Study on Electricity Purchase Optimization in Coordination of Electricity and Carbon Trading

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Abstract. With the establishment of carbon emissions trading market in China, the power industry has become an important part of the market participants. The power grid enterprises need to optimize their own strategies in the new environment of electricity market and carbon market coordination. First, the influence of electricity and carbon trading coordination on electricity purchase strategy for grid enterprises was analysed in the paper. Then a power purchase optimization model was presented, which used the minimum cost of low carbon, energy saving and environment protection as the goal, the power generation capacity, installed capacity and pollutant emission as the constraints. Finally, a provincial power grid was taken as an example to analyse the model, and the optimization order of power purchase was obtained, which provided a new idea for the low carbon development of power grid enterprises.

1. Introduction
With the establishment of carbon emissions trading market in China, the power industry has become an important part of the market participants in order to complete the goal of carbon emission reduction [1, 2]. The energy saving and emission reduction work of power grid enterprises can influence the production process through the environmental constraints, so as to achieve the purpose of energy conservation. Constraints can come from two aspects, namely, administrative means and market regulation [3]: administrative means requires the enterprise to complete the designated emission reduction tasks at the appointed time through the laws and regulations promulgated by government, which is achieved energy conservation through carbon emissions; Market regulation is to commercialize the carbon emissions rights and establish the carbon emissions trading market. Therefore, the development of power grid enterprises will face the double market of electricity trading and carbon emissions trading, and how they participate in the carbon market for power purchase under the new situation will be studied in the paper, so as to promote their development and energy conservation.

2. The influence of coordinated trading mode on electricity purchase strategy of power grid enterprises
Electric carbon coordination trading model refers to the new trading model that electricity trading in harmony with carbon emissions trading [4]. The main body is on the basis of balance of power supply and demand, to optimize the power purchase order of units on the environmental level by operational
research methods. Thus affecting the power production process and obtain trading optimization strategy, so as to provide the basis of decision-making and scheduling optimization for power grid enterprises [5].

Due to the total amount control of carbon emissions, the generation capacity of power generation enterprises has changed significantly compared with before. For low energy consumption units, because of their emission factor is lower than the average level, so they can send more electricity; but for high energy consumption units, they have to reduce their generation because their emission factor is higher than the average level [6]. Therefore, the contract quantity will also change a lot when the power grid enterprises sign the purchase contract with power generation enterprises. Especially for the power generation rights trading that high energy consumption units have beside the carbon emission quota, the benefit of it may be negative with the development of relevant trading mechanism, so the additional power generation right will become a burden for high energy consumption unis [7].

In addition, the power generation scheduling based on "open and fair" principle would be inappropriate. High energy consumption units will strictly control the power generation rights within the scope of carbon emissions quota allowed when they formulate the purchase contracts [8]. But for low energy consumption units, they would like to sign more contract quantity and get more power generation rights to expand their economic benefits.

In short, power generation rights may have the inventory constraints under the influence of total carbon emissions control (carbon emissions quota is not enough to support the power generation that determined based on "open and fair" principle). The introduction of carbon emissions trading will promote the power generation rights transfer trading vigorously. At the same time, the imbalance between the initial quota of carbon emissions and power generation rights will be self-balanced through carbon emissions quota trading or power generation rights trading.

3. Establishment of power purchase optimization model

The power purchase of provincial power grids mainly includes low-carbon power (such as: hydropower, wind power, photovoltaic, etc.) and thermal power. Under the coordinated trading mode of electricity and carbon, the objective function and constraints method was used to optimize the order of generating units in the province to achieve the purpose of purchase optimization. The idea is: minimizing the environmental cost under the consideration of low carbon, energy saving and environmental protection.

The generation costs of low carbon power mainly include investment costs and daily labor and maintenance costs. Low carbon power basically has no low carbon cost and no need to be carried out with low carbon treatment. However, due to the proportion of low carbon power is small, the optimization purchase of provincial power grid enterprises is to optimize the order of thermal power units in the province, and the local thermal power unit optimization model is as follows.

The objective function is the minimum cost of low carbon, energy saving and environmental protection, as shown in equation (1).

\[
\text{Min}C_{\text{local}} = \sum_{i=1}^{n}
\left(h_{CO_2_i} + h_{SO_2_i} + h_{NOx_i} + h_{PM_i} + h_{\text{sewage}_i} + h_{\text{water}_i} + h_{\text{coal}_i}\right)\times Q_i
\]

\[
h_{pi} = f_{pi} \times e_{pi} \quad (P = CO_2 , SO_2 , NOx , PM , sewage)
\]
Among them, $C_{local}$ is the cost of low carbon, energy saving and environmental protection for local units (yuan), $n$ is the total number of units, $h_{CO_j}$ etc. are the environmental costs of all pollutants (yuan/MWh), $f_{pi}$ etc. are the emission factors of all pollutants (t/MWh), $e_{pi}$ etc. are the emission equivalents of all pollutants (yuan/t), and $Q_i$ is the generated capacity of units (MWh).

