Research and Application of Green Power Market Mechanism Based on Blockchain Technology

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Abstract. In recent years, with the substantial increase in the installed capacity of new energy sources such as wind power and photovoltaics, emerging new energy market models such as green power trading have developed rapidly. However, green power transactions involve multiple entities, various links, and are faced with problems such as difficulty in information traceability and lack of transparency in trading links. Green power urgently needs authoritative and credible mechanism guarantee and technical proof means. This paper introduces blockchain technology into the green power market. First, it introduces the background and research status of the green power market. Second, it studies the key technologies of blockchain that adapt to the green power trading mechanism. Finally, the green electricity market mechanism based on block chain is designed and its application is described.

Keywords: Green power, Blockchain technology, Trading mechanism.

1 Introduction

Under the guidance of the goal of "carbon peaking and carbon neutrality", with the large-scale access of new energy sources such as wind power and solar power generation in my country, the power system will accelerate the development of clean and low-carbon energy. Green energy will gradually become the main component of electricity supply and market transactions as the main body to meet the incremental energy demand [1-2]. At the same time, emerging new energy market models such as green power trading are developing rapidly. However, green electricity transaction subjects are diverse, which involves various links such as issuance, distribution, transmission, delivery, and usage. It is difficult to trace the source of information, and the transparency of the transaction links is insufficient. Green electricity requires authoritative and credible mechanism guarantees and technical proof means. Blockchain technology has the technical characteristics of openness and mutual trust, multi-party consensus, non-tampering, and full traceability. It has a high degree of demand resonance and technical fit with the green power business. By credibly recording the whole link data of green power transaction, it can ensure the whole link traceability of green power production, transaction and consumption, which can guarantee the matching of green power production and consumption from the economic relationship and power generation and consumption behavior, providing visual, credible and reliable validity proof for the real consumption of green power [3-4].

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Scholars at home and abroad have carried out many studies on the green power market. Reference [5] introduces the development of the green power certificate market in Sweden. The construction of the green power certificate market has effectively increased the proportion of renewable energy on-grid electricity and promoted the development of energy-saving and emission-reduction technologies. Reference [6] studies the emission reduction cost under the renewable energy quota system policy, and believes that the introduction of the renewable energy quota system may increase the emission reduction cost. Literature [7] Yan Shu designed a positive incentive mechanism for peak shaving auxiliary services suitable for the northern Hebei power grid based on the practical experience of domestic peak shaving auxiliary services for many years and the spot balance mechanism of mature in foreign power markets, and constructed multi-timescale assessment techniques for green electricity consumption capacity. The incentive mechanism of auxiliary service cost was designed to promote the consumption of green energy. Guo Lei et al.[8] constructed a set of relatively complete power market evaluation index system framework, covering market supply and demand, market structure, market behavior, market efficiency, etc. aspect. Yang Jianhua et al. [9] constructed a model of the contribution of the inter-provincial market transaction mechanism to new energy consumption, and quantitatively analyzed its environmental benefits, power savings cost benefits, and power supply reliability improvement benefits.

Through the study of the key technologies of blockchain that adapt to the electricity market transaction mechanism,this paper mainly proposes a green electricity market-oriented transaction mechanism based on blockchain technology, and establishes a power transaction system model that ensures transparency, security and traceability of transactions. It provides theoretical support and rule suggestions for the construction of green electricity market system and trading mode under the target of the new power system.

2 Introduction

2.1 Blockchain-based transaction matching

The purpose of transaction matching is to integrate the needs of buyers and sellers, to achieve rapid matching of both parties, and to improve transaction efficiency [10]. In the transaction matching stage, this paper proposes a blockchain-based matching method, so that electricity transactions can directly face buyers and sellers. After the match, the clearing of the transaction is automatically completed through smart contracts and offline meters, triggering the distribution and collection of electricity.

The transaction matching in this article uses the high-low matching method: using O_s and P_s expressing the order and price of the electricity seller,and using O_b and P_b to represent the power purchaser's order and purchase price.Sort the orders of the electricity seller from low to high according to the quotation $\mathrm{Sort}(\mathrm{O_{s1}}, \mathrm{O_{s2}}, \mathrm{O_{sm}})$.At the same time, the power purchaser's order quotations are sorted from high to low $\mathrm{Sort}(\mathrm{O_{b1}}, \mathrm{O_{b2}}, \mathrm{O_{bm}})$.According to the order of the two order sequences, the listings of the buyers and sellers are matched, if $p_{b_i} \geq p_{s_j}$ the pairing is successful.The matching process of high and low matching can maximize the transaction volume when the market is balanced, and improve the transaction processing efficiency of the system.

