Analysis and research on the impact of carbon market on the clearing price of coal-fired power units

Ning Qiao[1*] and Chao Zhang[1] and Jisheng Zhang[1] and Haidong Chen[1] and Jing Zhang[1] and Hongjie Tian[1]

[1]State grid Ningxia electric power company, Yinchuan, Ningxia, 750010, China

Abstract: The coal power industry accounts for the largest proportion of carbon dioxide emissions, and is first included in the national carbon market, while the cost of carbon emissions has a certain impact on the coal power clearing price. Based on this, this paper constructs a bidding model of coal-fired power units considering the cost of carbon emissions; Taking Guangdong Province as an example, this paper simulates the change of the clearing price of the spot market of coal power units in the light, medium and heavy carbon market scenarios, and provides relevant suggestions for the construction of the electricity market and carbon market.

1. Introduction

The carbon emission trading system (ETS) makes use of the market mechanism to direct the distribution of carbon emission space resources, reduce emissions from energy-intensive businesses, and financially support low-emission businesses. As a result, the carbon market has developed into a practical, affordable mechanism for reducing carbon emissions [1]. One of the crucial ways to accomplish the "double carbon" aim is to fully utilize the emission reduction potential of the energy and carbon markets, and this trend of integration of the two markets is unavoidable.

With this context in mind, researchers from both home and abroad have conducted several studies on the mechanism by which the price of power is affected by carbon emissions. According to the literature [2], integrating the carbon and electricity markets is crucial for both improving the structure of the power grid and fostering the growth of new energy markets. A model for cooperative trading of carbon markets and green power certificates was developed in literature [3]. To investigate and assess the impact of China's carbon market on emission reductions and economic rewards, literature [4] developed a general equilibrium model. The rise in carbon prices will cause an increase in power prices, according to the literature [5]. According to the literature [6], the average carbon cost transmission rate of the Greek electrical market during the third phase of EUETS was close to 60%. The Stackelberg equilibrium was calculated using the formula from the literature [7] that theoretically examined the carbon cost transmission and environmental benefits in the emission trading market.

In summary, existing research has covered multiple perspectives of the electricity carbon coupling market, but there are still some shortcomings. Firstly, existing research on the coupling effects of carbon and electricity markets is mostly based on theoretical model analysis, and empirical research on specific power generation units is less involved. Secondly, the carbon market scenario setting is relatively rough and cannot accurately reflect the trend of changes in parameters such as carbon price, quota paid allocation ratio and quota benchmark value in the future Chinese carbon market.

In this paper, three carbon market scenarios, mild, moderate, and severe, are set up respectively, and a bidding model of coal electricity spot market considering carbon emission costs is constructed, and the impact of carbon costs on the unit clearing price under different carbon scenarios is simulated by numerical examples.

2. The bidding model of the coal electricity spot market considering the cost of carbon emissions

2.1. Basic assumptions

(1) This paper assumes that the clearing result of the spot market at each time can make the system marginal cost at that time the lowest value [8]. The expression of the coal-electric unit combination meeting this condition is as follows:

$$\min \sum_{t=1}^{T} \sum_{n=1}^{N} (CO_{nt} + CU_{nt} + CD_{nt}) \quad (1)$$

where, t is the time parameter, s; n is the number of coal power units, set; CO_{nt} is the operating cost of unit n at time t; CU_{nt} is the start-up cost of unit n at time t; CD_{nt} is the shutdown cost of unit n at time t.

*Corresponding author's e-mail: qiaoning@nx.sgcc.com.cn

(2) Based on the different levels of carbon market development, this paper sets three scenarios (see Table 1), namely, light carbon market, medium carbon market, and heavy carbon market, to study the impact of different levels of carbon market on the coal electricity grid price in the spot market.

Table 1. Carbon market scenario setting

index		mild scenario	moderate scenario	severe scenario
Paid quota proportion /%		6	40	100
Carbon valence /(Yuan per ton CO2）		26	82	187
CO2 emission factor/(ton CO2/MWh)	300MW≤P<600MW	0.941	0.941	0.941
	600MW≤P<1000MW	0.879	0.879	0.879
	P≥1000MW	0.823	0.823	0.823
Reference value of quota allocation/(ton CO2/MWh)	300MW≤P<600MW	0.876	0.858	0.785
	600MW≤P<1000MW	0.847	0.839	0.776
	P≥1000MW	0.801	0.767	0.682

2.2. Model establishing

(1) It is assumed that all coal power units at each time are quoted according to their short-term marginal cost under different load rates [9]. The unit bidding model based on marginal cost is shown in the following formula.

