Research on Economic Dispatching of Thermal Power Units Considering CO2 Emission Cost

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Abstract. This article describes the current status of clean dispatch and carbon tax research. An economic dispatch model of thermal power units considering the cost of CO2 emissions is constructed as a means to promote the reduction of emissions from polluting units, and then a particle swarm optimization algorithm is used to search the global optimal solution. Finally, combined with the model proposed in this paper, an IEEE 30-node system is used to carry out simulation examples to verify the accuracy of the model and the effectiveness of the algorithm.

1. Introduction
Fossil energy has high carbon emissions. Since the industrial revolution, human production has emitted a lot of CO2, which has a significant impact on global climate change. Therefore, the development of a low-carbon economy is conducive to environmental protection. Many countries have introduced carbon taxes to encourage clean energy production to reduce greenhouse gas emissions. At present, there are different CO2 emission permits for generator sets in the carbon emission market and the carbon trading market. Based on this permission, the maximum output of the generator set can be determined. In order to make full use of the power generation characteristics of the unit and avoid frequent start and stop of the unit, the output of the unit that meets the carbon emission standard can be appropriately increased. Due to the different carbon emission costs of different units, the output of the units is different, which in turn affects the operating costs of the units. Therefore, it is necessary to optimize between the unit cost and the unit output. Based on the cost of carbon emissions, the unit output is optimized to achieve the purpose of clean dispatch.

2. Status of Clean Dispatching and Carbon Tax Research
2.1. Research Status of Clean Dispatching
As environmental problems have worsened, more and more scholars are studying clean, environmentally friendly and energy-saving power generation dispatching. In terms of energy-saving power generation dispatch, the main energy-saving power generation dispatch modes under the market mechanism have their own characteristics [1]. The CO2 emission trajectory of the domestic power industry under different dispatch modes differs significantly, and energy-saving power generation dispatch schemes have a significant effect on improving low-carbon benefits [2]. There are currently four ways to coordinate energy-saving power generation scheduling plans and real-time control in the
past, which are significantly improved in comparison with traditional methods in the realization of energy-saving and consumption-reduction goals, the impact of system safety level, and the requirements of dispatching technology level [3]. It can be seen that the development of dispatching at this stage is not only a simple determination of unit output. In the context of prominent global environmental problems and the establishment of the "Global Energy Internet" on a large scale, dispatching must take into account environmental benefits, economic benefits and society. Benefits, make due contributions to controlling global carbon emissions, reducing power supply costs, and driving economic growth.

2.2. Carbon Tax Research Status
Since 2002, Chinese scholars have studied the impact of carbon taxes and carbon emissions on the entire country and society. The environmental protection tax officially replaced the sewage charges on January 1, 2018, becoming China's first "green tax system" after implementing the statutory tax principles. It can be seen that the mega trend is "fee-to-tax", which is of great significance for further improving environmental protection. Although there is still controversy over the implementation of carbon taxes, the rationality and necessity of carbon taxes will gradually become apparent under the general trend.

The current carbon tax systems in major countries provide a certain reference for the implementation of China's carbon tax [4]. Different carbon tax policies have different emission reduction effects, which may have an impact on China's economy [5]. China's implementation of carbon tax and the establishment of carbon tax laws are in line with the requirements of energy development and economic construction [6]. As China is still a large carbon emission country, the reduction of carbon emissions is still related to the development of the national economy and the effectiveness of environmental protection. In this case, a carbon tax should be appropriately introduced to collect a certain amount of carbon from companies with more carbon emissions. Taxes can play an incentive role in prices and promote energy conservation and emission reduction. On the other hand, they can also better promote the development of new energy sources, thereby turning electricity generation and transmission into "clean electricity."

3. Establishment of Economic Dispatch Model
The objective function of the model includes the cost of the thermal power plant, the cost of emissions, the cost of starting and stopping the thermal power unit, as follows:

\[
F_{\text{cost}} = \min \sum_{i=1}^{M} C^p_{i,t} + \sum_{i=1}^{M} C^e_{i,t} + \sum_{i=1}^{M} C^{\text{susd}}_{i,t}
\]  

(1)

Among them: \(M\) is the number of thermal power units;

\[
C^p_{i,t} = I(i,t)\alpha_i[P(i,t)];
\]  

(2)

\[
C^{\text{susd}}_{i,t} = SU(i,t) + SD(i,t);
\]  

(3)

\(I(i, t)\) is the start-stop status of unit \(i\) at time \(t\); \(\alpha_i[P(i, t)]\) is the fuel cost function of thermal unit \(i\) at time \(t\); \(SU(i, t)\) is the startup cost of unit \(i\) at time \(t\); \(SD(i, t)\) is the shutdown cost of unit \(i\) at time \(t\).

\[
\alpha_i[P(i,t)] = a_{i,t} + b_{i,t}P(i,t) + c_{i,t}P(i,t)^2 + d_i \sin[e_i(P_{i,\min} - P_i)]
\]  

