Economic Analysis of Source-Load Coordination of Integrated Energy System Considering Wind Power

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Abstract. Aiming at the wind abandonment problem of CCHP “determining electricity by heat”, this paper proposes an optimal scheduling method that takes into account the coordination of source and charge of the integrated energy system of wind power. Introduce a ground source heat pump on the source side, use wind power for heating, and decouple the CCHP’s "constant heat" operation constraints; use the price demand response on the charge side to assist wind power grid integration; finally, consider the coordination of source and charge to establish an integrated energy system. The upper layer adopts the electricity price demand response to guide users to respond to changes in wind power output. The lower layer considers the role of ground source heat pumps and determines the optimal output of each unit with the minimum total system cost in the dispatch cycle. The full text is solved using Matlab software. The calculation example shows that this method effectively improves the wind power consumption capacity of the system, reduces the system operating cost, and has good social and economic benefits.

1. Introduction
In the power system, demand-side response has been applied in engineering as an effective way to promote the absorption of wind and sunlight. With the continuous deepening of the coupling between various energy sources in the integrated energy system, the traditional power demand response has been extended to electricity, gas, response to comprehensive demand for hot and cold. Literature established the electricity / heat integrated demand response mechanism as the optimization goal to meet the demand of superior peak shaving, and increased the CHP output by increasing the peak heat purchase demand of electricity users, and reduced the power purchase power of the park. Reference takes the minimum sum of energy purchase cost and load reduction cost as the optimization goal, and improves the system operation reliability and economy by reducing the controllable electricity and heat load. It can be seen from the above literature that the current comprehensive demand response of electric heating is mostly to solve the problem of insufficient power supply due to CCHP thermoelectric coupling, and there is little research on the value of promoting renewable energy consumption. In addition, the above literature does not Considering the supply side, the system's renewable energy consumption under source-charge coordination needs further study.

This paper proposes a method for coordinated and optimized dispatch of source and charge that takes into account the integrated energy system of wind power. By analyzing the value of the ground
source heat pump and electric heating integrated demand response to promote wind power consumption, a two-layer optimization model of source and charge coordination is established with the goal of the minimum operating cost of the integrated energy system in the dispatch cycle, and the Matlab is used to solve it.

2. Thermoelectric optimization model with ground source heat pump

![Figure 1 Structure of an integrated energy system](image)

2.1. Wind power-ground source heat pump heating system

Wind power-ground source heat pump heating system wind power consumption improvement space includes $\Delta P_1$ and $\Delta P_2$ parts, $\Delta P_1$ is the ground source heat pump as the power load to absorb the wind power, $\Delta P_2$ is the amount of reduction in the power generation of the gas turbine “determined by heat” after the ground source heat pump participates in heating.

$$\Delta P_1 = \sum_{m=1}^{T} P_{w,dp}(t)$$  \hspace{1cm} (1)

$$\Delta P_2 = \sum_{m=1}^{T} P_{w,dp}(t)\mu_{hp,A}\lambda_{GT}$$  \hspace{1cm} (2)

In the formula: $P_{w,dp}(t)$ is the ground source heat pump for $t$ period to absorb wind power; $T_{wd}$ is the wind abandonment period; $T$ is the dispatch period.

2.2. Electricity price demand response modeling considering satisfaction of electricity consumption

Price-based DR (price-based DR, PBDR) is mainly for non-schedulable resources such as residential electricity load. Users adjust electricity demand according to the received price signals (time-sharing electricity price, real-time electricity price, peak electricity price), and respond to changes in system operating status. So this paper uses time-sharing electricity price for PBDR. At the same time, in order to prevent users' over-response from reducing their power consumption satisfaction, the user's
power consumption satisfaction rate \( r_{se} \) is introduced into the electricity price elasticity matrix \( E \) to describe the load adjustment situation after the PBDR is implemented.

\[
    r_{se} = 1 - \frac{\sum_{t=1}^{T} |\Delta P_{e}(t)|}{\sum_{t=1}^{T} P_{e}(t)}
\]

\[
    E = r_{se} \begin{bmatrix}
        \varepsilon_{11} & \varepsilon_{12} & \cdots & \varepsilon_{1n} \\
        \varepsilon_{21} & \varepsilon_{22} & \cdots & \varepsilon_{2n} \\
        \vdots & \vdots & \ddots & \vdots \\
        \varepsilon_{n1} & \varepsilon_{n2} & \cdots & \varepsilon_{nn}
    \end{bmatrix}
\]

\[
    P_{de}(t) = P_{e}(t) + \Delta P_{e}(t) = \begin{bmatrix}
        P_{e}(1) \\
        P_{e}(2) \\
        \vdots \\
        P_{e}(T)
    \end{bmatrix} + \begin{bmatrix}
        \Delta D(1)
        \\
        \Delta D(2)
        \\
        \vdots
        \\
        \frac{\Delta D(T)}{D(T)}
    \end{bmatrix}
\]

In the formula: \( \varepsilon \) is the electricity price elasticity coefficient, \( \varepsilon_{ii} \) and \( \varepsilon_{ij} \) are the self-elasticity coefficient and the mutual elasticity coefficient; \( P \) and \( \Delta P \) are the electricity quantity and its change amount; \( D \) and \( \Delta D \) are the electricity price and its change amount; \( P_{e}(t) \) and \( \Delta P_{e}(t) \) are the before and after response \( t \) Time period electricity load and its change amount; \( D(t) \), \( \Delta D(t) \) are the electricity price and its change amount in \( t \) period before and after response: \( P_{de}(t) \) is the electricity load in \( t \) period after PBDR is implemented.

