Blockchain-Based Whole-Chain Green Power Traceability

Xiaopeng Chen[1], Zhaomin Wang[1], Jinjing Cao[1], Hongwei Xing[2], Jianhui Zhang[2], Entang Li[2(✉)], Mingliang Mu[1], Chuankang Miu[1], Nianming Xue[2], and Chonghao Xu[2]

[1] Binzhou Power Supply Company of State Grid Shandong Province Electric Power Company, Binzhou, China

[2] Shandong Lusoft Digital Technology Co., Shenyang, China

ls_liet@163.com

Abstract. Green power is developing rapidly in the low-carbon context, and the traditional green power traceability method has problems of management efficiency and transaction trust, which does not meet the current rapidly increasing green power traceability background. By adopting blockchain technology to chain the optimized green certificate issuance process and green power transaction data, the transparency and tamper-evident characteristics of blockchain transactions are used to improve the efficiency of green power data traceability and solve the trust and security problems existing in the process. The cryptographic blockchain technology based on cryptography is used to encrypt the privacy data design and realize the whole process traceability of the five links of green power preparation, access to the Internet, metering, trading and traceability.

Keywords: green power traceability · green power metering · blockchain · CP-ABE

1 Introduction

Optimising the green power upstream process, the green power trading process and the green certificate issuance process is of great significance in strengthening the consumption of green energy power, increasing the proportion of green power energy and enhancing the rapid development of green energy in China. With the rapid development of cryptography technology and Internet technology, blockchain as a cryptography-based network technology has been widely used in multi-domain traceability and digital credentialing. Blockchain has the characteristics of distributed storage, immutability and complete transparency, and its application in the process of green electricity traceability can solve the problems of insufficient trust system and risk of tampering in the traditional green electricity traceability. At the same time, smart contracts can automatically compile the auditing and transaction process in accordance with the compiled mechanism, thus completing automatic auditing of authority and automatic execution of transactions and improving the efficiency of traceability.

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In the process of using blockchain to solve the problem of electricity traceability, the following issues should be addressed for the characteristics of the whole chain of green electricity.

1. There are many nodes, and in order to complete on-chain transactions all need to be uploaded as nodes in the blockchain for data transfer.
2. The uncertainty of green power in microgrid is high, and the feed-in tariff of each participant shows dynamic changes.
3. The scale of green electricity traceability data is large, the volume of traceability data is large, and the space in the blockchain block is limited, so the data space needs to be planned reasonably.
4. Power generation manufacturers to declare the amount of audit material content and should be encrypted processing.

In terms of electricity traceability, there is not much research on green electricity traceability based on blockchain but a lot of ideas have been proposed. Wang Ti-Xin et al. proposed a renewable energy traceability model based on the tide traceability model and designed an ethereum-based smart contract platform covering multiple links of renewable energy to realize the traceability of green electricity [5]. The traceability mechanism proposed by Xian Zhang et al. uses transaction information and GPCC flow information as a means to apply blockchain technology to make information on the chain to ensure the traceability of information at source [6]. Xinping Miao et al. analyzed the study of data traceability model in electric power enterprises and put forward the requirements of data application [4]. Xingzhi Li et al. analyzed the green power traceability method in blockchain key technology adaptation [3]. F Yuanji Cai et al. proposed the concept of blockchain-based green certificate trading platform and practiced it [2]. BERRY T took the Danish green certificate market as an example, analyzed the optimal way to establish the green certificate market, and predicted the possible problems and countermeasures during the operation of the market [1]. In summary, the blockchain structure and market analysis based on green certificates have been studied, but there is still a lack of systematic design to deploy all the processes of issuing green certificates for electricity metering in the blockchain and complete the traceability of the whole process.

Combining the characteristics of green electricity traceability and the current research status, a blockchain-based alliance chain green electricity traceability architecture is designed, with the main research contents including: optimizing the traditional green electricity trading process, so that all the data of green electricity metering, trading and consumption can be on the chain; making full use of the on-chain storage space in the block; designing a smart contract to meet the traceability of green certificates and green electricity trading, and realizing the traceability of green electricity and green certificates.

