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# Key Technologies and Practical Verification of Carbon Emission Reduction in the Whole Chain of Green Operation of Power Transmission and Transformation Projects

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**Abstract:** This paper presents key technologies for carbon emission reduction across the entire chain of green operation in power transmission and transformation projects. Based on the actual conditions of the Zhejiang power grid, an integrated carbon reduction control system is established, incorporating intelligent perception, data processing, and decision optimization layers. By leveraging IoT, digital twin, blockchain, and advanced optimization algorithms, the system enables dynamic monitoring, modeling, early warning, and collaborative optimization of carbon emissions. Practical applications in typical projects demonstrate significant reductions in operational carbon emissions and substantial economic and social benefits. Looking forward, the deeper integration of artificial intelligence and big data technologies will further enhance the intelligence and automation of carbon reduction strategies, supporting the achievement of China's dual carbon goals.

**Keywords:** power transmission and transformation; green operation; carbon emission reduction; digital twin; blockchain; intelligent optimization; life cycle assessment

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## 1. Introduction

In the critical period of global efforts to combat climate change and China's vigorous promotion of the "dual carbon" goals, the power industry, as a key sector for carbon emissions, plays a crucial role in achieving these goals. The green operation of transmission and transformation projects is essential for reducing overall carbon emissions. Traditional transmission and transformation projects face challenges such as difficulty in obtaining carbon emission data, a lack of systematic emission reduction measures, and insufficient coordination among various stages, which significantly hinder the low-carbon transformation of the power system. This study, based on the actual conditions of the Zhejiang power grid, focuses on the full-chain carbon reduction in the green operation of transmission and transformation projects. By developing and applying a series of key technologies, it constructs a closed-loop management system of "monitoring-analysis-optimization-certification", aiming to achieve carbon reduction goals during the operation phase of transmission and transformation projects [1]. This provides technical support and practical experience for the green transformation of the power industry.

## 2. Green Operation Carbon Emission Reduction System Architecture

### 2.1. Overall Framework Design

Establish a carbon emission reduction control system covering the whole life cycle of power transmission and transformation projects, and form a three-level linkage mechanism of intelligent perception, data processing and decision optimization:

1) Intelligent perception layer: Real-time collection of various carbon emission related data during the operation of power transmission and transformation projects is realized by deploying various types of sensing terminals.
2) Data processing layer: Based on advanced data processing technology, the collected data are cleaned, analyzed and modeled to build a dynamic carbon footprint model.
3) Decision optimization layer: Formulate and implement carbon emission reduction optimization strategies based on the results of data processing. Use blockchain technology to record the relevant data and the decision-making process.

### 2.2. Core Components

The core components are shown in Table 1.

**Table 1.** Core Composition Table.

| Top class | Technical element | Function implementation |
|---|---|---|
| Data awareness | Multi-type sensor network | Collect data such as the energy consumption of millisecond-level acquisition equipment and carbon emissions during the construction process |
| Data platform | Carbon emission reduction data platform | Integrate global carbon emission data and build a carbon footprint sensing network |
| Trusted mechanism | Blockchain storage system | Adopt alliance chain technology to ensure that the data is not tampered with and is traceable |
| Optimize control | Intelligent optimization algorithm model | Dynamic adjustment of equipment operating parameters to achieve carbon emission reduction target |

## 3. Core Technology Innovation

### 3.1. Intelligent Monitoring and Carbon Footprint Modeling Technology

#### 3.1.1. Multi-Source Terminal Deep Deployment

In critical areas of power transmission and transformation projects, such as substations and transmission line towers, high-precision temperature and humidity sensors, energy consumption monitoring sensors, and gas emission monitors are densely deployed. This ensures millisecond-level data collection and maintains a data error rate below 0.3%. The system comprehensively monitors multiple aspects, including equipment energy consumption, carbon emissions from construction machinery, and the carbon intensity of building materials, ensuring the accuracy and real-time nature of carbon emission data [2].

