Design and application of distributed photovoltaic transaction consensus mechanism based on blockchain

Qi Han¹, Yifei Qi*, Hua Deng¹ and Han Liu²

¹ State Grid Yantai Power Supply Company, Yantai, Shandong Province, 264000, China
² State Grid Shandong Power Supply Company, Jinan, Shandong Province, 250000, China

*Corresponding author’s e-mail: qyf.sd.sgcc.com.cn

Abstract. In recent years, distributed photovoltaic power generation has developed rapidly, but it has also brought many problems, such as poor equipment reliability, complex operation control, and many management subjects. Under the situation of the development of the electricity market, it is necessary to solve the problem of ensuring the data security of participating in the electricity market. Blockchain technology has the characteristics of traceability, non-tampering of information, openness and transparency, etc., which can satisfy massive transactions and reduce the burden of traditional power transactions. Therefore, based on the typical characteristics of blockchain, this paper analyzes the common attributes of blockchain and electricity market transactions, and adopts the DPOS (delegated proof of stake) consensus mechanism to realize distributed photovoltaic transactions. On this basis, this paper utilizes the consensus method based on node credit value and applies it to the actual microgrid distributed photovoltaic power station. The experimental results show that the transaction consensus mechanism proposed in this paper has certain advantages in transaction efficiency and transaction cost, which can provide a practical basis for blockchain to realize distributed photovoltaic transactions.

1. Introduction

In order to cope with global climate change and seize key opportunities in the transformation of new energy, China has established a goal of achieving a carbon peak by 2030 and a vision of achieving carbon neutrality by 2060. In this context, it is particularly important to promote the upgrading and adjustment of China's industrial structure and production capacity. It is necessary to implement new development concepts and create a clean, low-carbon, safe and efficient modern energy system. In recent years, distributed clean energy represented by photovoltaics has been rapidly developed due to significant social and economic benefits[1], not only can provide users with clean electricity directly, but also can improve the flexibility of the distribution network[2-3].

With social development, China is carrying out market-oriented transactions in distributed power generation. In May 2019, China's National Development and Reform Commission and Energy Administration jointly released the first batch of 26 distributed power generation market-oriented trading pilots[5]. In particular, with the promotion of distributed photovoltaic power generation and the liberalization of energy trading systems, more customers will participate in the photovoltaic power trading market, and blockchain technology will become the pioneering area of photovoltaic energy power trading reform.
Generally, distributed photovoltaic power generation capacity is small but large in quantity, and it is difficult to adopt the traditional power trading model[6]. Therefore, how to solve massive transactions has become one of the most important problems. With the rapid development of big data technology, obtaining energy big data through attacks can effectively analyze the target's energy consumption and the detailed location of the infrastructure. Under this condition, there is an opportunity to tamper with key nodes and data in the system, which can cause energy system failures or major safety accidents.

The energy network is a public utility company that serves the public. If detailed user data is leaked, it will have a great negative impact on society. Blockchain technology has a variety of characteristics, such as decentralization, traceability, autonomy, information cannot be tampered with, openness and transparency, etc., which can meet the needs of distributed power transactions[7]. Based on blockchain technology, users can freely select transaction objects within the physical limits of the power grid, and all transactions will be verified and recorded, which can greatly reduce the burden of traditional electricity transactions. For a large number of distributed photovoltaic transactions, this design scheme has many problems, such as slow synchronization speed and low transaction efficiency. In response to the above problems, this paper analyzes the principle of typical blockchain consensus mechanism, combined with the characteristics of distributed photovoltaic power generation transactions, proposes a consensus method based on node credit values, and applies it to actual microgrid distributed photovoltaic power plants.

2. Analysis of blockchain principles

Blockchain is a specific data structure that connects the data nodes generated in the system first in the form of a chain in chronological order. The blockchain adopts the principle of cryptography (hash algorithm) to ensure its secure decentralized data ledger[8], which is essentially a distributed database technology that maintains a chain structure. By changing the number of blockchain nodes and setting transaction rules for project implementation, automatic trust transactions can be realized. Therefore, the blockchain has a distributed ledger and an intelligent contract system, and it is becoming a solution for distributed energy power system transaction records. Since there is no centralized hardware or management organization, the blockchain adopts a distributed collective operation method to construct a point-to-point data structure mode. In summary, blockchain has many advantages, such as decentralization, traceability, and smart contracts[9-10].

