Electrothermal Comprehensive Scheduling Model Based on Electric Boiler

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Abstract. Currently, with the scale of wind power in the “Three Norths” region of our country is increasing constantly, the abandoning of wind phenomenon is getting worse, and the “wind-heat conflict” is becoming more evident. In this paper we establishes the combined heat and power dispatch model for power system with electronic boiler based on the “heat and power” constraint of the decoupled thermoelectric power units, aiming at the problem of large-scale wind power consumption. Considering the total coal cost and the wave range of reducing the output of the thermoelectric power unit, the operation economy of the unit is improved. Finally, the multiple objective cuckoo algorithm is used to solve the electric heating optimization scheduling model, and the analysis of the model under different scenarios is carried out. The numerical simulation results verify the economic and correctness of this model.

Introduction

At present, the main problem facing to the China’s wind power development still is the abandon of wind phenomenon. In order to fulfill the demand of heat load in winter, the CHP unit's “heat-electricity” mode of production has further compressed the space for wind power accepted, which is one of the major reason causes of abandoned wind\[1\]. So as to improve wind power acceptable, it is common to break the “heat-power” constraint to decouple the thermoelectric constraint, increasing the peak-shaving capacity of the power system.

Wind power for heating as an effective way to absorb the wind power, has a very brilliant prospects. Reference [2] takes the coal consumption as the objective function and proposes a scheme of adding peak-shifting electric boiler to consume wind power in the secondary heat network. Reference [3] proposed an optimized model for cogeneration scheduling of short-term wind energy forecasting. Reference [4] analyzed the application of cuckoo optimization algorithm in the combined heat and power dispatch model for power system and compared it with other algorithms. Reference [5] established a mathematical model of economy of wind farms based on electric boilers to reduce the forced output of wind turbines.

In this paper, we established the combined heat and power dispatch model for power system with electronic boiler to consume wind power, taking into account the cost of coal consumption and the minimal fluctuation of power output of thermal power plants. The multi-objective cuckoo optimization algorithm and the fuzzy optimization method are used to solve the problem. The effectiveness of the proposed model and algorithm is certified with the actual data of a provincial power grid.

The Combined Heat and Power System Principle

Combined heat and power (CHP) is the electric energy (or mechanical energy) and effective thermal energy from the same primary energy system. China's winter heating mode is central heating, and the CHP is one of the most common method\[6\]. Unlike conventional units, the operating principle of “heat...
and power” of a combined heat and power unit constrains the peaking and frequency modulation capabilities of the participating systems.

The electronic boiler is a way to increase the operational flexibility of the combined heat and power unit, and it’s a device that converts electrical energy into thermal energy and transfers thermal energy to the medium\cite{7}. Because of its high efficiency, quick start-up, high reliability, simple and flexible operation and many other advantages, it has been used in China for many years, so its technology is relatively mature. After install the electronic boiler, the adjustable range of the power generation of the steam turbine is obviously increased\cite{8}, and decoupling the “heat and power” operation constraints. Configuring the electric boiler can increase the electric load at the same time, and thereby improve the capacity of wind power dissipation\cite{9}.

**The Model**

**The Objective Function**

Due to China’s current implementation of energy-saving generation scheduling model, in this paper, we choice the minimum coal consumption as the objective function\cite{3}\cite{10}. Because of the cost of generating wind turbines is smaller than the thermal power units, it is negligible. In addition, in order to make the output of the thermoelectric generator smoother and improve the operating efficiency, the minimum output variance of the thermoelectric generator is taken as another objective function\cite{11}.

\[
E_1 = \min \left\{ \sum_{i=1}^{n} \left( \sum_{t=1}^{T} C_{e,i} + \sum_{t=1}^{T} C_{b,i} \right) \right\}
\]

\[
E_2 = \min \left\{ \sum_{t=1}^{T} \left( P_{e,t} + P_{r} - P_{q} - P_{w} \right) \right\}
\]

where \( P_{\text{av},t} \) is the average value of the net load, which is \( P_{\text{av},t} = \sum_{i=1}^{T} \left( P_{e,i} + P_{r} - P_{q} - P_{w} \right) / T \); \( C_{q,i,t} \) is the coal consumption cost of the ith thermal power plant at time \( t \), which is \( C_{q,i,t} = d_i p_{q,i,t}^2 + e_i p_{q,i,t} + f_i \); \( C_{b,i,t} \) is the coal consumption cost of the ith thermal power plant at time \( t \), which is \( C_{b,i,t} = a_i \left( p_{b,i,t} + \gamma_i h_{b,i,t} \right) + h_i \left( p_{b,i,t} + \gamma_i h_{b,i,t} \right) + c_i \cdot p_{b,i,t} \cdot h_{b,i,t} \), respectively, which is the electric power and thermal power of the ith thermoelectric generator at time \( t \); \( \gamma_i \) is the ith thermoelectric unit intake air volume invariably, the more the unit heat of the extraction of electric power reduction. \( p_{q,i,t} \) is the electric power of the ith conventional power unit at time \( t \); \( a_i, b_i, c_i, d_i, e_i, f_i \) are respectively the coal consumption coefficient of thermoelectric power plants and thermal power plants; \( P_{e}, P_{r}, P_{q}, P_{w} \) respectively, for the thermoelectric power units, conventional units, wind turbines, electric load and electric boiler power consumption.

