Calculation Model of Priority Generation Considered of Low-carbon Energy Saving

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Abstract. Based on the idea of low-carbon energy saving, this paper uses the differential power accounting method based on the minimum operation mode to calculate the priority power generation. Aiming at the coal consumption and environmental protection efficiency of coal-fired units, a model and evaluation index system are constructed. The coal consumption and environmental protection efficiency are converted into quantifiable economic benefits, which provides the evaluation criteria for selecting the priority generation method of coal-fired units. This paper accounts for Shanghai priority generation of coal-fired units.

1 Introduction

March 29, 2017, the National Development and Reform Commission and the National Energy Board jointly issued on the orderly release of the power plan to open the notice[1], the notice required to reduce the existing coal-fired power generation enterprises planned electricity, the new approved generating units to actively participate Market transactions, take practical measures to implement priority power generation, priority purchase system[2][3].

In order to alleviate the peak peaking problem, it is necessary to require the thermal power plant in the low load period, the stability of the minimum mode of operation to run, so that the equivalent of the entire grid to reduce the base load part of the peak power plant to leave a larger tune Peak space, so as to achieve mitigation peak pressure, with the role of peaking[4]. The minimum operating mode refers to a mode of operation where the system has the largest short-circuit impedance value when the system is running in this mode and the shortest current generated after the short circuit occurs. According to the minimum load of the system for a long time, the minimum number of inputs The most economically efficient units, lines and grounding points[5].

In recent years, most provinces and cities in China coal-fired units have negative growth in power generation situation[6]. While reducing power generation plans, not only to ensure that the power supply, but also to ensure environmental efficiency. Through the analysis and calculation of environmental costs, the establishment of coal-fired unit evaluation index system, accounting for coal-fired units priority power generation.

2 Differential Power Accounting Method Based on Minimum Operation Mode

The difference accounting method based on the minimum operation mode is as follows:
Priority generation of coal-fired units = Base power + Differential power

The priority generating amount of the coal-fired unit is composed of two parts of the electric power, the base power and the differential power, among which:

(1) Base power

Single capacity of 300,000 kilowatts and below the conventional coal units, the output can be reduced to at least 50% of the rated capacity; More than 300,000 kilowatts of units, the output can be reduced to at least 60% of rated capacity. The output of less than 60% of the part of the renewable energy peak load shedding part. The general area can take turns 7-10 days of downtime peaking; Peaked in difficult areas or difficult times, depending on the circumstances to extend the downtime peak time.”

(2) Differential power

Power generation efficiency sorting differential power: To consider the efficiency difference, the generator set to sort, in the annual base plan to arrange a certain number of hours of energy saving difference. According to the coal-fired power generation enterprises to test the results of coal consumption test, the same unit in the sort of the first unit to give a certain number of hours of power generation awards.

Based on the minimum mode of operation of the difference between the accounting method is as follows:

\[ h_i = h_{base} + h_{coal} + h_{green} \]

In the formula, \( h_i \) represents the power generation hours of the i-th coal-fired units corresponding to the capacity of the unit; \( h_{coal} \) represents the generation hours of the unit i corresponding to the coal consumption of coal-fired units; \( h_{green} \) indicates that the unit i corresponds to the coal- The number of hours found reward.

3 Study on Energy Efficiency and Environmental Protection Efficiency of Coal-fired Units and Evaluation Index System

3.1 Environmental Cost Analysis and Calculation Steps

The total cost of electricity production should be the sum of production costs and environmental costs (as shown in Figure 1).

\[ \text{Total cost} = \text{Production cost} + \text{Environmental cost} \]

The environmental cost of electricity production \( c_{environment} \) is:

\[ c_{environment} = c_{Resource\ consumption} + c_{Pollution\ control} + (c_{Water} + c_{Coal}) + (c_{SO_2} + c_{NO_x} + c_{Sewage} + c_{CO_2} + c_{PM}) \]

In the formula, \( c_{Water} \) and \( c_{Coal} \), respectively, water consumption costs and coal resource consumption costs; \( c_{SO_2} \) is due to the elimination of electricity production process of sulfur dioxide emissions caused by the cost of governance, the other same.

