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Research on the Optimization Scheduling of Integrated Energy System Considering Heat Recovery from Data Center

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Abstract: With the explosive growth of data centers, a large amount of waste heat resources generated by their operation need to be efficiently utilized. In order to improve the energy utilization efficiency of the integrated energy system and reduce the operating cost, an optimal scheduling model of the integrated energy system considering the waste heat recovery of the data center is proposed. Firstly, a data center integrated energy system framework including wind power, photovoltaic, gas turbine, electric boiler, heat pump and absorption chiller is constructed, and a data center waste heat recovery model is established. The heat dissipation is upgraded by heat pump and connected to the system heating network and absorption chiller. Secondly, with the goal of minimizing the sum of total operating costs, considering the power balance of electricity, heat and cold and the constraints of equipment output, an economic dispatch model is formed. Simulation verification is performed by setting a comparison scenario with or without waste heat recovery. The results show that after the waste heat recovery is enabled, the total cost of the system is reduced by 7.95%, and the cost of gas purchase is reduced by 16.86 %. It effectively replaces the gas h eating and drives the absorption refrigeration, and realizes the cascade utilization of thermal energy and the consumption of renewable energy.

Keywords: Integrated energy system, Optimal scheduling, Data Center, Waste heat recovery.

1. Introduction

With the rapid development of the digital economy and information technology, data centers, as the core of computing infrastructure, have seen continuous growth in scale and energy consumption. According to statistics, the electrical energy consumed by the IT equipment in data centers is almost entirely converted into heat. If not utilized, it not only leads to the waste of a large amount of waste heat resources but also requires additional cooling energy consumption to maintain the normal operation of the equipment, further increasing the burden on the energy system [1]. At the same time, the Integrated Energy System (IES), through multi-energy complementation and coordinated optimization, can effectively improve energy utilization efficiency, promote the consumption of renewable energy, and reduce system operation costs. It has become a current research hotspot in the energy field.

In terms of the integration of data centers with integrated energy systems, some scholars have conducted preliminary explorations. Lu Yuxin et al [2]. included data centers as a special energy consumption unit in the integrated energy system and constructed the basic framework of a park-level integrated energy system including data centers. Ding Z, Lan Zhou et al [3-4]. explored the time-scheduling flexibility of data center loads and provided modeling ideas and method support for their participation in the coordinated scheduling of the integrated energy system. Wen Xiyu et al [5]. further considered the dual-scale adjustable characteristics of data center loads in time and space, and constructed a low-carbon economic scheduling strategy for multiple data centers based on spatial-temporal coordination. Li Linhong et al [6]. proposed a multi-station integration architecture of energy station - substation - data center station, incorporating the waste heat from data centers into multi-energy coordination utilization, providing a stable heat source for the energy station, reducing waste heat loss and reliance on gas boilers, and improving system energy efficiency. However, existing research mostly focuses on the power demand response or computing power scheduling of data centers, and lacks systematic optimization scheduling analysis on how the large amount of waste heat generated by their operation can be deeply coupled with the multi-energy flows of the integrated energy system such as heat, cold, and electricity. Some studies do involve waste heat recovery, but do not fully consider the collaborative operation mechanism between waste heat recovery and multi-energy conversion equipment such as electricity, heat, and cold.

Therefore, An integrated energy system optimization scheduling model considering the waste heat recovery of data centers is constructed in this paper. Firstly, a framework of the data center integrated energy system (DC-IES) is established, which includes renewable energy equipment, multi-energy coupling conversion equipment, and energy storage devices. A data center waste heat recovery model is introduced to connect the heat dissipation of the data center after quality improvement by heat pumps to the system heat network. Secondly, with the objective of minimizing the sum of system energy purchase cost, equipment operation and maintenance cost, and wind and solar energy abandonment cost, an economic scheduling model is formed, considering the power balance of electricity, heat, and cold, as well as equipment output constraints. Finally, by setting comparison scenarios with and without waste heat recovery, the simulation verifies the effectiveness of the proposed model in reducing the total system cost, reducing energy purchase expenses, enhancing the utilization of renewable energy, and achieving the cascade utilization of thermal energy. This research provides theoretical basis and practical reference for the collaborative optimization of data centers and regional integrated energy systems.