2 Blockchain-Based Electricity Traceability Architecture

2.1 Traditional Green Power Traceability

Since 2017, China has adopted the green power certificate to prove the amount of green power consumption, and green power enterprises can buy green certificates to consumers in need after obtaining them, thus reducing the difficulty of power dispatch, but the mode

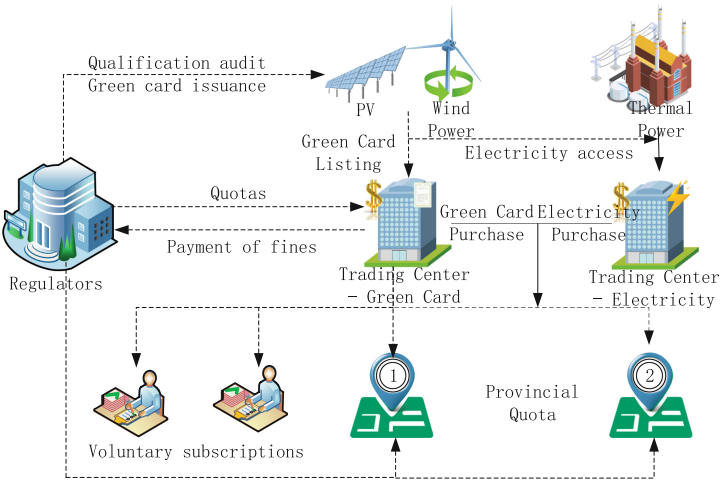

Fig. 1. Current Green Power Market Trading Structure

of separation of electricity and certificates cannot stimulate the recognition of green certificates, and the volume of green certificate trading is low, and the power on the Internet cannot complete the traceability. Therefore, after 2021 when China implements the quota system, in the context of green card trading under the quota system, green power trading mostly refers to medium and long-term power trading, and the enterprises that buy green power and sell power enterprises complete the transaction while the green card is transferred, and the green card is issued directly to end users, which realizes the unification of green power consumption and green card. The current green electricity market trading structure is shown in Fig. 1.

2.2 Blockchain Traceability Demand Analysis

Analyze the whole life cycle of green power, divide the links according to each flow process of the life cycle, upload the key data of each link of green power metering, grid connection and consumption into the blockchain, and at the same time deploy the process of green certificate application issuance and transaction in the smart contract, so as to improve the efficiency of green certificate with the whole process of green power traceability.

The data such as qualification audit materials and green certificate issuance materials of green power vendors are encrypted. In the green power trading system, there are many types and numbers of power generation vendors, and each vendor uses its own power generation products and key data. Through the encryption algorithm in the blockchain, it is guaranteed that the key data of each vendor in the green certificate audit process will not be leaked under the participation of multiple nodes.

In the whole traceability process, the smart contract automatically calculates the electricity consumption components of power users according to the renewable energy power tracking algorithm as a criterion to judge the consumption of users, and interacts with the smart contract of consumption calculation to derive the actual consumption

of power users and automatically update the consumption value stored by users in the blockchain. Through the division of the above nodes, the traceability of the whole process of green power from production to transmission to consumption is realized.

2.3 Related Technology Base

2.3.1 Blockchain Off-Chain Data Storage Technology

Because the essence of blockchain is a P2P network, the correct value is calculated by the miner node and broadcasted throughout the blockchain, and other nodes receive the broadcast and link the verified blocks to their own blocks after once the data in the blockchain is saved in all nodes in the network, and the system ensures the data immutability and security through high redundancy storage mechanism, so in order to make the blockchain space get reasonable Therefore, in order to make the blockchain space reasonable, the off-chain storage scalability of the blockchain is improved.

The principle of off-chain storage is to move the content of the block body to the off-chain storage system, and only the query key information and the "pointer" to the off-chain storage are retained in the block, which is usually an encrypted Hash value, so that the corresponding data on the chain is stored off-chain, which improves the scalability of the off-chain storage of the block chain.

2.3.2 Smart Contract Technology

Smart contracts are computer protocols deployed in the blockchain that are automatically formed, verified and executed in the form of code, which can automatically execute the logic and requirements under agreed conditions. In the green certificate issuance process, the logic of generating the equivalent amount of green certificates corresponding to the amount of electricity can be achieved through smart contracts by measuring the data content on the chain, while the qualifications of the seller and the vendor need to be checked with smart contracts in the green certificate trading process. In the traceability link, it is necessary to check whether the consuming party has completed the predetermined minimum targets and incentive targets through the quota criteria pre-programmed into the smart contract, so as to make corresponding penalties and rewards.

2.4 Blockchain Requirements Implementation Methods

2.4.1 Gate Data Measurement Methods

The gateway metering point is a metering point where electricity is settled and assessed between various market entities. Through the regulator's audit of green power generators, it confirms whether they have access rights, and provides registered access rights to those who have access rights. It enables green power that meets the requirements to be successfully uploaded to the chain.

