency and good economy of IES.

This paper focuses on energy coupling equipment such as cogeneration systems, photovoltaics, ground-source heat pumps, gas boilers, electric boilers, and configures energy storage and heat storage equipment to flexibly respond to system load changes, and establishes

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a planning model that considers system economy. Based on the improved cloud adaptive particle swarm algorithm, through the algorithm's good global and local optimization characteristics, combined with the constraints of equipment and buses in the IES, the planning model is solved, and the system is finally obtained. Economical and environmentally friendly indicators, as well as coupling unit capacity configuration and scheduling schemes. Compared with the traditional independent energy system, taking an IES park as an example, the accuracy of the algorithm is verified, and the advantages of IES are proved by economic indicators.

2 Integrated energy system modeling

2.1 Typical energy coupling unit model

This paper designs CHP, photovoltaic (PV), gas boiler (GB), ground source heat pumps (HP), gas boilers (GB), electric boilers (EB), electrical energy storage (ES) and thermal energy storage (HS) devices to better improve energy utilization.

2.2 Integrated energy system model based on unified bus

Considering the actual situation of the integrated energy system and establishing the electric bus, natural gas bus and thermal bus according to the type of coupling equipment, the power constraints of the three buses are specified as follows:

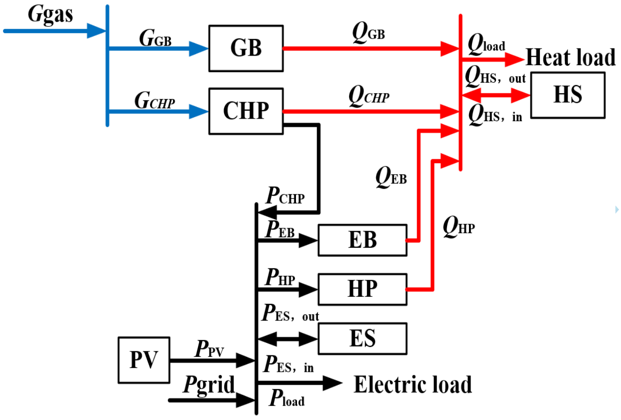

Figure 1. Unified bus-bar structure model of integrated energy system

2.2.1 Electric bus power balance constraint

$$\begin{aligned} &P_{CHP}(t)+P_{PV}(t)+P_{ES,out}(t)= \\ &P_{load}(t)+P_{HP}(t)+P_{ES,in}(t)+P_{EB}(t) \end{aligned} \tag{1}$$

Where, $P_{grid}(t)$ is the electric power input from the external grid at time t; $P_{ES,in}(t)$ is the charging power of the electrical energy storage device at time t; $P_{ES,out}(t)$ is the discharge power of the electrical energy storage device at time t; $P_{load}(t)$ is the electrical load demand power of the system at time t.

2.2.2 Thermal bus power balance constraint

$$\begin{aligned} &Q_{CHP}(t)+Q_{HP}(t)+Q_{EB}(t)+Q_{GB}(t) \\ &+Q_{HS,out}(t)=Q_{load}(t)+Q_{HS,in}(t) \end{aligned} \tag{2}$$

In the formula, $Q_{HS,out}(t)$ and $Q_{HS,in}(t)$ are the charging and dissipating power of the heat storage device at time t, respectively; $Q_{load}(t)$ are the heat load demand power of the system at time t.

2.2.3 Natural gas bus power balance constraint

$$G_{gas}(t)=G_{CHP}(t)+G_{GB}(t) \tag{3}$$

In the formula, $G_{gas}(t)$ is the natural gas power purchased from outside by the system at time t.

3 Integrated energy system design control model

This paper proposes a model that considers the optimal economic efficiency, combining different heat and electric load ratios and the system's full life cycle operating conditions, with the goal of minimum annual investment, establishing an economically optimal planning function, and using an optimization algorithm solve to determine the capacity of each coupling unit.