2. Framework and Model of the Integrated Energy System for Data Centers

The DC-IES in this paper mainly consists of four major parts: the power supply side, multi-energy coupling conversion equipment, energy storage devices, and the load side of the data center park. The power supply side includes wind power (wind turbine, WT), photovoltaic (photovoltaic, PV), and the power grid and gas network. The multi-energy coupling conversion equipment includes electric boilers (Electric Boiler, EB), electric chillers (Electric Chiller, EC), gas boilers (Gas Boiler, GB), gas turbines (Gas Turbine, GT), absorption chillers (Absorption Chiller, AC), and heat pumps (Heat Pump, HP). The energy storage devices include electric storage (Energy Storage, ES), thermal storage (Thermal Storage, TS), and cold storage (Cold Storage, CS). The constructed DC-IES framework is shown in Figure 1.

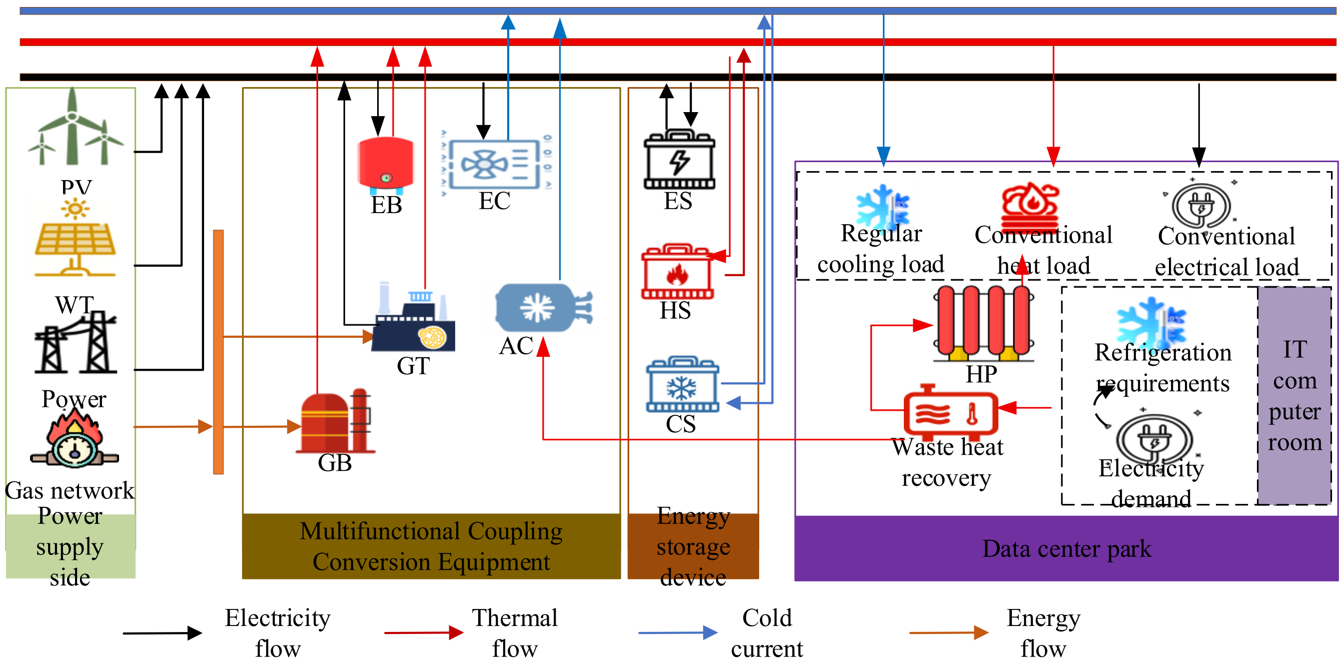

Figure 1. DC-IES structure diagram

2.1. Equipment Model

2.1.1. GT Model

The gas turbine generates electricity by consuming natural gas. The remaining heat is recovered from the flue gas through the waste heat boiler to meet the thermal load requirements of the system. The model is as follows:

$$\begin{cases} G_{\mathrm{GT},t} = V_{\mathrm{GT},t} L_{\mathrm{CH_4}} \\ P_{\mathrm{GT},t}^{\mathrm{e}} = \eta_{\mathrm{GT}}^{\mathrm{e}} G_{\mathrm{GT},t} \\ P_{\mathrm{GT},t}^{\mathrm{h}} = (1-\eta_{\mathrm{GT}}^{\mathrm{e}}) G_{\mathrm{GT},t} \eta_{\mathrm{WHB}}^{\mathrm{h}} \end{cases} \tag{1}$$

In the formula, $G_{\mathrm{GT},t}$ represents the power consumed by GT for natural gas; $L_{\mathrm{CH_4}}$ represents the amount of natural gas consumed by GT; $P_{\mathrm{GT},t}^{\mathrm{e}}$ represents the calorific value of natural gas; $P_{\mathrm{GT},t}^{\mathrm{h}}$ and respectively represent the electrical and thermal output powers of GT; $\eta_{\mathrm{GT}}^{\mathrm{e}}$ represents the power generation efficiency of GT; $\eta_{\mathrm{WHB}}^{\mathrm{h}}$ represents the thermal recovery efficiency of the waste heat boiler.

