Operation Optimization Technology of Integrated Energy System Considering Energy Storage and Automatic Demand Response

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Abstract. To solve the inefficient operation problem of integrated energy systems, a multi-objective collaborative optimization operation of integrated energy system considering automatic demand response and energy storage was constructed in this paper. And the model is solved by Tent mapping chaos optimization NSGA - II algorithm, applied to the actual example of a typical energy system in a typical park in China. The simulation results show that the integrated energy systems that consider automatic demand response and energy storage have significant economic, technical and environmental benefits compared to the other three scenarios, facilitating the integration of new energy.

Keywords: Integrated energy system, automatic demand response, energy storage, collaborative optimization operation.

1. Introduction
Automated Demand Response (Auto-DR), as an important interactive resource under the framework of the energy Internet, can greatly improve the reliability, robustness and cost-effectiveness of the integrated energy system by triggering the user-side demand response program by receiving external signals without relying on any manual operation[1]. With the improvement of energy storage technology and the widespread application of energy storage equipment, the load optimization caused by energy storage participation has become an important factor that cannot be ignored in the operation of integrated energy system[2]. Under the background of the development of Auto-DR, the coordinated optimization operation of integrated energy system considering demand response and energy storage can not only realize multi-energy complementarity, but also give full play to the comprehensive regulation potential of Auto-DR and energy storage equipment, promote the absorption of Distributed Renewable energy, realize the dynamic optimization balance between supply and demand, and enhance the optimal allocation of resources. It has important research significance. At present, the research on integrated energy system mainly focuses on theory, technology and planning. Few existing models only focus on the system planning problem, but there is little research on the optimal dispatch of integrated energy.
system considering the factors such as multi-type power supply, energy storage, demand response resources, large-scale grid interaction and so on.

In view of the above problems, a multi-objective optimization operation model considering Auto-DR and energy storage is constructed in this paper. On this basis, the Tent mapping chaos optimization NSGA-II algorithm is used to solve the objective function, and an example is given to optimize the integrated energy system of a typical park in China. Compared with three scenarios which do not fully consider the role of Auto-DR and energy storage, the multi-objective optimization algorithm is used to solve the objective function. The model built in this paper can significantly improve economic, technological and environmental benefits, and has more advantages.

2. Multi objective optimization operation model considering Auto-DR and energy storage

A multi-objective collaborative optimization model considering Auto-DR and energy storage is constructed in this paper to achieve the highest total operating cost, reliability and emission reduction rate of the system. Considerations for Auto-DR and energy storage are mainly embodied in demand response constraints based on adjustable loads and operational constraints for energy storage equipment. Monte Carlo sampling is used to simulate photovoltaic and wind power, and the Beta distribution and Weibull distribution are assumed to obey. At the same time, because the system is connected to the grid, when the internal power supply is insufficient, power is purchased from the external network; when the internal surplus is absorbed, power is transmitted to the grid[3]. In addition, since the existing hardware cannot realize the interactive coupling between natural gas and cold, heat and electricity at the network end and the user end, the natural gas load generated by the direct combustion of natural gas by the user is always independent of the cold, heat and electricity load, and does not affect the scheduling of other units. Therefore, in order to simplify the model without losing generality, the natural gas load at the terminal of the system is not modeled for the time being, but only considered as fuel at the power supply and heat source side.

2.1. Objective function

The total cost of the system is the lowest.

The total cost $C_{total,T}$ of the integrated energy system in the dispatching cycle $T$ consists of the production and maintenance cost $C_{opma,T}$, the clean unit compensation cost $C_{comp,T}$ and the net purchase cost $C_{netp,T}$.

$$C_{total,T} = C_{opma,T} + C_{backup,T} + C_{netp,T} \quad (1)$$

The cost of production and operation mainly comes from fuel consumption and regular maintenance cost of energy supply units. Since the unit power generation and heating costs of the unit can fully include fuel consumption and maintenance costs, the production, operation and maintenance costs of the system in cycle $T$ can be expressed as follows:

$$C_{opma,T} = \sum_{u \in U, t \in T} W_{u,t} C_u \quad (2)$$

In this formula, $U$ denotes the set of energy supply units in the system, $W_{u,t}$ denotes the unit $u$'s energy supply during the $t$ period, and $C_u$ denotes the unit cost of power generation and heating.