$$Y_{\cos t}=C_{inv}+C_{ope} \tag{4}$$

$$C_{inv}=\frac{r(1+r)^n}{(1+r)^n-1}\times\sum_{j=1}^{m}(P_{cap,j}\times C_j) \tag{5}$$

$$C_{ope}=\sum_{i=1}^{3}[D_i\times\sum_{t=1}^{24}(C_{fuel,t}+C_{grid,t}+C_{om,t})] \tag{6}$$

$$C_{fuel,t}=(Q_{CHP,t}+Q_{GB,t})\times C_{gas} \tag{7}$$

$$C_{grid,t}=Q_{ele,t}\times C_{ele,t} \tag{8}$$

$$C_{om,t}=\sum_{j=1}^{m}(P_{j,t}\times C_{ope,j}) \tag{9}$$

Among them, C_{inv} is the equivalent cost of the initial investment of the equipment; $P_{cap,j}$ is the rated capacity of the j-th equipment; C_j is the initial investment cost per unit capacity of the j-th equipment; the discount rate is r, and the service life is n. D_i is the number of the i-th typical day duration; $C_{fuel,t}$ is the cost of the system's fuel consumption; $C_{grid,t}$ is the cost of the system to purchase electricity from outside; $C_{om,t}$ is the total cost of system operation and maintenance; $Q_{CHP,t}$ is the heat generated by the cogeneration system, $Q_{GB,t}$ is generated by the gas boiler heat, $P_{j,t}$ is the energy consumption of the j-th device; C_{gas} is the fuel cost of the system that consumes natural conversion into electric energy; $Q_{ele,t}$ is the grid electricity consumption of the electric device; $C_{ope,j}$ is the operation and maintenance cost of the j-th device.

4 Improved CAPSO algorithm

4.1 New form of energy storage

The inertia weight w of the ordinary PSO algorithm is generally taken as a constant, which has the problem of easily falling into local optimality and premature convergence [24]. In order to overcome its shortcomings, cloud adaptive particle swarm optimization (CAPSO) combines fuzzy membership cloud [25] with PSO to adjust the inertia weight w to make it adaptive. The distribution of the membership degree $\mu(x)$ of the cloud model in the universe is called the membership cloud, or cloud for short. It is composed of many cloudy drops. A certain cloud drop is insignificant, but the overall shape of the cloud reflects its important characteristics. The normal cloud model is shown in Figure 2.

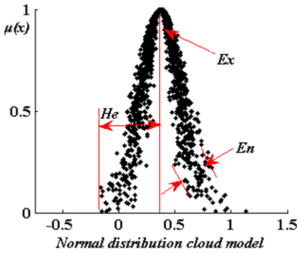

Figure 2. Normal cloud model

The cloud model contains three numerical characteristics: Expectation Ex, which expresses the expectation of the distribution of cloud drops in the universe of discourse; Entropy, which expresses the uncertainty measurement, reflecting the degree of dispersion of cloud drops; Hyperentropy He, which is the uncertainty of entropy Metric, the entropy of entropy. CAPSO uses X conditional cloud generator, the generator model is as follows:

$$\text{generator}=\begin{cases}\texttt{input:}\{E_x,E_n,H_e\},x_0,m\\ \texttt{output:}\{(x_0,\mu_1)\cdots(x_0,\mu_m)\}\end{cases} \quad (10)$$

$$\text{Internal loop } m\begin{cases}En^{'}=Randn(En,He)\\ \mu_i=e^{-x_0^*},x_0^*=\dfrac{(x_0-Ex)^2}{2(En^{'})^2}\end{cases} \quad (11)$$

Equation (13) means that m cloud drops (x0, μi) are generated from three digital features Ex, En, He and the input value; Equation (13) means the internal cycle of the cloud generator is m times, and Randn is the standard normal distribution Random function, x*0 is the intermediate variable, μ_i is the membership degree of the i-th cloud drop. With the change of the power grid structure and the updating of interaction with users, the concept of "Internet plus" and power ubiquitous Internet of things has become a new research direction. Smart microgrid, virtual power plant and electric vehicle can be the representative of energy storage operation mechanism in the new situation.

4.2 Algorithm flow of integrated energy system based on ICAPSO

Using the proposed ICAPSO algorithm, the optimization process of the proposed model includes: parameter initialization, rotating partition coding, parallel operation of 3 populations, loop operation of cloud adaptive particle iteration process, merging of parallel populations, and finally output optimization results.

