Research on Operation Optimization of Integrated Energy System

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Abstract. The increasingly severe energy-saving situation and the need for sustainable development have brought the construction of integrated energy systems to a new level. The integrated energy system integrates multiple energy systems such as power supply, heating supply, and cooling supply. It is an inevitable trend in the development of modern energy systems to fully utilize the energy-saving potential of integrated energy systems through multi-energy complementary coordination and optimization. In this paper, an integrated energy system optimization scheduling model including a combined cooling, heating and power unit (CCHP) is proposed, and the optimal operation strategy of the integrated energy system under multi-season load demand is studied. The research results show that the integrated energy system can meet the requirements of energy security, stability and efficient supply under different seasonal conditions, and can significantly reduce energy operation costs.

1. Introduction

Energy is an important foundation and guarantee for modern social functioning. With the rapid development of the economy, energy demand is growing, and the contradiction between energy quality and efficiency is prominent. Building a modern energy system with green, low-carbon, safe and efficient, and integrated management and control is an inevitable trend to achieve sustainable development of the whole society. Actively optimizing the energy supply structure, improving the level of energy utilization, and accelerating the construction of integrated energy systems to achieve safe, clean and efficient operation of energy systems are important technical guarantees for enhancing the capacity of sustainable economic development.

An important feature of an integrated energy system is that it takes the balance, transformation and circulation of electricity, heat, cold and other energy sources as the core, and makes full use of solar energy, wind energy and other renewable energy sources to realize self-control and management. At present, the research on integrated energy systems at home and abroad mostly focuses on the theoretical level, and few studies are applicable to the optimization of integrated energy system operation under the regional energy multi-season load demand. Based on the requirements of safety, stability and economic operation of the integrated energy system, this paper studies the optimal scheduling model of the integrated energy system and the operation strategy under different seasons. The results show that the integrated energy system can effectively reduce the energy cost under various seasonal conditions, improve the energy efficiency of the system and have a good application prospect.
2. Integrated energy system optimization scheduling model

The structure of an integrated energy system in a certain area is shown in Figure 1. The heat load in this area is provided by the gas boiler and the triple heat exchanger. The cooling load is provided by the electric refrigeration, the storage equipment and the lithium bromide absorption refrigerating machine of the CCHP unit; the electric load is provided by photovoltaic, energy storage equipment and power grid, and is mainly used for self-use, avoiding the surplus electricity.

![Energy System Diagram](image)

**Figure 1. Integrated energy system structure**

The rated power of each energy source in the system is shown in Table 1. It should be noted that when the energy storage (storage) power is positive, it indicates discharge (release), and when the power is negative, it indicates charging (cool storage). In addition, the electrical cooling power PEC refers to the input power of the refrigeration unit, not the cooling capacity.

| Type of energy | Rated power (MW) | Capacity (MWh) |
|----------------|-----------------|----------------|
| $P_{grid}$     | 0~100           |                |
| $P_{CCHP}$     | 0~20            |                |
| $Q_{CCHP}$     | 0~16            | /              |
| $H_{CCHP}$     | 0~16            | /              |
| $H_{BL}$       | 0~2             | /              |
| $P_{EC}$       | 0~10            | /              |
| $P_{PV}$       | 0~5             | /              |
| $P_{ST}$       | 0~1             | /              |
| $P_{ST}$       | -5~5            | 40             |
| $Q_{ST}$       | -24~24          | 192            |

The area is charged by peak-to-valley electricity price, and the time-sharing electricity price ($U_e$) is shown in Table 2. The natural gas agreement price ($U_g$) is 2.3 yuan/m³, and the standard heating value is 35MJ/m³.
Table 2. Time-sharing electricity price

| Type   | Time               | Price (yuan/kWh) |
|--------|--------------------|-----------------|
| Peak   | 23:00~07:00        | 0.38            |
| Flat   | 07:00~09:00; 12:00~19:00 | 0.73     |
| Valley | 09:00~12:00; 19:00~23:00 | 1.13     |

Based on the above integrated energy system structure, the minimum daily operating cost is the optimal scheduling target, which can be expressed by the following formula:

\[
f^* = \min \left[ \sum_{t=1}^{24} U^t \cdot P^t_{grid} \cdot \Delta t + U^t \cdot \sum_{t=1}^{24} \left( \frac{P^t_{CCHP}}{\eta_{gen}} + \frac{H^t_{BL}}{\eta_{BL}} \right) \cdot \Delta t \right]
\]

E1

In actual operation, economic dispatch must meet the supply and demand balance of various energy sources such as cold, heat and electricity, as well as the constraints on the operational characteristics of each equipment. In order to simplify the calculation, this paper uses the quasi-static model to model each energy equipment. The constrained conditions are as follows: E2-E10 (see Tab.1 for energy equipment output range constraints, not listed separately):

\[
P^t_{grid} + P^t_{CCHP} + P^t_{st} + P^t_{pv} + P^t_{wt} = P^t_{load} + P^t_{EC}
\]

E2

\[
\partial \cdot P^t_{CCHP} - Q^t_{CCHP} - H^t_{CCHP} = 0
\]

E3

\[
Q^t_{CCHP} + Q^t_{EC} + Q^t_{st} = Q^t_{load}
\]

E4

\[
H^t_{BL} + H^t_{CCHP} = H^t_{load}
\]