The compensation cost of cleaning unit is:

$$C_{comp} = \sum_{i=1}^{T} \sum_{q \in \alpha, d} \left( \lambda_{qi} P_{qi} + \lambda_{qi} P_{qi} \right) \quad (3)$$
Formula A is the set of clean energy units in the system; $P_{a,t}^o$ represents the power shortage caused by over-scheduling of clean energy unit $a$, $\lambda_{a,t}^{o}$ is the over-scheduling compensation coefficient of unit $a$; $P_{a,t}^{u}$ represents the dirty power caused by under-scheduling of clean energy unit $a$, and $\lambda_{a,t}^{u}$ is the under-scheduling compensation coefficient of unit $a$.

The net purchase cost $C_{netp,T}$ of periodic $T$ is the sum of the net purchase cost of each period:

$$C_{netp,T} = \sum_{t=1}^{T} (C_{purt, t} - D_{sale, t})$$  \hspace{1cm} (4)

In the formula, $C_{purt, t}$ denotes the cost of purchasing electricity in $t$-period, which is the product of the power supply of the main network and the price of purchasing electricity from the main network in that period; $D_{sale, t}$ denotes the revenue of selling electricity in $t$-period, which is the product of the amount of electricity sold to the main network and the price of electricity sold to the main network in that period.

The highest reliability of the system.

The system power failure rate LPSP (Loss of Power Supply Probability) refers to the ratio of the system's power shortage to the total demand power of the cycle system in a certain period. LPSP is a commonly used power supply reliability index in power system. Combining with the types of power supply in integrated energy system, the expression of LPSP can be found in formula (5).

$$\frac{\sum_{i=1}^{W_{load,T}} - \sum_{i=1}^{W_{gas,T}} + \sum_{i=1}^{W_{PV,T}} + \sum_{i=1}^{W_{wind,T}} + \sum_{i=1}^{W_{grid,T}} - \sum_{i=1}^{W_{sell,T}}}{\sum_{i=1}^{W_{sale,T}}}}$$  \hspace{1cm} (5)

In the formula, $T$ denotes the scheduling period of the system, $t$ denotes each period of the cycle, $W_{load,T}$ is the power demand of the $t$-period system; $W_{gas,T}$, $W_{PV,T}$, $W_{wind,T}$, $W_{grid,T}$ is the gas generating unit, photovoltaic, fan generating capacity and the power purchased from the main network in this period; $W_{sell,T}$, $t$ is the power sold to the main network.

The highest rate of system emission reduction.

Compared with the traditional CCHP unit, the system emission reduction rate is equivalent to the pollutant emission reduction rate of the traditional CCHP unit.

$$\ell_T = \left\{ \begin{array}{l}
\frac{2(G_{cw,T} + G_{op,T})}{\eta_{CCHP}} - \frac{(G_{cw,T} + G_{op,T})}{\eta_{IES}} \cdot \frac{E_{eco}}{E_{gaco}} \cdot \eta_{CCHP} \\
\frac{G_{total,T}}{\eta_{CCHP}} \cdot \frac{E_{gaco}}{E_{waco}} \\
\frac{G_{total,T}}{\eta_{CCHP}} - \frac{(G_{cw,T} + G_{op,T})}{\eta_{IES}} \cdot \frac{E_{waco}}{E_{gaco}} \\
\frac{G_{total,T}}{\eta_{IES}} \cdot \frac{(G_{cw,T} + G_{op,T})}{\eta_{CCHP}} \\
\end{array} \right\}$$  \hspace{1cm} (6)

In the formula, $\ell_T$ is the emission reduction rate of the integrated energy system in the $T$ cycle; $G_{cw,T}$ and $G_{op,T}$ are the wind power abandonment and photoelectricity abandonment reduced in the cycle; $G_{total}$ is the total energy needed for the system equivalent; $\eta_{IES}$ and $\eta_{CCHP}$ are the integrated
energy efficiency of the integrated energy system and the traditional CCHP system; $E_{gaco}$ is the pollution of the traditional energy supply system. $E_{eaco}$ is the pollutant emission coefficient of integrated energy system, and $\lambda_{cw}$ and $\lambda_{cp}$ are the energy consumption coefficients of wind power and photovoltaic power respectively.

