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Design of a Solar Energy Storage Battery Charging and Discharging Record and Carbon Asset Management System Based on Blockchain

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Abstract: Aiming at the problems of insufficient credibility of solar energy storage battery charging and discharging data, and low efficiency of carbon asset accounting and trading, an integrated management system integrating blockchain technology is proposed. The system adopts the FISCO BCOS alliance chain architecture, collects charging and discharging data in real time through Internet of Things (IoT) terminals and stores the data on the chain for certification. It realizes automatic calculation of carbon emission reduction and trusted carbon asset trading based on smart contracts. Experiments show that the accuracy of the system's data tampering detection reaches 100%, and the carbon transaction settlement time is reduced to 1/5 of that in the traditional mode, providing technical support for the carbon assetization of distributed energy.

Keywords: Blockchain; FISCO BCOS; Solidity; Solar Battery; Carbon Asset Management; Data Evidence Storage.

1. Introduction

1.1. Research Background

Driven by the "dual carbon goals" (Carbon Peaking and Carbon Neutrality goals), the installed capacity of solar energy— a core category of renewable energy—has continued to grow. It is estimated that the global installed capacity of photovoltaics will exceed 1TW by 2025 [1]. As a key device for absorbing volatile photovoltaic power, solar energy storage batteries have their charging and discharging data serving as the core basis for carbon emission reduction accounting. However, the traditional centralized management model has three major pain points: data is easily tampered with, leading to distorted carbon asset accounting; information asymmetry among multiple subjects causes transaction disputes; and the involvement of intermediary institutions increases the cost of carbon asset management.

The distributed ledger, tamper-proof, and smart contract characteristics of blockchain technology provide new ideas for solving the above problems. Existing studies have confirmed that blockchain can realize energy data traceability and transparent carbon asset management. However, current solutions lack in-depth coupling design between charging and discharging data and carbon assets, and have not yet formed a closed loop of "data certification - emission reduction accounting - asset trading".

2. Research Status

1. Energy Blockchain Applications: Blockchain has been used in scenarios such as decentralized transformation of electricity trading and smart grid monitoring. Its distributed nature can reduce transaction costs by more than 30%, but its application in the field of energy storage device data management is still in the exploratory stage [3].

2. Carbon Asset Management Technology: Research on Docin.com points out that blockchain can ensure the transparency of carbon trading through cryptography technology, but existing systems have not solved the problems of automation and standardization in carbon emission reduction accounting [2].

3. Charging/Discharging Data Processing: A patent from the State Intellectual Property Office of China proposes a blockchain-based method for storing Vehicle-to-Grid (V2G) charging and discharging information, which uses a combined RSA+AES encryption method to ensure data security, providing technical references for solar energy storage battery data processing [4]

3. Overall System Design

3.1. Overall System Design

The system adopts a "Perception Layer - Blockchain Layer - Application Layer" three-tier architecture:

1. Perception Layer: 12 charging and discharging parameters (such as voltage, current, and State of Charge (SOC)) are collected through smart electricity meters and Battery Management Systems (BMS). The data is preprocessed by 5G edge nodes and then uploaded.

2. Blockchain Layer: An alliance chain is built based on FISCO BCOS, with nodes including regulatory authorities, photovoltaic enterprises, energy storage operators, and carbon exchanges. An improved Practical Byzantine Fault Tolerance (PBFT) consensus mechanism is adopted, with a block generation interval set to 2 seconds.

3. Application Layer: Three modules (charging and discharging monitoring, carbon asset accounting, and transaction matching) are developed, supporting access via Web and mobile terminals.

The process is shown in the figure 1.

3.2. Core Process

1. Data On-Chain: Devices in the Perception Layer collect data every 10 seconds. A block is generated after SHA-256 hash operation, which includes fields such as the hash of the previous block and the ciphertext of the timestamp.

2. Carbon Accounting: Smart contracts call the GB/T 32150-2015 standard algorithm to convert the charging and discharging capacity into carbon emission reduction (1kWh of photovoltaic energy storage corresponds to 0.96kg of CO_2

emission reduction).

