Analysis of Energy Utilization Efficiency of Integrated Energy System

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Abstract. This paper considers the multi-energy flow characteristics of the integrated energy system and the impact of renewable energy access, and proposes an energy utilization index that is suitable for the energy efficiency assessment of the multi-energy collaborative integrated energy system. The index can comprehensively reflect the consumption rate of renewable energy and the utilization level of non-renewable energy in the park, and reflect the core characteristics of low-carbon and high-efficiency of the integrated energy system. The analysis compares the difference between the proposed indicator and other energy efficiency indicators. The result of the calculation example shows that, compared with the direct promotion of the traditional primary energy utilization rate, this indicator can more accurately reflect the advantages of multi-energy combined supply and energy cascade utilization in the park.

1. Introduction

The multi-energy complementary integrated energy system includes the input of various types of energy resources such as electricity, gas, solar energy, wind energy, waste heat, etc. Through the coordinated optimization and integration of resources and technologies, it provides users with cooling capacity, heat and electricity with high comprehensive energy efficiency [1-3]. The multi-energy complementary integrated energy system of the park can be regarded as an organic whole formed by the integration of the "energy resource development-conversion-transmission-storage-consumption" process. The various processes in the system interact and interact with each other to form a unique system. Function [4-5]. In order to examine the performance of a multi-energy complementary integrated energy system, its energy efficiency is an important indicator.

This paper analyzes the problems of traditional energy efficiency assessment methods, considers the multi-energy flow characteristics of the park-level integrated energy system and the impact of renewable energy access, and proposes a comprehensive energy utilization index suitable for the park energy efficiency assessment. This indicator is not a refinement or simple promotion of primary energy utilization rate. While considering the multi-energy flow characteristics of the park, it introduces an energy non-renewable coefficient and converts the purchased electricity to the corresponding primary energy according to the penetration rate. This indicator reflects the utilization rate of the park for non-renewable energy and the level of consumption of renewable energy.
2. Integrated energy system energy efficiency assessment

For the park-level integrated energy system, the input and output energy flow composition is shown in Figure 1.

![Figure 1. Composition of energy flow input and output of park-level integrated energy system](image)

With reference to Figure 1, taking $T$ as the evaluation period, the energy input of the integrated energy system park is divided into two parts: power purchase energy $E_{\text{grid},t}$ and other energy $E_{\text{other},t}$ according to whether it comes from an external power grid. Considering the impact of renewable energy access and the multi-energy flow characteristics of the park [6], the comprehensive energy utilization index is proposed, which is defined as follows:

$$\lambda = \frac{P_{k,t} + H_{k,t} + C_{k,t}}{E_{\text{grid},t} + E_{\text{other},t}}$$  \hspace{1cm} (1)

$$P_{k,t} = \int_0^T P_k(t) \, dt$$  \hspace{1cm} (2)

$$H_{k,t} = \int_0^T H_k(t) \, dt$$  \hspace{1cm} (3)

$$C_{k,t} = \int_0^T C_k(t) \, dt$$  \hspace{1cm} (4)

$$E_{\text{grid},t} = \int_0^T (\zeta_{re} \theta_{re}(t) + F_{\text{gas}}(t)) \, dt$$  \hspace{1cm} (5)

$$E_{\text{other},t} = \int_0^T (\zeta_{re} P_{re}(t) + F_{\text{gas}}(t)) \, dt$$  \hspace{1cm} (6)

In the above formula, $\lambda$ is the comprehensive energy utilization rate of the park; Respectively, $P_{k,t}$, $H_{k,t}$, $C_{k,t}$ are the power supply, heating and cooling capacity of the park during the $T$ period, $k$J; $P_k(t)$, $H_k(t)$, $C_k(t)$ are the electricity, heat and cooling load power of the park at time $t$ in kW; The subscripts ‘$re$’, ‘$\text{gas}$’ respectively indicate that the energy source is renewable energy, coal, natural gas, the same applies below; $\zeta$ is the energy non-renewable coefficient [7], which is 0 for renewable energy and for non-renewable energy; $\theta(t)$ is the penetration rate of different primary energy sources in purchased electricity at time $t$; $P_{\text{purchase},t}$ is the electrical energy power purchased by the park at time $t$, and the unit
is kW; $P_n(t)$ is the renewable energy power that the park is not connected to the grid at time t, and the unit is kW; $F_{gas}(t)$ is the low calorific value of the natural gas consumed, KJ.

It can be seen from equation (1) that this indicator focuses on the overall evaluation of the utilization of the non-renewable part of the primary energy in the park, and it does not consider the energy flow conversion relationship within the park. For example, the power supply of the park may have multiple sources such as purchased electricity and CCHP power generation, and the cooling capacity and the heat supply are the same.

From formula (1) to (6), we can know that: (1) for a comprehensive energy system Park, the higher the comprehensive utilization rate of primary energy, the less the corresponding primary energy consumption. (2) for an integrated energy system with a high percentage of renewable energy penetration, with the increase in the amount of renewable energy consumption, under a certain load, its non-consumption Renewable primary energy will also be reduced accordingly, so that its comprehensive energy utilization rate will increase, that is, this indicator can reflect the park's level of consumption of renewable energy.

