

The study focuses on the development of an intelligent system for measuring carbon emissions and managing carbon assets in thermal power plants

MengLin Zhou^{1,a}, ShiWei Lang^{2,b}, YuTong Li^{3,c}

¹ Guonei Taicang Power Generation Co., Ltd., No. 1 Taicang Port Power Plant Road, Taicang, Jiangsu, China.

² Guonei Taicang Power Generation Co., Ltd., No. 1 Taicang Port Power Plant Road, Taicang, Jiangsu, China.

³ China Electricity Council Science and Technology Service Center Co., Ltd., No. 168 Guangwai Dajie, Xicheng, Beijing, China.

^a20038767@ceic.com, ^b16160102@ceic.com, ^cliyutong@cec.org.cn

Abstract: A reliable carbon measurement system serves as the foundation for effective carbon asset management. This paper presents a sophisticated smart carbon emission measurement and carbon asset management system specifically designed for power plants. Leveraging the operational conditions of a power plant's DCS, it enables real-time carbon emission accounting based on live data. The system seamlessly integrates online monitoring to facilitate accurate carbon emission measurement, automating the calculation, collection and reporting of emissions data while also conducting pre-review checks for compliance with reporting standards. Additionally, it simulates enterprise allocation and conducts predictive analysis to visualize both carbon emission data and quotas. By tracking, analyzing, and predicting trends in carbon trading, the system offers strategies to optimize carbon asset trading. It effectively manages all aspects of carbon assets throughout their lifecycle. The implemented system has demonstrated stability at a specific power plant by successfully measuring emissions, managing monitoring activities, diagnosing emissions data issues, performing indicator analysis and warnings generation, generating comprehensive reports on emissions verification management as well as facilitating compliance with regulations related to carbon trading. This solution helps enterprises ensure the preservation and growth of their valuable carbon assets while promoting revenue growth from efficient carbon trading practices which ultimately showcasing the value of digitalized carbon emission measurement and intelligent carbon asset management for power enterprises.

Keywords: Coal-fired power plant, Carbon emissions, Measurement, Carbon assets, Management, System

1. Introduction

With the release of the "Guidelines for Greenhouse Gas Emissions Accounting and Reporting of Enterprises (Power Generation Facilities)" and the "Technical Guidelines for Greenhouse Gas Emissions Verification of Enterprises (Power Generation Facilities)"[1], major power generation groups have increasingly prioritized carbon emissions and group-level carbon asset management in recent years. They have established specialized institutions, collaborated with scientific research units and relevant academic institutions, and explored carbon measurement methods specifically tailored to power plants. Building upon these methods, they have intensified their research on carbon asset management and carbon trading strategies[2,3], resulting in active internal carbon trading initiatives and significant accomplishments.

The current international carbon measurement methods can be categorized into two groups based on data acquisition and accuracy: the verification method [4,5] and the online monitoring method. It could be found that the commonly used verification methods include the emission factor method and the material balance method. Meanwhile, it is worth noting that when accurate statistical data is lacking the emission factor method is straightforward, feasible and applicable. However, it requires complex and time-consuming traditional laboratory analysis for data measurement. On the other

hand, the material balance method relies heavily on coal consumption classification and related data accuracy to ensure calculation precision. At the same time, due to uneven flow field distribution in chimneys or flues, the online monitoring method exhibits significant measurement errors resulting in unstable results with a wide numerical range. Currently, algorithmic approaches are mainstream in international carbon emission accounting reporting rules as they facilitate alignment with global standards. Considering China's diverse economic conditions and technological development levels among carbon-emitting enterprises, the emission factor method suits China's economic development stage better than other methods do. However, for now, online monitoring remains insufficiently mature to become a national or industry standard within China's power industry sector. The utilization of monitoring-based data as references in numerous research projects in China is accompanied by the application of emissions factors derived from other sources for correction, accordingly ensuring the maintenance of an acceptable error range.

In addition, the Ministry of Ecology and Environment has conducted special supervision and inspection on the quality of carbon emission reporting for enterprises with emissions control. The main challenges identified in carbon emission reporting include unclear guidelines, difficulties in regulating data acquisition processes, management issues and inaccuracies caused by high limit values for elemental carbon content.

This paper aims to address the complexities associated with data acquisition and improve data accuracy using a nuclear algorithm. It proposes developing an online carbon emission accounting system based on the operating conditions of power plant DCS (Distributed Control System) while integrating online monitoring methods for measuring carbon emissions. Additionally, it will develop information technology solutions to enable real-time reporting and uploading of data, fulfilling various requirements set by government agencies for nuclear algorithms such as real-time data sampling, data quality diagnosis, analysis and archiving. These efforts aim to ensure accurate and credible reporting of carbon emission data while exploring strategies for optimizing carbon emissions and managing carbon assets. Ultimately, this study seeks to demonstrate the value of digitalization and intelligent approaches in monitoring and managing carbon emissions.

