Research on Distributed Green Electricity Transaction and Management of Power System Based on Blockchain Technology

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Abstract. The establishment of scientific and efficient distributed green electricity trading and management mode is an important means to improve the production level of the power system. The application of blockchain technology in the distributed green electricity trading and management in the power system can promote the further construction and development of the power system toward the dual-carbon goal. This paper mainly analyzes the application advantage of block chain technology in the power system, build based on block chain technology power system distributed green electricity trading and management platform, and in the perspective of the seller market and seller's market quotation and transaction management, finally establish the game Nash equilibrium model, under this model using adaptive iterative algorithm to calculate the best interests of the market, in order to provide reference for the power system green electricity trading market transaction management.

Keywords: blockchain technology; power system; distributed; green electricity transaction; green electricity management

1. Introduction

General Secretary Xi Jinping clearly stressed that the development of new energy should adhere to the two-carbon goal, and constantly innovate the development mode of power system around the construction and development of new energy. The trading and management of green electricity can effectively enhance the society's ability to absorb green electricity, accelerate the realization of the goal of "carbon peak, carbon neutral", promote the high-quality development of the power system, relieve the pressure of carbon emission of enterprises, and promote the realization of low-carbon electricity. At present, blockchain technology has been valued by major related industries in China due to its advantages of multi-party participation, high openness, strong security, traceability and decentralization. The application of the blockchain technology in the distributed green electricity transaction of the power system can realize the innovative development of the power system in the production, management, operation and

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other aspects, optimize the industrial structure, and further improve the efficiency, security and stability of the green electricity transaction management.

2. Research background

In 2017, China's Energy Administration and the National Development and Reform Commission jointly issued the Notice on Carrying out the Pilot Market Trading of Distributed Generation, which regulated the trading process of distributed energy. Since then, the development of distributed green electricity trading has developed very rapidly in China[1]. In 2019, some provinces and cities in China formulated the market development standards of distributed power energy in the province according to their own development status, and realized the implementation of distributed green electricity transaction. Through the summary of the current situation of distributed green electricity energy transaction in the pilot, it is found that there are problems such as low income, insufficient construction of basic service system, and not strong reliability, which affect the development of distributed green electricity transaction. In 2019, General Secretary Xi Jinping put forward the concept of distributed energy trading based on blockchain, and proposed that the distributed energy trading innovation should be strengthened to realize the green development strategy. In 2023, the National Development and Reform Commission No.1044 proposed to actively promote the dual-carbon target, further promote the green transformation of the power system, pointed out that the electricity environmental attribute of renewable energy in China is proved to be green certificate, the green certificate of one unit represents 1000 kilowatt-hours of renewable energy electricity, and further standardize the trading and management of green electricity in China[2]. In the same year, the Ministry of Ecology and Environment (No.332,2023) pointed out that China's power generation industry should manage and compile relevant reports in strict accordance with the Administrative Measures for Carbon Emission Trading (Trial). Blockchain itself has the characteristics of distributed ledger, and has a strong adaptability to distributed green electricity management. It can provide a variety of distributed green electricity trading community unified construction mode (as shown in Figure 1), so as to effectively reduce transaction costs and improve the security of all kinds of transaction data.

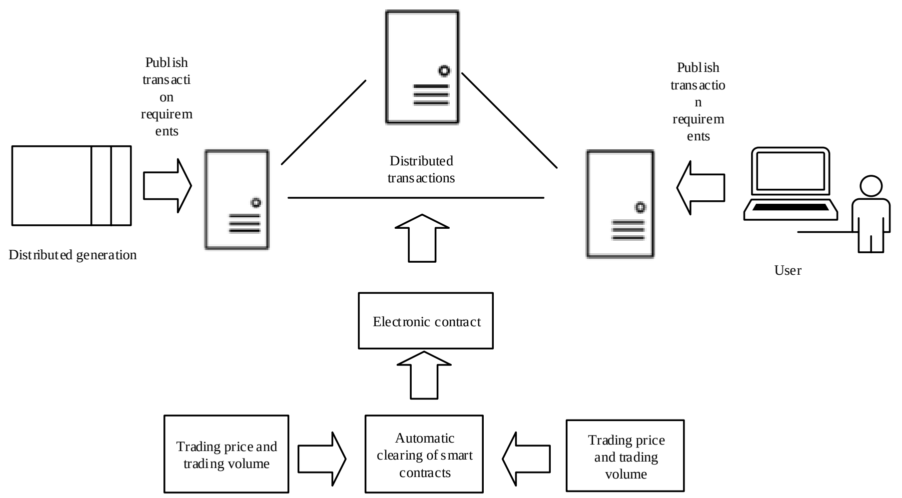

Figure 1 Distributed Green electricity energy transaction and management based on blockchain