Transaction matching is a timed task, and only one node in the blockchain (that is, the matching node) will actively trigger execution at any time. In order to avoid a single point of failure and "central authority", the matching node is not always served by a certain node, but is determined by a specific node rotation method. The rotation time interval is t. Considering that the matching process is not particularly frequent, it can be measured in minutes. In each rotation interval, each node calculates the time of the next matching transaction e and the matching node serial number d according to the last transaction matching time s recorded by itself. Due to the influence of network factors, it is difficult to ensure real-time consistency of records s recorded in the ledger of each node. Therefore, the next transaction matching time e cannot be obtained simply through the method $e = s + t$, but the system time c (the error from the standard time is Δt and $\Delta t \ll t$) and should be used and calculated by formula (1).

$$\begin{aligned} e &= Min(\{x > c | x = s + k_i \times t, k_i \in N_+\}) \\ &= \begin{cases} c + t - c\%t, (t - c\%t) > \Delta t \\ c + 2t - c\%t, (t - c\%t) \leqq \Delta t \end{cases} \end{aligned} \tag{1}$$

Although different nodes *s* and *c* will lead to different values of k_i, the time point of transaction matching is determined in this form $(t, 2t, 3t, \ldots)$, and the time error of each node is kept within a small range, ensuring the consistency of the matching time e calculated by formula (1).

When calculating the number d of matching nodes, assuming that the list of surviving nodes in the current system is a , the total time required for these nodes to complete a round of transaction matching is $len(a) \times t$, so we can use $e\%(len(a) \times t)$ to calculate the proportional position of the matching time e in a round of transaction matching, and obtain the matching node serial number d. The above process is expressed by formula (2) as:

$$d = a[\frac{e\%(len(a) \times t)}{t}] \tag{2}$$

This paper proposes a blockchain-based transaction matching process, which automatically executes the clearing of transactions through smart contracts. The sequence diagram of transaction matching is shown in the figure below.

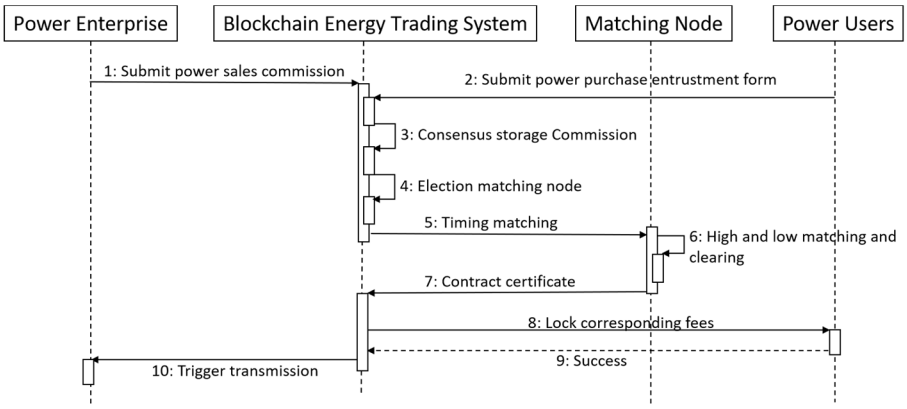

Figure 1 Transaction matching sequence diagram

Blockchain-based green energy transaction matching can be divided into four steps: submitting orders, selecting matching nodes, transaction matching, and electronic contract depository:

Step 1: The power generation enterprise is the electricity seller in the transaction, and needs to submit the electricity sales order to the blockchain-based energy trading system, which includes basic information such as the power, price, and whether it is renewable energy. The power user is the power purchaser in the transaction, and needs to submit a power purchase order to the blockchain platform, including the power, price, location and other information of the purchased power. The blockchain nodes will store the received orders in consensus to ensure the traceability and immutability of the listing information of both parties in the electricity transaction.

Step 2: As the order information continues to accumulate, the platform will regularly initiate transaction matching to match the listing information of the electricity seller and electricity buyer. In order to ensure the credibility and credibility of the transaction and avoid system paralysis caused by a single point of failure, the node that initiates the transaction matching can be determined by the matching node election method described above, or it can be determined by using the random rotation method.