2. System design

2.1 Carbon Emissions Data Monitoring

The system tracks carbon emissions data by utilizing energy consumption information gathered from the DCS system. This includes monitoring coal usage levels as well as electricity production and distribution. The monitored carbon emissions data encompasses various metrics such as quota volumes and any surpluses or deficits in quotas. It also covers emission volumes along with specific details like coal usage for power generation and heating purposes. Additionally, it measures the intensity of carbon emissions related to both power generation and heating activities. Other factors taken into account include unit efficiency measurements along with boiler efficiency ratings. Furthermore, it evaluates heat supply capabilities alongside boiler thermal output figures. The calculation methods employed to derive these values are outlined below.

Table 1 Calculation Table for Monitoring Data

Data item	Units	Computational Formula	Reference to standard documents
Quota quantity	t	Quota = power supply * Cooling mode correction factor (water cooling 1) * power supply reference value * (1-0.22* heating ratio) * Unit load factor correction factor + heat supply * heating reference value	Implementation Plan for the Setting and Allocation of Total National Carbon Emission Trading Quotas in 2021 and 2022
Quota surplus and shortage	t	Quota surplus = approved quota - emissions of key emitting units in the current year	Ditto

discharge	t	Coal consumption * coal elemental carbon content *99%*44/12+ fuel consumption * low calorific value (set value 42.652) * carbon content per unit calorific value (set value 0.0202) *98%*44/12	Guidelines for Accounting and Reporting of Greenhouse Gas Emissions for Enterprises Power generation facilities
Coal consumption for power generation	tce/MWh	Coal consumption for power generation = (coal consumption * low calorific value of coal /29.3076* (1- heating ratio) + fuel consumption * Low calorific value of fuel (set value 42.652) /29.3076* (1- heating ratio))/power generation	Ditto
Coal consumption for heating	tce/GJ	Coal consumption for heating = (coal consumption * low calorific value of coal /29.3076* heating ratio + fuel consumption * Low calorific value of fuel (set value 42.652) /29.3076* heating ratio)/heating amount	Ditto
Power generation emission intensity	tCO ₂ /MWh	Power generation emission intensity = emissions * (1- heating ratio)/power generation	Ditto
Heat supply emission intensity	tCO ₂ /GJ	Heating emission intensity = emissions * heating ratio/heating quantity	Ditto
unit efficiency	%	Unit 1 efficiency = (power generation *3.6+ heat supply) /[(coal consumption * low calorific value of coal) + (fuel consumption * low calorific value of fuel (set value 42.652))]	Ditto
boiler efficiency	%	Boiler efficiency = Unit 1 Boiler efficiency = Unit 1 heat production /[(coal consumption * low calorific value of coal) + (fuel consumption * low calorific value of fuel (set value 42.652))]	Ditto
heating load	GJ	Heat supply = gas supply * (gas supply enthalpy -83.74) /1000	Ditto
Boiler heat production	GJ	Heat production = (gas production * enthalpy of gas production - water supply * enthalpy of water supply) /1000	Ditto
Heating ratio	%	Heating ratio = heat supply/heat production	Ditto

2.2 Carbon Emissions and Carbon Quota Prediction Calculation

2.2.1 Prediction methods

According to the actual production situation, the production scenarios are divided into three categories: low (0-0.75), medium (0.75-0.85), and high (0.85-1) load rates. The calculation is based on data from the past three years, mainly based on load rate, emission intensity of power generation, and emission intensity of heating.

Table 2 Emission Intensity and Load Factor Values for Electricity and Heat Generation

Project	L (0-0.75)	M (0.75-0.85)	H(0.85-1)
Emission intensity of power generation	0.54089	0.48559	0.42758
Heating emission intensity	0.10277	0.09594	0.09759

2.2.2 Methods for Emission Forecasting

Select low, medium, and high load rates and the data monitoring month.

Emissions = Generated electricity * emission intensity of electricity generation + heating energy
* emission intensity of heating generation

2.2.3 Allocation forecast method

Select low, medium, and high load rates and the data monitoring month.