3. Distributed green electricity transaction and management architecture of power system based on blockchain technology

Blockchain technology has the advantages of algorithm encryption, smart contracts, and mechanism consensus. The application of blockchain technology in the transaction management of green electricity energy in the power system has the advantages of high security and strong independence. In particular, the consensus mechanism of blockchain itself is an important guarantee for imtamability, openness and transparency in distributed green electricity transaction and management. At the same time, the data storage of blockchain technology mainly uses hash value to connect, with higher security. Therefore, compared with traditional centralized transactions, the distributed green electricity energy transaction and management of power system based on blockchain technology has more obvious advantages (such as Table 1).

Table 1 Comparison of advantages and disadvantages of centralized energy trading and distributed trading of blockchain technology

The shortage of centralized trading	Blockchain technology advantages
Transaction data can be attacked and tampered with	Decentralization, reliable data storage, and traceability
Privacy issues and trust issues of the participants	Protect your privacy, and trust you
Lack of information openness and transparency	Information is open and transparent
High transaction costs and difficult settlement costs	Smart contracts are cheap and fast to execute

On this basis, this paper uses blockchain technology to build a distributed and green electricity transaction management platform for power system. The platform is mainly divided into three architectures: blockchain layer, hardware layer and application layer (as shown in Figure 2). The hardware layer mainly provides various hardware support for distributed green electricity transaction management, including smart meter, energy storage system, etc. The application layer mainly includes various distributed applications and user interfaces and management at the application layer[3]; finally, the construction layer of block chain is mainly used to handle various types of transaction requests, provide transaction data, transaction data and transaction storage, and smart contracts are mainly used to restrict the trading process of green electricity energy, ensure the standardization of transaction and effectively maintain the operation of block chain.

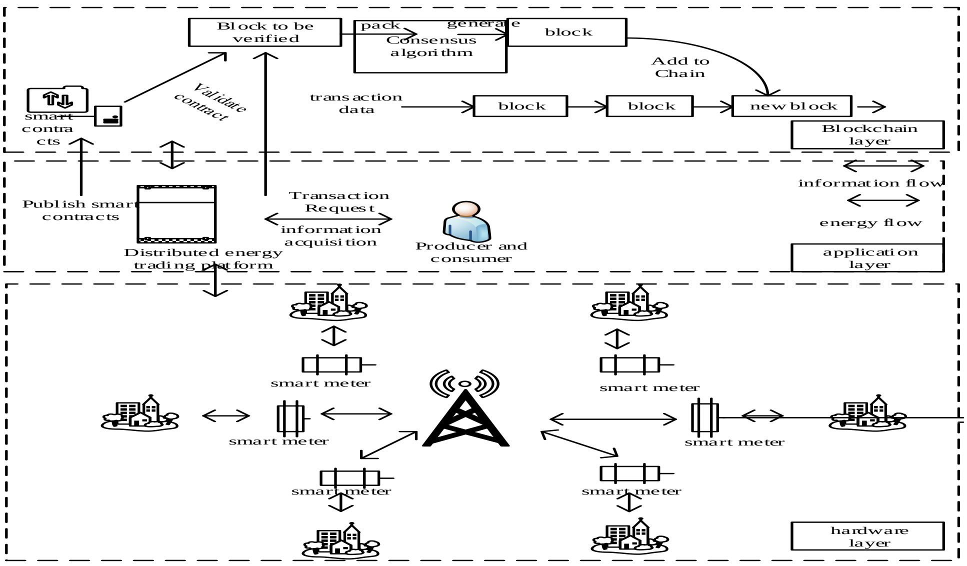

Figure 2 Distributed Green electricity transaction structure of power system based on blockchain technology

