Coordinated allocation method of opportunity constraints for thermal power units considering source load uncertainty

Guan Duojiao*, Liu Siyu, Qian Xiaoyi, Ye Peng
Shenyang Institute of Engineering, Shenyang
guandj@sie.edu.cn

Abstract: Cogeneration units usually adopt the "heat based electricity" as the main operation mode in heating season, which will lead to the shortage of peak load regulation capacity and a large number of wind abandonment in power grid. Therefore, a stochastic optimal allocation method of thermal power units is proposed for the uncertainty of wind power output and load. The wind power prediction method based on interval discretization is adopted. On this basis, the chance constraint model of thermal power unit based on wind heat complementary and heat storage device configuration is proposed, and the coordinated scheduling solution strategy based on real coded quantum evolution is proposed. Finally, the proposed coordinated scheduling strategy is applied to typical thermal power units to verify its effectiveness.

1. Introduction
At present, wind power generation has a high degree of maturity in technology and market. In order to accelerate the development of wind power industry, the Chinese government has introduced a number of incentive measures for wind power investment and operation. The sharp decline of peak load regulation capacity caused by heating demand in winter heating period is one of the main reasons for air abandonment [1-2].

Literature [3-7] considered the impact of wind power uncertainty and established a joint operation scheduling model for wind farms and cogeneration units, and the joint operation scheduling strategy is formulated with the goal of maximum final revenue.

In this paper, a stochastic optimal allocation method of thermal power units for wind power and load uncertainty is proposed. The wind power prediction method based on interval discretization is adopted. On this basis, the chance constraint model of thermal storage units based on wind thermal complementarity is proposed, and the coordinated scheduling solution strategy based on real coded quantum evolution is proposed.

2. Electric heating characteristics of heat storage thermoelectric units
There is a linear relationship between the power range and the change of thermal power, as shown in equation (1) and equation (2):

\[ P_{\text{heat}}^{\text{max}} = P_{\text{heat}}^{\text{max}} - K_t P_{\text{heat}}^{\text{max}} \]
\[ P_{\text{heat}}^{\text{min}} = \begin{cases} P_{\text{heat}}^{\text{min}} - K_t P_{\text{heat}}^{\text{min}}, & 0 \leq P_{\text{heat}} \leq P_{\text{heat}}^{\text{max}} \\ P_{\text{heat}}^{\text{min}} - K_t P_{\text{heat}}^{\text{min}} + K_t (P_{\text{heat}}^{\text{max}} - P_{\text{heat}}^{\text{max}}), & P_{\text{heat}}^{\text{min}} \leq P_{\text{heat}} \leq P_{\text{heat}}^{\text{max}} \end{cases} \]
Where: \( P_{\text{min}} \) and \( P_{\text{max}} \) are the minimum and maximum values of generating power when the heating power of the unit is \( P_{\text{heat}} \) at time \( t \), \( P_{\text{0min}} \) and \( P_{\text{0max}} \) are the minimum and maximum values of generating power when the unit is in condensing mode, \( P_{\text{heat}} \) is a certain heating power of the unit, and \( K_1 \), \( K_2 \) and \( K_3 \) are coefficients.

Equation (3) is the energy relationship between the input and output of the extraction heating unit:

\[
Q_{\text{coal}} = \frac{P_{\text{0}}(1 + \varepsilon)}{\lambda_{\text{coal}}}
\]

Where: \( Q_{\text{coal}} \) refers to the energy of coal combustion, \( P_{\text{0}} \) refers to the power generation, \( \varepsilon \) refers to the thermal power ratio and \( \lambda_{\text{coal}} \) refers to the unit efficiency.

3. Stochastic optimization of thermal power units for wind power and load uncertainty

3.1. Wind power prediction based on interval discretization

Wind power prediction error presents a certain probability distribution characteristics. The probability density function of normal distribution is:

\[
f(x) = \frac{1}{\sqrt{2\pi \sigma}} e^{-\frac{(x-\mu)^2}{2\sigma^2}}
\]

The statistical values of wind power data of a wind farm in heating period are shown in Table 1.

| Scene | Empirical probability value |
|-------|-----------------------------|
| initial stage | 0.21 |
| metaphase | 0.47 |
| late | 0.32 |

The predicted value of wind power can be obtained by multiplying the statistical value of each period and the empirical probability, as shown in Figure 1.

\[
C_{e}(i,t) = a_{i} \cdot (P_{\text{0},i,j})^2 + b_{i} \cdot P_{\text{0},i,j} + c_{i}
\]

Where: \( a_i, b_i, c_i \) are the coal consumption coefficient of unit I respectively; \( P_{\text{0},i,j} \) is the generating power of unit I at time \( t \).

The relationship between coal consumption \( CE \) and thermal power and electric power of extraction unit is as follows:
\[ C_i(t) = A_i \cdot (P_{el,i}^t)^2 + B_i \cdot P_{el,i}^t + C_i \]  

(6)

Where: \( A_i \), \( B_i \), \( C_i \) are the coal consumption coefficients of unit \( i \).

Based on the cost functions of the above two types of units, the following objective functions can be established:

\[ C(i,t) = \sum_{j=1}^{T} \left( \sum_{i \in G_c} C_i(i,t) + \sum_{j \in G_e} C_j(j,t) \right) \]

(7)

Where: \( T \) is the total number of time periods; \( G_c \) is the set of conventional thermal power units; \( G_e \) is the set of cogeneration units.