Step 3: The matching algorithm is implemented in the transaction matching smart contract, which can match the orders of the electricity seller and the electricity buyer stored in the consensus of the current blockchain. The matching process of high and low matching can maximize the transaction volume when the market is balanced, and improve the transaction processing efficiency of the system.

Since the transaction powers entrusted by buyers and sellers are highly likely to be different, the smart contract needs to calculate the power that the buyer or seller can trade in this match, and modify the power information in the order so as to enter the next round match. Therefore, each order may need to be completed by multiple transactions.

Step 4: After the match successful, each transaction will generate an electronic contract signed by both the buyer and the seller, and make an immutable certificate on the chain. After completing the deposit of the electronic contract, the transaction matching smart contract will freeze the corresponding quota in the consumer account of the power purchaser according to the contract and automatically trigger the equipment of the power generation enterprise to generate electricity. The maximum transaction processing time is set. If the transaction is not completed within the timeout period, the freeze on the corresponding amount of the electricity purchaser will be automatically released.

2.2 Power market transaction data management based on blockchain

At present, most blockchain systems still use the same underlying database to store block data and state data, which the most commonly used is LevelDB [11]. However, the data types and characteristics of block data and state data are quite different. According to the characteristics of block data and state data, it is best to design or select mature databases for storage.

In terms of block data, blocks are written one by one in an orderly manner, forming a chain in series, and data is only appended after the latest block. Therefore, the storage of block data does not require high random write performance. When performing a query operation on block data, the query is not necessarily performed in the order of the blocks. In addition, the blocks that have been written will not be changed, but the data volume of block data will continue to grow

as the block increases. Based on the above considerations, for the storage of block data, a database with superior sequential write and random read performance can be reasonably used, and high random write performance is not required, but the storage capacity factor needs to be considered.

2.3 Blockchain-based green electricity data traceability mechanism

Using the technical characteristics of blockchain technology such as decentralization, multi-party consensus, non-tampering, and non-repudiation, the technical implementation of blockchain technology in the issuance and traceability of green electricity certificates is studied.

The core of blockchain technology is that blockchain technology can turn green electricity certificates into digital assets registered on the chain, and can transfer the value of digital assets in a point-to-point network, increaseing the liquidity of certificate assets, and achieving full traceability. It also can solve the problem of cumbersome certificate issuance process and strengthen the attractiveness of certificates to buyers [12].

The issuance of green electricity certificate is the registration or issuance of green electricity certificate to the subscribed enterprise by the authorized competent authority through the alliance chain. After the contract is signed between the trading companies, the peer-to-peer green power certificate transaction is carried out through the alliance chain. The trading company can verify each green power certificate through the power trading chain to determine the authenticity of the green power certificate and achieve transaction traceability. At the same time, the overall application process of the above-mentioned blockchain green electricity certificate is stored on the Tianping Chain of Beijing Internet Court through a cross-chain method.

The green electricity certificate includes the signature of the power generation unit, the signature of the electricity purchase unit, transaction time, electricity quantity, electricity price, channel and other information. Power generation certificate with the signature of the power generation unit, cannot be traded and can be used as the basis for accounting. Electricity consumption certificate has the signature of the power generation unit and the signature of the current affiliated unit. After the transaction occurs, the purchaser's signature will be added to the end of the certificate data, and the previous owner's signature will be invalid. Using the decentralization and non-tampering characteristics of the blockchain and the time stamp on the transaction block, through the trusted deposit certificate and electronic signature of the blockchain, the statistics and traceability of the green electricity certificate can be realized.

The data structure of the green power certificate adopts the json data format, and the information of the certificate is defined in the form of K (Key) and V (Value). For example, K is for the signature of the power generation unit, V is for the specific signature value.

3 Green electricity market mechanism and application based on blockchain

3.1 Blockchain-based green power market-based transaction mechanism

Entities such as power generation enterprises, power grid companies, power users, regulators, and financial institutions jointly form a peer-to-peer network, which maintain the same ledger

together and implement an audit mechanism for access to the network. Based on the blockchain network, power generation companies, grid companies and power users can trade directly without the need for third-party agencies. The electricity seller publishes electricity sales information on the blockchain, and the electricity buyer submits encrypted quotation information. After the transaction intention is reached, both parties to the transaction can sign the blockchain electronic contract and store it in the chain. In addition, smart contracts can also be generated based on contract terms. The contract terms can be automatically enforced, avoiding the occurrence of defaults and false accounts.