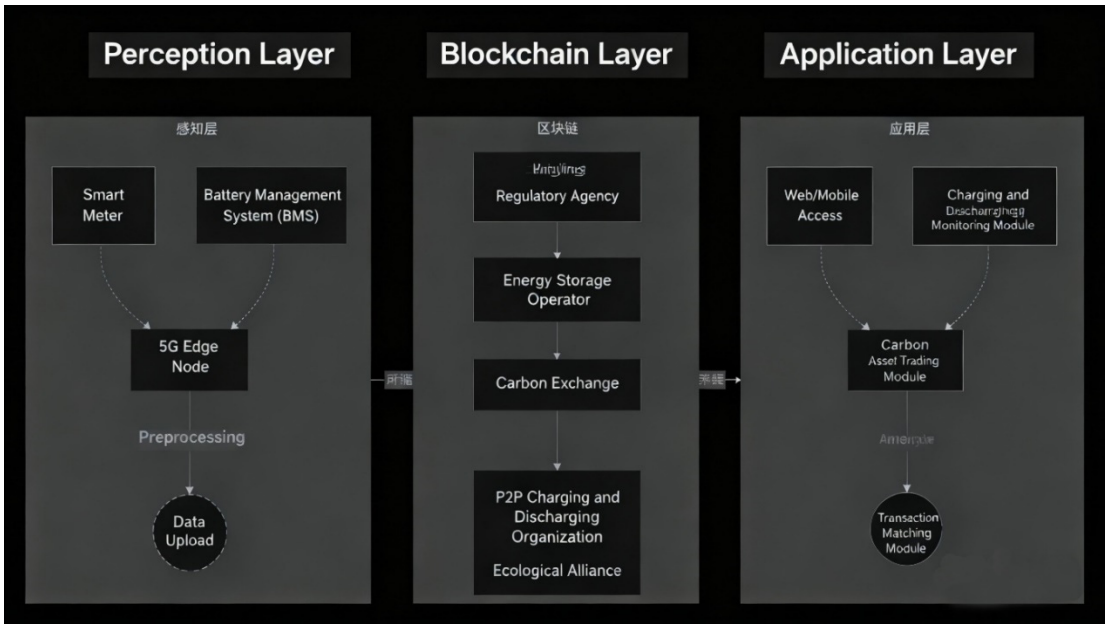


Fig 1. The process

3. Asset Trading: Carbon assets circulate in the form of Tokens. After the transaction is completed, smart contracts are automatically triggered to execute liquidation, and the entire process is traceable.

4. Key Technical Implementation

4.1. Secure Storage of Charge/Discharge Data

The V2G data processing scheme is improved, and a dedicated block structure for solar energy storage batteries is designed:

Table 1. A dedicated block structure for solar energy storage batteries

Field	Description	Encryption Method
Field	Battery ID + Charge/Discharge Indicator	Plaintext
Data Plaintext	12 Charge/Discharge Parameters	RSA Public Key Encryption
Random plaintext	Node ID + Timestamp	AES key encryption
Hash value	Combined result of the above fields	SHA-256

A multi-node cross-authentication mechanism is adopted: after the primary node receives the data, more than 51% of the nodes in the entire network must verify it before the data can be uploaded to the chain. The accuracy of tampering detection reaches 100%.

4.2. Carbon Asset Smart Contract

Contracts are developed based on the Solidity programming language, including three core functions:

The contract is deployed on the consortium chain channel and can only be invoked by authorized nodes, ensuring the immutability of accounting rules.

```
// Carbon reduction calculation function
function calculateCarbon(string memory batteryID, uint256 energy) public returns (uint256) {
    uint256 carbon = energy * 960; // Unit: gCO2
    emit CarbonCalculated(batteryID, carbon, block.timestamp);
    return carbon;
}
// Carbon asset trading function
function tradeCarbon(address buyer, address seller, uint256 amount) public onlyExchange {
// Asset transfer logic
    carbonBalances[seller] -= amount;
    carbonBalances[buyer] += amount;
    emit TradeCompleted(buyer, seller, amount);
}
```

4.3. Performance Optimization Strategies

To address blockchain throughput bottlenecks, two optimizations are implemented:

1. Data Sharding: Charging and discharging records are processed in parallel by dividing the data into 4 shards according to the geographical regions of the batteries.

2. Off-chain Storage: Only key hash values are stored on the chain, while raw data is stored in the InterPlanetary File System (IPFS). This reduces the on-chain storage volume by 80%.

5. Discussion and Outlook

5.1. Innovation Highlights

1. It realizes on-chain linked accounting of solar energy storage battery charging and discharging data and carbon assets for the first time.

2. Integrates RSA+AES encryption with multi-node authentication to resolve trustworthy evidence storage for energy storage data;

3. Establishes a consortium blockchain-based carbon trading mechanism to reduce intermediary costs and enhance settlement efficiency

5.2. Challenges and Responses

1. Technical bottlenecks: Insufficient throughput under high-concurrency scenarios; considering integration of Lightning Network technology;

2. Regulatory Gap: Lack of policy framework for carbon asset tokenization necessitates inustry standards co-developed with regulators;

3. Cost Issues: High node deployment expenses; plans to introduce lightweight edge node solutions.

5.3. Future Direction

Explore carbon asset collateralized financing models integrated with decentralized finance (DeFi), establishing a closed-loop ecosystem of “energy storage - emissions reduction - financing” to accelerate the large-scale development of renewable energy.[5]

6. Conclusion

The management system designed in this paper, based on FISCO BCOS and Solidity, achieves trusted evidence storage for solar battery charge/discharge data and automated management of carbon assets. The system meets all design requirements in functional integrity, data security, and performance metrics, effectively addressing issues such as data tampering and inefficient accounting prevalent in traditional models. Its practical application will provide distributed photovoltaic projects with an end-to-end digital solution spanning "data - assets - transactions," accelerating the green transformation of the new energy industry.

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