**The Constraints**

1) CHP Unit and Thermal Power Unit Operational Constraints:

\[ \begin{align*}
\begin{cases}
\frac{b_{i,t}}{P_{\text{up},b}} & \geq \max \left( \frac{C_{m,i} h_{i,t} + K_r}{P_{\text{up},i} - C_{r,j} h_{i,j}} \right) \\
\frac{b_{i,t}}{P_{\text{down},b}} & \leq \frac{P_{\text{up},i} - C_{r,j} h_{i,j}}{P_{\text{up},b}} \\
0 & \leq h_{i,t} \leq h_{i,\text{max}} \\
-P_{\text{down},b} & \leq P_{b,i,t} - P_{b,j_t} \leq P_{\text{up},b}
\end{cases}
\end{align*} \]
where $p_{b,t}$ is the Cogeneration unit generation power at time $t$; $c_{m,t} = \Delta P / \Delta h$, which is for the thermoelectric unit thermoelectric ratio; $K$ is a constant; $c_{e,t}$ for the same intake air volume, more extraction unit heating the amount of electric power reduction; $h_{ij}$ is the heating power of the thermoelectric unit at time $t$. $p_{uq,b}$ and $p_{dwn,b}$ for the largest thermoelectric unit up and down the slope of the output.

2) Thermal Power Unit Operating Range Constraints and Unit Climbing Constraints:

$$P_{q,min} \leq P_{q,t} \leq P_{q,max} \quad (6)$$

$$-P_{dwn,q} \leq P_{q,t+1} - P_{q,t} \leq P_{up,q} \quad (7)$$

$P_{q,t}$ is the conventional unit generation power at time $t$; $p_{up,q}$ and $p_{dwn,q}$ for the largest conventional unit up and down the slope of the output.

2) Electronic boiler operating constraints:

$$0 \leq P_{e,t} \leq P_{e,max} \quad (8)$$

$$h_{e,t} = \mu P_{e,t} \quad (9)$$

where $P_{e,t}$, $h_{e,t}$ are the power consumption of electric boiler and the heat production at time $t$; $\mu$ for electric boiler electric conversion efficiency, the value of $\mu$ takes 0.99$^{[8]}$.

3) Wind power constraints:

$$P_{w,t} < P_{w,t,f} \quad (10)$$

$P_{w,t}$, $P_{w,t,f}$ are the actual power and predicted power of the wind farm at time $t$.

4) Comprehensive optimization scheduling constraints:

Electric power balance constraint:

$$\sum_{i=1}^{N_e} P_{q,t,i} + \sum_{i=1}^{N_e} P_{b,t,i} + P_{w,t} = P_{L,t} + P_{e,t} \quad (11)$$

where $P_{q,t,i}$ is the ith thermal power plant power at time $t$; $P_{b,t,i}$ is the ith thermoelectric power plant power at time $t$; $P_{L,t}$ is the load power at time $t$; $P_{e,t}$ is the electric boiler power consumption at time $t$.

Thermal power balance constraint:

$$\sum_{i=1}^{N_e} h_{b,t,i} + h_{e,t} = h_{L,t} \quad (12)$$

where $h_{b,t,i}$ is the heat production of the ith thermoelectric power plant at time $t$; $h_{L,t}$ is the value of thermal load at time $t$.

**Improved Multi-objective Cuckoo Algorithm In Scheduling Model**

The multi-objective cuckoo algorithm (MOCS) has the advantages of simpleness, high-efficiency and strong search ability, and has been applied in many fields$^{[12]}$. In standard MOCS, the discovery probability initially $p$ and the step size $\alpha$ is generally set to fixed value, therefore, may result too many algorithm iterations or poor convergence accuracy$^{[13]}$. Therefore, we change $p$ and $\alpha$ to dynamic variables. In the early iteration, the values of the two are large enough to enhance the diversity of the solution vector and the operation running speed. In the latter part of the iteration, the
values of the two are reduced to find the optimal solution locally. The specific formula of dynamic discovery probability and step size is as follows:\(^{(14)}\):

\[
P_s(t) = P_{s,\text{max}} - \frac{t}{g}(P_{s,\text{max}} - P_{s,\text{min}})
\]

\[
\alpha(t) = \alpha_{\text{max}} \exp(c.t)
\]

\[
C = \frac{1}{g} \ln\left(\frac{\alpha_{\text{min}}}{\alpha_{\text{max}}}\right)
\]

where \(g\) is the total number of iterations of the algorithm; \(t\) is the current evolution algebra, \(P_{s,\text{min}}\) and \(P_{s,\text{max}}\) are the control parameters of \(P_s\); \(\alpha_{\text{min}}\) and \(\alpha_{\text{max}}\) are the control parameters of \(\alpha\).

we draws on non-dominated sorting NSGA-II algorithm to obtain non-dominated solution set. The non-dominated solutions obtained from non-dominated sorting are stored in an external archive and the external archive is maintained by calculating the crowded distance. In order to ensure the uniformity of the frontier distribution of Pareto solutions, we adopted the fuzzy optimal decision model for decision making.