2.2. System constraints
(1) system energy balance constraint
1) reliability constraints
This paper considers that when the reliability of power supply is improved to a certain extent, the further improvement of power supply reliability will be at the cost of increasing cost and energy consumption. Combined with the current macro situation, pursuing the biggest pursuit of reliability is not necessarily the best choice. Therefore, in the consideration of electricity balance, it is not required that the unit output and the main network purchase plus the result must not be less than the load. It is to optimize reliability as an optimization goal. However, according to the relevant provisions of the state, it is necessary to design a lower limit for the reliability of power supply:

$$LPSP(t) \leq \bar{LPSP}$$  \hspace{1cm} (7)

Among them, $\bar{LPSP}$ is the upper limit of system power shortage, and reference to the state's requirements for power supply reliability of microgrid project, take $\bar{LPSP}=3\%$.

2) heat balance constraint
Including heat balance and cold balance constraints, its physical meaning is that the heat obtained from each heat source is converted into cold load and heat load respectively after considering the efficiency of the equipment and related losses.

The thermal balance constraint is:

$$Q_{\text{recl},t} \cdot \eta_{\text{recl},t} + Q_{\text{gas},t} \cdot \eta_{\text{gas},t} + Q_{\text{solar},t} \cdot \eta_{\text{solar},t} = Q_{\text{heal},t}, \forall t \in T$$  \hspace{1cm} (8)

$$Q_{\text{recl},t} = W_{\text{gas},t} \left( \frac{1}{\eta_{\text{gas},t}} - 1 \right) \eta_{\text{recl},t}$$  \hspace{1cm} (9)

$$Q_{\text{solar},t} = \theta(t) \cdot S_{\text{solar},t} \cdot \eta_{\text{solar}}$$  \hspace{1cm} (10)

$Q_{\text{recl},t}$, $Q_{\text{gas},t}$ and $Q_{\text{solar},t}$ are the heat recovered by the waste heat boiler in t period, the heat burned by gas and the light and heat collected by the solar hot water boiler respectively; $Q_{\text{heal},t}$ is the heat load in t period. $\eta_{\text{recl},t}$, $\eta_{\text{gas},t}$ and $\eta_{\text{solar}}$ are the heat utilization efficiency of the above equipment respectively. $W_{\text{gas},t}$ represents the generating capacity of the gas turbine in t period, $\eta_{\text{elec, gas}}$ is the electrical efficiency of the gas turbine, $r_{\text{recl},t}$ represents the recovery rate of waste heat. $\theta(t)$ is the local solar radiation in t period; $S_{\text{solar},t}$ is the collector area of solar hot water boiler; $\eta_{\text{solar}}$ is the conversion efficiency of solar hot water boiler.

The cold balance constraint is:

$$Q_{\text{abew},t} \cdot \eta_{\text{abew},t} + W_{\text{elec},t} \cdot \eta_{\text{elec},t} = Q_{\text{coel},t}, \forall t \in T$$  \hspace{1cm} (11)

$$Q_{\text{abew},t} = \theta(t) \cdot S_{\text{abew},t} \cdot \eta_{\text{abew}}$$  \hspace{1cm} (12)
Among them, \( Q_{\text{cool}, \text{absor}} \) is the light and heat collected by t-period absorption refrigerators, \( W_{\text{cool}, \text{elec}} \) is the power consumption of t-period electric refrigerators, and the power consumption curve of electric refrigerators will be superimposed on the initial power load curve of the system in the dispatching cycle to participate in co-optimization; \( \eta_{\text{absor}} \) and \( \eta_{\text{elec}} \) are the efficiency of absorption refrigerators and electric refrigerators respectively; \( Q_{\text{cool}} \) is the cooling load of t-period. \( S_{\text{absor}} \) is the collector plate area of the absorption chiller, and \( \eta_{\text{absor}} \) is the conversion efficiency of the solar hot water boiler.