Allocation quota = Generated electricity * emission baseline value of electricity generation
(1-heating ratio * heating correction coefficient (0.22)) * cooling correction coefficient (1) +
heating energy * emission baseline value of heating generation

(According to the "Implementation Plan for Total Allocation Quota Setting and Allocation of National Carbon Emission Right Trading in 2021 and 2022", the emission baseline value of electricity generation is 0.9303, and the emission baseline value of heating generation is 0.1105)

2.2.4 Allocation surplus/deficit forecast method

Select low, medium, and high load rates and the data monitoring month.

Allocation surplus/deficit = Allocation quota - Emissions,

Allocation surplus/deficit ratio = Allocation surplus/deficit / Emissions

3. Carbon Trading Strategy Research

3.1 Current Status of Power Generation Companies

A power generation company within a specific conglomerate adopts a centralized carbon trading management model, with the company serving as a subsidiary enterprise responsible for unified management under the parent group. The current three-tier carbon trading management model of the group, provincial company, and power generation company is outlined as follows:

Group's Carbon Trading Management Organization: Formulates regulations for carbon trading management, establishes comprehensive management systems, and develops carbon emission information management systems; devises plans and annual schedules for carbon trading activities while assigning corresponding tasks; oversees carbon emission accounting and CCER (Carbon Credit Emission Reduction) development; coordinates implementation of carbon trading operations and approves subsidiary enterprises' carbon trading plans and funding proposals.

Provincial Company: Develops enterprise-specific regulations for managing operations; supervises subsidiary enterprises in completing assigned tasks related to carbon trading activities; reviews and reports on the subsidiary enterprises' carbon emission data; evaluates funding proposals from subsidiary enterprises regarding their respective carbon trading initiatives; facilitates coordination in CCER development among the subsidiary enterprises.

Power Generation Company: Clearly identify the primary individual responsible for carbon emission management within the company, as well as the department accountable for specific carbon emission management tasks. Implement the carbon trading regulations established by both the parent group and provincial company, while also formulating enterprise-specific management regulations. Develop and execute a comprehensive plan for carbon trading activities, including monitoring plans, reporting of carbon emission data, conducting carbon emission accounting, reporting greenhouse gas emissions, and collaborating with third-party verification entities. Additionally, devise and implement a plan for the establishment of a carbon trading fund: open relevant accounts for carbon trading purposes, provide necessary funds for transactions, cooperate in executing trades effectively, and fulfill all compliance obligations.

3.2 Carbon Trading Strategy of Power Companies

Considering the optimization of resource allocation, risk reduction, capital efficiency improvement, and focus on core businesses, power companies should flexibly adjust and optimize

their carbon trading strategies based on their specific circumstances and market conditions. They can choose among three carbon trading strategies: quota and CCER spot trading, quota and CCER swap, or custody model.

3.2.1 Quota and CCER Spot Trading

The strategy of quota and CCER spot trading involves purchasing carbon quotas and CCERs for compliance at different times according to the enterprise's actual situation while selling any excess carbon quotas held by the company. Currently, most enterprises with emissions control primarily adopt spot trading.

Reason analysis: Short position enterprises often confirm their positions late due to time-consuming carbon management processes; therefore they tend to purchase spot in the near period before compliance. Long position enterprises are reluctant to sell excess quotas in advance as they fear potential shortages or price increases in the future. Enterprises with emissions control prefer tender bidding when purchasing or selling large amounts of quotas or CCERs to obtain more favorable prices.

Risk factor: supply-demand imbalance.

3.2.2 Quota and CCER Swap Strategy

The quota and CCER swap strategy is a commonly employed method by enterprises to offset the required quota proportion using lower-priced CCERs. It allows for the swapping out of a portion of the quota or selling it for arbitrage purposes, as well as holding it for future use to reduce compliance costs. This trading strategy prevails in the pilot market, irrespective of whether enterprises hold long or short positions.

Reason analysis: Due to its general carbon asset nature, quotas are priced higher than carbon assets with restricted use conditions, such as CCERs, creating an opportunity for arbitrage. Enterprises can benefit from cash flow without altering their positions, while investment institutions can optimize their asset portfolios by earning profits through selling CCERs.

Risk point: Uncertainty surrounding the policy on CCER offsets.

3.2.3 Custody Model

The custody model involves entrusting carbon assets primarily consisting of quotas and sometimes including CCER swaps to professional institutions. Revenue sharing modes vary and are mainly categorized into fixed income types and floating income types. This model serves as a common business approach for small and medium-sized enterprises engaged in carbon asset management.

Reason analysis: Enterprises often lack dedicated teams, professional knowledge, and relevant personnel for managing carbon assets effectively. By entrusting these assets to professional institutions, they can activate them while sharing certain benefits. Institutions can acquire low-cost (mainly guarantee 金) rights to manage carbon assets through trading or operations in order to generate profits.