Figure 2 is the environmental cost analysis and calculation steps:
### 3.2 Calculation of Environmental Factors

#### 3.2.1 Calculation of Resource Consumption Factor

The resource consumption factor includes two indicators, water consumption factor and coal consumption rate, which reflect the consumption of water resources and coal resources.

1. **Calculation of water consumption factor**
   
   The actual formula for water consumption is:
   
   $f_{\text{water}} = \frac{M_{\text{water}}}{Q}$  \(\text{(4)}\)
   
   In the formula, $M_{\text{water}}$ is the total water consumption (t); $Q$ is the total unit power (MWh). The above data can be obtained from the actual survey of the power plant, or based on the average level of different installed capacity units.

2. **Calculation of Coal Consumption Rate Factor**
   
   The actual formula for calculating the coal consumption rate is:
   
   $f_c = \frac{M_c}{Q}$ \(\text{(5)}\)
   
   In the formula, $M_c$ is the total amount of coal resource consumption (t); $Q$ is the total unit power consumption (MWh). The above data can be obtained from the actual survey of the power plant, or based on the average level of different installed capacity units.

#### 3.2.2 Calculation of Pollution Factor

Pollution control factors include five indicators of pollutant pollution, sewage, carbon, sulfur, nitrate and smoke.

1. **Calculation of average emission factors for sewage**
   
   The average emission factor for sewage is calculated as follows:
   
   $f_{\text{sewage}} = \frac{M_{\text{sewage}}}{Q}$ \(\text{(6)}\)
   
   In the formula, $M_{\text{sewage}}$ is the total amount of sewage (t), can be calculated by the calculation; $Q$ for the unit total power (MWh).

(2) Calculation of Average Emission Factor of Carbon Dioxide
The formula is as follows:

\[ f_{CO2} = \frac{M_{CO2}}{Q} = \frac{FC_i \times NVC_i \times h_{CO2,i}}{Q} \]  

(7)

In the formula, \( M_{CO2} \) is the total amount of CO2 emissions (t); \( Q \) is the unit total power consumption (MWh); \( FC_i \) is the unit fuel \( i \) consumption (mass or volume unit); \( NVC_i \) is the fuel \( i \) net calorific value (energy content, GJ / mass or volume units); \( h_{CO2,i} \) is the CO2 emission factor for fuel \( i \) (tCO2 / GJ); \( i \) is the type of fossil fuel consumed by the unit.

(3) Calculation of average emission factors for sulfur dioxide

The average emission factor for sulfur dioxide is calculated as follows:

\[ f_{SO2} = \frac{M_{SO2}}{Q} \]  

(8)

In the formula, the total amount of pollutant SO2 emissions (t), can be calculated by the calculation; for the unit total power (MWh).

(4) Calculation of average emission factors for nitrogen oxides

The average emission factor for nitrogen oxides is calculated as follows:

\[ f_{NOX} = \frac{M_{NOX}}{Q} \]  

(9)

In the formula, \( M_{NOX} \) is the total amount of NOX emissions (t), can be calculated by the calculation; \( Q \) for the unit total power (MWh).

(5) Calculation of Average Emission Factor of PM

PM The average emission factor is calculated as follows:

\[ f_{PM} = \frac{M_{PM}}{Q} \]  

(10)

In the formula, \( M_{PM} \) is the total PM discharge (t), can be calculated by the calculation; \( Q \) for the unit total power (MWh).

According to the actual research data and related literature, the environmental factors of each generating unit are shown in Table 1.