The blockchain application platform will automatically update transaction records, including transaction time, transaction power, power distribution routes, etc., and store them in the block formed in the corresponding time period in real time for subsequent query. The entire transaction process is recorded in real time and can be traced back as shown in Figure 1. According to the transaction content, the users participating in the transaction are sent to the distribution network communication bus for transaction matching based on the smart contract rules. After the matching is successful, the public key is used to establish a transaction contract, and then both parties use their private keys to sign the transaction and generate transaction data. The final transaction record is stored in the blockchain, which can be viewed by other users and their respective transaction parties, with traceability.

Blockchain is a data ledger shared by all nodes, which is formed by connecting blocks first in chronological order. Each block is composed of a block header and a block body. The block header contains the block identification number, the address of the previous block, the block size, the timestamp, and the root of Markle. The main body of the block mainly includes the detailed transaction information of the block and the markle tree and transaction database of the corresponding hash value. The block chain structure is shown in Figure 2.
3. Consensus mechanism design

Distributed photovoltaics have a large number of participating users, frequent transactions, and high requirements for the synchronization performance of the transaction system. However, the synchronization of transaction systems based on POW and POS usually takes tens of seconds or even minutes, which cannot meet the needs of massive transactions. Therefore, DPOS is chosen as the blockchain consensus mechanism for distributed photovoltaic transactions. The essence of the consensus mechanism is the process of selecting proxy nodes and packaging the transaction information of all nodes to generate new blocks. Competitive agency rights will increase the difficulty...
and burden of work. This article believes that electricity users only want to purchase electricity within the specified time and will not participate in competition to become an agent node.

The proxy node is selected according to the consensus value. The larger the consensus value, the more likely it is to be selected as the proxy node. The consensus value mainly includes the credit value and the voting value. The calculation formula is as follows.

\[ C = \lambda C_{\text{credit}} + \alpha C_{\text{vote}} \]  

(1)

In the above formula, \( \lambda \) is the weighting factor of the credit value, \( \alpha \) is the weighting factor of the voting value. \( C \) is the consensus value, \( C_{\text{credit}} \) is the credit value, \( C_{\text{vote}} \) is the voting value. To solve using the above steps, these two weighting factors are set to 0.5.

The transaction quality value is calculated according to the following formula. Through principle analysis, the closer the actual trading power is to the planned trading power, the smaller the transaction deviation and the greater the transaction quality value.

\[ T = k(1 - \frac{|E_{\text{real}} - E_{\text{plan}}|}{E_{\text{plan}}}) \]  

(2)

In the above formula, \( T \) is the transaction quality value, \( E_{\text{real}} \) is actual trading electric energy, which is taken from the user-side electric energy meter. \( E_{\text{plan}} \) is the planned trading electric energy reported to the trading platform, \( k \) is the scale factor, usually set to 10.

The workflow of the consensus mechanism based on credit value is shown in Figure 3. In the process of using the public and private key pairs of the trading account, the implementation process is consistent with the traditional blockchain consensus mechanism. These mainly include manufacturing blocks, verifying the validity of blocks, and entering the chain of data. Considering that distributed photovoltaics are usually equipped with energy storage systems, this paper also introduces energy storage systems into the comprehensive analysis of electricity market transactions. Because distributed photovoltaics can operate in the state of surplus electricity on the Internet, the photovoltaic power that cannot be fully consumed among blockchain node users is given priority to satisfy the members of this group. If there is still wealthy, it will be sold according to the appropriate price, otherwise it will be stored internally. When the internal storage is full, the large power grid will purchase it. The power consumption that cannot be met by the members of each group unit is determined independently based on the price advantage.