(2) equipment operation constraints

operation constraints of generating units

a) Operational constraints of photovoltaic units: the upper limit of the output of photovoltaic units is the product of local solar radiation, solar panel area and solar conversion efficiency, and should also be less than the rated power of the unit. The output of photovoltaic units can be reduced by discarding light when dispatching is needed, but the output must be kept above the minimum limit[4].

\[
\bar{P}_{\text{PV}}(t) = \min\{P_{\text{capa}}, \theta(t) \cdot S_{\text{PV}} \cdot \eta_{\text{PV}}\} \\
\frac{P_{\text{PV}}}{P_{\text{capa}}} \leq \frac{P_{\text{PV}}(t)}{\bar{P}_{\text{PV}}(t)} 
\]

In the formula, \( P_{\text{PV}}(t) \) is the power of the photovoltaic unit in the t-period, \( P_{\text{capa}} \) is the rated installed capacity of the PV unit, \( \eta_{\text{PV}} \) is the solar energy conversion efficiency, \( \theta(t) \) is the local solar radiation in the t-period, and \( S_{\text{PV}} \) is the area of the solar panel, and \( \frac{P_{\text{PV}}}{\bar{P}_{\text{PV}}} \) and \( \bar{P}_{\text{PV}} \) are the minimum and maximum power of the photovoltaic unit, respectively.

b) Operation Constraints of Natural Gas Internal Combustion Engine Units: Real-time output of units should be between the upper and lower limits, while the rate of change of unit power is limited by climbing rate.

\[
P_{\text{gas}} \leq P_{\text{gas}}(t) \leq \bar{P}_{\text{gas}} \quad (15)
\]

\[
P_{\text{gas}}(t) - P_{\text{gas}}(t - 1) \leq U_{\text{gas}} \cdot \Delta t 
\]

\[
P_{\text{gas}}(t) - P_{\text{gas}}(t - 1) \geq D_{\text{gas}} \cdot \Delta t 
\]

In the formula, \( P_{\text{gas}}(t) \) is the generation power of the gas turbine, \( P_{\text{gas}} \) and \( \bar{P}_{\text{gas}} \) are the minimum and maximum power respectively, and \( U_{\text{gas}} \) and \( D_{\text{gas}} \) are the upward and downward climbing rates of the gas turbine.

c) Operation constraints of wind turbines: The physical meaning of wind turbine constraints is similar to photovoltaic constraints, but the upper limit of output is piecewise functional relationship with meteorological conditions.

\[
P_{\text{wind}}(t) = \min\{P_{\text{wind}, \text{capa}}, \theta(t) \cdot S_{\text{wind}} \cdot \eta_{\text{wind}}\} \\
\frac{P_{\text{wind}}}{P_{\text{wind}, \text{capa}}} \leq \frac{P_{\text{wind}}(t)}{\bar{P}_{\text{wind}}(t)} 
\]
Formula \( P_{\text{wind}}(t) \) is the generation power of the wind turbine in \( t \) period, \( P_{\text{wind}}^{\min} \) and \( P_{\text{wind}}^{\max} \) are the minimum and maximum power of the wind turbine respectively, \( P_{\text{rate}} \) is the rated output power of the wind turbine, \( v_{\text{in}} \) and \( v_{\text{out}} \) are the cut-in and cut-out wind speed respectively, and \( v_{\text{rate}} \) is the rated wind speed.

