Proceedings of CONF-FMCE 2025 Symposium: Semantic Communication for Media Compression and Transmission
DOI: 10.54254/2755-2721/2025.GL24772

Planning of the Carbon Trading Market Mechanism Considering the Uncertainty of Source Load and Interactivity

Chen Song

Institute of Electrical Engineering, Hebei Vocational and Technical University of Science and Technology Engineering, Xingtai, China
anqi0301@outlook.com

Abstract. Since the implementation of the "dual carbon" strategy, clean and low-carbon development has become the core task. The traditional "source following load" one-way qualitative balance model has evolved into an interactive energy supply system integrating source and load. At the same time, the load side exhibits diverse load curve characteristics, which have been meticulously designed to promote the low-carbon transformation of the power grid. To cope with the uncertainties caused by the interaction between source and load, and to enhance the interactivity of the power system and fully utilize its functions, this paper explores the role of the carbon trading market in the new power system. A two-level carbon trading market framework is proposed, which optimizes the power system from both the source and load perspectives, thereby achieving the goal of reducing carbon emissions. In addition, through a progressive pricing mechanism, the cost of carbon trading becomes more scientific and reasonable. The findings indicate that integrating the carbon trading market mechanism into the new power system with uncertain source-load interactions contributes to reducing the carbon emissions of the power system and achieving carbon reduction goals.

Keywords: Source-load uncertainty, source-load interaction, carbon trading market, new power system

1. Introduction

Currently, due to the uncertainty and interactivity of power load, relevant research mainly focuses on flexible load [1], distribution network optimization, and energy storage optimization. However, there is a lack of discussions on directly integrating power load with the carbon trading market for analysis to achieve the goal of carbon reduction. This paper will mainly introduce how to combine the carbon trading market mechanism to analyze the uncertainty and interactivity of power load in the new power system and achieve the goal of carbon reduction. This understanding will enable us to explore how to combine this interaction with the carbon trading market mechanism to achieve the goal of carbon reduction.The advantages and disadvantages of source charge interaction.

1.1. The advantages of source-charge interactivity

Source-load interaction can enhance energy utilization efficiency and optimize the allocation of power resources. It can ensure energy security and achieve the upgrading of diversified supply [2]; through

© 2025 The Authors. This is an open access article distributed under the terms of the Creative Commons Attribution License 4.0 (https://creativecommons.org/licenses/by/4.0/).

DOI: 10.54254/2755-2721/2025.GL24772

various forms of interaction, the development and utilization of peak-valley period electricity prices and interruptible loads can reduce the peak-valley difference of the power grid and improve the stability of power supply. Integrating clean energy into the new power system can reduce power consumption costs [3].

1.2. The drawbacks of source-charge interaction

The implementation of source-load interaction requires advanced communication, control and coordination technologies, and these technologies will make the design and operation of the new power system more challenging. Moreover, the cost of the source-load interaction system is higher; this will lead to a wider fluctuation range in the electricity market price.The Carbon Reduction Mechanism of Source-load Interaction