2.1.2. GB Model

The gas boiler uses natural gas as fuel to generate heat energy. The model is as follows:

$$P_{\mathrm{GB},t}^{\mathrm{h}} = \eta_{\mathrm{GB}}^{\mathrm{h}} V_{\mathrm{GB},t} L_{\mathrm{CH_4}} \tag{2}$$

In the formula, $P_{\mathrm{GB},t}^{\mathrm{h}}$ represents the thermal energy output power of GB; $\eta_{\mathrm{GB}}^{\mathrm{h}}$ represents the thermal energy conversion efficiency of GB; $V_{\mathrm{GB},t}$ represents the natural gas fuel consumption of GB.

2.1.3. EB Model

The electric boiler converts electrical energy into thermal energy and serves as a rapid peak-shaving heat source for the system's heat load. The model is as follows:

$$P_{\mathrm{EB},t}^{\mathrm{h}} = \eta_{\mathrm{EB}}^{\mathrm{h}} P_{\mathrm{EB},t}^{\mathrm{e}} \tag{3}$$

In the formula, $P_{\mathrm{EB},t}^{\mathrm{h}}$ represents the thermal energy output power of EB; $\eta_{\mathrm{EB}}^{\mathrm{h}}$ r epresents the electrical-to-thermal conversion efficiency of EB; $P_{\mathrm{EB},t}^{\mathrm{e}}$ represents the electrical input power of EB.

2.1.4. EC Model

The electric refrigeration machine outputs coldness by consuming electrical energy to drive the refrigeration cycle. The model is as follows:

$$P_{\mathrm{EC},t}^{\mathrm{l}} = \eta_{\mathrm{cop,EC}}^{\mathrm{l}} P_{\mathrm{EC},t}^{\mathrm{e}} \tag{4}$$

In the formula, $P_{\mathrm{EC},t}^{\mathrm{l}}$ represents the cooling output power of EC; $\eta_{\mathrm{cop,EC}}^{\mathrm{l}}$ represents the refrigeration performance coefficient of the electric refrigeration unit; $P_{\mathrm{EC},t}^{\mathrm{e}}$ represents the electric power input to the electric refrigeration unit.

2.1.5. AC Model

Absorption refrigerators use recovered waste heat as the driving heat source to output cooling capacity. The model is as follows:

$$P^{\mathrm{l}}_{\mathrm{AC},t} = \eta^{\mathrm{l}}_{\mathrm{cop,AC}} \cdot P^{\mathrm{h}}_{\mathrm{AC},t} \tag{5}$$

In the formula: $P^{\mathrm{l}}_{\mathrm{AC},t}$ represents the cooling output power of AC; $\eta^{\mathrm{l}}_{\mathrm{cop,AC}}$ represents the cooling performance coefficient of AC; $P^{\mathrm{h}}_{\mathrm{AC},t}$ represents the input power of the driving heat source of AC.

2.1.6. HP Model

Heat pumps achieve the efficient utilization of low-grade thermal energy by consuming a small amount of electrical energy. The model is as follows:

$$P^{\mathrm{h}}_{\mathrm{HP},t} = P^{\mathrm{e}}_{\mathrm{HP},t} \cdot COP_{\mathrm{hp}} \tag{6}$$

In the formula, $P^{\mathrm{h}}_{\mathrm{HP},t}$ and $P^{\mathrm{e}}_{\mathrm{HP},t}$ represent the heat power output by the heat pump and the electric power consumed by the heat pump, respectively; COP_{hp} is the performance coefficient of the heat pump.

2.1.7. Energy Storage Model

The electric refrigeration machine outputs coldness by consuming electrical energy to drive the refrigeration cycle. The model is as follows:

$$\begin{cases} S_t^e = S_{t-1}^e + \eta_{ch}^e F_t^{ech} - \dfrac{P_t^{pedis}}{\eta_{dis}^e} \\ S_T^e = S_0^e \\ 0 \overset{min}{\le} \overline{S}_t^e \le S_{max}^e \\ 0 \overset{max}{\le} F_t^{ech} = \mu_{max}^{ech} \\ 0 \overset{max}{\le} P_t^{pedis} = \mu_{max}^{pedis} \\ \mu^{ch} + \mu^{dis}, 1 \end{cases} \tag{7}$$

