New Applications of Smart Meters in Carbon Emissions Trading and Energy Conservation and Carbon Emission Reduction Activities

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Abstract

This paper discusses the situation where the power generation industry has taken the lead in launching carbon emissions trading activities domestically, and emphasizes the importance of the judicious application of artificial intelligence in carbon emissions management. The article introduces the management measures and implementation schemes for carbon emissions trading, with particular focus on the relationship between carbon emissions accounting for generating units and their power supply, as well as the specific characteristics and new requirements of grid gateway settlement electricity metering devices (smart meters) in the measurement and verification of carbon emissions. The article also notes that energy conservation and carbon emission reduction initiatives in the power system will advance new applications of next-generation smart meters.

Full Text

New Applications of Smart Meters in Carbon Emission Trading and Energy Conservation for Carbon Reduction

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Abstract

This article discusses the power generation industry's pioneering role in domestic carbon emission trading activities and emphasizes the importance of the judicious application of artificial intelligence in carbon emission management. The paper introduces carbon emission trading management measures and implementation plans, focusing on the relationship between carbon emission accounting for power generation units and their power supply, as well as the particularities and new requirements of grid gateway settlement energy metering devices (smart meters) in carbon emission assessment and measurement. The article further notes that energy conservation and carbon reduction initiatives in the power system will drive new applications for the next generation of smart meters.

Keywords: Smart Meter, Carbon Emission Trading, Electric Power System

The Ministry of Ecology and Environment has issued the *Carbon Emission Trading Management Measures (Trial)* (hereinafter referred to as "Document A") and the *2019-2020 National Carbon Emission Trading Quota Allocation Implementation Plan (Power Generation Industry)* (hereinafter referred to as "Document B"). Building upon these management measures, the Ministry will subsequently formulate and release normative documents covering greenhouse gas accounting, reporting and verification, as well as carbon emission rights registration, trading, and settlement.

Thus, the power generation industry will be the first sector in China to launch carbon emission trading activities. Carbon dioxide emissions from power generation units are calculated as the product of the unit's power supply and its carbon dioxide emission equivalent. This power supply is measured by grid gateway settlement energy metering devices (smart meters). Simultaneously, energy savings at power plants, grid companies, and user sides in the power system directly reduce carbon emissions, necessitating the gradual organization and implementation of carbon emission assessment measurement. This article serves as a supplement to the manuscript dated April 28, 2021, discussing the process of the power generation industry's pioneering carbon emission trading, the relationship between unit carbon emission accounting and power supply, the particularities of grid gateway settlement energy metering devices (smart meters), and strengthened metering requirements. It also explains how energy conservation and carbon reduction activities in the power system will advance new applications for the next generation of smart meters.

1. The Power Generation Industry's Pioneering Role in Carbon Emission Trading: A Market-Based Mechanism to Achieve China's Carbon Neutrality Goals

Carbon emissions refer to greenhouse gas emissions from fossil fuel combustion (coal, oil, natural gas) and industrial processes, land use changes, forestry activities, and emissions from purchased electricity and heat.

1.1 China's Total Carbon Emissions and Primary Measures for Greenhouse Gas Reduction

Reports indicate that China's annual carbon dioxide emissions exceed 10 billion tons, surpassing the United States to become the world's largest greenhouse gas emitter, accounting for approximately one-quarter of global emissions. In 2020, China's total energy consumption reached 4.98 billion tons of standard coal equivalent, with coal consumption comprising 56.8%, oil 20.3%, and natural gas 10.4%. These three fossil fuels combined represent 87.5% of total energy consumption, with coal alone accounting for 65% of this subtotal. Consequently, reducing carbon emissions from coal combustion is China's primary task for greenhouse gas reduction.

1.2 The Power Generation Industry's Heavy Coal Consumption and Carbon Reduction Burden

Compared with other coal-consuming industries such as steel, building materials, and chemicals, the power generation sector exhibits exceptionally large annual coal consumption and faces a heavy carbon reduction burden. In 2020, China's total installed power generation capacity reached 2.2 billion kW, with coal-fired units accounting for 1.08 billion kW (49.1% of the total). National electricity generation exceeded 7.4 trillion kWh, with coal-fired units generating over 5 trillion kWh (68% of the total). Based on an average coal consumption rate of 310 grams of standard coal per kWh, coal-fired units consumed 1.55 billion tons of standard coal annually, representing 54.8% of national coal consumption and emitting 4.03 billion tons of carbon dioxide.

Reference Data: According to 2018 reports, national coal consumption totaled 3.2 billion tons, with the power generation industry consuming 1.94 billion tons (60% of the total), followed by steel (4.5%), building materials cement (9.2%), and chemical industry coal-to-chemicals (5.6%).

