Coordination of Electricity and Heat Dispatch Strategy Combining Carbon Trading and Peak Shaving Compensation Mechanism

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Abstract. Integrated power generation group’s participation in the carbon trading market and peaking auxiliary service market is one of the effective ways to promote low carbon power development and wind power consumption. Aiming at the serious problem of wind abandonment during the low temperature period of winter heating period in Northeast China, a multi-market mechanism is proposed. The carbon trading is analysed. Firstly, and the regional peak demand optimization model based on multi-scenario stochastic programming and the maximum wind power acceptance power calculation model of regional power grid is constructed to calculate the peak shaving demand and existing peak shaving in each period of the regional power grid. Maximum wind power acceptance under resources; Based on the coordination of carbon quotas among power generation groups and the subsection compensation mechanism of compensated peak shaving costs, and aiming at the minimum sum of total coal consumption costs, wind abandonment penalties and compensation costs, integrated dispatching model considering carbon trading and peak shaving compensation is established. Finally, an example is given to verify the rationality and effectiveness of the proposed strategy.

Keywords: Power Generation, Carbon Trading Market, Wind Power, Peak Shaving

1. Introduction
The environmental problems caused by the large-scale use of fossil energy are increasingly prominent [1]. The 13th five years plan outline of China has included the research on "green and low-carbon development" into the national major development topic [2], and the carbon emissions of the power industry have accounted for about 50% of the total carbon emissions of the country. In recent years,
renewable energy has continued to develop violently, and wind power resources have played an increasingly important role in the development of low-carbon power [3].

However, the use of the combustion supporting method of thermal power units to improve the depth of peak shaving not only increases the level of pollutant emissions, but also is uneconomical for thermal power enterprises [4-5]. Therefore, at this stage, the Northeast region vigorously implements thermal power reconstruction projects, promotes the construction of peak shaving supporting service markets and carbon emission trading markets, and improves the initiative of generating units by peak shaving by constructing peak shaving facilities such as power station boilers [6-7] The content of peak shaving compensation for thermal power units in literature [8] is introduced, and the participation of power plant boilers in peak shaving is studied from the aspects of economics and carbon emissions of thermal power plants. The influence of improving the acceptance capacity of abandoned air in thermal power plant. In [9], under the peak shaving compensation mechanism, a peak shaving cost model of a thermal power unit considering peak shaving compensation was established, and the enthusiasm of the thermal shaving of the thermal power unit was analyzed. In [10], a ladder type carbon trading cost model is established to study the cost of thermal power units participating in deep peak shaving. In [11-12], a carbon trading mechanism was introduced, and a three-stage scheduling method was used to analyze the economic and environmental benefits of the system.

On the basis of the existing work, this paper fully considers the impact of flexible resource allocation on carbon emission cost and wind power consumption of power generation group, calculates the carbon emission cost, and establishes the calculation model of paid peak shaving demand of regional power grid and the calculation model of maximum wind power acceptance of regional power grid according to whether there is peak shaving resource or not. On this basis, considering the coordination and promotion relationship between peak shaving depth and carbon emission reduction of the group, to build a multi-objective coordinated dispatching model of electric heating with carbon trading and peak shaving compensation.

2. Cost analysis of carbon trading in power generation group

Calculation of carbon quota distribution in power generation group.
The essence of carbon quota is to allocate certain free carbon emission quota for thermal power units.

\[ D_t = \theta(P_t + H_t - P^{CL}_t)\Delta t \]  
\[ (1) \]

where \( D_t \) refers to the approved carbon quota of the power generation system in time period \( t \); \( \theta \) refers to the distribution coefficient of regional unit carbon emissions; \( P_t \) refers to the electric load in time period \( t \) of the region; \( H_t \) refers to the heat load in time period \( t \) of the region; \( P^{CL}_t \) refers to the power exchanged with other regions in time period \( t \); \( \Delta t \) refers to the dispatching period.

The carbon quota of each power generation group \( D_{a,t} \) can be expressed as:

\[ D_{a,t} = \theta_a D_t \]  
\[ (2) \]

Where, \( \theta_a \) is the carbon quota distribution coefficient of power generation group \( a \).