### 4. Example analysis

In this paper, two cogeneration units and four conventional thermal power units in reference [6] are selected. The basic parameters are shown in Table 2.

| Crew | Upper limit of output | Lower limit of output | Unit climbing rate | Fuel cost factor |
|------|-----------------------|-----------------------|-------------------|-----------------|
|      | \( P_{\max} \) MW    | \( P_{\min} \) MW    | \( r_{ui} \) MW/h | \( a \) RMB/MW | \( b \) RMB/MW² | \( c \) RMB |
| 1    | 50                    | 25                    | 25                | 0.012           | 17.82           | 10.150    |
| 2    | 35                    | 10                    | 18                | 0.069           | 26.24           | 31.670    |
| 3    | 30                    | 10                    | 15                | 0.028           | 37.69           | 17.940    |
| 4    | 40                    | 12                    | 20                | 0.010           | 12.88           | 6.778     |
| 5    | 30                    | 10                    | 15                | 0.028           | 37.69           | 17.940    |
| 6    | 35                    | 10                    | 18                | 0.069           | 26.24           | 31.670    |

Through solving, the comprehensive cost under different confidence levels can be obtained. As shown in Table 3, the optimal result of this experiment is 495400 yuan when \( \alpha_1 = 0.9 \) and \( \alpha_2 = 0.8 \). At this time, the power output dispatching of each unit is shown in Figure 2, and the generation power dispatching value of the unit is shown in Figure 3. The equivalent heat load curve of heat storage device of cogeneration unit is shown in Figure 4.

| Situation | \( \alpha_1 \) | \( \alpha_2 \) | Comprehensive cost |
|-----------|---------------|---------------|--------------------|
| 1         | 0.7           | 0.7           | 56.29              |
| 2         | 0.7           | 0.8           | 53.61              |
| 3         | 0.7           | 0.9           | 53.75              |
| 4         | 0.8           | 0.7           | 53.69              |

Figure 2 prediction curve of thermal load, electric load and wind power output.

It can be seen from Figure 3 that under this dispatching mode, the sum of the electric output and...
thermal output of the unit at each time is equal to the electric load and thermal load.

![Figure 3 dispatching value of generating power](image)

Figure 3 dispatching value of generating power

From the curve in Figure 4, it can be seen that the period of no reduction capacity of thermal power mostly occurs in the low valley operation period of power grid. While the period of no reduction capacity of thermal power coincides with the period of heat storage input, which is less than the period of no reduction capacity of thermal power or the period of heat storage input, indicating that the power grid is in the low valley period.

![Figure 4 equivalent heat load curve of heat storage device of cogeneration unit](image)

Figure 4 equivalent heat load curve of heat storage device of cogeneration unit

5. Summary
Considering the uncertainty of wind power and load, this paper proposes a stochastic optimal allocation method for cogeneration units based on chance constraint. The wind power prediction method based on interval discretization is adopted. Finally, the coordinated dispatching strategy of thermal power units is applied to typical thermal power units to verify its effectiveness. The experimental results show that under certain conditions, it can significantly reduce the comprehensive operation cost, increase the consumption of wind power, and reduce the output of thermal power units and cogeneration units. To sum up, achieve the goal of energy conservation and emission reduction.

Reference
[1] National Energy Administration. 2017 wind power grid operation. [2018-01-26].
[2] Xu Dan, Ding Qiang, Huang Guodong, et al. Dynamic dispatch model of cogeneration heat load considering peak load regulation. Protection and control of power system, 2017,45 (11): 59-64.
[3] Yuan Guili, Wang LiNbO, Wang Baoyuan. Load optimal dispatch and economic benefit analysis based on "thermoelectric decoupling" of virtual power plant. Chinese Journal of electrical engineering, 2017, 37 (17): 4974-4985 + 5217.
[4] Abdolmohammadi H R, Kazemi A. A Benders decomposition approach for a combined heat and power economic dispatch. Energy Conversion and Management, 2013(71): 21-31.
[5] Chen Lei, Xu Fei, Wang Xiao, et al. Implementation mode and effect analysis of heat storage to improve wind power consumption capacity. Chinese Journal of electrical engineering, 2015, 35 (17): 4283-4290.
[6] Cui Yang, Chen Zhi, Yan Gangui, et al. Coordinated dispatching model of wind curtailment and absorption based on cogeneration unit with heat storage and electric boiler. Chinese Journal of electrical engineering, 2016, 36 (15): 4072-4081.
[7] MUELLER S, TUTH R, FISCHER D, et al. Balancing fluctuating renewable energy generation...
using cogeneration and heat pump systems. Energy Technology, 2014, 2(1): 83-89.

[8] MATHIESEN B V, LUND H. Comparative analyses of seven technologies to facilitate the integration of fluctuating renewable energy sources. IET Renewable Power Generation, 2009, 3(2): 190-204.

[9] STRECKIENE G, MARTINAITIS V, ANDERSEN A N, et al. Feasibility of CHP-plants with thermal stores in the German spot market. Applied Energy, 2009, 86(11): 2308-2316.

[10] RINNE S, SYRI S. The possibilities of combined heat and Power production balance large amounts of wind power in Finland. Energy, 2015, 40: 1034-1046.