The constraints are as follows:

Power generation constraints

$$\sum_{i=1}^{n} Q_i = Q_{all}$$

(3)

Installed capacity constraints

$$0 \leq Q_i \leq Q_{ci}, i = 1, 2, 3, \ldots, n$$

(4)

Pollutant emissions constraints

$$\sum_{i=1}^{n} f_{pi} \times Q_i \leq W_p$$

(5)

In the above constraints, $Q_{all}$ is the total demand of calculation period, $Q_{ci}$ is the maximum installed capacity of current units, and $W_p$ etc. are the pollutant emission quota of calculation period.

4. Case study

4.1. Power generation constraints

Through the local electricity consumption - external electricity - hydropower forecast, can get the local electricity demand for local thermal power generation is 5100000 MWh. In order to meet the local electricity demand, the local power generation cannot less than it.

4.2. Power plant installed capacity constraints in a month

The data in table 1 were the maximum power output of each power plant after subtracting the plant power consumption.

| Number | Power plant | Power supply limits with installed capacity constraints (MWh) | Number | Power plant | Power supply limits with installed capacity constraints (MWh) |
|--------|-------------|---------------------------------------------------------------|--------|-------------|---------------------------------------------------------------|
| 1      | 1           | 627810                                                        | 11     | 11          | 548679                                                        |
| 2      | 2           | 618101                                                        | 12     | 12          | 534481                                                        |
| 3      | 3           | 389940                                                        | 13     | 13          | 603474                                                        |
| 4      | 4           | 394476                                                        | 14     | 14          | 627931                                                        |
| 5      | 5           | 340831                                                        | 15     | 15          | 171562                                                        |
| 6      | 6           | 390217                                                        | 16     | 16          | 147879                                                        |
| 7      | 7           | 216187                                                        | 17     | 17          | 202665                                                        |
| 8      | 8           | 212228                                                        | 18     | 18          | 183790                                                        |
| 9      | 9           | 164836                                                        | 19     | 19          | 315102                                                        |
| 10     | 10          | 168358                                                        |        |             |                                                              |
4.3. **Pollutant emissions constraints**

The emissions of power generation enterprises have to be controlled according to the requirements of environmental protection departments. The power plants have to buy more indicators from other plants whose indicators are surplus if they exceed the emission limit constraints. If the power plants have more indicators, they can have economic transactions with the other plants who need these indicators.

The data in table 2 were the pollutant emissions quote of a power plant in a month, and the data in table 3 were the pollutant emission factors of a power plant in a month. All the data were adopted from the power grid enterprise.

**Table 2.** The pollutant emissions quote in a month

|       | CO2 (t) | SO2 (t) | NOx (t) | Solid particulates (t) | Sewage (t) |
|-------|---------|---------|---------|------------------------|------------|
| 1     | 3545666 | 1701    | 8025    | 641                    | 3542889    |

**Table 3.** The pollutant emission factors in a month

| Number | CO2 emissions (t/MWh) | SO2 emissions (t/MWh) | NOx emissions (t/MWh) | Solid particulates emissions (t/MWh) | Sewage emissions (t/MWh) |
|--------|-----------------------|-----------------------|-----------------------|--------------------------------------|-------------------------|
| 1      | 0.54246               | 0.000169              | 0.00053               | 0.000073                             | 0.851                   |
| 2      | 0.54355               | 0.000152              | 0.00203               | 0.000087                             | 0.701                   |
| 3      | 0.52160               | 0.000262              | 0.00066               | 0.000082                             | 1.044                   |
| 4      | 0.50788               | 0.000261              | 0.00072               | 0.0000113                            | 1.283                   |
| 5      | 0.46754               | 0.000254              | 0.00117               | 0.000171                             | 0.681                   |
| 6      | 0.47343               | 0.000375              | 0.00132               | 0.000162                             | 0.947                   |
| 7      | 0.52077               | 0.000387              | 0.00116               | 0.000159                             | 0.825                   |
| 8      | 0.52074               | 0.000382              | 0.00176               | 0.000159                             | 1.126                   |
| 9      | 0.52347               | 0.000321              | 0.00122               | 0.000089                             | 1.494                   |
| 10     | 0.58394               | 0.000274              | 0.00130               | 0.000046                             | 0.897                   |
| 11     | 0.60012               | 0.000232              | 0.00188               | 0.000054                             | 1.255                   |
| 12     | 0.60095               | 0.000232              | 0.00054               | 0.000043                             | 1.255                   |
| 13     | 0.53677               | 0.000204              | 0.00240               | 0.000118                             | 1.201                   |
| 14     | 0.53649               | 0.000193              | 0.00211               | 0.000075                             | 1.393                   |
| 15     | 0.64418               | 0.000247              | 0.00255               | 0.000086                             | 1.133                   |
| 16     | 0.64870               | 0.000247              | 0.00297               | 0.000331                             | 0.601                   |
| 17     | 0.59168               | 0.000532              | 0.00258               | 0.000288                             | 0.742                   |