Therefore, the power generation industry's pioneering role in carbon emission trading demonstrates its sectoral responsibility and commitment to advancing carbon neutrality goals.

2. Carbon Emission Accounting for Generation Units and Power Supply Measurement

2.1 Construction of China's National Carbon Emission Trading Market

This section is adapted from Document A. The Ministry of Ecology and Environment is responsible for constructing the national carbon emission trading market, including determining covered greenhouse gas types and industry scopes, and organizing the development of national carbon emission registration and trading systems. Key emission units are defined as those within covered industries with annual greenhouse gas emissions reaching 26,000 tons of CO_2

equivalent. These units must control emissions, report carbon data, surrender emission allowances, disclose trading information, and accept supervision from ecology and environment authorities.

Carbon emission trading products consist of carbon emission allowances, transacted through the national trading system via negotiated transfers, one-way auctions, or other approved methods. Key emission units must compile annual greenhouse gas emission reports for provincial ecology and environment authorities. Verification results serve as the basis for allowance surrender, with units required to surrender previous year's allowances to provincial authorities within specified timeframes.

Power Generation Industry: Carbon emission trading implementation began on January 1, 2021, marking the first compliance period for the national carbon market, with 2,225 power enterprises receiving emission allowances. Allowances are allocated to enterprises with annual emissions exceeding 26,000 tons of CO_2 equivalent.

2.2 Carbon Emission Accounting and Power Supply Measurement for Generation Units

Accounting Methodology: Following Document B's provisions, unit carbon emission quotas are calculated using the benchmark method:

Unit Quota = (Power Supply Benchmark × Actual Power Supply × Correction Coefficient) + (Heat Supply Benchmark × Actual Heat Supply)

Correction coefficients improve allocation fairness by accounting for unit-specific characteristics. The 2019-2020 benchmarks are:

- **Class I Units:** >300MW conventional coal-fired; Power supply: 0.877 tCO_2/MWh; Heat supply: 0.126 tCO_2/GJ
- **Class II Units:** $ 300MW conventional coal - fired; Power supply : 0.979tCO{2}/MWh; Heat supply : 0.126tCO{2}$/GJ
- **Class III Units:** Non-conventional coal-fired; Power supply: 1.146 tCO_2/MWh; Heat supply: 0.126 tCO_2/GJ
- **Class IV Units:** Gas-fired; Power supply: 0.392 tCO_2/MWh; Heat supply: 0.059 tCO_2/GJ

This methodology establishes power supply as the primary basis for carbon emission accounting, measured by grid gateway settlement smart meters.

Data Reporting Requirements: Document B mandates completion of the "2019-2020 Key Emission Unit Quota Pre-allocation Data Form," including unit information, fuel type, installed capacity, 2018 generation and supply quantities, heat supply, correction coefficients, cooling method, load factor, and pre-allocated quotas. Both generation and supply quantities are measured by smart meters managed by power plants.

Applications of Carbon Emission Accounting: Key emission units use it for annual emission reporting; the Ministry of Ecology and Environment uses it for national emission forecasting and quota allocation scheme development; provincial authorities use it for verifying actual annual emissions.

3. Strengthening Grid Gateway Settlement Smart Meter Management and Expanding Next-Generation Applications

3.1 Strict Metering Assessment and Advanced Technology Adoption

Particularities of Grid Gateway Settlement Metering: For units $ $300MW, power supply is measured by grid gateway settlement smart meters classified as Class I metering devices—the highest capacity and most critical settlement devices between power plants and grid enterprises, requiring modern metering technology and high-precision instruments.

Impact of Meter Error Fluctuation: A 300MW unit operating at 80% load, 0.8 power factor, 5,000 hours annually with 9% auxiliary power rate generates 873 million kWh supply, yielding approximately 349 million RMB in settlement revenue. A 0.04% smart meter error fluctuation causes 349,000 kWh supply variation and 139,000 RMB annual revenue fluctuation.

These metering systems comprise smart meters, voltage transformers, current transformers, and secondary circuits. Due to high voltage/current, long secondary circuits, and variable transformer loads, comprehensive assessment is exceptionally complex. Each system employs primary and backup smart meters for strict data verification. Management responsibilities are divided: power plants handle configuration and maintenance, while grid enterprises manage acceptance, calibration, and field testing.

Technical Requirements (DL/T448-2016): Accuracy requirements specify Class 0.2S active energy meters and Class 2 reactive meters; Class 0.2 voltage transformers and Class 0.2S current transformers; secondary voltage drop $ $0.2% of rated voltage. Trade settlement meters must use dedicated transformers or secondary circuits without unrelated equipment connections. Primary and backup meters must share identical models and accuracy classes with $ $4x overload capacity, optimized selection based on combined transformer/secondary circuit errors, and specific operational data collection protocols.