In the formula: $S_{\mathrm{ES},t}$ represents the storage capacity of electrical energy storage; $\eta^{\mathrm{e}}_{\mathrm{ch}}$ and $\eta^{\mathrm{e}}_{\mathrm{dis}}$ represent the charging and discharging efficiencies of electrical energy storage; $P_{\mathrm{ES\_chr},t}$ and $P_{\mathrm{ES\_dis},t}$ represent the charging and discharging powers of electrical energy storage; $\mu_{\mathrm{ES\_chr},t}$ and $\mu_{\mathrm{ES\_dis},t}$ represent the state positions of charging and discharging of electrical energy storage; $S^{\max}_{\mathrm{ES},t}$ and $S^{\min}_{\mathrm{ES},t}$ represent the upper and lower limits of the capacity of electrical energy storage; $P^{\max}_{\mathrm{ES,chr}}$ and $P^{\max}_{\mathrm{ES,dis}}$ represent the upper limits of the charging and discharging powers of electrical energy storage. The thermal energy storage and cold energy storage models are similar to the electrical energy storage model and will not be elaborated further.

2.2. Data Center Waste Heat Recovery System Model

In the waste heat recovery system of this article, a heat pump is utilized to increase the low-temperature heat, and then it is input into the system to supply the heat load of the area or the absorption refrigeration machine. The main source of waste heat in the data center is the electrical energy consumption caused by the operation of IT equipment, and its heat dissipation is approximately equal to the energy consumption of the IT equipment. The unrecycled waste heat requires additional cooling to remove and cool it, which can be expressed as:

$$\begin{cases} P_{\mathrm{rec},t} = P^{\mathrm{e}}_{\mathrm{DC},t} \cdot \eta_{\mathrm{rec}} \\ P^{\mathrm{c}}_{\mathrm{DC},t} = (1-\eta_{\mathrm{rec}}) \cdot P_{\mathrm{ser},t} \cdot \xi_{cool} \end{cases} \tag{8}$$

In the formula, $P_{\mathrm{rec},t}$ represents the recoverable waste heat power of the data center; η_{rec} represents the waste heat recovery efficiency; $P^{\mathrm{e}}_{\mathrm{DC},t}$ and $P^{\mathrm{c}}_{\mathrm{DC},t}$ respectively represent the electrical load of the data center and the cooling load required for heat dissipation; ξ_{cool} is the coefficient for converting the unrecovered waste heat power into cooling demand.

The relationship between the actual high-temperature heat power output by the data center after being heated by the heat pump and the recoverable residual heat power of the data center can be expressed as:

$$P^{\mathrm{h}}_{\mathrm{HP},t} = P_{\mathrm{rec},t} \cdot \eta_{\mathrm{hp}} \tag{9}$$

In the formula, $P^{\mathrm{h}}_{\mathrm{HP},t}$ represents the actual high-temperature heat power output by the data center after being heated by the heat pump; η_{hp} represents the coefficient by which the heat pump increases the low-temperature heat of the data center to high-temperature heat.

3. An Economic Scheduling Model For DC-IES Considering Waste Heat Recovery and Load Transfer in Data Centers

3.1. Objective Function

The economic dispatch model established in this paper aims to minimize the total operation cost. This cost mainly includes: power purchase cost (C_{buy}), equipment operation and maintenance cost (C_{om}), and wind and solar energy abandonment cost (C_{cur}). The objective function is:

$$\min F = C_{\mathrm{buy}} + C_{\mathrm{om}} + C_{\mathrm{cur}} \tag{10}$$

Among them, the specific calculation formulas for each part of the cost are as follows:

$$C_{\mathrm{buy}} = \sum_{t=1}^{T} \left(\mathrm{q}^{\mathrm{e}}_{\mathrm{buy},t} P^{\mathrm{e}}_{\mathrm{buy},t} + \mathrm{q}^{\mathrm{g}}_{\mathrm{buy},t} (V_{\mathrm{GT},t} + V_{\mathrm{GB},t} \right) \tag{11}$$

$$C_{\mathrm{om}} = \sum_{t=1}^{T} \left(c^{x}_{\mathrm{om},t} P_{x,t} \right) \tag{12}$$

$$C_{\mathrm{cur}} = \sum_{t=1}^{T} \left(c_{\mathrm{cur}} P_{\mathrm{cur},t} \right) \tag{13}$$

In the formula, $\mathrm{q}^{e}_{\mathrm{buy},t}$ represents the time-based electricity price of the power grid; $P^{\mathrm{e}}_{\mathrm{buy},t}$ represents the power purchase capacity of DC-IES; $\mathrm{q}^{\mathrm{g}}_{\mathrm{buy},t}$ represents the gas price of the gas network; $c^{x}_{\mathrm{om},t}$ represents the unit power operation and maintenance cost price of the equipment x; $P_{x,t}$ represents the input power of the equipment x; c_{cur} represents the unit penalty cost for wind and solar power outages; $P_{\mathrm{cur},t}$ represents the power of wind and solar power outages.