The mechanism of the blockchain-based energy trading system is shown in the figure below, showing the equal interconnection of all parties in the system. The consensus nodes of the blockchain can be composed of representatives of power generation enterprises, power grid enterprises, and power users. Considering the transaction performance, this solution uses the alliance chain as the underlying platform to provide functions such as blockchain peer-to-peer network construction, consensus, block generation, data synchronization, and smart contract operation. We can deploy smart contracts on the blockchain to realize core operations such as unified identity authentication of users, energy transaction matching, and fee clearing, then trigger smart contract calls from upper-level business systems or power equipment to build a complete energy trading system.

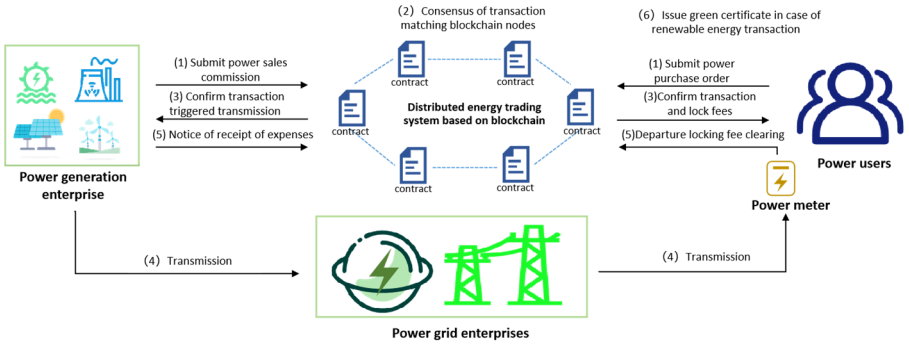

Figure 2 Energy trading mechanism based on blockchain

According to the energy trading system of this scheme, electricity sellers and electricity buyers work together through power equipment and smart contracts to directly conduct transactions without human intervention. The transaction matching smart contract is credibly executed on the blockchain, matching buyers and sellers to reach a transaction intention, completing the signing and deposit of the electronic contract. The execution result of the contract will start the electricity seller's power equipment to transmit the corresponding amount of electricity to the electricity buyer , and the electricity purchaser triggers the smart contract to run the fee settlement after consuming the electricity, and finally records the fee settlement details of the transaction in the distributed ledger of the blockchain, that is, the electricity production costs paid by the electricity buyer to the electricity seller and the electricity transmission costs paid to grid companies. The above mechanism realizes the goal of first-hand payment and first-hand delivery (electricity) efficiently, automatically and credibly in electricity transactions. The serial numbers in Figure 2 represent the overall flow of the transaction, which is described in detail as follows:

(1) Power generation enterprises submit power sales orders to the system, and power users submit power purchase orders to the system.

(2) The system regularly selects transaction matching nodes to trigger smart contracts, matching orders submitted by buyers and sellers, and completes consensus on blockchain nodes.

(3) Through the operation of the above smart contract, the electronic contract deposit certificate for transaction matching is generated. The corresponding amount in the power user account is locked, and the equipment of the power generation enterprise is started to produce the corresponding power.

(4) The power generation enterprise transmits the electricity traded in (3) to the electricity users through the power grid company.

(5) After the power user receives the power, the transaction clearing is automatically triggered through the power meter, and the fees locked in the process (3) are transferred to the power generation enterprise and the power grid enterprise.

(6) If the electricity type of the transaction is renewable energy, the fee clearing smart contract will issue a corresponding amount of consumption certificate for the current consumption of renewable energy power users, and store it in his blockchain account to become a follow-up certificate Circulating Genesis Transactions.

3.2 Blockchain-based green power transaction model

Considering the constraints of decentralization, real-time, incentive compatibility, and convenient operation, a complete set of quotation, review, bidding, clearing, and settlement mechanisms are designed. The designed transaction process includes:

(1) User registration and qualification review. Power generation companies and users first register as required, and only after approval can they conduct transactions on the platform. Registered market members need to submit an application if they want to change their information or withdraw from the market, and the approval will take effect. User registration information includes user name, meter ID, credit value, user address, bank account number, etc.