(4)
\( a_i, b_i, c_i \) are the cost coefficients of unit \( i \); \( d_i, e_i, f_i \) are the fuel consumption coefficients of thermal unit \( i \).

\[
\sum_{i=1}^{M} C_{i,t}^c \text{ is the cost term, the specific expression is as follows:}
\]

\[
\sum_{i=1}^{M} C_{i,t}^e = C_{tax} E_{EM_i}(P_i) \tag{5}
\]

\[
E_{EM_i}(P_i) = \rho_{fe,i}(f_i + g_i P_i + h_i P_i^2) \tag{6}
\]

Among them, \( E_{EM_i} \) is the carbon emission of thermal power unit \( i \), \( \rho_{fe,i} \) is the CO2 emission factor of thermal power unit \( i \), \( f_i, g_i, h_i \) are fuel consumption coefficients respectively; \( C_{tax} \) is the market carbon tax price.

The model is designed to reduce emissions and operating costs, and at the same time to meet operating constraints, including system active power constraints, network constraints, unit output restrictions, system rotation reserve constraints, thermal power unit start-stop time restrictions, and unit climbing rate restrictions.

4. Simulation

4.1. System Description

![IEEE30 node wiring diagram.](image-url)
This article uses IEEE30 machine node system for simulation, as shown in Figure 1. This node system reflects a section of the US Midwest power system in December 1961, which can reflect the characteristics of the distribution network and contains the generator set, which is suitable for the analysis of the examples in this paper. The system voltage threshold is set to 0.95pu and 1.05pu. It is assumed that the power factor of the load is constant at each load level. The scheduling period is 24 hours.

The transmission loss is negligible in this simulation. The simulation is divided into two scenarios. Scenario 1: Scheduling without considering CO2 emission costs; Scenario 2: Scheduling with considering CO2 emission costs.

Table 1. Unit fuel cost coefficient.

| Unit | ai  | bi  | ci   | di  | ei  |
|------|-----|-----|------|-----|-----|
| G1   | 2000| 10  | 0.02 | 200 | 0.084 |
| G2   | 2500| 15  | 0.0025| 300 | 0.035 |
| G3   | 6000| 9   | 0.0018| 400 | 0.042 |
| G4   | 925 | 18  | 0.00315| 150 | 0.063 |
| G5   | 950 | 20  | 0.0032| 100 | 0.084 |
| G6   | 125 | 25  | 0.0034| 80  | 0.098 |

Table 2. Unit emission cost coefficient.

| Unit | fi   | gi  | hi   | Pmin | Pmax |
|------|------|-----|------|------|------|
| G1   | 40   | 0.2 | 0.00004| 20   | 110  |
| G2   | 50   | 0.3 | 0.00005| 20   | 100  |
| G3   | 80   | 0.12| 0.000024| 120 | 600  |
| G4   | 2462 | 48  | 0.0085| 110  | 520  |
| G5   | 2500 | 50  | 0.0095| 110  | 500  |
| G6   | 1.24 | 0.234| 0.000003| 40  | 200  |

Assume that units G1 - G3 are traditional coal-fired units, G4 and G5 are gas-fired units, and G6 are oil-fired units. See the appendix for specific parameters. The CO2 emission cost is 1.5 $ / t.

Solving the economic dispatch model without considering the cost of CO2 emissions, the results are as follows:

Table 3. Results without considering CO2 emission costs

| Unit | Output (MW) | Power generation cost ($) |
|------|-------------|--------------------------|
| G1   | 96.9586     | 2968.04                  |
| G2   | 99.4258     | 4125.33                  |
| G3   | 593.5863    | 12359.45                 |
| G4   | 259.1281    | 5808.26                  |
| G5   | 110.6583    | 3204.56                  |
| G6   | 40.3265     | 1076.32                  |

The solution considers the cost of CO2 emissions, and the results are shown in the table below:
Table 4. Results considering CO2 emission costs

| Unit | Output (MW) | Power generation cost ($) | Emission cost ($) |
|------|-------------|---------------------------|-------------------|
| G1   | 95.5402     | 2688.36                   | 3201.33           |
| G2   | 20.4456     | 2823.08                   | 3011.25           |
| G3   | 586.3564    | 11195.35                  | 8544.23           |
| G4   | 223.1151    | 5231.59                   | 582.14            |
| G5   | 56.259      | 1233.89                   | 591.22            |
| G6   | 1600.354    | 35256.54                  | 458.07            |

5. Conclusion

From the comparison of the above two tables, it can be seen that considering the cost of CO2 emissions will increase the cost of the unit, which is disadvantageous from the perspective of the unit, but it can be clearly seen that after considering the cost, the output of unit G1-G5 There are different degrees of decline, which shows that the emission cost can restrain a large number of units' emissions to a certain extent, and on the premise of meeting the load demand, use as many units with lower emissions costs as possible. In terms of total costs, considering CO2 emissions is not good for power producers, but in terms of overall environmental benefits, social benefits have been improved. Therefore, from this perspective, the environmental benefits of considering the cost of CO2 emissions are very obvious.

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