3.2. Constraints

3.2.1. Power Balance Constraint

To ensure the stable supply of different energy forms within the system and the matching of load demands, power balance constraints for electricity, heat and cold are established.

$$\begin{cases} P_{\mathrm{buy},t}^{\mathrm{e}} + P_{\mathrm{wind},t} + P_{\mathrm{pv},t} + P_{\mathrm{GT},t}^{\mathrm{e}} + P_{\mathrm{ES\,dis},t} = \\ P_{\mathrm{EB},t}^{\mathrm{e}} + P_{\mathrm{EC},t}^{\mathrm{e}} + P_{\mathrm{HP},t}^{\mathrm{e}} + P_{\mathrm{ES\,chr},t} + P_{\mathrm{load},t}^{\mathrm{e,base}} + P_{\mathrm{DC},t}^{\mathrm{e}} \\ P_{\mathrm{GT},t}^{\mathrm{h}} + P_{\mathrm{GB},t}^{\mathrm{h}} + P_{\mathrm{EB},t}^{\mathrm{h}} + P_{\mathrm{HP},t}^{\mathrm{h}} + P_{\mathrm{HS\,dis},t} = \\ P_{\mathrm{HS\,chr},t} + P_{\mathrm{load},t}^{\mathrm{h,base}} \\ P_{\mathrm{AC},t}^{\mathrm{l}} + P_{\mathrm{EC}}^{\mathrm{l}} + P_{\mathrm{CS\,dis},t} = P_{\mathrm{CS\,chr},t} + P_{\mathrm{load},t}^{\mathrm{c,base}} + P_{\mathrm{DC},t}^{\mathrm{c}} \end{cases} \tag{14}$$

In the formula, $P_{\mathrm{load},t}^{\mathrm{e,base}}$, $P_{\mathrm{load},t}^{\mathrm{h,base}}$, and $P_{\mathrm{load},t}^{\mathrm{c,base}}$ represent the basic DC-IES electric, thermal and cooling loads respectively.

3.2.2. Equipment Output and Climbing Slope Constraints

To ensure the stable supply of different energy forms within the system and the matching of load demands, power balance constraints for electricity, heat and cold are established.

$$\begin{cases} P_x^{\min} \le P_{x,t} \le P_x^{\max} \\ P_x^{\mathrm{down,min}} \le P_{x,t}^{x} - P_{x,t-1}^{x} \le P_x^{\mathrm{up,max}} \end{cases} \tag{15}$$

In the formula, $P_x^{\max}$ and $P_x^{\min}$ represent the upper and lower limits of the output power of the unit; $P_x^{\mathrm{up,max}}$ and $P_x^{\mathrm{down,min}}$ represent the upper and lower limits of the ramp-up power of the unit.

4. Example Analysis

4.1. Simulation Settings

To verify the validity of the model in this paper, the simulation period is set to 24 hours. The wind and solar power output and the DC-IES electric heating and cooling load curves are shown in Figure 2, the time-of-use electricity price is shown in Figure 3, and the natural gas price is 2.5 yuan/m3. The modeling is carried out using the YALIMP toolbox under the MATLAB R2021b platform, and the solution is completed by directly calling the CPLEX 12.8 commercial solver.