Based on the above analysis, unlike the traditional index, this index considers the multi-energy flow characteristics of the integrated energy system and the impact of renewable energy access, and comprehensively reflects the utilization level of the park's non-renewable primary energy and the consumption rate of renewable energy. It can reflect the core features of low-carbon and high-efficiency of the integrated energy system, and provide a reference for the determination and evaluation of the planning and dispatching plan of the integrated energy park.

3. Case study

3.1. System parameters

In this paper, the integrated energy system of a certain place in China is taken as an example, and the equipment parameters in the system are shown in Table 1. The typical load data of summer and winter are calculated according to the predicted values of the two seasons, and the specific data are shown in Figure 2 and Figure 3 respectively. The renewable energy penetration rate of the regional grid is 0.25.

Table 1. Main equipment parameters and values

| Device name         | Parameter      | Numerical value |
|---------------------|----------------|-----------------|
| Gas turbine         | Rated power $P_{G,E}$ (MW) | 2.1             |
|                     | Cutting factor $\phi_{cut}$ | 0.3             |
|                     | Efficiency coefficient $a_p$ | 0.406           |
|                     | Efficiency coefficient $d_p$ | -145.5          |
|                     | Efficiency coefficient $s_p$ | 0.556           |
|                     | Efficiency coefficient $k_p$ | -442.3          |
| Waste heat recovery boiler | Rated power $H_{WHR}$ (MW) | 2               |
|                     | Heat recovery efficiency $\lambda_{WHR}$ | 0.85 |
| Absorption chiller  | Rated power $C_{AC}$ (MW) | 2.1             |
|                     | Cooling coefficient $\alpha_{AC}$ | 1.3             |
| Gas boiler          | Rated power $H_{PGN}$ (MW) | 2               |
|                     | Boiler steam efficiency $\lambda_{PG}$ | 0.916 |
| Electric refrigerator | Rated power $C_{ERN}$ (MW) | 3               |
|                     | Cooling coefficient $\alpha_{IR}$ | 4.2             |
Figure 2. Typical daily load in summer

Figure 3. Typical daily load in winter

3.2. Summary of typical system scenarios

The energy efficiency of the system depends on the input-output conversion relationship of the multi energy system and the operation strategy selected by the system. The distributed multi energy system contains many devices, which can meet the needs of cold, hot and electric loads at the same time, so its energy supply mode is complex and the operation strategy of the system is diverse. In the process of distributed multi energy system operation, under different seasons and different operation strategies, its comprehensive energy efficiency will be quite different. Based on the system operation strategy and considering the different seasons, this paper summarizes five typical scenarios of the integrated energy system as shown in Table 2.

Table 2. Energy efficiency assessment scenarios

| Scene number | Evaluation scenario                                      |
|--------------|----------------------------------------------------------|
| S1           | Adopting "priority to meet electric load" operation strategy on typical winter days |
| S2           | Adopting "priority to meet heat load" operation strategy on typical winter days |
| S3           | Adopting "priority to meet electric load" operation strategy on typical summer days |
| S4           | Adopting "priority to meet cool load" operation strategy on typical summer days |

3.3. Calculation results of energy efficiency indicators in various scenarios

Table 3. Calculation results of energy efficiency indicators

| Number | Energy efficiency index | Scene number |
|--------|-------------------------|--------------|
|        |                         | S1           | S2           | S3           | S4           |
| 1      | Primary energy utilization | 0.7628       | 0.7543       | 1.0199       | 0.922        |
| 2      | Primary energy saving rate | 0.5504       | 0.5454       | 0.4526       | 0.3944       |
| 3      | Comprehensive energy utilization rate | 0.7115 | 0.6808 | 0.8322 | 0.7871 |

It can be seen from the actual operation of the equipment in each scenario that S3 has a large photovoltaic power generation in summer. Because the system preferentially uses photovoltaic power
generation, a large part of the energy in the system comes from solar energy, which makes the secondary energy utilization rate exceed 1; S4 Due to the system's priority to meet the cold load demand and the large cold load demand of the system, CCHP fails to make full use of photovoltaic power generation and consumes a lot of natural gas while operating at full load, making the primary energy saving rate lower than other scenarios.

4. Conclusion
After fully considering the use of non-renewable energy, the consumption of renewable energy and the degree of energy conversion by the system, a comprehensive evaluation index model for energy efficiency of an integrated energy system was established. Finally, an example analysis was carried out. By analyzing the load characteristics of the actual case of an integrated energy system in a certain place in China, and using the evaluation indicators and evaluation methods established in this paper to obtain specific values of the comprehensive energy efficiency of the system under specific scenarios, the results show that compared with the direct promotion of traditional primary energy utilization, The mentioned indicators can more accurately reflect the advantages of multi-energy combined supply and energy cascade utilization in the park, and effectively evaluate the energy efficiency of the park under different seasons and operating strategies.

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