3. Two-layer model of source-charge coordination considering wind power consumption

3.1. Upper model

In order to improve the matching degree of wind power and power load, and to improve the wind abandonment caused by the reverse peaking characteristics of wind power, the upper model uses PBDR to guide the power load to follow the change of wind power output \( P_{w}(t) \), and increase the wind power absorption capacity of the load valley system. The objective function of the upper model is as follow:

\[
    \min \sum_{t=1}^{T} (P_{de}(t) - P_{w}(t))^{2}
\]

3.2. Underlying model

Substitute the electricity load solved by the upper model into the electricity balance constraint of the lower model, introduce the ground source heat pump to participate in the optimal scheduling and
implement the incentive demand response to the heat load, and solve the problem with the minimum total operating cost in the scheduling period of the regional integrated energy system. The optimal output of each unit to formulate a dispatch plan. The lower objective function is:

$$\min C_{\text{tot}} = \sum_{t=1}^{T} \left( C_{FC}(t) + C_{OC}(t) + C_{EX}(t) + C_{EN}(t) + C_{WD}(t) \right)$$  \hspace{1cm} (7)$$

Where: $C_{\text{tot}}$ is the total operating cost of the system during the dispatch cycle; $C_{FC}(t)$, $C_{OC}(t)$, $C_{EX}(t)$, and $C_{EN}(t)$ are the system fuel cost, operation and maintenance cost, environmental cost, and wind curtailment cost during the $t$ period; $C_{WD}(t)$ is the energy interaction between the system and the main grid during the $t$ period cost.

4. Comparative analysis of different scheduling models

In order to explain the rationality of the low-carbon economic dispatch model built, this paper first compares and analyzes the scheduling results of the three models: ① low-carbon economic dispatch model considering the ladder-type carbon transaction cost; ② low-carbon economic dispatch considering the unified carbon transaction cost. In the model, the unified carbon trading cost does not divide the carbon emissions interval, which is derived from the unified formula $F_c = \lambda (E_p - E_I)$; ③ In the ladder-type carbon trading mode, only the minimum cost of outsourced energy $F_E$ is the goal function of the traditional economic dispatch model. The scheduling results of the three models are shown in Table 1 and Table 2.

| model | Carbon trading model | Carbon emissions / t | Carbon transaction cost / 10,000 USD | Energy cost / USD 10,000 | Total cost / ten thousand dollars |
|-------|----------------------|----------------------|-------------------------------------|--------------------------|---------------------------------|
| 1     | Stepped              | 2100.2               | 0.67                                | 25.32                    | 25.99                           |
| 2     | Unified              | 2124.7               | 0.61                                | 25.02                    | 25.63                           |
| 3     | Stepped              | 2656.0               | 1.76                                | 24.87                    | 26.63                           |

Table 2. Outsourcing energy costs of the three model scheduling results

| model | Purchased energy |
|-------|------------------|
|       | Electricity / (MW h) | Natural gas / 10,000m^3 |
| 1     | 1509.0           | 68.20 |
| 2     | 1510.7           | 68.01 |
| 3     | 1567.5           | 67.54 |

Table 2 shows the outsourcing energy data of the scheduling results of the three models. Combining Table 1 and Table 2, when the control of the carbon emissions of the system is increased, the outsourcing energy of the system will be shifted from electricity to natural gas, resulting in an increase in energy costs. Model 1 has the most stringent control on carbon emissions, so IES has the least outsourcing power and the most natural gas. Correspondingly, the dispatch results of Model 1 have the lowest carbon emissions and the highest energy costs.

5. Conclusion

This paper builds a IES low-carbon economic dispatch model based on carbon trading. This paper compares and analyzes the scheduling results of the ladder-type low-carbon economic dispatch, unified low-carbon economic dispatch and traditional economic dispatch model and draws the
following conclusions:

1) Carbon trading uses market means to achieve carbon emission control, so that companies can actively reduce emissions to obtain carbon trading income, and the means are reasonable and effective. The IES low-carbon economic dispatch model based on the ladder-type carbon transaction cost has stricter control over carbon emissions, while taking into account the overall economics of the system.

2) The low-carbon economic dispatch model is sensitive to changes in carbon trading prices, and can coordinate the carbon trading costs and energy costs of the system according to the carbon trading prices. Within a certain range, the increase in carbon trading prices can reduce the total cost of system operation.

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