(2) Quotations from power generation companies and users. The power generation company and the user submit the electricity price and quantity of electricity for the next trading cycle to the trading platform (the electricity price of the specific trading period may not be distinguished, or the electricity price and electricity quantity of the specific period of time may be specified, that is, the price is guaranteed by the amount of time reported).

(3) Match the transaction. The platform matches the quotations of both the power generation company and the user to form an electronic reservation order. In addition to matching transactions, electronic booking orders can also be formed in the form of bilateral transactions or listed transactions. Bilateral transactions are generally signed offline and submitted online. Listed transactions are listed online, usually issued by the user side or the power generation side unilaterally, and the online delisting of the other side is regarded as a transaction mode.

(4) The contract is signed. A safety check is required before the contract is signed. Both the power generation company and the user shall sign a power generation contract, and a three-

party power supply contract shall be signed with the power grid company as the power transmission service provider. The contract needs to stipulate the transaction period, the transaction volume, the settlement method, the settlement electricity price, the “Internet fee” standard to be implemented, and the liability for breach of contract.

(5) Clearing and settlement. According to the transaction rules, the result is calculated and connected to the financial system of the power grid enterprise for cash flow settlement.

The result formed after security check, or the result of automatic matching without security check requirement, reaches a point-to-point smart contract, which is broadcast to the whole network to reach a consensus, integrateing the actual transaction information of the previous period to form a block. Issue a transaction license to the approved transaction plan, and reject the transaction that has not been approved by the dispatch chain, closing its application authority in this period, then announce that the power generation quota this time is invalid, so as to ensure the rationality of the transaction and real-time, preventing the potential hidden danger of distributed denial of service attacks caused by the repeated submission of several unapproved transaction applications in a short period of time.

3.3 Blockchain technology application supporting green power consumption

3.3.1 Issuance and tracking of green certificates

In order to solve the problem of consumption of distributed energy, the country implements a renewable energy quota system to encourage generators to produce clean electricity and users to buy green electricity. The green certificate can be certified by combining blockchain technology in the green certificate trading market [13]. The smart meter combined with blockchain technology can record the output of renewable energy generators. The immutability of the blockchain ensures the authenticity of the data. Therefore, the certification process can be simplified when the corresponding certificate is issued, thereby reducing the cost of green certificates and, improving certificate liquidity. At the same time, the traceability of the blockchain enables the historical ownership of each green certificate to be recorded on the blockchain, which avoids repeated sales of certificates, thereby maintaining the interests of all subjects in the process of issuing and subscribing green certificates.

3.3.2 Carbon Emission Certification

In order to cope with climate change and protect the environment, actively developing green power is an effective way to promote sustainable development[14]. Considering the openness, transparency and traceability of blockchain technology, applying it to carbon trading solutions can realize real-time tracking and recording of the whole process data of carbon trading quota allocation, trading, consumption and other processes. At the same time, various data such as enterprise information, transaction prices are attached to the quota data, which is convenient for comprehensive analysis of various data in the later stage. It effectively solves the problems of inauthentic data, difficult traceability, and difficult supervision in existing transactions.

3.3.3 Powering the Internet of Things

Given that distributed Internet, the core technology of power Internet of Things, is compatible with the characteristics of blockchain,, which can change the original central structure of the power Internet of things with the help of the decentralized architecture of the blockchain, greatly

reducing the computing pressure of the central organization[15]. At the same time, the blockchain with storage function and non-tampering characteristics can record the real data of electricity generation and consumption collected by the terminal equipment of the power Internet of things, such as smart meters, and verify it in the settlement link to ensure the fairness of the transaction.

4 Conclusions

This paper focuses on the key blockchain technologies and implementation methods required to support the green power market-oriented guarantee mechanism, and proposes a green power market-based transaction mechanism and settlement model based on blockchain technology. Blockchain technology is used to build a green power consumption support system, and an intelligent adaptation, safe and credible green power market-oriented transaction mechanism based on blockchain technology is established. According to the current scale of market entities, it can save nearly 100 million yuan in certificate management cost. At the same time, it will improve the transparency and openness of green power market-oriented management, and actively promote the active participation of multiple parties in green power consumption, which can rapidly expand the scale of users and increase user activity, thereby promoting the rapid development of the green power market. Under the background of structured supply-side reform, by integrating blockchain technology into the green power trading system, the effective integration of business data between the supply and demand of energy and power upstream and downstream enterprises can be achieved, and the coordination of multiple parties to formulate reasonable supply and demand trading rules can be realized.

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