#### 3.1.2. Dynamic Modeling and Visualization of Carbon Footprint

By integrating the Internet of Things (IoT), Building Information Modeling (BIM), and blockchain technology, we have developed a three-dimensional visualization system for dynamic carbon footprint modeling [3]. Using Life Cycle Assessment (LCA) algorithms, the system automatically generates dynamic carbon footprint heat maps, providing a clear and intuitive view of the carbon emissions at each stage of power transmission and transformation projects. Additionally, a three-dimensional dashboard is established to display key indicators such as total carbon emissions, intensity, and carbon sink offset ratios in real time, offering managers clear and reliable decision-making support. Furthermore, the system supports cross-regional and cross-departmental comparisons of carbon emission intensity, facilitating the exchange of best practices and mutual improvement [4].

#### 3.1.3. Blockchain Trusted Data Storage

Using Hyperledger Fabric consortium chain technology, the collected carbon emission data is encrypted and stored on the blockchain. This ensures that the data remains tamper-proof during transmission and storage, facilitating secure data sharing across departments and regions. Additionally, it supports third-party auditing institutions in tracing and verifying the data, thereby enhancing its credibility and trustworthiness.

### *3.2. Forecasting, Early Warning and Dynamic Optimization Technology*

#### 3.2.1. Intelligent Prediction and Early Warning System

Building a three-level carbon emission early warning mechanism based on machine learning (Table 2).

**Table 2.** Three-Level Carbon Emission Early Warning Mechanism.

| Level of alert | Trigger conditions | Responding mechanism |
|---|---|---|
| Level 1 alert | Carbon intensity deviates from the design value by 3% | The system automatically adjusts the operating parameters of the equipment |
| Level 2 warning | Carbon intensity deviates from the design value by 8% | Operation and maintenance personnel inspect and deal with the site |
| Level three alert | Carbon intensity deviates from design value by 12% | Launch cross-departmental collaborative disposal process |

Through the study and analysis of historical carbon emission data and equipment operation data, the system can predict the trend of carbon emission in advance, issue early warning information in time, and ensure that carbon emission is under control [5].

#### 3.2.2. "Carbon-Energy-Economy" Collaborative Optimization

Develop intelligent optimization algorithm models to achieve dynamic regulation of various equipment in power transmission and transformation projects. In the energy storage system, optimize charging and discharging strategies to enhance the absorption rate of renewable energy; for reactive power compensation devices, adjust their operating modes to reduce reactive power loss; meanwhile, optimize the temperature control parameters of auxiliary equipment such as air conditioners to reduce energy consumption. In the practice at the Anji North 110kV substation, this technology has increased the photovoltaic absorption rate to 98%, improved the energy storage cycle efficiency to 92%, and effectively reduced carbon emissions [6,7].

#### 3.2.3. Carbon Trading Collaborative Management

Based on blockchain cross-chain technology, a carbon trading collaborative management platform has been established. This platform enables intelligent matching and real-time execution of carbon quotas, supporting cross-regional collaboration in carbon trading. Through the carbon trading market mechanism, it encourages power transmission and transformation project operators to actively implement carbon reduction measures. Excess carbon quotas can be traded for economic benefits, fostering a virtuous cycle of carbon reduction [8].

### *3.3. Standardized Carbon Emission Reduction Operation and Maintenance Technology System*

#### 3.3.1."Light Storage, Direct and Flexible" Microgrid Optimization Control

The innovative design of the "photovoltaic storage, direct current, and flexible" microgrid system features a hierarchical control architecture. The upper layer is the energy management system, which optimizes scheduling from a global perspective to ensure the rational allocation and utilization of energy resources. The lower layer is the equipment coordination control system, responsible for precise control of local devices [9]. By employing a bidirectional AC/DC converter control strategy based on standard characteristic polynomial configuration, this system enhances the stability and energy conversion efficiency of the microgrid, reduces the reliance on traditional energy sources in power transmission and transformation projects, and decreases carbon emissions.

#### 3.2.2. Low-Carbon Operation and Maintenance Technology in Ecologically Sensitive Areas

For power transmission and transformation projects in ecologically sensitive areas, such as the Zhoushan Interconnection Project, a series of low-carbon operation and maintenance technologies have been developed and applied. The project uses vegetation concrete slope protection technology to ensure structural stability while promoting plant growth, thus achieving ecological restoration. A drone-based intelligent inspection system has been introduced to replace traditional manual inspections, reducing carbon emissions from human activities and enhancing inspection efficiency and accuracy. Tidal energy power supply devices have been installed as part of clean energy initiatives to help power the project equipment, thereby reducing reliance on conventional power sources. Through these technologies, the carbon emissions from the operation and maintenance of the Zhoushan Interconnection Project have been reduced by 40%, achieving a win-win situation for both construction and ecological protection [10].