Based on the above constraints and comprehensive allocation of provincial power grids’ resources, minimizing the low-carbon, energy saving and environmental protection costs of the provincial units, this case study only calculated low-carbon, energy saving and environmental costs. The results of the linear programming were shown in table 4.

**Table 4.** Calculation results

| Number | Power plant | Power supply quote (MWh) | Power generation (MWh) | Number | Power plant | Power supply quote (MWh) | Power generation (MWh) |
|--------|-------------|--------------------------|------------------------|--------|-------------|--------------------------|------------------------|
| 1      | 1           | 627810                   | 627810                 | 11     | 11          | 548679                   | 0                      |
| 2      | 2           | 618101                   | 618101                 | 12     | 12          | 534481                   | 30509                  |
| 3      | 3           | 389940                   | 389940                 | 13     | 13          | 603474                   | 603474                 |
The generation plan results of above units were meet the constraints, and pollutant emissions were also within the constraints, as shown in table 5.

|   | CO2 emissions (t) | SO2 emissions (t) | NOx emissions (t) | Solid particulates emissions (t) | Sewage emissions (t) |
|---|------------------|------------------|------------------|----------------------------------|---------------------|
| 4 | 394476           | 394476           | 14               | 14                               | 627931              |
| 5 | 340831           | 340831           | 15               | 15                               | 171562              |
| 6 | 390217           | 390217           | 16               | 16                               | 147879              |
| 7 | 216187           | 216187           | 17               | 17                               | 202665              |
| 8 | 212228           | 212228           | 18               | 18                               | 183790              |
| 9 | 164836           | 164836           | 19               | 19                               | 315102              |
|10 | 168358           | 168358           |                  |                                  | 315102              |

As can be seen from table 5, there were surplus of pollutants emissions and these pollutants emissions right can be sold in the region to get more benefits.

According to the optimization model, the minimum environmental cost $\text{Min} C_{\text{local}}$ of the grid can be calculated as 1581000000 yuan, which makes the environmental cost of unit power as 0.31 yuan/kWh. Under the optimization results, the grid can obtain additional benefit due to the reduction of pollutant emissions and low-carbon operation. According to the calculation of pollutant emissions for each pollutant, the benefit can be calculated as 357000000 yuan, which makes the benefit of unit power as 0.07 yuan/kWh.

5. Conclusion

With the advance of China's carbon market and the deepening of the coordination of electricity and carbon, it is urgent for power grid enterprises to optimize their electricity purchase strategy under the new environment. A power purchase optimization model was presented in the paper, which used the minimum cost of low carbon, energy saving and environment protection as the goal, the power generation capacity, installed capacity and pollutant emission as the constraints. And to optimize the order of generating units in the province to achieve the purpose of purchase optimization. Finally, a provincial power grid was taken as an example to analyze the model, and the optimization order of power purchase was obtained, which verified the practicability of the model.

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References

[1] Shen H. E. 2012  The theory system of carbon emissions trading in power industry (Beijing: North China Electric Power University)
[2] Michael Grubb, Tooraj Jamasb and Michael G 2008 Delivering a Low-Carbon Electricity System (England: Cambridge University Press)
[3] Fan ZHANG and Zuojun LI 2012 China Population, Resources and Environment.22 20-25
[4] Grubb M, Butler L and Tworaey P 2006 Energy Policy. 34 4050-62
[5] Ian A. Mackenzie, Nick Hanley and Tatiana Kornienko 2008 Environ Resource Econ. 39 265- 82
[6] Svante Mandell 2007 *Journal of Environmental Economics and Management*. **12** 1-10
[7] Damien Crilly and Toshko Zhelev 2008 *Energy*. **5** 1-10
[8] James J. Murphy and John K. Stranlund 2007 *Journal of Environmental Economics and Management*. **53** 196-212