Risk points: Conducting background checks on custodian institutions' expertise and capabilities is essential to prevent loss of carbon assets due to policy uncertainties.

4. System Functions

The power company has implemented a carbon measurement method based on DCS operating conditions and nuclear algorithms to establish a sophisticated smart carbon accounting and asset management system, as depicted in the Figure 1 below. Following over six months of operation, it has successfully stabilized the functionalities encompassing carbon monitoring and management, reporting of carbon emissions, administration of carbon verification, data diagnosis, indicator

analysis and warning systems, as well as managing carbon trading activities and ensuring compliance with regulations.



Figure 1 Interface of the Carbon Accounting and Carbon Asset Intelligent Management System

Carbon Monitoring Management: Comprising of three components which namely Monitoring Data Overview, Data Quality Control and Equipment Management, this system assists enterprises in establishing an online monitoring and quality control system for data. It ensures the authenticity and compliance of data.

Emission Reporting: In accordance with the enterprise end reporting system of the national carbon market management platform and the specified greenhouse gas emission reporting format outlined in the Guide for Calculation and Reporting of Greenhouse Gas Emissions by Enterprises (Power Facilities), this platform is equipped with report review, automatic extraction and calculation of data, a calculation tool library, etc. Users can pre-report their monthly and annual carbon emissions through the reporting system provided by the carbon emission data monitoring and asset management platform before formal reporting. This allows them to complete internal reviews of reports, ensuring compliance with regulations regarding power plant's carbon emissions report.

Audit Management: Following audit institution's processes and specific work content designations, power plants organize their preparation work for carbon audits through programmed requirements such as audit material management, audit progress management, pre-audit work management, audit work management, re-audit work management and audit conclusion management. This enhances both quality and efficiency in preparing for audits.

Data Diagnosis: By analyzing and processing data, this feature provides timely feedback on abnormal data so that managers can promptly identify problems and resolve them accordingly. This helps avoid potential risks associated with inaccurate or unreliable data while ensuring its overall quality.

Carbon Emission Indicator Analysis and Early Warning: The system automatically analyzes key parameters/indicators that significantly impact carbon emission intensity. Based on the analysis results and alarm threshold values provided by the indicator analysis, it predicts emission volume and quota through the platform algorithm, considering the completion of the enterprise's production plan. It supports setting a deficit threshold value for quotas and provides timely feedback on surplus or deficit of power plant quotas, offering auxiliary decision-making reference for carbon asset trading.

Carbon Trading Management: Following the carbon trading compliance management process, the system assists enterprises in displaying market dynamics of carbon trading. It utilizes models for predicting carbon prices and intelligent compliance plans to reduce enterprises' compliance costs. The carbon trading management system serves as a technical support system for enterprises' market transaction business, providing functions such as transaction strategy suggestions, market price prediction (including dynamic tracking), and transaction risk management.

Carbon Market Price Prediction: The carbon market price prediction utilizes manually reported trading prices to analyze and forecast future trading prices in the carbon market. It provides comprehensive analysis of market price fluctuations, price risk, and liquidity risk.

Compliance Management: In accordance with the rules governing carbon quota allocation and carbon trading markets, a rolling calculation is performed to update the carbon quota for power plants. A corresponding compliance management system is established to predict surplus or deficit of carbon quotas for each unit of the power plant. This system also reviews the compliance strategy of the power plant and audits compliance costs. Real-time comparison with transactional data from the carbon market enables formulation of transaction strategies that minimize compliance costs for controlled emission enterprises. Controlled emission enterprises can operate based on their compliance plans, while automatic recording captures key information such as compliance year, compliance time, and compliance structure (CCERs, quota usage). Enterprises have access to view and manage this information along with monitoring progress. Timely reminders are provided to ensure adherence to regulatory requirements.

5. Conclusions

The intelligent system for carbon emission measurement and carbon asset management in a thermal power plant is built upon precise carbon measurement, aiming to optimize the efficiency of carbon asset management. It integrates the requirements of both the government and the company regarding grassroots enterprises' carbon asset management. By leveraging advanced technologies such as big data, Internet of Things and cloud computing, it establishes a smart monitoring and management system which presents as real-time, reliable, user-friendly and open. This system enables dynamic evaluation of carbon assets as well as intelligent control and construction processes, enhancing the enterprise's ability to collect carbon data while comprehensively analyzing and managing its carbon assets. It provides robust support for effective carbon asset management within the enterprise while also playing a crucial role in deeply integrating into the new power system's carbon market. Furthermore, it acts as a "ballast stone" and "stabilizer," offering flexible adjustment capabilities along with safety reserves.

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