### Table 1 The results of environmental factors of generating units

| Unit                  | Unit type | Water (g/kWh) | Coal (g/kWh) | Sewage (g/kWh) | CO2 (g/kWh) | SO2 (g/kWh) | NOX (g/kWh) | PM (g/kWh) |
|-----------------------|-----------|---------------|--------------|----------------|-------------|-------------|-------------|------------|
| Coal - fired unit     | 1000MW    | 241.148       | 307.594      | 3.990          | 674.554     | 0.284       | 0.385       | 0.081      |
|                       | 600MW     | 318.840       | 319.878      | 34.381         | 849.953     | 0.586       | 0.908       | 0.080      |
|                       | 300MW     | 501.193       | 347.326      | 120.536        | 632.694     | 0.298       | 1.816       | 0.090      |
| Hydropower unit       | Years of adjustment | --           | --           | --             | --          | --          | --          | --         |
|                       | Year adjustment      | --           | --           | --             | --          | --          | --          | --         |
|                       | Runoff                | --           | --           | --             | --          | --          | --          | --         |
| Gas turbine unit      | 9E        | 106           | 286.53       | 0.145          | 450.8       | 0.003       | 1.382       | 0.053      |
|                       | 9F        | 90            | 272.32       | 0.142          | 432.3       | 0.003       | 1.346       | 0.051      |
| Nuclear power unit    | Nuclear power unit    | --           | --           | --             | --          | --          | --          | --         |
| Wind turbine          | Wind turbine         | --           | --           | --             | --          | --          | --          | --         |

### 3.3 Calculation of environmental cost equivalents

The so-called environmental cost equivalent refers to the various types of resources for each unit and a variety of pollutants per discharge of a unit to deal with the environment to pay the cost of compensation. For the consideration of the two major environmental costs of resource consumption and pollution control in power production, the unit cost of energy consumption (water and coal) is called the cost of resource consumption. The wastewater, carbon dioxide, sulfur dioxide, nitrogen oxides and The unit management cost corresponding to the discharge of solid particulate matter is called the cost equivalent of pollution control. The following will be the two categories of cost equivalents to make a specific calculation.

#### 3.3.1 Calculation of cost equivalence of resource consumption
Resource consumption class cost equivalent is represented by $e_r$, to measure the long-term adverse effects of primary energy consumption. Different types of primary energy resource taxes are shown in Table 2.

| Tax items              | Amount of tax          |
|------------------------|------------------------|
| 1. Crude               | 8-30 Yuan/ton          |
| 2. Natural gas         | 2-15 Yuan/thousand cubic meters |
| 3. Coal                | 0.3-5 Yuan/ton         |
| 4. Other non-metallic ore ore | 0.5-20 Yuan/t or cubic meter |
| 5. Black metal ore ore | 2-30 Yuan/ton          |
| 6. Non-ferrous metal ore ore | 0.4-30 Yuan/ton |
| 7. Salt                | --                     |
| 8. Solid salt          | 10-60 Yuan/ton         |
| 9. Liquid salt         | 2-10 Yuan/ton          |

3.3.2 Calculation of cost equivalence of pollution control

Pollution control class cost equivalent is represented by $e_p$, measuring the cost of emissions from various pollutants. For the sewage treatment costs, if the discharge standards only need to levy sewage treatment fees, if there is a class of pollutants still need to levy sewage charges; Sewage charges charge amount = 0.7 Yuan × the first three pollutants in the sum of the amount of pollution equivalent, the first and second class pollutants are classified according to the Integrated Wastewater Discharge Standard (GB8978-1996); For excessive pollutants need to be based on the original sewage charges plus 1 times the collection of excessive standard sewage charges. For the cost of carbon dioxide treatment, due to excessive carbon tax levy on the national economy and the impact of corporate resilience, so the current tax will generally be set at 10-50 Yuan per ton of carbon dioxide levy. For the sulfur dioxide, nitrogen oxides and solid particles of governance costs, according to China's "sewage charges levy standards management approach" to calculate.