4. Distributed green electricity trading mechanism of power system based on blockchain technology

A reasonable trading mechanism is an important guarantee to maintain the safe, orderly and fair development of transactions. In order to ensure the interests of the producers and sellers in the trading market, this paper mainly studies the distributed green electricity trading mechanism from the perspective of the producers and sellers. Users participating in the production and marketing of users must install smart electricity meters and trading clients in accordance with the regulations to record and participate in the green electricity trading. They also need to review the market entry and delisting of users, and clarify the electricity capacity and voltage level of users. At the same time in order to ensure the market order, producers in trading can only choose the buyer or the seller, the seller in the excess green electricity resources should be completed in the market, the energy storage equipment to complete the maximum top-up, after selling to the grid, and the buyer should first buy from the trading platform and use of energy storage equipment in the energy supply, then to buy from the grid[4]. Finally, the transaction is conducted according to the relevant trading process and trading mechanism (see Figure 3 and Figure 4).

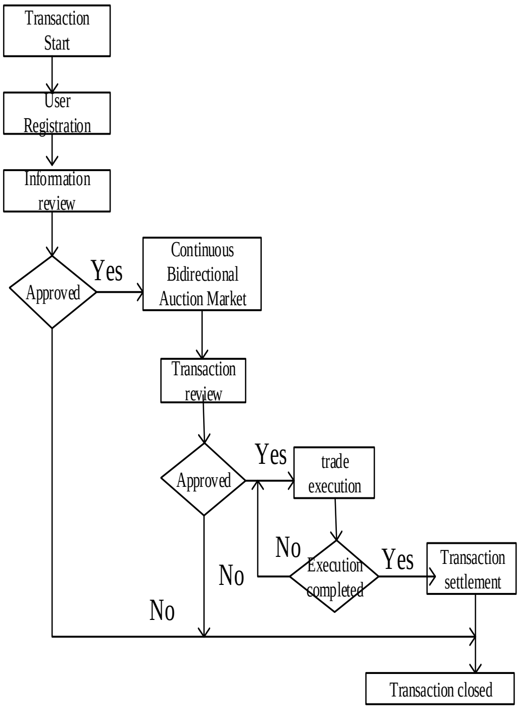

Figure 3 Distributed distributed energy transaction process

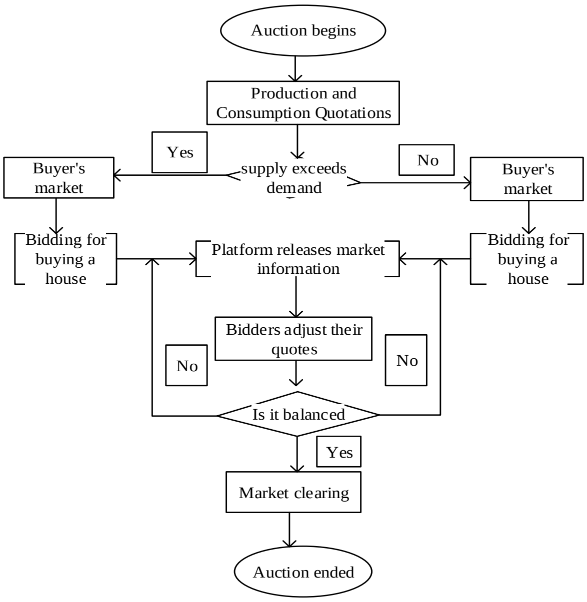

Figure 4. Auction mechanism

5. Pricing and energy rules

5.1. A buyer's market

A buyer's market refers to the situation where green electricity energy in the trading market exceeds demand. At this time:

$$\sum_{n\in N_s^t} P_{n,sell}^t > \sum_{n\in N_b^t} P_{n,buy}^t \tag{1}$$

Among them, N_s^t represents the total quantity of the seller, N_b^t represents the total quantity of the buyer, and $P_{n,sell}^t$ represents the excess green energy of the seller. At this time, the seller's quotation is $b_s^t = \{b_{n,s}^t\}$, and the quotation arrangement is:

$$b_{1,s}^t \leq b_{2,s}^t \leq \ldots \leq b_{N_s^t,s}^t \tag{2}$$

The purpose of sorting quotations is to find producers and sellers who can match, and assign energy sales indicators to the seller according to the sorting order. Assuming that the last producer and seller assigned to the indicator is m_s^t, the final energy that the seller can sell and its transaction price are:

$$P_{n,sell}^t(P_n^t, b_s^t) = \begin{cases} P_{n,sell}^t & n < m_s^t \\ \sum_{n\in N_b^t} P_{n,buy}^t - \sum_{j=1}^{j=m_s^t-1} P_{j,sell}^t & n = m_s^t \\ 0 & n > m_s^t \end{cases}$$

$$P_s^t(P_s^t, b_s^t) = \begin{cases} b_{m_s^t,s}^t & P_{m_s^t,sell}^t(P_s^t, b_s^t) < P_{m_s^t,sell}^t \\ b_{m_s^t+1,s}^t & P_{m_s^t,sell}^t(P_s^t, b_s^t) < P_{m_s^t,sell}^t \end{cases} \tag{3}$$

In this formula, $P_{n,sell}^t(P_n^t, b_s^t)$ represents the green electricity that seller n can trade at this time, and $P_s^t(P_s^t, b_s^t)$ represents the trading price of the green electricity.

After comprehensive analysis of the above formula, it is found that when the quotation is m_s^t-1. At this point, if all the sellers' excess green electricity has been sold, it can meet the buyer's green electricity purchase needs[5]. When the quotation is m_s^t and the seller still has the remaining green electricity, the seller's quotation in the order of m_s^t will be the final transaction price. When the seller is m_s^t, all remaining energy is sold, then the m_s^t+1 seller's quotation is the final transaction price.

5.2. The Seller's market

The seller's market refers to the situation that the supply of green electricity energy in the trading market is less than the demand. At this time:

$$\sum_{n\in N_s^t} P_{n,sell}^t < \sum_{n\in N_b^t} P_{n,buy}^t \tag{4}$$

Assuming that the energy that the green electricity buyer needs to buy at this time is, the quotation is arranged as follows: $P_b^t = \{P_{n,buy}^t\}$

$$b^t_{1,b} \geq b^t_{2,b} \geq \ldots \leq b^t_{N^t_b,b} \quad (5)$$

Assuming that the last buyer assigned to the indicator is m^t_b, the energy that the buyer can buy and the final transaction price are:

$$P^t_{n,buy}(P^t_b, b^t_b) = \begin{cases} P^t_{n,buy} & n < m^t_b \\ \sum_{n \in N^t_s} P^t_{n,sell} - \sum_{j=1}^{j=m^t_b-1} P^t_{j,buy} & n = m^t_b \\ 0 & n > m^t_b \end{cases} \quad (6)$$

$$P^t_b(P^t_b, b^t_b) = \begin{cases} b^t_{m^t_b,b} & P^t_{m^t_b,buy}(P^t_b, b^t_b) < P^t_{m^t_s,buy} \\ b^t_{m^t_b+1,b} & P^t_{m^t_b,buy}(P^t_b, b^t_b) < P^t_{m^t_b,buy} \end{cases} \quad (7)$$

Among them, $P^t_n(P^t_b, b^t_b)$ represents the green energy that buyer n can buy, and $P^t_b(P^t_b, b^t_b)$ represents the unit price of purchasing electricity.

In summary, after buyer $m^t_b - 1$ completes the final purchase of green energy, buyer m^t_b can only make purchases based on the remaining amount of green energy at that time. If the remaining energy cannot meet the energy needs of buyer m^t_b, the final transaction price will be buyer m^t_b's quotation. If the remaining green energy meets the energy demand of buyer m^t_b, the final transaction price is the buyer's m^t_b+1 quotation.

5.3. A Nash equilibrium model for the non-cooperative game

Whether in the buyer's market or the seller's market, the buyer can adjust his purchase demand through the relevant information in the distributed green electricity trading platform[6]. Analysis the Nash equilibrium model of non-cooperative game can find the best trading strategy of the buyer:

When there is a buyer's market, assuming that any participant in the Nash equilibrium model of a non cooperative game is n, the relationship between green power purchase strategy $b^{t^*}_s = b^*, b^{t^*}_{-n,s}$ in the Nash equilibrium model and participant n is:

$$U^t_{n,sell}\left(P^t_s, \left(b^*, b^{t^*}_{-n,s}\right)\right) \geq U^t_{n,sell}\left(P^t_s, \left(b, b^{t^*}_{-n,s}\right)\right) \quad (8)$$