2) Refrigerator operating constraints: absorption refrigerators and electrical refrigerators must be positive power, and can not exceed the upper limit of power.

\[
0 \leq P_{\text{cold}}^{\text{in}}(t) \leq P_{\text{cold}}^{\text{max}} \quad (20)
\]

\[
0 \leq P_{\text{elec}}^{\text{in}}(t) \leq P_{\text{elec}}^{\text{max}} \quad (21)
\]

Among them, \( P_{\text{cold}}^{\text{in}}(t) \) and \( P_{\text{cold}}^{\text{max}} \) are the refrigeration power and the maximum power at \( t \) time of the absorption refrigeration machine, \( P_{\text{elec}}^{\text{in}}(t) \) and \( P_{\text{elec}}^{\text{max}} \) are the refrigeration power and the maximum power at \( t \) time of the electric refrigeration machine, respectively.

3) Energy storage constraint

The energy storage battery has 2 states of charge and discharge, and its charging and discharging process can be described as follows:

When the battery is in charge state:

\[
S_{t+1}^{C} = S_{t}(1-\varepsilon) + P_{\text{SOC},t+1}^{C} \eta_{C} \quad (22)
\]

When the battery is in discharge state:

\[
S_{t+1}^{D} = S_{t}(1-\varepsilon) - P_{\text{SOC},t+1}^{D} / \eta_{D} \quad (23)
\]

When the battery is neither charged nor discharged:

\[
S_{t+1} = S_{t}(1-\varepsilon) \quad (24)
\]

In the formula, \( S_{t+1} \) is the residual power of the energy storage battery at the end of \( t+1 \) period, \( P_{\text{SOC},t+1}^{C} \) and \( P_{\text{SOC},t+1}^{D} \) are the charge and discharge rates of the battery at that period, \( \eta_{C} \) and \( \eta_{D} \) are the charge and discharge efficiency of the battery respectively, and \( \varepsilon \) is the leakage rate. Further considering the life and safety of storage battery, the following constraints should be added:

The first is the charge discharge rate constraint: the charge discharge rate is positive and does not exceed the upper limit.

\[
0 \leq P_{\text{SOC},t}^{C} \leq P_{\text{SOC},t}^{\text{max}} \quad (25)
\]

\[
0 \leq P_{\text{SOC},t}^{D} \leq P_{\text{SOC},t}^{\text{max}}
\]
\( \bar{P}_{SOC,i}^c \) and \( \bar{P}_{SOC,i}^d \) are the upper limits of battery charging and discharging rates respectively.

Second, the state of charge constraints: the remaining battery capacity should be maintained within a certain range, neither too close to the full state, nor too close to the state of complete empty.

\[
\begin{align*}
B_{SOC,i} &= \frac{S_i}{\bar{S}} \\
B_{SOC} &\leq B_{SOC,i} \leq B_{SOC}
\end{align*}
\] (26)

In the formula, \( B_{SOC,i} \) is the ratio of the remaining energy \( S_i \) to the total energy \( \bar{S} \) at the end of the \( t \) period, i.e. the battery's state of charge; \( B_{SOC} \) and \( \bar{B}_{SOC} \) are the upper and lower limits of the battery's state of charge, respectively.

(4) demand response constraints

Demand side load can be divided into three categories: fixed load, random load and transferable load. Compared with the irregularity of fixed load and the unpredictability of random load, the transferable load is the load that users transfer the load from one time period to another. It is controllable. Using high-density information flow to dispatch transferable load reasonably is an important means to realize Auto-DR in integrated energy system. Demand response constraints based on transferable load include two aspects:

First, the transfer capacity constraints, that is, the turn-out time and turn-in time should be less than the upper limit, namely:

\[
\begin{align*}
\Delta W(t_{out}) &\leq \Delta W(t_{out}) \\
\Delta W(t_{in}) &\leq \Delta W(t_{in})
\end{align*}
\] (27)

In the formula, \( t_{out} \) and \( t_{in} \) denote the period of load transfer and the period of load transfer respectively; \( \Delta W(t_{out}) \) and \( \Delta W(t_{in}) \) denote the amount of power transfer in the period of \( t_{out} \) and in the period of \( t_{in} \) respectively; \( \Delta W(t_{out}) \) and \( \Delta W(t_{in}) \) denote the upper limit of the amount of power transfer out and in the period of \( t_{out} \) respectively.