1.3. Analysis of carbon reduction mechanisms

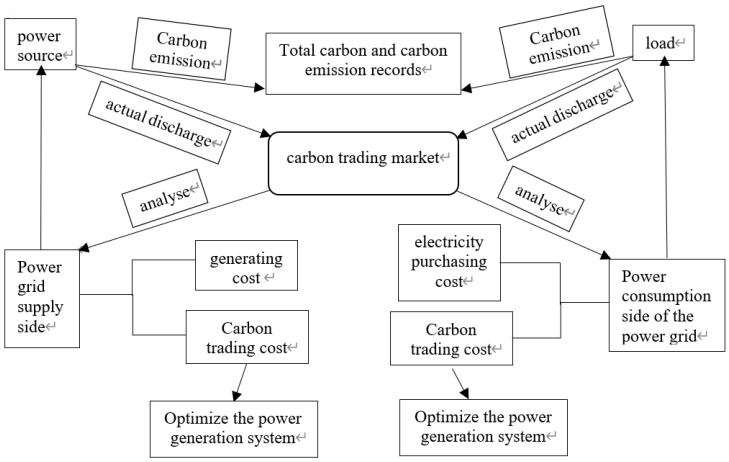


Figure 1: Carbon emission mechanism analysis framework

According to the above figure 1, first record the carbon emissions of the power grid supply measurement and the power grid consumption measurement, that is, the source and load measurement, and put them into the carbon trading market [4]. Since in practice, there will be recording errors in the carbon emissions on both the source and load sides, we need to also include the actual carbon emissions in the carbon trading market, and then conduct a carbon trading cost analysis on both the source and load sides according to the carbon trading market mechanism. The cost is divided into two parts. The source side consists of power generation cost and carbon trading cost, while the load side is composed of power purchase cost and carbon trading cost [5]. Finally, the cost results are summarized and analyzed. The source side results are used to optimize the power generation system, while the load side is used to optimize the power consumption system. On the source side, this framework marketizes the cost of carbon emissions through market-based mechanisms, combining the power generation cost on the supply side with the carbon trading cost. This forces them to adopt low-carbon technologies or improve resource utilization to reduce power generation costs, thereby reducing carbon emissions, lowering carbon trading costs, and ultimately achieving green power supply, low-carbon power supply, and sustainable development. On the load side, by recording actual carbon emissions, a dynamic carbon trading price is formed in the carbon market, and on the electricity side, peak electricity consumption is reduced to lower electricity costs. Through the analysis and optimization of carbon trading costs on both sides, it will prompt the two sides to carry out coordinated optimization and improvement, guide

DOI: 10.54254/2755-2721/2025.GL24772

resources to flow to low-carbon and environmentally friendly regions and reduce excessive carbon emissions, achieving a low-carbon transformation.

1.4. Analysis of carbon emission costs

There is a direct correlation between carbon emission flows and power flow [6].

We can establish a formula for calculating the carbon emissions generated by a motor set as [7]:

$$\mathrm{Em_i}\left(\mathrm{P_{G_i}}\right)=\alpha_i\left(\mathrm{P_{G_i}}\right)^2+\beta_i\mathrm{P_{G_i}}+\delta_i\forall_i\in\Omega_g \tag{1}$$

In the formula, $\mathrm{Em_i}\left(\mathrm{P_{G_i}}\right)$ is the carbon emissions of the generator set, α_i , β_i indicate plural, δ_i indicates expression, $\mathrm{P_{G_i}}$ indicates the power generation capacity of the unit. The greater the power of the generator set is, the higher the corresponding carbon emissions will be.

1.5. Analysis of carbon trading costs

In the new power system, to effectively curb the total actual carbon emissions on the power generation side during the actual power generation process, we require power suppliers to participate in the carbon trading market and impose constraints on them through market mechanisms. When the total actual carbon emissions of power generation units exceed the carbon quotas allocated by the market, power suppliers need to enter the carbon trading market to purchase carbon quotas. As part of the carbon trading cost [8].

The relationship between the carbon quota of the generator set and the power generation capacity is shown in the formula as follows:

$$\mathrm{E_i^0}=\lambda_i\mathrm{P_i^G} \tag{2}$$

In the formula: $\mathrm{E_i^0}$ is the carbon trading quota of the generator set 1. λ_i and $\mathrm{P_i^G}$ are respectively its carbon quota coefficient and power generation capacity [9].

Therefore, the carbon trading cost of power suppliers can be expressed as:

$$\mathrm{F}=\alpha\left(\mathrm{E}-\sum_{n=1}^{\infty}\mathrm{E_i^0}\right) \tag{3}$$

In the formula: α is carbon trading unit price, E is the total amount of carbon emissions generated during the power generation process of the integrated unit. Based on the stepped pricing benchmark, we also apply it to the calculation of carbon trading costs, as shown in the formula (4)

$$\mathrm{F_1}=\begin{cases}\mathrm{F_1^0}=\sigma_0\mathrm{E_i},0<\mathrm{E_i}\le\sum_{i=1}^{\mathrm{N_i}}\mathrm{E_i^0}\\ \mathrm{F_1^1}=\sigma_1\left(\mathrm{E_i}-\sum_{i=1}^{\mathrm{N_i}}\mathrm{E_i^0}\right),0<\mathrm{E_i}-\sum_{i=1}^{\mathrm{N_i}}\mathrm{E_i^0}\le k\\ \mathrm{F_1^2}=\sigma_1 k+\sigma_2\left(\mathrm{E_i}-\sum_{i=1}^{\mathrm{N_i}}\mathrm{E_i^0}-\mathrm{k}\right),k<\mathrm{E_i}-\sum_{i=1}^{\mathrm{N_i}}\mathrm{E_i^0}\le 2k\\ \mathrm{F_1^3}=\mathrm{k}(\sigma_1+\sigma_2)+\sigma_3\left(\mathrm{E_i}-\sum_{i=1}^{\mathrm{N_i}}\mathrm{E_i^0}-2\mathrm{k}\right),2k<\mathrm{E_i}-\sum_{i=1}^{\mathrm{N_i}}\mathrm{E_i^0}\le 3k\end{cases} \tag{4}$$

In the formula: k is carbon trading range length; σi is carbon trading unit price, We stipulate that the high-level carbon trading range should increase by 20% on the basis of the low-carbon trading range. That is σ3=1.2σ2=1.44σ1;Es is the carbon emission values of grid power suppliers participating in the carbon trading market. The carbon emission values of grid power suppliers participating in the carbon trading market [10].

