Planning Optimization of Integrated Energy System Considering Economy and Integrated Energy Efficiency

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Abstract. The integrated energy system is the concrete realization of the energy Internet in the region by coupling various energies and carrying out multi-dimensional coordinated management and distribution of various energies such as electricity, gas, cold and heat. An integrated energy system planning method is proposed. Firstly, a heterogeneous energy network model of a typical integrated energy system is developed. Aiming at minimizing the total operating cost and maximizing the integrated energy efficiency of the integrated energy system, NSGA-II algorithm is used to realize optimization in MATLAB program. Through the TOPSIS method, multiple sets of solutions are compared and analyzed, thus the optimal planning scheme of the system is obtained quickly and accurately. Through optimization calculation, the optimal capacity allocation and operation strategy of major equipment can be obtained. On the premise of meeting users' various energy demands, the system investment and energy consumption cost can be reduced to the maximum extent, and the efficient utilization and sustainable development of various energy sources can be promoted.

1. Introduction
With the world's clearer understanding of the energy crisis and environmental protection issues and more and more attention, the research on integrated energy systems integrating various renewable energy sources, such as wind energy and solar energy, is receiving great attention from scholars around the world [1–3]. In order to make rational and rational use of renewable energy, researchers discussed various system operation strategies to meet different system operation objectives, such as the lowest operation cost and the lowest pollution emission [4-6]. As the utilization of renewable energy has brought various benefits, the capacity allocation of integrated energy systems is no longer a single-target optimization problem [7-8]. On the other hand, due to the access of renewable energy, some new optimization methods need to be explored to solve the capacity allocation problem for integrated energy systems [9-10], if we are deficient in predictability, then we have a problem that is contrary to the original intent of renewable energy development. In order to solve this problem, many scholars are committed to analyzing and studying renewable energy systems with random variables through different stochastic simulation techniques. There are two approaches to this research, fuzzy theory and stochastic optimization based on probability distributions. In general, fuzzy theory treats random variables as fuzzy numbers [11], and it is necessary to define very precise membership functions for these random variables. In addition, in order to objectively describe the relationship between investment cost and investment risk and avoid the influence of different investors' subjective
judgment on the allocation results, we optimize the cost and energy efficiency simultaneously, and use NSGA-II algorithm to obtain the Pareto optimal solution set of the multi-objective optimization problem. Then the multi-attribute decision method based on evidence reasoning is applied to select the final planning scheme from Pareto front solutions.

2. Integrated energy system

Integrated energy systems can provide users with a variety of heterogeneous energy sources, so the results in the system are complex and the devices are highly synergistic and complementary. For the energy conversion characteristics of the devices in the system, the devices are divided into 3 main categories, which are energy supply side devices, energy storage side devices and demand side Equipment. Of course, with renewable energy becoming a major focus of national energy development, integrated energy systems also include PV Renewable energy distribution equipment such as generators and wind turbines. The typical structure of an integrated energy system consists of four subsystems of source-grid load and storage. The construction of an electric-thermal integrated energy system in the paper is a typical integrated energy scenario. It allows for spatially coordinated and complementary optimization of the electrical and thermal subsystems, thus enabling improved economics, integrated energy efficiency, and a more sustainable energy system. The consumption rate of renewable energy is structured as shown in Figure 1.

![Figure 1. A schematic diagram of a typical integrated energy system](image)

3. Modeling based on economic and energy efficiency optimization

3.1. Function

(1) Economic optimum

The total operating cost of an integrated energy system typically includes the cost of purchased energy, equipment operation and maintenance, and pollutant discharge costs. The specific expression is:

$$\min C_d = C_E + C_G + C_{OM} + C_W$$

Where $C_d$ is operation cost of the IES (yuan); $C_E$ electricity network purchase tariffs (yuan); $C_G$ is gas net purchase gas charges (yuan); $C_{OM}$ is the daily operation and maintenance cost of each equipment in the IES (yuan); $C_W$ the pollutant emission cost of the IES (yuan).

(2) The integrated energy efficiency is the best

The calculation formula of integrated energy consumption is:

$$E = \sum_{i=1}^{n} (e_i * p_i)$$
Where \( E \) is the integrated energy consumption, kJ, which is expressed in kg of standard coal kgce (1kgce=29307kJ); \( n \) is the number of energy varieties consumed; \( e_i \) is the physical quality of type \( i \) energy consumed in industrial production, kg; \( p_i \) is the standard coal conversion coefficient of the \( i \) energy source.

Considering the energy storage loss of various types of energy storage in cold \( C \), heat \( H \) and electricity \( P \), the expressions of the cold, heat and electric energy provided by the system are as follows:

\[
C = \int_0^T C_i(t) \, dt
\]

\[
H = \int_0^T (H_{steam}(t) + H_{water}(t)) \, dt
\]

\[
P = \int_0^T P_i(t) \, dt
\]

Where \( C_i(t) \) is the system cooling load demand, kW; \( H_{steam}(t) \) and \( H_{water}(t) \) are the steam load and the hot water load of the system respectively; \( P_i(t) \) is the system electrical load; \( C \), \( H \), \( P \) are respectively the cooling, heating and power supply quantity of the system in time slot \( T \), kJ.