Carbon emission accounting mechanism of power generation group.

\[ E_{a,t} = \sum_{j=1}^{J_a} \lambda_j (P^{\text{CHIP}}_{j,t} + H^{\text{CHIP}}_{j,t} + P^{\text{CON}}_{j,t})\Delta t \]  
\[ (3) \]

Where, \( E_{a,t} \) is the total carbon emission of the thermal power unit in the period \( t \) of the regional power grid; \( J_a \) is the sum of the number of thermal power units and pure condensing units in the power generation group \( a \); \( \lambda_j \) is the carbon emission coefficient of the thermal power unit \( j \); \( P^{\text{CHIP}}_{j,t} \) and \( H^{\text{CHIP}}_{j,t} \) are the electrical output and thermal output of the thermal power unit in the period \( t \); \( P^{\text{CON}}_{j,t} \) is the electrical output of the pure condensing unit in the period \( t \).
The carbon transaction cost of the generation group in the dispatching period can be expressed as follows:

$$F_{g}^{C_{ab}} = \varepsilon_{a} \sum_{i=1}^{T} \Delta D_{a,i}$$ 

(4)

$$\Delta D_{a,i} = E_{a,i} - D_{a,i}$$

(5)

Where, $F_{g,a}^{C_{ab}}$ is the carbon trading cost of power generation group $a$; $\varepsilon_{a}$ is the carbon quota trading price; $\Delta D_{a,i}$ is the carbon quota trading volume of power generation group $a$ in the period $t$.

3. Calculation of paid peak load regulation demand of regional power grid

**Objective function.**

$$\min F = \sum_{g=1}^{G} \delta_{g} (F_{g}^{C_{IP}} + F_{g}^{CON} + F_{g}^{Wd})$$

(6)

$$F_{g}^{C_{IP}} = \sum_{i=1}^{T} \sum_{j=1}^{N} (a_{0} + a_{1} P_{i,j,g}^{C_{IP}} + a_{2} (P_{i,j,g}^{C_{IP}})^{2} + a_{3} H_{i,j,g}^{C_{IP}} + a_{4} (H_{i,j,g}^{C_{IP}})^{2} + a_{5} P_{i,j,g}^{Wd} )$$

(7)

$$F_{g}^{CON} = \sum_{i=1}^{T} (b_{0} + b_{1} P_{i,j,g}^{CON} + b_{2} (P_{i,j,g}^{CON})^{2})$$

(8)

$$F_{g}^{Wd} = \sum_{i=1}^{T} (c_{Wd} \sum_{m=1}^{M} (P_{i,m,g}^{Wd} - P_{i,m,g}^{Wd}) \Delta t)$$

(9)

Where, $F$ is the expected value of the total coal consumption cost of the system; $G$ is the number of wind power forecast scenarios; $\delta_{g}$ is the probability of scenario $g$; $T$ is the number of periods in a scheduling cycle; $F_{g}^{C_{IP}}$ is the operating coal consumption cost of the thermal power unit; $F_{g}^{CON}$ is the operating coal consumption cost of the pure condensing unit; $F_{g}^{Wd}$ is the penalty cost of wind power abandonment; $a_{0} - a_{5}$ are the fitting coefficients of the consumption characteristics of the thermal power unit; $P_{i,j,g}^{C_{IP}}$ and $H_{i,j,g}^{C_{IP}}$ is the $i$th thermal power unit in the $t$ period under scenario $g$ the output power and thermal power of the generating unit; $b_{0} - b_{2}$ is the fitting coefficient of the consumption characteristics of the pure condensing unit; is the output power of the $s$ pure condensing unit in time period $t$ under scenario $g$; $P_{i,j,g}^{CON}$ is the penalty factor for wind abandonment; $P_{i,m,g}^{Wd}$ is the predicted power of the $m$th wind farm in time period $t$ under scenario $g$; $P_{i,m,g}^{Wd}$ is the online power of the $m$th wind farm in time period $t$ under scenario $g$; $\varepsilon_{e}$ is the penalty factor for carbon emission; $P_{i,max}$ is the maximum output of the thermal power unit $i$.