In the process of winding up, the smart contract program automatically compares the gateway power metering value and the on-site power meter metering displayed value, and prohibits winding up and returns the error when e data is inconsistent or incomplete. The smart contract completes the traceability of the data of metering failure and data

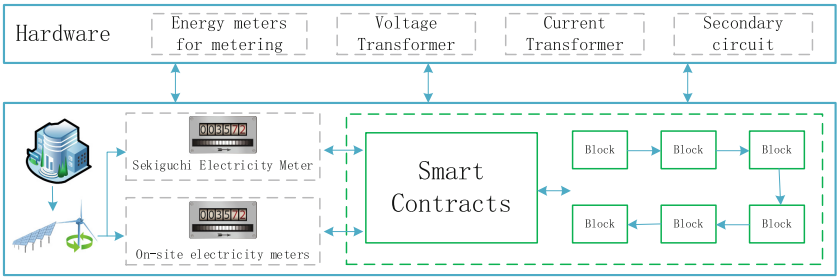

Fig. 2. Flow of data measurement at the gateway

abnormality, completes the data according to the agreed fitting rules, and re-chains the displayed value after completing it according to the traceability principle.

Ensure that each green power generator passes the audit of the regulator before it can participate in the chain transaction and issue access rights, and at the same time, all the metering data are uploaded to the chain to ensure that the green power data from the upstream metering source is real, valid and untamperable. The flow of the gate data measurement is shown in Fig. 2.

2.4.2 CP-ABE Data Encryption Algorithm

The integrity and authenticity of data in blockchain networks support digital signatures and proprietary data structures. The traditional ABE algorithm describes the ciphertext by attributes, while embedding the policy into the user's key. In CP-ABE, the user's private key is associated with a set of attributes, and only the user's attributes match the access structure of the ciphertext to decrypt this ciphertext.

The regulator encrypts the declared material data through audit, stores it in a distributed off-chain DHT, and returns the cryptographic hash value for uploading to the chain. Both parties completing the transaction can apply for a key from the platform. The regulator verifies their identity and sends the corresponding key to the consuming party, and the user uses the corresponding key to retrieve and decrypt the data in the DHT to obtain information related to the green certificate declaration and obtain complete traceability information from the green certificate content recorded in the comprehensive process.

The specific encryption steps are as follows.

***setup*(*k*)** is randomly initialized based on the CP-ABE algorithm, and the security parameter $\boldsymbol{k}$ is entered, and the key generation center randomly generates the system public key $\boldsymbol{PK}$ and the system master key $\boldsymbol{MK}$ as shown in Eq. (1).

$$setup(k) \rightarrow (PK, MK) \tag{1}$$

***Encrypt*(*PK*, *M*, $\boldsymbol{\tau}$)** encrypts the plaintext $\boldsymbol{M}$ under the access structure $\boldsymbol{\tau}$ and outputs the ciphertext, the access structure $\boldsymbol{\tau}$ adopts a hierarchical encryption method of tree diagram structure, the low-frequency access content is stored in the leaf node, the high-frequency access content is stored in the root node, after generating the access control

tree, a recursive calculation method is used to access, all the leaf nodes in the access structure $\boldsymbol{\tau}$ and the encrypted ciphertext is $\boldsymbol{SE}$. As the Eq. (2).

$$Encrypt(PK, M,) \rightarrow SE \tag{2}$$

$\boldsymbol{KenGen(MK, S, PK)}$ generates the key $\boldsymbol{SK}$ for the attribute set $\boldsymbol{S}$, the user selects the random number and sends the generated function to the attribute verification center, the attribute verification center selects the random number and sends it to the key generation center, the random number in the attribute seti $\boldsymbol{S}$ returned to the user and the key is obtained, the process is shown in Eq. (3).

$$KenGen(MK, S, PK) \rightarrow SK \tag{3}$$

Decrypts the ciphertext using the system public key $\boldsymbol{PK}$ and the key $\boldsymbol{SK}$ to get the plaintext $\boldsymbol{M}$. Finish the encryption and decryption process. As the Eq. (4).

$$Decrypt(PK, SE, SK) \rightarrow M \tag{4}$$

3 Blockchain-Based Traceability System Design

DHT is called Distributed Hash Table, which is a distributed storage method. The distributed network storage does not need a central node, only each node is responsible for a small range of routing and data, thus realizing the storage of the whole DHT network, while the distributed hash table technology can replicate redundant information on the nodes near the keywords, thus avoiding the single DHT makes the SE and index values form a kind of mapping through data structure and hash function. $hash(SE) \rightarrow index$ where SE is the ciphertext of the declared data after encryption and index is the IP address of the stored file, when the content is queried, only the SE value needs to be provided to find the storage node address index and return it to the query node. Index points to an index table that will be split into multiple parts and distributed to the whole node according to predefined rules, and each node only needs to maintain a part of the index table. When querying a file, just point the query keyword to the corresponding node. It is guaranteed to speed up the data query time of the power regulator without data leakage. The system architecture is shown in Fig. 3.