E5

\[
\text{COP} \cdot P^t_{EC} - Q^t_{EC} = 0
\]

E6

\[
\sum_{t=1}^{24} P^t_{st} = 0
\]

E7

\[
\sum_{t=1}^{24} Q^t_{st} = 0
\]

E8

\[
SOC_{max} \leq SOC_0 + \sum_{t=1}^{i} P^t_{st} \leq SOC_{min}
\]

E9

\[
Q_{RTH,max} \leq Q_{RTH,0} + \sum_{t=1}^{i} Q^t_{st} \leq Q_{RTH,min}
\]

E10

Among them, the parameter value:

\[
\eta_{gen} = 0.45 \quad \eta_{BL} = 0.9 \quad \eta_{s} = 0.655
\]

\[
\partial = \frac{\eta_{s} \cdot (1 - \eta_{gen})}{\eta_{gen}} = 0.8
\]

\[
\text{COP} = 5
\]

\[
SOC_0 = -10000 \quad SOC_{max} = -40000 \quad SOC_{min} = 0
\]

\[
Q_{RTH,0} = -48000 \quad Q_{RTH,max} = -192000 \quad Q_{RTH,min} = 0
\]

The dynamic economic scheduling model established above with the economic optimal scheduling goal can be solved by a mixed integer linear programming algorithm or a genetic algorithm.
3. Multi-season operation strategy of integrated energy system

According to the integrated energy system model and the optimized scheduling algorithm described in the previous section, the equipment operation strategy under different load conditions can be obtained. The optimal scheduling curves for the typical days of each season are calculated based on the cold, heat and electric load forecast curves and the renewable energy power forecast curves for typical days in summer, winter and transition seasons.

It can be seen from Figure 2(a) that the summer cold load and electric load reach the peak at about 15:00-16:00. The industrial production, commercial activities and daily energy consumption decrease at night from 21:00-06:00. The load is at a low point. Comparing the load curve of Figure 2(a) with the optimized scheduling curve shown in Figure 2(b), it can be seen that the results of the optimized scheduling maximize the use of energy storage and cold storage means: charging and cold storage during the nighttime, discharging and cooling during the daytime, so as to achieve the purpose of peak clipping and valley filling, improve the economics of the operation of the integrated energy system.

As can be seen from Figure 3, the cold load in the region is almost zero in winter, and the heat load is greatly increased. The result of the optimized dispatch is that the electric refrigerator and the cold storage system should be shut down, and the heat load is preferentially provided by the CCHP unit. When the heating capacity of the unit is insufficient, the gas boiler is turned on for heating.
Figure 4(a). Load and solar energy prediction of transition season  4(b). Equipment output

As can be seen from Figure 4, the typical daily cooling heat load in the transitional season is more evenly distributed with time, and there is no obvious peak load period. At this point, both the refrigeration unit and the gas boiler are shut down, and the cold and heat loads are mainly provided by the CCHP unit. It is noteworthy that, because the energy storage system can use the electric refrigeration unit as the cold source or the CCHP unit as the cold source, it can still operate normally in the case of the shutdown of the electric refrigeration in the transitional season to achieve economical optimal scheduling.

The above results show that when the cold, heat and electric load changes, it is necessary to adjust the output of each energy device in time, and adopt an optimized scheduling strategy to give full play to the advantages of the integrated energy system. Further, it is possible to calculate the change in typical daily energy operating costs for each season when a certain energy device is missing, as shown in Table 3.

|                      | Summer | Winter | Transition |
|----------------------|--------|--------|------------|
| Integrated energy system | 851.7  | 775.3  | 762.3      |
| Eliminate cold storage | 873.0  | 775.3  | 783.2      |
| Eliminate power storage | 879.7  | 805.0  | 789.7      |
| Eliminate CCHP         | 1015.5 | 966.7  | 903.5      |
| Eliminate solar energy  | 898.3  | 808.1  | 802.3      |

It can be seen from Table 3 that in the integrated energy system, each form of energy contributes to the reduction of overall energy costs. Among them, whether in summer, winter or transition season, the energy operation cost can be greatly reduced by the application of the CCHP unit under the premise of satisfying the needs of various energy sources, such as cold, heat and electricity, which is the core of the integrated energy system to achieve optimal scheduling.

The above is only a specific case of the application of integrated energy system optimization scheduling technology. When the energy supply form, operation requirements and optimization objectives change, the integrated energy system can have many different optimization strategies. To realize the safety, stability and economic operation of the integrated energy system under different conditions, it is necessary to realize the control of the whole process of source, network, load and storage and the coordinated control of cold, heat and electricity in the energy system by means of the integrated energy management and control system.

4. Conclusion
This paper studies the optimal energy system optimization scheduling model and the integrated energy system optimization operation strategy under multi-season load demand. The main conclusions are as follows:
(1) The integrated energy system includes multiple energy subsystems such as cooling, heating, and power supply. By coordinating and controlling various energy subsystems and exerting multi-energy complementary advantages, energy operation costs can be greatly reduced.

(2) For areas with simultaneous load requirements such as cold, heat and electricity, the application of the CCHP unit is the key to realize the optimal dispatch of the integrated energy system.

(3) The integrated energy system optimization operation strategy is closely related to the load demand. When the load demand changes, the system operation strategy can be flexibly adjusted to maintain the optimal operation state of the integrated energy system.

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