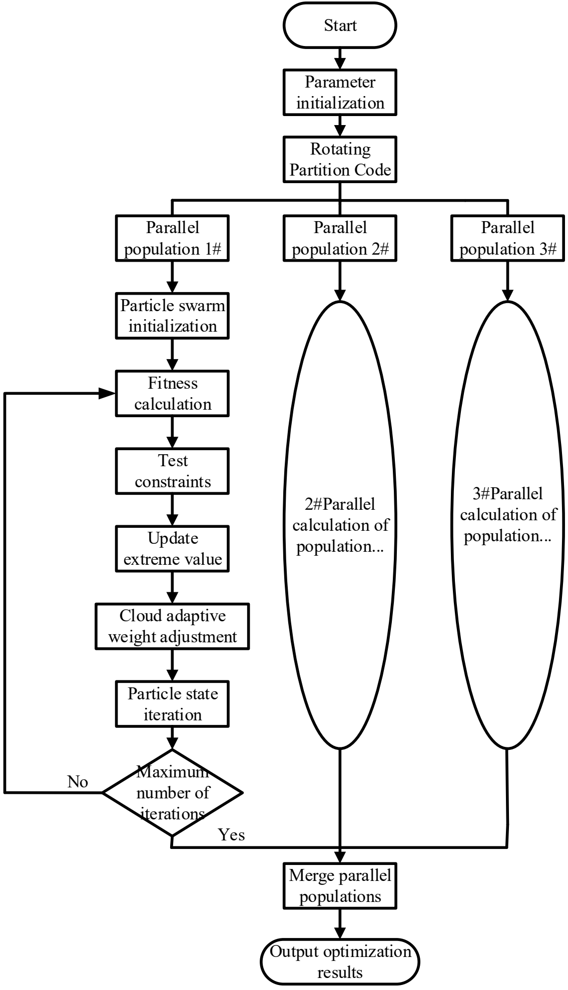

Figure 3. Flow chart of the algorithm

5 CASE STUDY

An industrial park in the north part of China is under IES optimal planning, where the energy demand is concentrated, containing sustainable electricity and heat. The price of natural gas is 2.45 ¥/m3. The price of electricity is 0.3369(t=1-6h), 1.1933(t=7-18h) and 0.7525(t=19-24h)¥/kWh respectively. The subsidy price for photovoltaic power generation is 0.42 ¥/kWh.

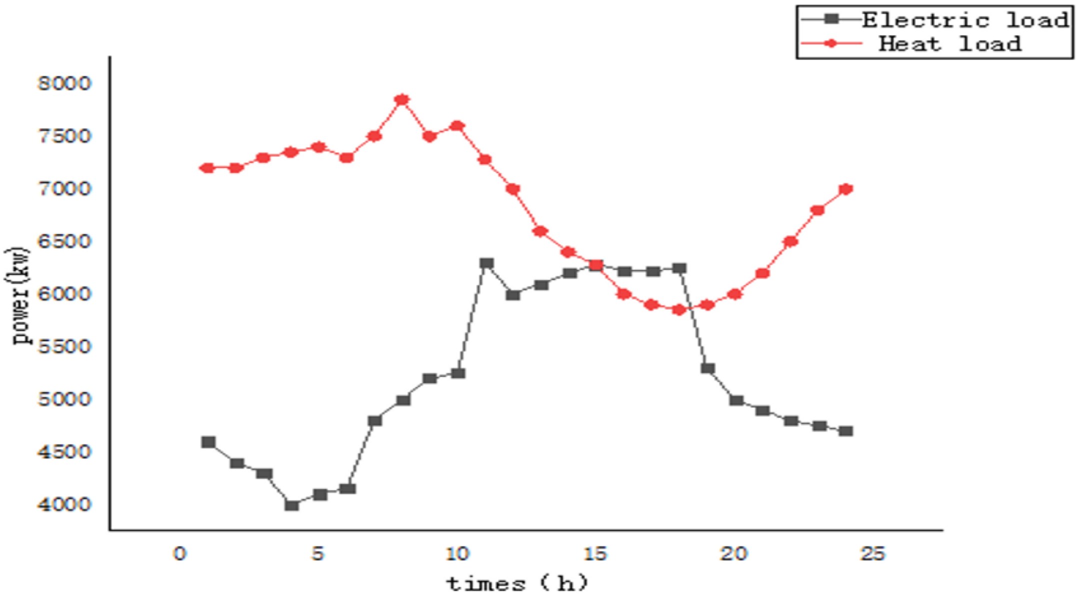

Figure 4. Demand curve of a typical day

Particle swarm optimization parameters: the size is 40, the acceleration factor is C1 = C2 = 1.2, the speed limit is Wmax = 600, the upper and lower limits of cloud adaptive inertia factor are wmin = 0.4 and wmin = 0.9, and the maximum number of iterations is 200. The particle positions of 1 # population in the iterative process of icapso are mapped in the planning area, and a total of 200 positions of 40 particles in n-dimensional space are represented by hollow points.