Based on the above analysis and system design, the architecture of green power traceability system is designed based on Hyperledger platform. In the preparation link: green power vendors apply to the regulator for green power access authority, the regulator reviews the applications submitted by green power vendors, and after passing the review, the regulator issues access authority to the green power vendors, and at the same time stores the application materials in ciphertext SE through CP-ABE encryption to the offline distributed storage system DHT, and after storage, the DHT storage structure returns the Hash value and is chained. The Hash value corresponding to the declaration material is stored in the blockchain. Realize the function of access qualification audit data encryption and port metering device regulatory audit.

In the link of feed-in metering: After the green power manufacturer gets access, it generates electricity and the power generation is measured by the port metering device.

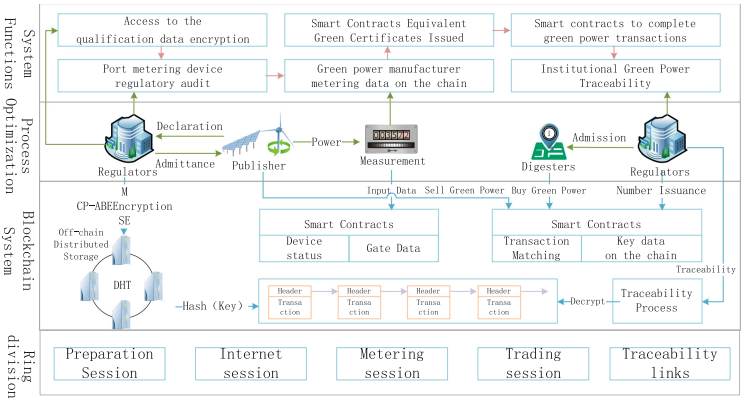

Fig. 3. Structure diagram of Green Power traceability system

And through the smart contract and the on-site metering device data for comparison, the value within the error range will be power measurement value, power type and other keywords for the chain, while the regulatory agencies issued with the measured power corresponding to the value of the green card number. Realize the function of green power manufacturer metering data uploading and green card equal issuance.

In the transaction link, the green power vendor and the consumer complete the transaction through smart contract matching, transfer the green certificate authority, and store the transfer record, purchase and sale information and date and other related information in the blockchain. After the transfer of rights, the green power vendor does not have the listing and access rights of the green certificate, avoiding the secondary sale of green power certificates.

In the traceability link, the regulator and the consumer with green certificates can trace the whole process of green power through blockchain. Through the authorization of the regulator to the consumer, the consumer gets the block set containing all the query keywords, extracts the Hash (Key), downloads the file from the database under the DHT chain and decrypts it to get the plain text of green power declaration M. Through the above process, the whole process of green power traceability and green certificate authorization and issuance are realized.

4 Example Application of a Blockchain-Based Traceability System

A small distribution network system was built on the basis of a blockchain platform built by a consensus server, an application server, a database server and an application program interface server, and the above-mentioned traceability system was used to test the blockchain network performance and system capability of the system. The throughput of testing one kind of arithmetic case executed under this system, and the results are shown in Table 1.

The response time and throughput of Green Power transactions were also tested for data metering at different numbers of concurrency, as shown in Table 2.

Table 1. Blockchain Network Performance Test Results

Item	1 st(TPS)	2 nd (TPS)	3 rd(TPS)
Execution speed	28670.53	28575.03	28574.51

Table 2. Traceability system capability test results

Item	VU	RTT	TPS
Data metering	14	0.0095	10239.47
	18	0.0096	10418.23
	20	0.0106	10593.33
Green Power Trading	14	0.0064	10205.37
	18	0.0066	10303.42
	20	0.0074	10387.51

5 Conclusions

The paper proposes a response solution to the problems of the existing green power market architecture including doubtful accuracy of feed-in tariff data, low traceability efficiency, and centralized data storage susceptible to tampering, and designs a traceability architecture based on the Hyperledger platform, which optimizes the traditional green certificate issuance process and improves traceability efficiency, and the metering data is uploaded onto the chain through smart contracts to ensure the authenticity of the uploaded data, and the regulatory The regulator directly issues the green card number to the measured data and the smart contract automatically matches the transaction to improve the overall operational efficiency of the system. The reliability of the data under the chain is ensured by using the way of encrypted storage under the chain to call the Hash value. The whole process traceability of green power is realized.

This paper has not yet proposed a targeted algorithm to improve the traceability efficiency. The traceability efficiency is low, but the consumption assessment of the responsible subjects of the quota system is conducted afterwards, and does not emphasize the timeliness of the calculation, but focuses more on the verification and calculation afterwards. Therefore, the requirements for calculation effectiveness are not very strict.

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