3.3.3 Cost equivalence analogue estimate

From the table 3 we can see: China has only carried out the collection of resource tax, carbon tax policy has not yet been implemented, can be similar to the situation at home and abroad to determine the equivalent of emissions trading is still in the pilot phase, it can be in accordance with China's sewage charges collection standards And then determine the value of the relevant equivalent.

| Country / tax          | Resource tax (taking coal as an example) | Carbon tax       | Emissions Trading Price (Emissions) |
|------------------------|------------------------------------------|------------------|-------------------------------------|
| The United States      | 15%-30%                                   | 50-80 Yuan/t     | Emissions trading has been implemented |
| Japan                  | 50%                                       | 150-250 Yuan/t   |                                     |
| The European Union     | 15-70%                                    | 200-300 Yuan/t   |                                     |
| China                  | 0.3-5 Yuan/t                              | 0                | Emissions trading is carried out in some areas |

Water resources tax reference to the implementation of Chaoyang District, Beijing to take 1.1 Yuan/kg; for sewage treatment fees, according to emission standards and management practices, the current number of coal-fired The unit and the gas turbine unit will use the sewage treatment system under the impetus of the national policy. The processing cost is 0.27 Yuan/cubic meter. For the carbon dioxide tax, according to the actual situation of our country and the international experience (Table 5-3) 10-50...
yuan in the middle of 30 yuan / ton; for sulfur dioxide, nitrogen oxides and solid particles, according to "sewage charges collection standard management approach" to calculate the sulfur dioxide pollution fee of 0.632 yuan / kg, nitrogen oxide is also 0.632 Yuan / kg, solid particles due to difficult to detect, so take the average of 3 yuan per ton of coal.

3.4 Calculation of environmental cost
The total cost of the environment (in yuan / kWh) that should be paid for the unit charge, which is:

\[ C_{\text{synthesis}} = C_r + C_p \]

\[ = f_r \times e_r + f_p \times e_p \]

\[ = f_{\text{water}} \times e_{\text{water}} + f_e \times e_e \]

\[ + f_{\text{sewage}} \times e_{\text{sewage}} + f_{\text{CO}_2} \times e_{\text{CO}_2} + f_{\text{SO}_2} \times e_{\text{SO}_2} + f_{\text{NO}_x} \times e_{\text{NO}_x} + f_{PM} \times e_{PM} \]

In the formula, \( Cr, Cp \) were the unit power consumption and pollution control class cost.

4 Case Analysis of Differential Power Accounting Based on Minimum Operation Mode
An example analysis of Shanghai. According to the coal consumption of the unit sort, statistics coal-fired units of the power generation hours as shown in the following table 4:

| Unit name                  | Installed capacity (MW) | Base hours | Coal consumption (t/MWh) | Sorting | Energy reward | Similar rankings reward | The final number of hours of power generation |
|----------------------------|-------------------------|------------|--------------------------|---------|---------------|-------------------------|--------------------------------------------|
| Waigaoqiao third power plant_5 machine | 1000                    | 3004       | 0.2716                   | 1       | The first gear: reward 120 hours | 30 hours | 3154 |
| Waigaoqiao third power plant_7 machine | 1000                    | 3004       | 0.27255                  | 2       | 3124 |
| Shangdian Caojing Power Plant_2 machine | 1000                    | 3004       | 0.27572                  | 3       | 3124 |
| Shangdian Caojing Power Plant_1 machine | 1000                    | 3004       | 0.27698                  | 4       | 3124 |
| Waigaoqiao third power plant_5 machine | 900                     | 3004       | 0.28937                  | 5       | 3124 |
| Waigaoqiao third power plant_6 machine | 900                     | 3004       | 0.29026                  | 6       | 3094 |
| Shidongkou second power plant_1 machine | 600                     | 3004       | 0.29083                  | 7       | 3124 |
| Shidongkou second power plant_2 machine | 600                     | 3004       | 0.30115                  | 8       | 3094 |
| Waigaoqiao third power plant_4 machine | 320                     | 3004       | 0.30969                  | 9       | 3094 |
| Waigaoqiao third power plant_3 machine | 320                     | 3004       | 0.31122                  | 10      | 3094 |
| Waigaoqiao third power plant_6 machine | 320                     | 3004       | 0.31173                  | 11      | 3064 |
| Wujing second power plant_1 machine | 600                     | 3004       | 0.31351                  | 12      | 3064 |
| Wujing second power plant_2 machine | 600                     | 3004       | 0.3155                   | 13      | 3064 |
| Waigaoqiao third power plant_1 machine | 320                     | 3004       | 0.31733                  | 14      | 3064 |
| Shidongkou Power Plant_4 machine | 660                     | 3004       | 0.32036                  | 15      | 3064 |
| Shidongkou Power Plant_1 machine | 600                     | 3004       | 0.32046                  | 16      | 3034 |
| Shidongkou Power Plant_2 machine | 600                     | 3004       | 0.32188                  | 17      | 3034 |
| Shidongkou Power Plant_3 machine | 660                     | 3004       | 0.32412                  | 18      | 3034 |
| Wujing Thermal Power Plant_12 machine | 300                     | 3756       | 0.32911                  | 19      | 3786 |
| Wujing Thermal Power Plant_11 machine | 300                     | 3756       | 0.33462                  | 20      | 3786 |