**Constraint condition.**

(1) Electric power balance constraint

$$\sum_{j=1}^{N} P_{i,j,g}^{CON} + \sum_{j=1}^{N} P_{i,j,g}^{C_{IP}} + \sum_{m=1}^{M} P_{i,m,g}^{Wd} - P_{i,g}^{CL} = P_{i}$$

(10)

$$\sum_{j=1}^{N} P_{i,j,g}^{CH} = (1 - e) \sum_{j=1}^{N} P_{i,j,g}^{C_{IP}} - \sum_{l=1}^{L} P_{i,j,g}^{E}$$

(11)
Where, $P_{t,i,j,g}^{f}$ refers to the on grid power of the $i$th thermal power unit in time period $t$ under scenario $g$; $P_{t}$ refers to the electric load in time period $t$; $e$ refers to the auxiliary power rate; $P_{t,i,j,g}^{e}$ refers to the electric power of the first electric boiler in time period $t$ under scenario $g$.

(2) Heat balance constraint

$$H_{t,i,j,g}^{f} + \eta_{f}P_{t,i,j,g}^{f} = H_{t}$$

(12)

Where, $\eta_{f}$ is the electric heat conversion efficiency of the first electrode type $f$ electric boiler.

4. Coordinated dispatching of electric heating considering carbon trading and peak load regulation compensation

**Objective function.**

$$F_{a} = \sum_{g=1}^{G} \delta_{g} (F_{a}^{\text{Peak}} + F_{g,a}^{\text{Carb}} + F_{g,a}^{W} + F_{g,a}^{\text{CHP}} + F_{g,a}^{\text{CON}})$$

(15)

$$F_{a}^{\text{Peak}} = \rho (P_{a,j} - P_{a}^{a})$$

(16)

$$F_{g,a}^{W} = \varepsilon_{\text{wind}} \sum_{r=1}^{M} \sum_{m=1}^{N} (P_{r,m}^{W} - P_{r,m}^{W}) \Delta t$$

(17)

Where, $F_{a}^{\text{Peak}}$ refers to the peak load adjustment compensation fee of power generation group $a$ under scenario $g$. $F_{g,a}^{W}$ is the wind power deviation penalty cost of the $a$ power grid and the centralized dispatching depth peak load resources of the lower power generation group under scenario $g$; $\rho$ is the peak shaving compensation coefficient; $P_{a,j}$ is the total power generation of the power generation group $a$ in the period $t$; the total power generation of the power generation group $a$ in the $t$ period $P_{a,j}^{a}$ is only invoked under the peak load free resources of the generating unit; the penalty factor $\varepsilon_{\text{wind}}$. The mutual promotion effect between the current carbon trading income and deep peak shaving; $M_{a}$ is the number of wind farms of power generation group $a$ and the expected online power of wind farm $m$ of power generation group $a$ in $t$ period under the condition that only free peak shaving resources of units are used.

Considering that the electric heat coordinated scheduling model constructed in this chapter is a multi-objective model, the equivalent objective function of optimization treatment by using the linear weighted sum method can be expressed as follows:

$$\text{min} \ Z = \sum_{a=1}^{A} \sigma_{a} F_{a}$$

(18)

Where, $\sigma_{a}$ is the weighted coefficient of each group's objective.

**Constraint condition.**

In order to ensure the full utilization of carbon quota, set carbon emission restrictions:

$$\Delta D_{g,a,j} \leq \sum_{a=1}^{A} (D_{a,j} - E_{g,a,j})$$

(19)

Where, $\Delta$ is the number of other power generation groups in the region; $A$ is the total number of power generation groups in the region.

5. Example analysis

**Example description**
In the calculation example part, there are 9 thermal power units and 2 wind farms, including 4 pure condensing units, 5 extraction thermal power units and 4 electrode type electric boilers. Table 1 shows carbon quota coefficient and relevant coefficient, and electronegativity. To increase the calculation efficiency of the model, the heuristic synchronous generation reduction method [13] is adopted to reduce the generated scenarios, and 20 scenarios are reserved. As shown in Figure 1.