Transformer rated secondary loads must ensure actual loads fall within 25%-100% of rated capacity, with current transformer power factor 0.8-1.0 and voltage transformer power factor matching actual load conditions.

Addressing Long-Standing Metering Challenges: Grid gateway smart meters require technological upgrades. Domestic high-end meters must achieve primary meter status at grid gateways.

Currently, active metering accuracy can improve from Class 0.2S to 0.1S, and fundamental reactive metering from Class 2 to 0.5S. Product standards (IEC, national standards, State Grid 2020 smart meter standards, and intelligent IoT meter enterprise standards) are complete, with high-accuracy products being launched.

Historical Context: Since 2004, IEC's highest accuracy for static meters was Class 0.2S. Domestic 0.2S electronic meters typically controlled factory errors at 70% of class limits, while imported Landis+Gyr 0.2S ZQ-type meters using digital multiplier technology achieved $±$0.04% factory accuracy (20% of class limit). Despite 8-10x higher prices, imported meters dominated primary/backup configurations.

In 2011, Wasion launched Class 0.1S meters using digital multiplier technology, achieving $±$0.04% factory accuracy and improving error stability and reliability. This shifted configurations: backup meters now commonly use domestic high-end meters, with some primary meters adopting domestic 0.1S units.

Around 2018, IEC published Class 0.1S static meter standards. Landis+Gyr is developing 0.1S E860 series next-generation high-precision meters with advanced anti-tampering capabilities. Currently, imported meters still dominate critical grid gateway primary metering positions. Grid metering departments and meter manufacturers should monitor Landis+Gyr's 0.1S product launches and performance indicators to guide domestic 0.1S meter improvements, aiming for comprehensive domestic meter adoption at grid gateways.

Voltage Transformer Secondary Voltage Drop Challenges: Drops often exceed 0.2% of rated secondary voltage (100V). High-voltage transformers installed in substations are typically 100-300 meters from meters in control rooms, with heavy secondary loads causing drops exceeding 1% even with parallel cables.

Preparing for Comprehensive Error Assessment: For a 1-million-kW unit, a 0.01% combined error fluctuation from smart meters, high-voltage transformers, and secondary circuits causes 290,000 kWh annual supply variation. Comprehensive error assessment is reasonable but currently impractical due to: (1) dynamic load variations requiring secondary load monitoring, (2) lack of standardized combined error calculation formulas for different wiring configurations, and (3) absence of implementation schemes for optimal meter selection based on transformer/secondary circuit combined errors.

3.2 Developing Online Carbon Emission Monitoring Systems for Power Enterprises

Two approaches exist for building online monitoring systems:

Approach 1: Jiangsu Electric Power's precise carbon emission metering system, developed by Jiangsu Tianfang Power Technology Company, integrates over 2,000 monitoring parameters from boilers, turbines, and desulfurization systems. It monitors flue gas flow, humidity, and CO_2 concentration in real-time, enabling precise carbon emission quantification through critical parameter analysis and calibration. The system has been piloted at eight major thermal power plants in Jiangsu, with plans to establish a provincial low-carbon dispatch management system by end-2022.

Approach 2: The authors propose a system where provincial electric power companies calculate unit carbon emission quotas using the benchmark method from Document B. Generation supply and heat quantities are collected via provincial dispatch communication systems, transferred to electricity information acquisition systems, and combined with plant-provided correction coefficients to compute:

Unit Carbon Emissions = (Power Supply Benchmark × Actual Power Supply × Correction Coefficient) + (Heat Supply Benchmark × Actual Heat Supply)

Enterprise-level emissions are aggregated from unit-level data.

3.3 User-Side Applications: Promoting Energy Conservation and Smart IoT Meter Expansion

Grid Marketing Departments should develop quantified carbon reduction assessment indicators for industrial, commercial, and residential users; establish electricity consumption baselines for carbon accounting; propose optimized energy-saving solutions; and aggregate implementation results to calculate total carbon reductions from energy conservation.

Grid Metering Departments should develop smart IoT meter expansion module software for user-side energy optimization; research hardware and software improvements (including carbon emission displays) to adapt meters for carbon monitoring; and organize procurement of smart IoT meters with carbon accounting capabilities.

Grid Integrated Energy Management Departments should promote and coordinate energy conservation and carbon reduction project implementation across user segments.

The power generation industry's carbon emission trading activities rely on accurate and reliable metering data from grid gateway settlement smart meters. Advancing new technology applications and implementing comprehensive error assessment are crucial measures to improve grid gateway metering accuracy.

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Note: Figure translations are in progress. See original paper for figures.