$$C_{GV_{t,n}} = C_{F_{t,n}} + C_E + C_W + C_{S_n} \quad (2)$$

$$C_{F_{t,n}} = b_{g_{t,n}} * (1 - L_{cy_n}) * P_{coal} \quad (3)$$

$$C_E = (\tfrac{\alpha_1}{0.95} + \tfrac{\alpha_2}{2.18} + \tfrac{\alpha_3}{0.95}) * k \quad (4)$$

$$C_W = \omega * P_{water} \quad (5)$$

where, $C_{GV_{t,n}}$ is the quotation of the nth unit at the time t, yuan/kWh; $C_{F_{t,n}}$ is the marginal fuel cost of the nth unit at time t, yuan/kWh; C_E is the marginal environmental protection tax cost, yuan/kWh; C_W is the marginal water consumption, yuan/kWh; C_{S_n} is the marginal production consumable material cost of the nth unit, yuan/kWh; $b_{g_{t,n}}$ is the power supply coal consumption of the nth unit at time t, g/kWh; L_{cy_n} is the auxiliary power rate of the nth unit,%; P_{coal} is the coal price, yuan/ton of coal; α_1、α_2、α_3 is the emission of nitrogen oxide, smoke and sulfur dioxide per unit power generation, g/kWh; k is the local environmental protection tax rate, yuan/pollution equivalent; ω is water consumption rate, kg/kWh; P_{water} is the water price, yuan/m3.

(2) After the introduction of the carbon market, the bidding model of coal-fired power units considering the cost of carbon emissions is shown in Formula (6) and Formula (7).

$$C_{GV_{t,n}}' = C_{F_{t,n}} + C_E + C_w + C_S + C_{O_{t,n}} \quad (6)$$

$$C_{O_{t,n}} = (E_{CO2_n} - B_{h_n} * i) * \delta_t * P_{CO2} \quad (7)$$

where, $C_{GV_{t,n}}'$ is the new quotation of the nth unit at time t, yuan/kWh; $C_{O_{t,n}}$ is the carbon emission cost of the nth unit at time t, yuan/kWh; E_{CO2_n} is the carbon dioxide emission factor of the nth unit, tCO2/MWh; B_{h_n} is the carbon quota allocation reference value of the nth unit, tCO2/MWh; i is the distribution proportion of free quota,%; δ_t is the carbon emission cost conductivity at time t,%; P_{CO2} is the carbon quota price, yuan/tCO2.

(3) In this paper, the carbon emission cost conductivity is set to reach 100% in the peak period (8:00 to 20:00), and 80% [10] in the low peak period (other times), as shown in Formula (8).

$$\begin{aligned}\delta &= \Delta P / \Delta MC \\ &= \Delta P / (\Delta P + \Delta S) \quad (8) \\ &= -D_q / (S_q - D_q)\end{aligned}$$

where, ΔP is the change in electricity price; ΔMC is the change of carbon emission cost; ΔS is the change in marginal cost curve; D_q is the slope of the electricity demand curve; S_q is the slope of the marginal cost curve.

3. Case analysis

This paper selects three specific coal-fired power generation units (300MW, 600MW, 1036MW) for simulation research, and calculates the carbon emission cost and the marginal cost of three coal-fired power units under three scenarios, as shown in Figure 1 and Figure 2. Taking the No.1 coal-fired power unit (300MW) as an example, under the mild, moderate, and severe carbon market scenarios, its marginal power cost increased by 1.6%, 13.9%, and 86.8% respectively compared with that when the carbon market was not introduced, and the proportion of carbon cost to the marginal power cost was 1.4%, 13.6%, and 47.9% respectively. It can be seen from the figure that the lower the installed capacity of thermal power units, the higher the carbon emission cost; The deeper the carbon market, the higher the carbon cost of the unit.