DOI: 10.54254/2755-2721/2025.GL24772

2. The two-tier framework of the carbon trading market mechanism

2.1. Two-layer model

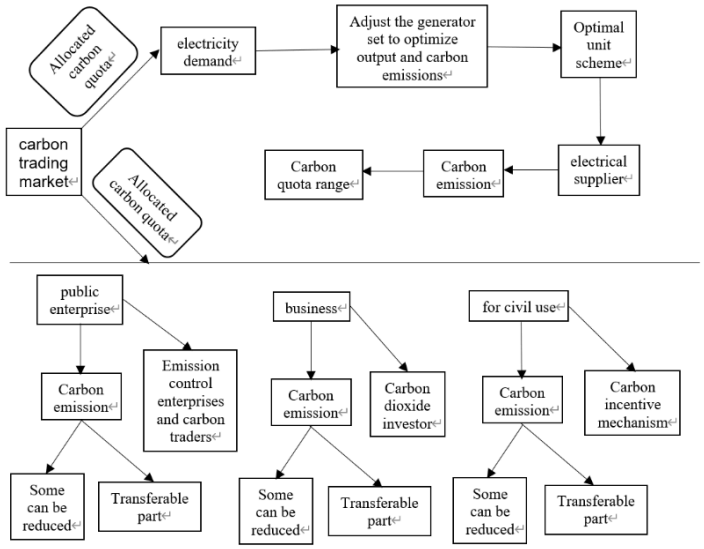


Figure 2: The two-tier framework of the carbon trading market mechanism

This dual-layer framework, through the interconnection of "quota allocation - market trading - incentive mechanism", enables the carbon emission cost to play the role of market factors in the carbon trading market. This process optimizes the carbon emissions on the power generation side and improves the efficiency of resource utilization. Moreover, it establishes a multi-level market to achieve rational resource allocation. Ultimately, this framework promotes a comprehensive low-carbon transformation of the entire power system chain from the source to the load.

2.2. Frame analysis

2.2.1. Upper-level framework analysis

Firstly, carbon quotas are allocated through the carbon trading market based on electricity demand. Then, the generator sets are adjusted to optimize the power generation output of the units and reduce carbon emissions. Subsequently,based on the adjustment results, select the optimal unit scheme. Finally, the carbon quota range is obtained based on the optimized carbon emission results.

2.2.2. Lower-level framework analysis

Firstly, through the carbon trading market and based on electricity demand, carbon quotas are allocated. The sources of carbon emissions are divided into three parts: industrial, commercial and residential. Then, the carbon trading mechanism is applied to respectively identify the reduced and transferable parts of carbon emissions. Finally, a special reward mechanism is used to further restrict the carbon emissions of the three parties [11].

Industry: Establish emission control enterprises and enter the carbon trading market with factories as carbon traders.

DOI: 10.54254/2755-2721/2025.GL24772

Business: Establish carbon investors and have large enterprises enter the carbon trading market as carbon investors.

Civilian use: Establish a HP mechanism and set up a welfare mechanism for residents. The less carbon emissions there are, the more benefits there will be.

3. Analysis of examples

3.1. Example setting

Combine the above two charts Figure 1. Carbon emission mechanism analysis framework and Figure 2. The two-tier framework of the carbon trading market mechanism. We can conduct the following example analysis on this optimization:

Suppose the main power generation entities of the power system in a certain area:

Power generation side: 2 thermal power plants and 1 solar generating unit

Electricity consumption side: 1 industrial enterprise, 1 shopping mall, and ordinary residents

Carbon trading market: The trading price is 40 yuan per ton of CO2, and it is priced in a stepped manner, with k=10.

Table 1: Records of power generation and carbon emissions by different entities

Power generation/consumption entities	Power generation/consumption (MWh)	Unit carbon emissions (tons of CO2/MWh)	Initial market carbon quota (tons of CO2)	Actual carbon emissions (tons of CO2)	Power generation/purchase cost (yuan /MWh)
Thermal Power Plant A	800	0.8	600	640	2
Thermal Power Plant B	600	0.75	470	450	2
Solar power plant	450	0	0	0	1
Industrial engineering	500	0.65 (Indirect carbon emissions)	350	325	80
Shopping mall	350	0.65 (Indirect carbon emissions)	200	227.5	70
Ordinary resident	275	0.65 (Indirect carbon emissions)	180	178.75	50

3.2. Analysis of examples

Based on the carbon emission records and the carbon quota regulations of the carbon market, according to the tiered pricing system, power plant A needs to pay an additional carbon trading fee of 2147.2 yuan. Power plant B earns 880 yuan through carbon trading. The solar power plant has no additional transaction costs. An industrial enterprise earns 1168 yuan through carbon trading. A shopping center needs to spend an additional 1312 yuan due to carbon trading. Ordinary residents can receive 50 yuan in welfare funds based on the welfare mechanism.