When there is a seller's market, assume that the relationship between purchasing strategy $b^{t^*}_s = b^*, b^{t^*}_{-n,s}$ and participant n is:

$$U^t_{n,buy}\left(P^t_b, \left(b^*, b^{t^*}_{-n,b}\right)\right) \geq U^t_{n,buy}\left(P^t_b, \left(b, b^{t^*}_{-n,b}\right)\right) \quad (9)$$

Build the solution model to solve the distributed green electricity transaction model and establish an adaptive iterative algorithm (see Figure 5):

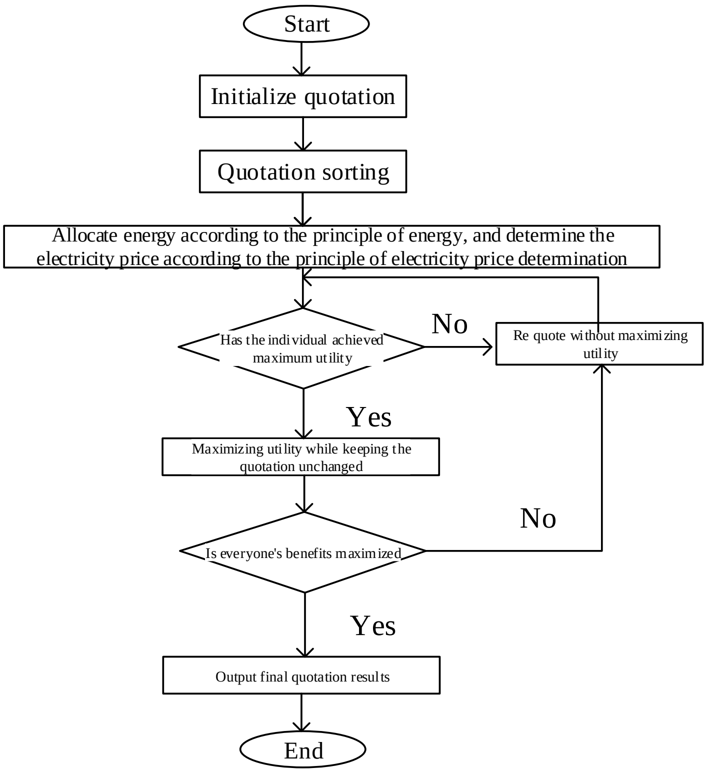

Figure 5 solves the process

5.4. Equilibrium process analysis

equilibrium process of energy transaction from two aspects: buyer's market and seller's market, taking the seller's market at time 23 and the buyer's market at time 24 as examples, verifies the Nash equilibrium under the iterative algorithm through calculation examples, so that the buyer's interests participating in the bidding can maximize[7].

Seller Market Analysis.Assuming that at time 23, the total green electricity is 16 kWh, and the total electricity demand in the market is 31 kWh, which is the seller's market. The specific transaction results of each producer and seller are shown in Table 2.

Table 2 Nash's equilibrium results

buyer	Energy deficit amount (kWh)	Pre-transaction battery SOC	minimum price	Equilibrium price (RMB)	Pre-transaction market power purchase (kWh)	Battery discharge (kWh)	Grid purchase (kWh)	Post-transaction battery SOC
A	4	59%	0.68	0.68	0	4	0	52%
B	11	41%	0.81	0.69	11	0	0	42%
C	6	63%	0.65	0.65	0	6	0	52%
D	10	57%	0.69	0.68	5	5	0	48%

According to Table 2, in the first round of quotation, the power purchased of B and D is 11kWh and 5 kWh respectively, and the power purchased of A and C is 0. Therefore, in the first round of quotation, B and D are successfully matched to the corresponding price. In order to maintain their own benefits, they can choose to change the original quotation, as the last person to decide the selling price, or maintain the original quotation. However, A and C fail in the first round of matching, and further increasing the quotation in the subsequent quotation will reduce their own utility, so it is necessary to maintain the first round of quotation [8]. In the subsequent quotation, in order to maximize its own interests, the final quotation is 0.69 yuan / kWh. At this time, D is the last successful match and seller. In order to ensure its own utility, the final quotation is 0.68 yuan / kWh, which is consistent with the low price of A. In the end, the green electricity transaction cleared B to make up all the energy shortage at the price of 0.69 yuan / kWh, while D bought 5kWh of energy at the price of 0.68 yuan / kWh, and finally determined the equilibrium price of 0.68 yuan / kWh.