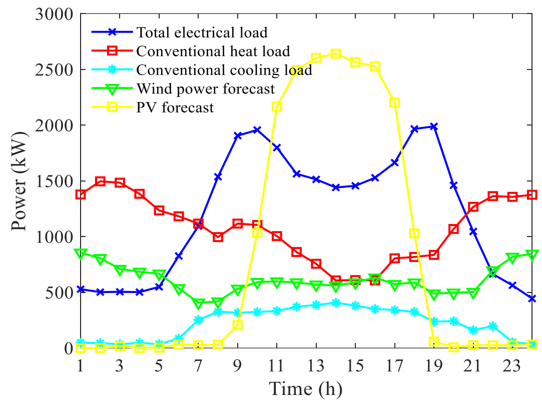

Figure 2. Wind power output prediction and heat, electricity and cold load

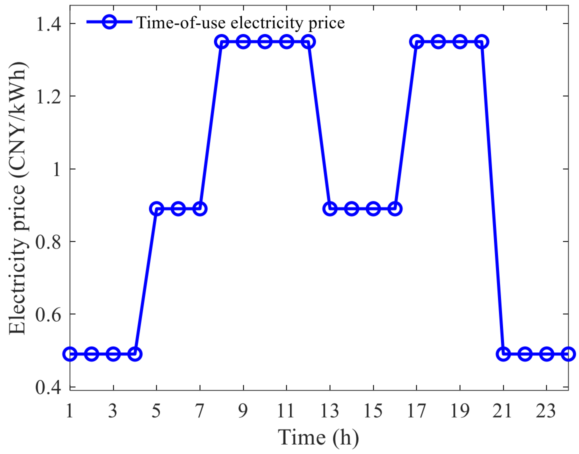

Figure 3. Time-of-use electricity pricing

4.2. Simulation Settings

To verify the optimization effect of waste heat recovery and utilization in the DC-IES, this paper sets up two typical comparison scenarios for comparison.

Scenario 1: Without considering the recovery of waste heat from data centers in DC-IES, and without conducting delay-tolerant load transfer;

Scenario 2: Considering the recovery of waste heat from data centers in DC-IES, but without conducting delay-tolerant load transfer;

The comparison analysis of operating costs in different scenarios is shown in Table 1.

Table 1. Three Scheme comparing

Scene Number	Total Cost/Yuan	Power purchase cost/yuan	Cost of purchasing gas/yuan	Operation and Maintenance Cost/Yuan	Cost of abandoning wind power and solar energy/yuan
1	17077.8	5673.3	8161.0	2172.3	1071.2
2	15720.2	5806.6	6784.4	2012.0	1117.2

Table 1 shows the comparison of operating costs for DC-IES in different scenarios. By comparing Scenario 1 with Scenario 2, it can be seen that the total system cost decreased from 17,077.8 yuan to 15,720.2 yuan, a reduction of 7.95%. This is because DC-IES enabled the reuse of residual heat from data centers, allowing the residual heat generated by IT equipment in the data center to meet the heating requirements of the system, replacing the consumption of a large amount of purchased gas. The output strategy of the unit changed, and the system's gas purchase cost dropped by 16.86%, although the electricity purchase cost slightly increased, the overall economic performance improved, thereby reducing the system cost.

4.3. Scheduling Result Analysis

To better verify the effectiveness of enabling the utilization of data center waste heat for the economic operation of DC-IES, an analysis of the power balance of electricity, heat and cold was conducted for scenarios 1 and 2 respectively. The details are as follows.

4.3.1. Power Balance Analysis of DC-IES When Data Center Waste Heat Recovery is Not Enabled

Scene 1: The relationships of electrical power balance, thermal power balance, and cold power balance are shown in Figures 4, 5, and 6 respectively.

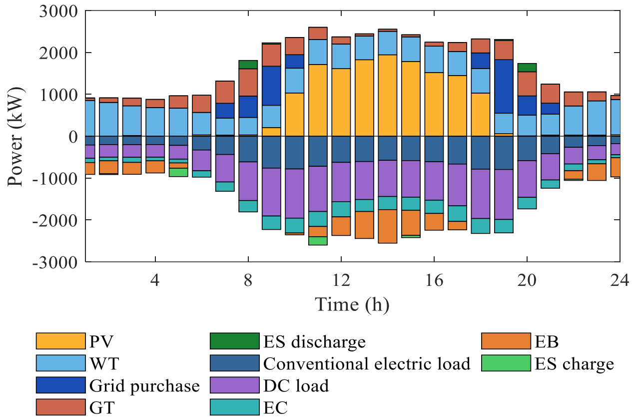

Figure 4. Scene 1 Electrical Power Balance Diagram

As shown in Figure 4, the conventional electrical load of DC-IES and the DC load can be met by PV, WT and GT for most of the time, and only during peak electricity consumption do external purchased electricity be needed. From 0:00 to 6:00, when electricity consumption is low, the output of wind turbines is relatively high. Due to the limitation of the gas turbine's climbing rate, the system generates surplus electricity, which is consumed by the electric boiler and electric cooling equipment to meet the heat and cold loads and reduce power loss. From 7:00 to 10:00 and from 18:00 to 21:00, during peak electricity consumption periods, the conventional electrical load and the computing power user requests of the data center increase rapidly. The combined output of WT, PV and GT is insufficient, and electricity needs to be purchased from the higher-level power grid. At the same time, the battery releases the low-peak electricity to smooth out the load. From 12:00 to 16:00, the electricity consumption is stable. From 11:00 to 17:00, the output of photovoltaic power reaches its peak. Renewable energy and the gas turbine basically cover the electricity consumption, and no electricity purchase is needed. From 22:00 to 24:00, electricity consumption decreases, and there is still remaining wind power at night. The electricity is consumed by electric cooling and electric boilers to supply heat and cold loads.