The second is the balance constraint, that is, the total amount of load transferred out in each period is equal to the total amount of load transferred in the whole dispatching cycle.

\[
\sum_{\varnothing_{out}} \Delta W(t_{out}) = \sum_{\varnothing_{in}} \Delta W(t_{in})
\] (28)

The load after transfer can be expressed as follows:

\[
W_{af}^d(t_{out}) = W_{be}^c(t_{out}) - \Delta W(t_{out})
\] (29)

\[
W_{af}^d(t_{in}) = W_{be}^c(t_{in}) + \Delta W(t_{in})
\] (30)

In the formula, \( W_{af}^d(t_{out}) \) and \( W_{be}^c(t_{out}) \) denote the load of the post-transfer and pre-transfer \( t_{out} \) periods respectively; in the formula, \( W_{af}^d(t_{in}) \) and \( W_{be}^c(t_{in}) \) denote the load of the post-transfer and pre-transfer \( t_{in} \) periods respectively.
3. Case analysis

3.1. basic data input

In this paper, a typical park in North China is taken as the research object, and the optimization algorithm proposed in the literature [5] is used to solve the problem. According to the actual situation of the operation of the park, the basic data required for the example are shown in Table 1, and other data required for the example are shown in [6]. Due to the limitation of computer performance, this paper does not carry out the whole-time simulation on the whole year. Only the typical daily load of the system with a period length of T=24 hours is considered. On this basis, the typical daily load curve of the system is set to t=1 hours, which is shown in Figure 3. The time-of-use electricity price for purchasing electricity from the main network is shown in Figure 4. The electricity price for selling electricity to the main network refers to the price of the distributed power supply benchmarks across China, taking a constant value. Without loss of generality, the average on-grid price of natural gas units, wind turbines and photovoltaic units is 0.525 yuan/KWh as the selling price to the main network.

The parameters of the chaotic optimization NSGA-II algorithm are as follows: the number of individuals in each generation is 200; the chaotic optimization process always produces a chaotic solution three times the required vector, which is used for preferential selection; The mutation rate in the NSGA-II algorithm is 0.8, and the crossover rate is 0.2; Set the maximum number of iterations of the algorithm tmax=1000. Monte Carlo simulation parameters and related beta distributions, Weibull distribution parameters, see the literature.

Table 1. Technical parameters of typical equipment or device in Micro Energy Internet system

| Types                  | Parameters and units | Numerical value | Parameters and units | Numerical value |
|------------------------|----------------------|-----------------|----------------------|-----------------|
| Gas Turbine            | Number of units / stations | 2               | Single machine maximum power / kW | 60              |
|                        | Operating cost / (yuan / kWh) | 0.064           | Minimum power / kW    | 20              |
|                        | Climbing rate        | 10              | Downhill rate / (kW / min) | 5               |
| Wind Turbine           | Number of units / stations | 2               | Single machine maximum power / kW | 20              |
|                        | Operating cost / (yuan / kWh) | 0.045           | Minimum power / kW    | 0               |
| Photovoltaic unit      | Number of units / stations | 2               | Single machine maximum power / kW | 30              |
|                        | Operating cost / (yuan / kWh) | 0.0096          | Minimum power / kW    | 0               |
| Energy storage         | Operating cost / (yuan / kWh) | 0.045           | Maximum charging rate | 25              |
|                        | Maximum energy storage (kWh) | 90              | Maximum discharge rate | 45              |
|                        | Leakage rate / (% / h) | 0.14            | Minimum stored energy / (kWh) | 10              |
| Waste heat boiler      | Number of units / stations | 1               | Waste heat utilization rate (recovery and conversion) /% | 70              |
| Solar hot water boiler | Number of units / stations | 4               | Single machine maximum power / kW | 40              |
|                        | Operating cost / (yuan / kWh) | 0.005           | Thermal efficiency%   | 52              |
| Natural gas boiler     | Number of units / stations | 2               | Single machine maximum power / kW | 100             |
|                        | Operating cost / (yuan / kWh) | 0.002           | Thermal efficiency%   | 81              |
| Absorption chiller     | Number of units / stations | 2               | Single machine maximum power / kW | 30              |
|                        | Operating cost / (yuan / kWh) | 0.0008          | Thermal efficiency%   | 75              |
| Electric refrigerator  | Number of units / stations | 1               | Single machine maximum power / kW | 40              |
|                        | Operating cost / (yuan / kWh) | Real-time electricity price/ | Electrical efficiency | 95              |
3.2. Optimization result analysis