According to the analytic hierarchy process, we can conclude that the weighting factor of this factor is shown in the following table, as shown in Table 5.

| Water | Coal | CO₂  | SO₂  | NOₓ  | Solid particles | Sewage |
|-------|------|------|------|------|-----------------|--------|
| 0.0377| 0.1823| 0.0003| 0.3026| 0.1246| 0.57249| 0.00001|

According to the above factors, the environmental factors of the thermal power units can be obtained. The units with small environmental factors are given priority, and the calculation results are shown in the following table 6.
Table 6 Number of hours of coal-fired units to be Considered for environmental sequencing

| Unit name                                      | Installed capacity (MW) | Environmental factors | Classification bonus | Similar rankings reward |
|-----------------------------------------------|-------------------------|-----------------------|----------------------|-------------------------|
| Waigaoqiao second power plant _6 machine      | 900                     | 0.02173               |                      |                         |
| Waigaoqiao Power Plant _4 machine             | 320                     | 0.02322               |                      |                         |
| Waigaoqiao Power Plant _3 machine             | 320                     | 0.02404               |                      |                         |
| Waigaoqiao second power plant _5 machine      | 900                     | 0.02411               |                      |                         |
| Shidongkou Power Plant _4 machine             | 660                     | 0.02412               |                      |                         |
| Shidongkou Power Plant _3 machine             | 660                     | 0.02457               |                      |                         |
| Waigaoqiao Power Plant _1 machine             | 300                     | 0.02457               |                      |                         |
| Shangdiancaojing Power Plant _1 machine       | 1000                    | 0.02471               |                      |                         |
| Shangdiancaojing Power Plant _2 machine       | 1000                    | 0.02483               |                      |                         |
| Shidongkou Power Plant _2 machine             | 600                     | 0.02544               |                      |                         |
| Waigaoqiao third power plant _3 machine       | 1000                    | 0.02572               |                      |                         |
| Waigaoqiao third power plant _8 machine       | 1000                    | 0.02583               |                      |                         |
| Waigaoqiao Power Plant _1 machine             | 320                     | 0.02736               |                      |                         |
| Shidongkou second power plant _1 machine      | 660                     | 0.02755               |                      |                         |
| Shidongkou Power Plant _3 machine             | 660                     | 0.02781               |                      |                         |
| Shidongkou second power plant _2 machine      | 660                     | 0.02942               |                      |                         |
| Wujing second power plant _2 machine          | 600                     | 0.02977               |                      |                         |
| Wujing Thermal Power Plant _12 machine        | 300                     | 0.03029               |                      |                         |
| Wujing second power plant _1 machine          | 600                     | 0.03072               |                      |                         |
| Waigaoqiao Power Plant _2 machine             | 320                     | 0.03138               |                      |                         |

Combined with the number of power generation base hours and coal consumption and environmental factors caused by the difference in the number of hours, summarized as follows:

Table 7 Analysis on the number of hours of generating electricity and the environmental benefit of coal-fired units

| Unit name                                      | Installed capacity (MW) | Priority generation hours | Environmental costs (yuan/MWh) |
|-----------------------------------------------|-------------------------|---------------------------|--------------------------------|
| Waigaoqiao third power plant _8 machine       | 1000                    | 3214                      | 88.67                          |
| Waigaoqiao third power plant _7 machine       | 1000                    | 3184                      | 89.94                          |
| Shangdiancaojing Power Plant _2 machine       | 1000                    | 3214                      | 84.7                           |
| Shangdiancaojing Power Plant _1 machine       | 1000                    | 3229                      | 86.16                          |
| Waigaoqiao third power plant _5 machine       | 900                     | 3274                      | 91.71                          |
| Waigaoqiao third power plant _6 machine       | 900                     | 3229                      | 101.95                         |
| Shidongkou second power plant _1 machine      | 600                     | 3184                      | 97.56                          |
| Shidongkou second power plant _2 machine      | 600                     | 3124                      | 97.36                          |
| Shidongkou second power plant _4 machine      | 600                     | 3124                      | 91.63                          |
| Waigaoqiao third power plant _3 machine       | 320                     | 3214                      | 95.19                          |
| Waigaoqiao third power plant _2 machine       | 320                     | 3094                      | 82.18                          |
| Wujing second power plant _1 machine          | 600                     | 3094                      | 97.66                          |
| Wujing second power plant _2 machine          | 600                     | 3094                      | 98.72                          |
| Waigaoqiao third power plant _1 machine       | 320                     | 3124                      | 93.6                           |
| Shidongkou Power Plant _4 machine             | 660                     | 3199                      | 101.8                          |
| Shidongkou Power Plant _2 machine             | 660                     | 3124                      | 83.9                           |
| Shidongkou Power Plant _3 machine             | 660                     | 3094                      | 88.05                          |
| Wujing Thermal Power Plant _12 machine        | 300                     | 3816                      | 99.26                          |
| Wujing Thermal Power Plant _11 machine        | 300                     | 3876                      | 92.2                           |
According to the results of statistical analysis, coal-fired units priority to the average number of hours of power generation 3238 hours, the environmental cost of 91.83 yuan / MWh.

5 Conclusion
In this paper, the priority calculation method based on the minimum operation mode is studied deeply, and the following research work is completed:

(1) A comprehensive analysis based on the minimum mode of operation of the difference between the accounting method, the priority of coal-fired units of the two parts were described.

(2) Aiming at the coal consumption and environmental protection efficiency of coal-fired units, a model and evaluation index system are constructed. The coal consumption and environmental protection efficiency are converted into quantifiable economic benefits, which provides the evaluation criteria for selecting the priority generation method of coal-fired units.

(3) This paper accounts for the priority generating capacity of coal-fired units.

Based on the actual operation data of Shanghai power grid, combined with the evaluation and evaluation index system of energy saving and environmental protection efficiency of coal-fired units, the paper analyzes the priority generation of different power consumption based on the minimum operation mode. The calculation results show that the difference calculation method of the minimum operation mode Practicality, the estimated generation of coal-fired units priority generation hours recommended value of 3293 hours.

References
[1] Ordered development of electricity plans [J]. China Power Enterprise Management, 2016,(22):7.[2017-08-09].
[2] Wang Yi. National Development and Reform Commission, Energy Bureau: orderly development of electricity development plan [J]. Rural electrician, 2017,25 (06): 1. [2017-08-09]. DOI: 10.16642 / j. cnki. ncdg.2017.06.001
[3] orderly development of electricity plans to reduce the existing coal-fired power generation enterprises plan electricity [J]. Resource conservation and environmental protection, 2017, (01): 8. [2017-08-09].
[4] Ren Xiaoying, Du Yiwei. On the power system in the maximum mode of operation and the minimum mode of operation to understand [J]. Inner Mongolia Petrochemical, 2008,34 (24): 57 [2017-08-08].
[5] Zhang Lingling. Thermal power plant minimum operation mode analysis and supervision research [D]. North China Electric Power University (Beijing), 2011.
[6] China's thermal power installed capacity of 881 million kW [J]. Power safety technology, 2014,16 (09): 46 [2017-08-09].