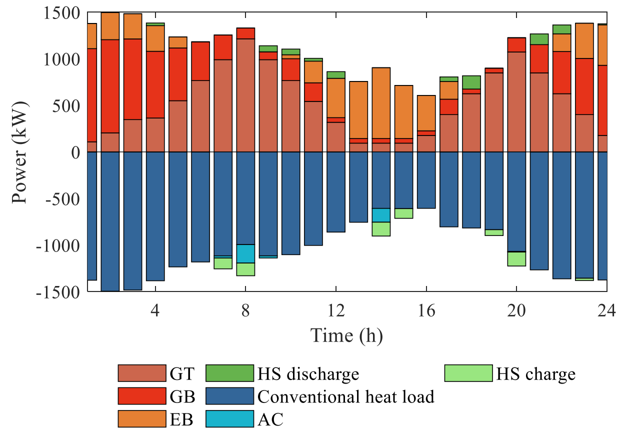

Figure 5. Scene 1: Thermal Power Balance Diagram

As shown in Figure 5, the heat load demand is higher at night and in the late afternoon, and lower during the day. The heat load is high from 0:00 to 5:00 and from 21:00 to 24:00, with abundant wind power. Gas turbines are prioritized to generate heat and are combined with electric boilers to consume wind power. The shortfall is made up by gas boilers. From 7:00 to 10:00 and from 18:00 to 21:00, there is a peak in electricity consumption. Gas turbines prioritize power supply, and the remaining heat basically meets the heat load. The output of gas boilers is not large. From 10:00 to 17:00, photovoltaic power generation is at its peak, and the electric boiler becomes the main heating source. It consumes photovoltaic power to generate heat based on the residual heat from the gas turbines, but due to the low heat load, there is a situation of discarding photovoltaic power. Overall, Scenario 1 relies on the cooperation of electric boilers, gas turbines, and gas boilers, prioritizing the conversion of electricity to heat to consume renewable energy. However, it does not recover the residual heat of the data center. It is constrained by the rigidity of the heat load, has limited adjustment flexibility, and discards photovoltaic power when it is at its peak. The energy efficiency needs to be improved.

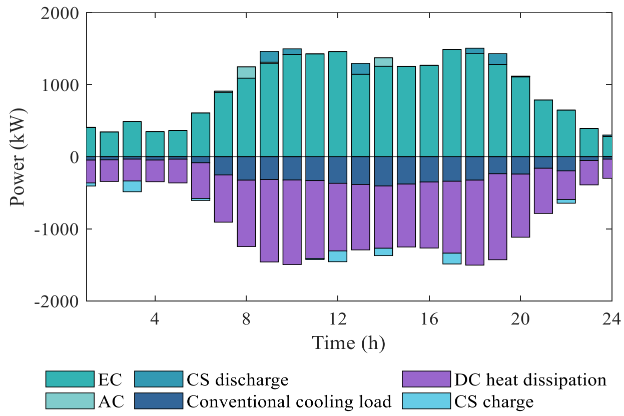

Figure6. Scene 1: Cold Power Balance Chart

As shown in Figure 6, the cooling load of DC-IES is mainly for the heat dissipation of the IT equipment in the data center, and its demand is strongly correlated with the DC power load: the electricity consumption is high and the heat dissipation is large during the day, while it is lower at night. The cooling load is small from 0:00 to 7:00 and from 19:00 to 24:00 at night, and it can be met by relying solely on electric cooling to consume wind power. After 7:00, the cooling load gradually increases, reaching a peak from 9:00 to 18:00. A large amount of electricity is consumed by electric cooling for photovoltaic and grid power, significantly increasing the electricity pressure. Since Scenario 1 does not recover the residual heat of the data center, the output of the absorption refrigeration is limited and cannot effectively share the pressure of electric cooling.

4.3.2. Power Balance Analysis of DC-IES When Enabling Data Center Waste Heat Recovery

The relationships of electrical power balance, thermal power balance, and cold power balance are shown in Figures 7, 8, and 9 respectively.