4. Summary and prospect

This article elaborates on the significance of integrating the carbon trading market into the new power system to achieve effective carbon reduction under the "dual carbon" target. Given the continuous deterioration of the natural environment and the increasing frequency of extreme weather events, the

DOI: 10.54254/2755-2721/2025.GL24772

new power system has shown significant uncertainties in both supply and demand. This article emphasizes the impact of these uncertainties and their interactions on the new power system. Through the structural analysis of the carbon emission system, this study proposes to incorporate the carbon trading market mechanism into the new power system to limit carbon emissions. It also advocates introducing a hierarchical pricing method to conduct more scientific and unified calculations of carbon emission costs. A two-level framework for the carbon trading market mechanism has been established. At the upper level, the optimal unit scheme is obtained through optimization analysis and then introduced into the market. Additionally, in the industrial, commercial, and residential sectors within the market, carbon emissions have been further optimized and reduced, and corresponding carbon welfare mechanisms have been established in each sector to encourage the reduction of carbon emissions.

In the future, people will further deepen the case analysis work. By applying uncertainty modeling and robust optimization methods, we will conduct in-depth research on the uncertainties involved in wind and solar power generation.

References

[1] Chen Qingbin, Yang Genghuang, Geng Liqing, et al. Low-carbon operation scheduling of integrated energy systems considering source-load uncertainty and flexible loads [J]. Journal of Solar Energy, 2025, 46(04): 183-192.DOI: 10.19912/j.0254-0096.tynxb.2023-2143.

[2] Han Haiteng. Research on Optimal Dispatching of Power System Considering Source-Load Interaction [D]. Southeast University, 2019.DOI: 10.27014/d.cnki.gdnau.2019.003876.

[3] Zhou Huan. Research on Key Issues of Source-Load Interaction in New Energy Power Systems [D]. North China Electric Power University (Beijing), 2016.

[4] Peng Chunhua, Lou Yujie, Fan Guozhu, et al. Robust and optimized dispatching of the new power system based on node carbon potential response [J/OL]. Power System Technology, 1-15 [2025-05-11].https: //doi.org/10.13335/j.1000-3673.pst.2024.0691.

[5] Hong Chong. Research on the Low-Carbon Economic Operation of an Integrated Energy System Considering Source-Load Uncertainty under the Carbon Trading Mechanism [D]. Chongqing University of Technology, 2024.DOI: 10.27753/d.cnki.gcqgx.2024.000224.

[6] Bie Pei, Lin Shaohua, Wang Ning, et al. Calculation of carbon emission factors on the power consumption side of enterprises based on power flow tracking and green power trading [J]. Southern Power Grid Technology, 2023, 17(06): 34-43.DOI: 10.13648/j.cnki.issn1674-0629.2023.06.005.

[7] Tang Xiaodong, Zhang Bailing. Analysis of Carbon Emission Costs from the Perspective of Resource Value Circulation [J]. business accounting, 2013, (04): 17-20.

[8] Zhang Ning, Liu Qingjun. Research on the Cost-Benefit Mechanism of Carbon Trading for the Goals of Carbon Peaking and Carbon Neutrality: A Simulation Based on High Energy-consuming Industries in Pilot Provinces and Cities [J]. Guangdong Social Sciences, 2022, (02): 46-58.

[9] Wuri Gen and Xige, Yang Chan, Yu Tao, et al. Research on the Trading Strategy of Thermal Power Units under the Linkage of Carbon Trading - Energy Use Rights - Electricity Market [J]. Engineering Research - Engineering from an Interdisciplinary Perspective, 2025, 17(01): 126-139.

[10] Zeng Wenshuai, Xie Jingwei, Zeng Linjun, et al. Consider the low-carbon optimization of the integrated energy system combining stepped negative carbon trading and biomass gas [J]. Electric Power Science and Engineering, 2024, 40(10): 42-57.

[11] Gao Xiangxiao, Li Zhen, Lu Xiuru. Research on the Information Spillover Effect between the Carbon Market and the Commodity Market - Based on the Analysis Framework of Spillover Structure and Spillover Level [J]. reform of the economic system, 2024, (06): 170-178.