The electricity traded through the blockchain will be traded first according to the low price of the bidder. A game model is formed between electricity sellers and electricity buyers, and distribution principles need to be designed to maximize the benefits of both parties. When the general user energy storage system is not full, the general user may not respond to demand. This will cause the general user to have electricity but not sell it. Under this circumstance, enterprise users will inevitably increase the price of electricity to purchase electricity from users or purchase electricity from large power grids. If the general user energy storage system is full, but there is no balance, only the corporate user electricity price can be accepted. If users don't do this, they must sell electricity to the large grid or abandon the electricity. At this time, since the power supply of general users is greater than the power purchased by enterprise users, it belongs to the buyer's market. The system determines the electricity sold by general users according to the principle of smart contracts, and the excess electricity sold is sold to the large power grid. In order to minimize the cost of power purchasers, the total power sold by the microgrid must be distributed proportionally to the needs of each user. The specific flow chart is shown in Figure 4.
Start
Count the number of system nodes and select the appropriate proxy node
Analyze the transaction frequency, transaction capacity, credit loss and other characteristics of each node
Conduct mutual voting among nodes, and select the one with the largest consensus value as the proxy node
Record the transactions during this period and pack them into blocks for functional verification of each node
Verify that 51% of the nodes are satisfied
start rewarding proxy nodes, and other proxy nodes take turns to book accounts
End

Figure 3. Calculation process of consensus mechanism based on credit value

Start
Determine input demand and price range
meet the expected price
N
Y
full storage capacity
Energy storage waits for the next opportunity
Transactions under functional contracts
End

Figure 4. The flow algorithm of electricity trading

| Time  | Electricity/(kW·h) | A   | B   | C   |
|-------|-------------------|-----|-----|-----|
| 6:00  |                   | 0.00| 0.00| 0.00|
| 6:10  |                   | 0.00| 0.00| 0.00|
| 6:20  |                   | 0.04| 0.03| 0.06|
| 6:30  |                   | 0.12| 0.15| 0.22|
| 6:40  |                   | 0.25| 0.28| 0.36|

Table 1. Power generation data of users from 6:00 to 8:00
Through data analysis, the time of transaction consensus mainly depends on the time taken to select agent nodes. The time used for the 50 consensus procedures is shown in the figure below. The shortest time is 0.9 s, and the longest time is 1.09 s. Therefore, the transaction structure shows that the method proposed in this paper can effectively improve transaction efficiency and make it practical in specific transactions.

4. Conclusion
In response to the demand for distributed photovoltaic participation in power market transactions, this paper analyzes the typical characteristics of the blockchain, constructs an application scenario based on the marketization of photovoltaic microgrid transactions under the blockchain, and proposes a consensus mechanism based on node credit. Finally, actual case analysis and calculations are carried out. The results show that the market-oriented transactions of photovoltaic microgrids based on the blockchain have the characteristics of strong flexibility, high efficiency, and reduced transaction costs, which provide new ideas for future distributed photovoltaic participation in power market transactions.

Acknowledgments
This work was supported by science and technology project of state grid shandong electric power company(Research on Blockchain Application Technology for power source-network-load-storage energy-5206002000RX).

References
[1] Yang Decang., Zhao Xiaoyu., et al. (2017) Developing status and prospect analysis of blockchain in energy Internet. Proceedings of the CSEE, 37:3664-3671.
[2] Lu Jing., Song bin., et al. (2017) Smart contract for electricity transaction and charge settlement based on blockchain. Computer Systems & Applications, 26:43-50.
[3] Yuan Yong., Wang Feiyue., et al. (2016) Blockchain: the state of the art and future trends. Acta Automatica Sinica, 42:481-494.
[4] Yan Yong., Ni Xiaochun., et al. (2018) Blockchain consensus algorithms: the state of the art and future trends. Acta Automatica Sinica, 44:2011-2022.
[5] Wang Beibei., Li Yachao., et al. (2019) Key technologies on blockchain based distributed energy transaction. Automation of Electric Power Systems, 43:53-64.
[6] Zhao Yuehao., Peng Ke., et al. (2019) Status and prospect of pilot project of energy blockchain. Automation of Electric Power Systems, 43:14-22.
[7] Ding Wei., Wang Guocheng., et al. (2018) Research on key technologies and information security issues of energy blockchain. Proceedings of the CSEE, 38:1026-1035.
[8] Chen Guanting., Zhang Li., et al. (2020) Blockchain based transaction mechanism for residential users demand response. Electric Power Automation Equipment, 40:9-16.
[9] Chen Si., Wang Haoran., et al. (2020) Rethinking the value of blockchain: direction and boundary of blockchain applications. Proceedings of the CSEE, 40:2123-2132.
[10] Zhang Xian., Xie Kai., et al. (2020) Excessive consumption trading system for the accommodation of renewable energies based on blockchain. Electric Power, 53:60-70.