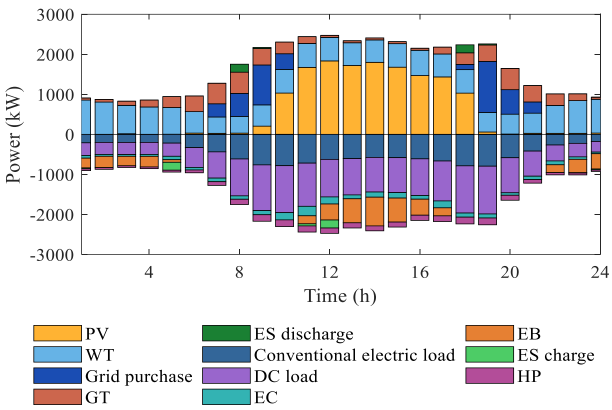

Figure 7. Scene 2 Electrical Power Balance Diagram

As shown in Figure 7, after enabling the recovery of residual heat from the data center, the power consumption of the heat pump is coupled with the residual heat recovery. The waste heat from the data center is consumed by the heat pump, and then converted into high-quality heat to supply the heat network, increasing the power consumption pressure of the system. The system still mainly relies on WT, PV, and GT for power supply, and only purchases electricity from the outside during the peak hours of 7:00-10:00 and 18:00-21:00. The purchased electricity has increased from 4,487.41 kWh in Scenario 1 to 4,592.60 kWh, and the electricity purchase cost has increased by 133.32 yuan. Overall, the heat pump converts the residual heat into thermal energy, effectively replacing the GB heating system.

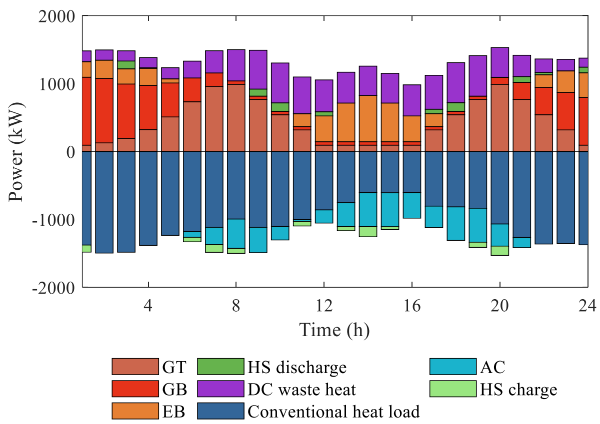

Figure 8. Scene 2 Thermal Power Balance Diagram

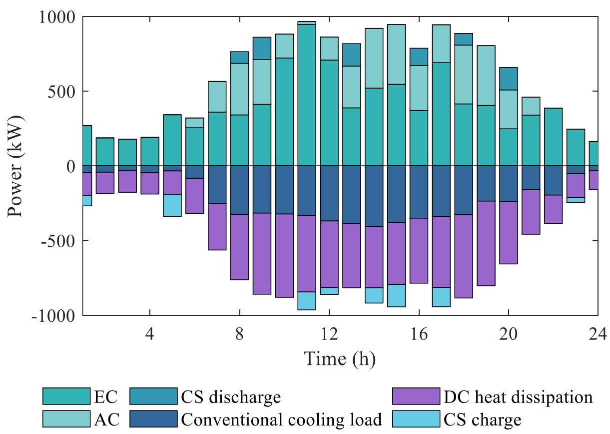

Figure 9. Scene 2 Cold Power Balance Chart

As shown in Figure 8, in Scenario 2, the waste heat from the data center is utilized for heat recovery, replacing part of the gas heating. Compared with Scenario 1, the output of the gas turbine and gas boiler has decreased by 2256.85 kWh and 1180.09 kWh respectively, and the cost of purchasing gas has significantly decreased. During the period from 6:00 to 20:00, the waste heat is simultaneously used for heating and driving absorption refrigeration. Overall, heat recovery has reduced the cost of purchasing gas and improved energy efficiency. As shown in Figure 9, the demand for data center cooling has significantly decreased, and absorption refrigeration has been added, making the cooling structure more diverse.

5. Conclusion

This paper constructs an optimization scheduling model for the integrated energy system of data centers considering the recovery of waste heat from data centers, and verifies its effectiveness through case comparisons. The results show that after enabling the recovery of waste heat from data centers, the total system cost decreases by 7.95%, the cost of gas purchase drops by 16.86%, and the economy is significantly improved. After the waste heat is enhanced by a heat pump, it can replace part of the heating provided by gas boilers and drive absorption refrigeration, reducing the pressure on electricity for refrigeration machines, while also reducing the cooling demand for data centers and achieving the hierarchical utilization of thermal energy. In addition, waste heat recovery helps to accommodate excess wind power and photovoltaic energy, and reduces the loss of wind and solar power. The research in this paper can provide a reference for the coordinated economic operation of data centers and regional integrated energy systems.

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