This method is introduced into this scheduling model, and the population number is set to 100; the external file is size set to 60 and the maximum number of iterations is 200.

**Case Study**

**Basic Data**

In this paper, a certain proportion of the actual power supply structure of a provincial power grid in northern China, using six-unit system simulation, four thermoelectric units, two conventional units, unit parameters shown in Table 1. An example is a scheduling cycle of 24h a day, 1h for a period of time. Assuming the system heat load basically unchanged throughout the day, which is 1000MW. There is a wind farm in the system, and an electric boiler with a maximum capacity of 200MW. Electrical demand and available wind power are shown in Figure 4, \(C_{a,j}, K_{j}, C_{r,j}\) values are 0.75, 0, 0.15 respectively\(^{[8]}\).

<table>
<thead>
<tr>
<th>unit</th>
<th>(P_{\text{max}}/\text{MW})</th>
<th>(P_{\text{min}}/\text{MW})</th>
<th>(h_{\text{max}}/\text{MW})</th>
<th>(a/(t^*\text{MW/h}))</th>
<th>(b/(t^*\text{MW/h}))</th>
<th>(c/(t/h))</th>
<th>(P_{\text{up}}/\text{MW})</th>
<th>(P_{\text{down}}/\text{MW})</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>300</td>
<td>150</td>
<td>400</td>
<td>0.0532</td>
<td>190.12</td>
<td>13175.4</td>
<td>80</td>
<td>80</td>
</tr>
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<td>400</td>
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<tr>
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<td>100</td>
<td>250</td>
<td>0.1197</td>
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<td>8075.9</td>
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<td>50</td>
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<tr>
<td>5</td>
<td>400</td>
<td>200</td>
<td>0</td>
<td>0.1197</td>
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<td>8075.9</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>6</td>
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<td>200</td>
<td>0</td>
<td>0.0266</td>
<td>190.12</td>
<td>26351.5</td>
<td>130</td>
<td>130</td>
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</table>
Simulation Results Analysis

In order to compare the various scenarios of wind power consumption, set up four different scenarios: Scenario 1: the system does not contain heat storage and electric boiler; Scenario 2: The system contains Electric boiler.

As can be seen from the Figure 5, there is a large amount of abandoned wind in Scene 1 between 23:00 and 6:00 the next day, with a total amount of abandoned wind reaching 638.16MW • h. This is the period of low load, while the wind power is larger, and the thermoelectric units meet the heating demand, its electric power output cannot be reduced by the restriction of “heat electricity“ constraint, resulting in a large amount of abandoning wind. Scenarios 2 with electric boilers, the total amount of abandonment of 106.8MW • h, the abandoned wind volume is significantly reduced.

The power output of the CHP unit is shown in Figure 6. In scenario 1, during the windbreaking period (23:00 to 6:00 the next day), the power output of the units is constant to be 750MW, it’s maintain the minimum output because of the “heat electricity” constraint, thus causing consume wind power difficultly. In Scenarios 2 due to the addition of electric boilers, the power output of CHP unit is below the lower limit, so that wind power can be further consumed.

As can be seen from the table 2, the cost of coal consumption is higher due to the excessive amount of abandoned wind volume in scenario 1; scenario 2 reduce the cost of coal consumption obviously due to the reduction of the amount of abandoned wind volume due to the addition of electric boiler.
### Table 2. Coal cost of two scenarios.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>1</th>
<th>2</th>
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<tbody>
<tr>
<td>Coal Consumption/yuan</td>
<td>8753290</td>
<td>8573157</td>
</tr>
</tbody>
</table>

### Conclusion

In this paper, through the configuration of thermoelectric power units and Install electric boilers we solve the problems of abandoned wind phenomenon in our country. A comprehensive electric and thermal dispatching model based on electric boiler is proposed. With the goal of minimizing the coal consumption cost and minimizing the output variance of the thermoelectric generators. Multi-objective cuckoo algorithm is used to solve the model. The example shows that we increase the consumption of wind power by configuring the electronic boiler to decouple the thermoelectric plants “heat-power” operation constraints; increasing the fluctuation range of the output of the thermoelectric integrated electric heating scheduling model based on electric boiler can better solve the problem of abandoned wind.

### References