The calling model solves the optimal scheduling problem of the system, and it can be concluded that the electrical load optimization of the typical scheduling day of the system is shown in Fig. 6. It can be seen that the original load on a typical dispatch day has a peak load period during daytime and nighttime, and is at a low load period in the early morning and afternoon. After the demand response load transfer, the equivalent electric load curve, although the peak-to-valley characteristics of the load are similar to the original load curve, the overall curve is more gradual, indicating the system realizes peak clipping and valley filling by regulating the transferable load resources, and optimizes the load characteristics of the system. Further analysis of the output of each unit shows that the typical energy demand for the integrated energy system is met with energy storage (SE), distributed wind power (WT), power grid purchase (GR), gas power generation (GT) and distributed photovoltaic (PV). The wind resources available in the area are abundant. When the load demand is low at night, part of the power generated by the wind is stored by means of energy storage equipment. At the same time, the lighting conditions...
are better at 11:00-15:00, the wind power is strong, and the energy storage equipment continues working. From 18:00 to 21:00, it gradually rises to the peak period of power consumption. At this time, energy is released from the energy storage equipment to supply power users, and the power generation demand during peak hours is alleviated. At 22:00-6:00, the electricity consumption decreases, and gradually transits to the valley period. First, wind power should be absorbed. If it is insufficient, it will be generated by gas turbines and purchased from the grid. In the early morning, the price of electricity purchased from the grid will be lower. The demand for electricity in this period mainly depends on the grid and wind power supply.

Fig. 3 Optimization of Electric Load on Typical Dispatching Day

![Optimization of Electric Load on Typical Dispatching Day](image)

Fig. 4 The optimization results of heating load supply

The thermal load optimization of the typical dispatch day is shown in Figure 4. As shown in Fig. 4, the thermal load of the system is relatively stable. As the operation cost of waste heat recovery boiler is the lowest, so as long as the gas turbine has the capacity, it is preferred to use waste heat boiler for heating. At the same time, daylight conditions are better, so if the waste heat boiler output is insufficient, the solar hot water boiler to meet the heat load requirements. Finally, the heat load gap is met by the highest cost natural gas hot water boiler.

In addition, the cooling load optimization result of the system is similar to that of the thermal load: the cooling load demand is supplied by two cooling modes, the electric refrigerator and the absorption
refrigerator. Due to the low cost of absorption refrigerators, the cooling load is mainly supplied by absorption refrigerators through co-optimization, while the electric refrigerators are mostly operated in night Valley period.

4. Conclusion
This paper studies the multi-objective cooperative optimization operation technology of integrated energy system. Auto-DR and energy storage are introduced into the system scheduling. A multi-objective optimization model with the lowest system cost, the highest system reliability and the highest system emission reduction rate is constructed. When there are constraints and contradictions in multiple objectives, the model can provide support for the comprehensive energy system to achieve economic, technological and environmental planning objectives. Through the synergistic effect of Auto-DR and energy storage, the optimized operation scheme proposed in this paper can obviously improve the load characteristics of the system, effectively suppress the random fluctuation of wind power and photovoltaic output, improve the economy and reliability of the system while improving the level of clean energy consumption.

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