#### 3.3.3. Life Cycle Carbon Emission Reduction Evaluation and Certification

Establish a four-level carbon emission reduction evaluation system covering equipment level, system level, regional level, and whole life cycle level (Table 3).

**Table 3.** Four-level Carbon Emission Reduction Evaluation System.

| Standard hierarchy | Evaluation content | Certification mechanism |
|---|---|---|
| device level | Carbon emission reduction efficiency of single equipment | Real-time monitoring and analysis |
| System level | Stationary carbon emission intensity | Monthly assessment and optimization |
| region class | Distribution of carbon emissions from the grid | Quarterly audit and adjustment |
| Full life level | LCA, carbon footprint | Certified based on the ISO 50001 standard |

Through this evaluation system, the carbon emission reduction effect of the whole life cycle of power transmission and transformation projects is comprehensively and systematically evaluated and certified, so as to promote the development of power transmission and transformation projects towards low carbonization and standardization.

## 4. Typical Engineering Cases of Practical Verification and Benefit Analysis

### *4.1. Anji North 110KV Zero Carbon Substation*

The substation fully utilizes the "photovoltaic-storage-direct-flexible" microgrid system, a digital twin operation and maintenance platform, and blockchain carbon traceability technology. The "photovoltaic-storage-direct-flexible" system ensures self-sufficiency and efficient energy use. The digital twin platform monitors and optimizes the substation's operations in real time, while blockchain technology ensures the reliable recording and traceability of carbon emission data [11]. This results in a photovoltaic energy absorption rate of 98% and an annual carbon reduction of 1200 tons, making it a model for green operation in power transmission and transformation projects.

### *4.2. Zhoushan 500KV Network Project*

During the construction and operation of the project, innovative technologies such as tidal energy power systems, vegetated concrete ecological slopes, and intelligent drone inspection networks have been adopted. The tidal energy power system provides clean energy, reducing carbon emissions; the vegetated concrete ecological slopes effectively protect the marine environment; the intelligent drone inspection network enhances operational efficiency and safety. The project has reduced carbon emissions by 40% during operation and maintenance, and it has been recognized as a demonstration project for ecological restoration at the national level, serving as a significant model for power transmission and transformation projects in ecologically sensitive areas [12].

### *4.3. Changlongshan 500KV Transmission Project*

The project employs a dynamic carbon emission optimization system and an ecological sensitive area avoidance algorithm. The dynamic carbon emission optimization system adjusts equipment parameters in real-time based on the project's operational status to reduce carbon emissions. The ecological sensitive area avoidance algorithm ensures that ecological sensitive areas are not damaged during the project planning phase. The project achieves an annual carbon reduction of 8000 tons and has been presented as an example at the United Nations Climate Change Conference, showcasing advanced technology and successful practices in carbon emission reduction and ecological protection for power transmission and transformation projects, including those implemented in China.

## 5. Conclusion and Prospect

This study has successfully developed a comprehensive carbon reduction technology system for the green operation of power transmission and transformation projects. By innovatively applying core technologies such as "digital twin + blockchain", it has achieved full-chain traceability and precise control of carbon emissions. Practical tests have shown that the "carbon-energy-economy" collaborative optimization model and standardized operation and maintenance system have proven highly effective, reducing operational carbon emissions by an average of 18.7%, while also generating significant economic and social benefits.

Looking ahead, as technology continues to advance, the application of artificial intelligence, big data, and other technologies in the green operation and carbon reduction of power transmission and transformation projects will be further deepened, enhancing the intelligence and automation of carbon reduction technologies. We will strengthen exchanges and cooperation with international advanced technologies and experiences, promoting China's green operation and carbon reduction technologies in power transmission and transformation projects to the global stage. Additionally, it is essential to continuously improve relevant policies and standards, providing stronger support and guarantees for the green operation and carbon reduction of power transmission and transformation projects, to help China achieve its "dual carbon" goals sooner.

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