The analysis of the buyer's market assumes that at time 24, the total green electricity is 29 kWh, and the total electricity demand in the market is 13 kWh, which is the seller's market. The specific transaction results of each producer and seller are shown in Table 3[9].

Table 3 Nash's equilibrium results

buyer	Energy deficit amount (kWh)	Pre-transaction battery SOC	minimum price	Equilibrium price (RMB)	Pre-transaction market power purchase (kWh)	Battery discharge (kWh)	Grid purchase (kWh)	Post-transaction battery SOC
E	12	86%	0.5	0.64	10	2	0	90%
F	13	66%	0.64	0.64	0	13	0	92%
G	1	52%	0.74	0.74	0	1	0	54%
H	3	100%	0.4	0.5	3	0	0	100%

As can be seen from Table 3, in the first round of quotation, E sells 10kWh of energy, H sells 3 kWh of energy, the quantity of energy sold by F and G is 0, and the price is 0.5 yuan / kWh. E and H are the successful producers and sellers in the first round of this quotation. In order to maintain their own benefits, they can choose to change the original quotation as the last person to decide the selling price, or maintain the original quotation[10] . If F and G fail in the first round of match, a further increase in the quotation in the subsequent quotation will reduce their own utility, so it is necessary to maintain the first round of quotation. At this time, the interests of the group were maximized. Finally, E sold 10kWh of green electricity, and the remaining electricity was put into the battery. H sold 3 kWh of green electricity energy, and the equilibrium price was finally determined to be 0.64 yuan / kWh.

6. Conclusion

Under the influence of double carbon policy in China, the power system of distributed green electricity energy volatility and random trading is more and more big, on this paper based on block chain technology established the power system distributed green electricity energy trading platform, from the perspective of the seller's market and the buyer's market, build the cooperative game Nash equilibrium model, and design the model force, for the power system in the distributed green electricity energy trading and management to provide effective reference, realize the benefit of the producers of maximize, to build a stable and harmonious power system distributed green electricity trading market to provide effective reference.

References

[1] Haike Q ,Zijun Z ,Qin S . Blockchain technology adoption of the manufacturers with product recycling considering green consumers [J]. Computers & Industrial Engineering,2023,177

[2]Yung K Y ,Huin H C ,Jaromír J K .Blockchain technology for distributed generation: A review of current development, challenges and future prospect[J].Renewable and Sustainable Energy Reviews,2023,175

[3]Gousia H ,Sparsh S ,Sara I , et al.Blockchain Technology: Benefits, Challenges, Applications, and Integration of Blockchain Technology with Cloud Computing[J].Future Internet,2022,14(11):341-341.

[4]Zheng X ,Ji L .Research on Architecture of Digital Bond Trading Contract System Based on Blockchain Technology[J].Mobile Information Systems,2022,2022

[5]HIVE Blockchain Technologies Ltd.; HIVE Blockchain Continues Increasing Bitcoin Mining Power Through Additional Purchase of Next Generation Miners for Green Energy-Powered Quebec Facility [J].Medical Letter on the CDC & FDA,2020,

[6] Wang Shenghan, Guo Chuangxin, Feng Bin, et al. Application of blockchain technology in power system: Prospect and thinking [J]. Automation of electric power System, 2020,44 (11): 10-24.

[7] Li Xingzhi, Han Bei, Li Guojie, et al. The challenges of distributed green energy carbon trading mechanism and carbon data management [J]. Journal of Shanghai Jiao Tong University, 2022,56 (8): 977-993.

[8] Shi Zhuyu, Wang Dong, Li Da, et al. Standardization research in the typical application scenarios of energy and power blockchain [J]. Global Energy Internet, 2023,6 (2): 196-206.

[9] Wang Qixin, Lu Baotong, Wang Beibei, et al. Blockchain-based renewable energy power tracking method in the context of quota system [J]. Automation of electric power System, 2022,46 (23): 11-19.

[10] Pei Fengque, Cui Jinrui, Dong Chenjing, et al. Research field and status quo analysis of blockchain in distributed power transaction [J]. Chinese Journal of Electrical Engineering, 2021,41 (5): 1752-1770, middle insertion 20.