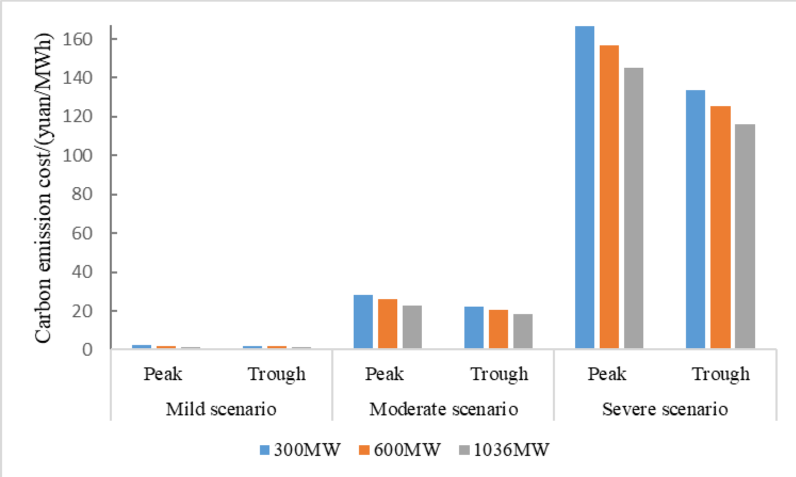

Figure 1. Carbon emission costs under different carbon scenarios

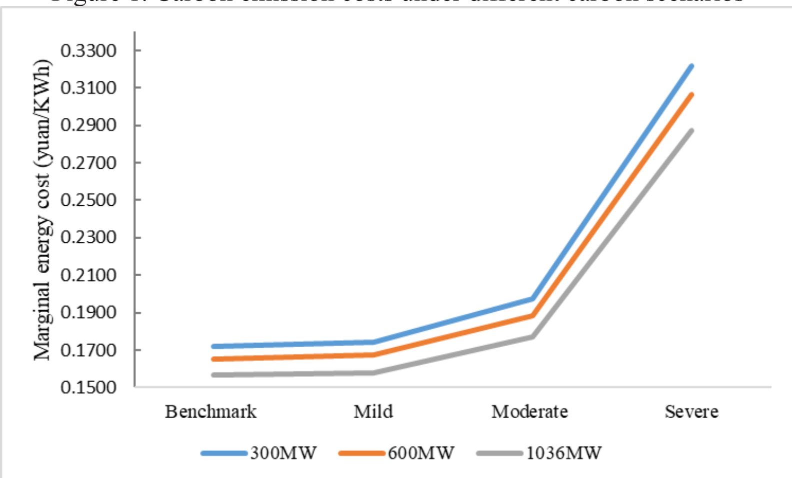

Figure 2. Marginal electricity costs of units under different carbon scenarios

As shown in Figure 3, the clearing situation of coal power units in typical scenarios of the working day is that the light carbon market has little impact on the feed-in price of coal power units, the feed-in price in the medium carbon market has increased significantly, and the feed-in price in the heavy carbon market has increased significantly, and the coal power will gradually withdraw from the spot market competition and assume the responsibility of safe power supply.

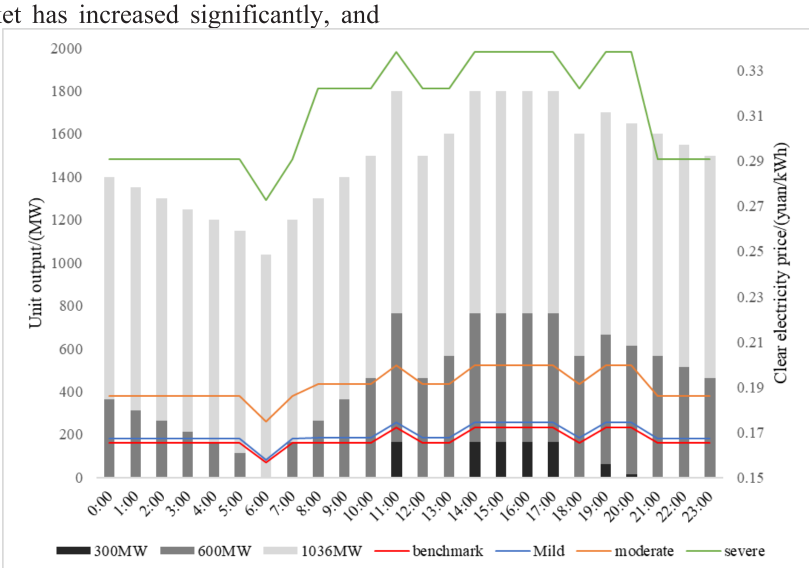

Figure 3. Typical weekday scenario coal power unit clearing situation and electricity price

4. Conclusions and suggestions

By combining the scenario analysis of the carbon market, this paper constructs a coal electricity unit pricing model based on carbon quota trading and simulates and analyzes the impact of the carbon market on the coal electricity grid price in the spot market. The results show that the carbon market has a small impact on the coal electricity grid price in the short term, while in the medium and long term, with the deepening of China's carbon market, the carbon market will greatly increase the power generation cost of coal electricity units, So that coal power units gradually withdraw from the electricity market.

Because carbon cost is not fully conductive in the electricity market, the carbon price linkage mechanism based on planned electricity generation and consumption should be considered in the future, which is conducive to promoting the close coupling and healthy development of the electricity market and the carbon market, and provides effective support for China to achieve the "double carbon target".

Author information

Ning Qiao, State grid Ningxia electric power company, senior engineer, qiaoning@nx.sgcc.com.cn;
Chao Zhang, State grid Ningxia electric power company, engineer, zhangchao@nx.sgcc.com.cn;
Jisheng Zhang, State grid Ningxia electric power company, senior engineer, zhangjisheng@nx.sgcc.com.cn;
Haidong Chen, State grid Ningxia electric power company, senior engineer, chenhaidong@nx.sgcc.com.cn;
Jing Zhang, State grid Ningxia electric power company, senior engineer, zhangjing@nx.sgcc.com.cn;
Hongjie Tian, State grid Ningxia electric power company, senior engineer, tianhongjie@nx.sgcc.com.cn.

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