Table 1. Equipment cost

Equipment type	Initial investment cost (yuan / kWh)	Operation and maintenance cost (yuan / kWh)
PV	5500	0.02
CHP	7780	0.95
HP	1970	0.03
EB	400	0.01
GB	600	0.01
ES	300	0.005
HS	500	0.003

Table 2. Optimal capacity allocation

Equipment type	Configuration capacity (kW)
PV	4000
CHP	6523
HP	1083
EB	3500
GB	1480
ES	2000
HS	2165

Equipment scheduling results:

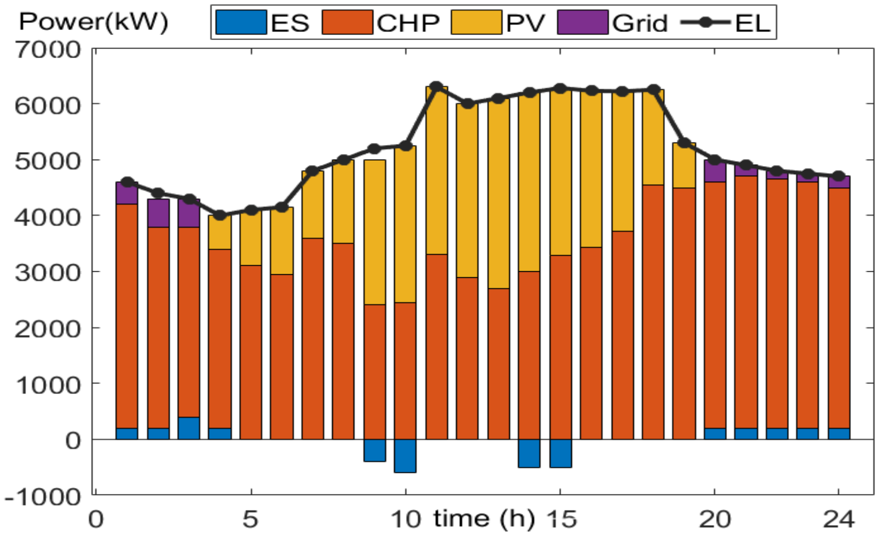

Figure 5. Power dispatching diagram

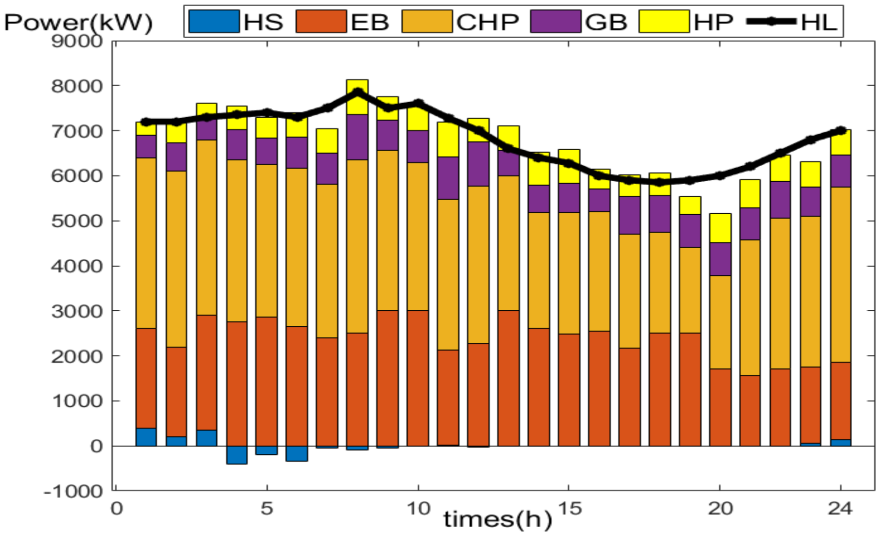

Figure 6. Thermal power dispatching diagram

6 Conclusion

In this paper, a comprehensive energy system design control method based on cloud adaptive particle swarm algorithm is proposed. The established economic model is solved, and the capacity configuration information is obtained. The example analysis guides the integrated energy system planning and equipment operation scheduling. The results show that the optimized IES gives full play to the coupling advantages of electricity, gas, heat and multi energy equipment, and the energy utilization efficiency of IES and IES has been significantly improved.

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