**Table 1.** Coal combustion parameters

| Distribution coefficient of carbon emission per unit of electricity (ton/MWh) | Weights for group 1 | Weights for group 2 |
|---|---|---|
| 0.72 | 0.583 | 0.417 |

![Figure 1. Wind power output of each scenario](image)

**Result analysis**

5.1.1. Peak load regulation demand analysis of power generation group

As shown in Figure 2, only the system free peak shaving resources are called. From Figure 1, it shows that the regional power grid has peak regulation demand during 0:00-9:00 and 21:00-24:00, so it is divided into system deep peak regulation periods.

![Figure 2. Wind power output of power generation groups](image)

Table 2 summarizes the relevant calculation results of the system's actual peak shaving demand. It can be seen that power generation group 1 has obtained more carbon quota due to the large capacity of the pyroelectric motor assembly. In this scheduling stage, due to the high rate of abandoned air, the carbon emission level of each group far exceeds the allocated carbon quota, which also results in the carbon emission of the whole region far higher than that of the ground.

**Table 2.** Scheduling results under three experimental schemes

| Power generation group | Coal consumption /ton | Carbon emissions /ton | Wind power absorption rate /% | Carbon quotas /ton |
|---|---|---|---|---|
| 1 | 6576.7 | 15656 | 73.3 | 13987.6 |
| 2 | 5702.1 | 11220.4 | 74.9 | 10972.3 |
| Total | 12278.8 | 26876.4 | 74.3 | 24959.9 |

The relationship between the regional carbon emission and the peak shaving depth of the thermal power unit is shown in Figure 3. It shows that with the increase of the peak shaving depth of the thermal power unit, the carbon emission of each period in the region gradually decreases. It shows that
when the unit load rate is higher than 50%, the peak shaving cost is 0, because the electric boiler is not used for peak shaving in this stage.

![Figure 3](image-url) Carbon emissions are linked to the CHP load rate

5.1.2. Analysis of deep peak regulation results of power generation group.

The dispatching results are shown in Table 3. From Table 1, it can be seen that in case 1, the power generation group is limited by the increase of peak shaving cost, so its peak shaving resources are not enough to fully accept its own abandoned wind, so there is no coordination of surplus peak shaving resources among power generation groups, so there is no peak shaving compensation fee; in case 2, because the power generation group reduces the carbon emission level by participating in peak shaving, the carbon emission level is reduced.

Table 3. Scheduling results under three experimental schemes.

| Power generation group | Coal consumption /ton | Carbon cost / thousand yuan | Peak load compensation / thousand yuan | Wind power absorption rate /% |
|------------------------|----------------------|-----------------------------|---------------------------------------|-------------------------------|
| 1                      | Case 1               | 6381.4                      | /                                     | 0                             | 86.7                          |
|                        | Case 2               | 6382.6                      | 167                                   | 309                           | 100                           |
| 2                      | Case 1               | 5295.9                      | /                                     | 0                             | 85.6                          |
|                        | Case 2               | 5162.3                      | -167                                  | -309                          | 92.9                          |
| Total                  | Case 1               | 11677.3                     | /                                     | /                             | 88.6                          |
|                        | Case 2               | 11544.9                     | /                                     | /                             | 95.3                          |

Case 2 unit output is shown in Figure 4. It can be seen that power generation group 1 has a high installed capacity of its own thermal power and a large proportion of the output of thermal power units in the whole. It produces more carbon emissions than its own quota and pays the corresponding purchase cost of carbon emission rights. In general, its economic benefits in the peak shaving process have been improved. Since the peak shaving resources of power generation group 2 are relatively small, it can be seen from Figure 1 that the demand for peak shaving resources of power generation group 2 is much higher than that of group 1.

![Figure 4](image-url) Unit output

6. Conclusion

Aiming at the problem of severe wind abandonment during the winter heating period in Northeast China, a coordinated electric-heating dispatching strategy combining carbon trading and peak shaving compensation mechanism was proposed. The following conclusions are reached through case analysis:
A variety of policy mechanisms will form a complementary relationship to a certain extent, and power generation groups can not give full play to their peak shaving capacity under the constraints of a single market mechanism limited by the impact of economic benefits. By coordinating the carbon trading mechanism and peak shaving auxiliary service mechanism, it can effectively improve the economic benefits of power generation groups, enhance their enthusiasm for active peak shaving, and help to reduce the overall carbon emissions of the region.

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