Then the integrated energy efficiency expression of the multi-energy system is:

\[
\eta = \frac{(C + H + P)}{E}
\]

3.2. Constraint condition

(1) Power balance constraint

\[
P_{ele\_MG\_grid}(t) + P_{De}(t) + P_{ES\_dis}(t) = P_{load}(t) + P_{ES\_char}(t)
\]

Where \( P_{ele\_MG\_grid}(t) \) is the power exchange between power grid and IES, kW; \( P_{De}(t) \) represent the output power of distributed device, kW; \( P_{ES\_dis}(t) \) and \( P_{ES\_char}(t) \) are the discharge he charge power of battery, kW; \( P_{load}(t) \) is the total load within the system, kW.

(2) Thermal balance constraint

\[
H_{hold\_MG\_grid}(t) + H_{De}(t) + H_{TES\_dis}(t) = H_{load}(t) + H_{TES\_char}(t)
\]

Where \( H_{hold\_MG\_grid}(t) \) is the thermal exchange between heating company and IES, kW; \( H_{De}(t) \) represent the output power of distributed device, kW; \( H_{TES\_dis}(t) \) and \( H_{TES\_char}(t) \) is the charge he power of the heat storage system, kW; \( H_{load}(t) \) is the thermal load within the system, kW.

3.3. Model solving algorithm

Since the model developed in this paper is based on economical and energy efficient multi-objective operation optimization model. After comparing the solution characteristics and adaptability of various multi-objective algorithms. In this paper, NSGA-II algorithm is chosen to solve the model, and the solution procedure is as follows:
Figure 2. NSGA-II algorithm solution flow

1) Parameter initialization. Enter system parameters: historical load, climate data, equipment parameters, etc.
2) Sample initialization. Initialize sample p; algebra n1, t=1.
3) Simulation. Invoke a low-level optimal scheduling strategy to calculate economic and energy efficiency target values.
4) Iteration. Perform genetic operations on the parent population: selection, crossover, and 1 mutation to generate the offspring population q.
5) Simulation calculations. Calculate the combination of economic and environmental target values and individual adaptation of q.
6) Merging. Merge to obtain a population q, calculate the distance of superiority and inferiority, and perform Pareto ordering.
7) Termination condition. Determine the termination condition, if the termination condition is met, output the equipment operation strategy, total system operating cost and energy efficiency value, otherwise return to step 4.

4. Case Study

4.1. Parameter
The article chooses a regional integrated energy system project in China as the object of study, and verifies the reliability of the established planning optimization model. For the planning of the park, three planning schemes are proposed.

Scheme 1: Traditional Centralized Energy Supply System.
Scheme 2: Cold Hot Spot Triple Energy Supply System.
Scheme 3: Energy System Planning Optimization Model
Figure 3. Typical Daily Load Curve

Table 1. Technical Parameters of the IES

| Equipment Type | Capacity (kW) | Unit Investment Cost (Yuan/kW) | Unit Maintenance Cost (Yuan/kW) |
|----------------|--------------|-------------------------------|-------------------------------|
| Photovoltaic   | 150          | 5000                          | 0.00120                       |
|                | 300          | 6500                          | 0.00125                       |
| Photovoltaic   | 350          | 6000                          | 0.0665                        |
|                | 500          | 7500                          | 0.0689                        |
| CCHP           | 2M           | 4600                          | 0.05                          |
|                | 4M           | 7210                          | 0.07                          |
| Battery        | 500          | 3000                          | 0.05                          |
| Heat storage tank | 1000     | 1600                          | 0.05                          |
| Electric refrigerator | 3500  | 1500                          | 0.05                          |
| Absorption refrigerator | 4000  | 3000                          | 0.3                           |

Six gas turbines rated at 1MW and 2MW and wind turbines rated at 300kw and 500kw were selected. Generators are used as energy supply side equipment. The photovoltaic option has a maximum installed capacity of 350 kW. The number of gas turbines is capped at 4 based on historical load. The upper limit for the installed capacity of both batteries and heat storage tanks is set at 3.5MW. In the NSGA-II algorithm, the number of populations are 1000, the number of iterations T was 300, the crossover rate was 0.75, and the mutation rate was 0.15.

4.2. Planning optimization simulation

According to the calculation example in section 4.1, tables 4-1 are the optimal solutions for the system equipment capacity planning results of the three schemes respectively.

Table 2. Three schemes System Equipment Capacity Planning Optimization Results

| scheme | Cost (billion yuan) | Energy efficiency |
|--------|---------------------|-------------------|
| 1      | 4.18357             | 1.2049            |
| 2      | 4.1721              | 1.3405            |
| 3      | 4.2138              | 1.5632            |

Through the data in the table, we can find that the Integrated energy efficiency of scheme 3 is the largest. Therefore, scheme 3 is the optimal scheme combining economy and Integrated energy efficiency, thus proving the effectiveness of the capacity allocation planning optimization model of the Integrated energy system proposed in this paper.
5. Conclusion
This paper describes an integrated energy system and proposes an optimization model for capacity allocation planning of the integrated energy system. Based on NSGA-II algorithm, the reasonable allocation scheme of energy supply equipment capacity is solved. In addition, in order to verify the effectiveness of the proposed optimization model for capacity allocation planning of integrated energy systems, we chose a regional integrated energy system park in China for simulation. The results show that, combined with economy and Integrated energy efficiency, the proposed scheme 3 (Integrated energy system capacity allocation planning optimization model) is optimal compared with scheme 2 (cold and hot spot triple energy supply system) and scheme 1 (traditional centralized energy supply system). In the future, I will further study the coupling and complementation mechanism between the capacity planning and system operation of the integrated energy system, expecting to realize the balance between the capacity allocation and operation optimization of the integrated energy system, not only to realize the economic optimization and energy efficiency maximization, but also to realize the minimization of carbon emissions and the maximization of system reliability.

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