2021 4th International Conference on Advanced Electronic Materials, Computers and Software Engineering (AEMCSE) | 978-1-6654-1596-5/21/$31.00 ©2021 IEEE | DOI: 10.1109/AEMCSE51986.2021.00015

Architecture Design and Application of distributed power trading System based on blockchain Asynchronous Consensus

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***Abstract*—With the deepening of electric power system reformation and the enhancement of distributed energy permeability, distributed energy in power generation and sales side of effective configuration is facing opportunities and challenges. The traditional centralized power trading mode is centralized trading, which has many problems such as low transparency, high cost, low efficiency and unreliable data, so it's unable to adapt to the large-scale distributed power trading scenario. In this context, this paper proposes a distributed power trading mechanism based on blockchain asynchronous consensus mechanism, analyzes the compatibility between blockchain technology and distributed power trading mode, carries out research on the asynchronous consensus mechanism, designs the blockchain-based distributed power trading system architecture and process method and carries out trial application to improve the consensus efficiency of the system consensus. Meanwhile, the mechanism could solve the trust problem in the process of distributed power trading, and ensure the transparency and fairness of distributed power trading.**

Keywords- Blockchain; Asynchronous consensus; Trading mechanism; distributed power trading; System architecture

I. INTRODUCTION

In recent years, with the large-scale centralized development of new energy, the installed capacity of new energy power generation has been increasing. According to related statistics, by the end of 2020, China's cumulative installed capacity of new energy has exceeded 530 million kW, which ranks the first place of the world. Distributed power generation utilizes clean energy resources and completes energy production and consumption nearby. It has the advantages of low energy consumption, high energy efficiency, low emission, high energy saving, and represents a new direction and new form of energy development [1]. With the development of new energy technology and the reformation of electricity market, the power generation plan for operational power users has been fully opened, the participation of small and medium-sized users in market transactions has gradually increased, and the types and management modes of electricity transactions have presented a diversified development trend [2].

The traditional centralized power trading mode is a centralized transaction, which has the problems of low transparency, high cost, low efficiency and unreliable data, etc., so it is not suitable for the distributed power trading mode. Blockchain, as a distributed ledger with asymmetric encryption, can effectively solve the problem of information asymmetry in the transaction process [3]. Blockchain has the characteristics of decentralization and immutability, so it has become a research trend to apply it to distributed power tradings. At present, many institutions and domestic and foreign scholars have carried out research and pilot studies of blockchain in distributed electricity trading. In terms of pilot construction, the 'Tansactive Gird' project [4] in Brooklyn, New York, USA, has verified the feasibility of distributed power trading based on blockchain. The German electric vehicle 'Share&Charge' project [5] proposes to apply blockchain in the field of shared charging stake, and adopts blockchain distributed ledger to make the transaction price transparent between the two parties. In terms of academic research, literature [6] briefly describes the research status of blockchain technology in energy internet field, and carries out a preliminary prospect on the P2P transaction of electric energy and the mode of energy interconnection. Literature [7] compares the technical realization of blockchain with the energy Internet, and proposes that it has the potential to realize the intelligence of energy transactions. Literature [8] proposes the different attributes and realizable functions reflected in the mapping of blockchain technology to the power system, and provides implementation ideas for the application of blockchain to carbon emission rights and the design of green license trading system. Literature [9] explores the blockchain technology, which is suitable for large users' direct power purchase transactions, and establishes the overall framework. Literature [10] proposes a comprehensive demand-side response resource trading framework based on blockchain technology. Literature [11] proposes a decentralized multilateral transaction mode of distribution network with "multi-transaction request and multi-response quotation", and builds a practical operational distributed power trading platform. Literature [12] analyzes the similarities and differences between the blockchain technology in weakly centralized and

978-1-6654-1596-5/21/$31.00 ©2021 IEEE
DOI 10.1109/AEMCSE51986.2021.00015

decentralized transaction management in view of the market-based transaction of distributed power generation.

Most of the literature mentioned above focus on the exploration of the scene, direction and value of the application of blockchain technology, while, they do not reflect the detailed architecture design and process method of distributed electric power trading system based on blockchain technology. And the research of applying the asynchronous consensus mechanism of blockchain to distributed power trading and making it adapted to large-scale distributed power trading application, is still in the initial stage. Based on this background, this paper studies the distributed power trading mode based on blockchain technology, analyzes the compatibility between blockchain technology and distributed power trading characteristics, carries out the research and application of key technologies based on asynchronous consensus mechanism, designs the distributed power trading system architecture and trading process based on blockchain, and develops the pilot application, which solves the trust problem in the distributed power trading process, ensures the transparency and fairness of the transaction, and effectively enhances the enthusiasm of the transaction subjects.

II. BLOCKCHAIN TECHNOLOGY AND DISTRIBUTED ELECTRICITY TRADING

A. Blockchain Technology

a. Concept and principle of blockchain

Blockchain is an emerging information technology in the Internet era. It tracks and analyzes the behavior of participants through credit, evidence and transaction records, and is suitable for any decentralized trust network. There are narrow and broad definitions of blockchain. In a narrow sense, blockchain is a decentralized shared ledger that combines the data blocks generated in the system into a specific data structure in the form of a chain in the order of time, and guarantees that they cannot be tampered with or forged based on the principle of cryptography. It can safely store simple, time-sequential and verifiable data within the system. In a broad sense, blockchain is a new decentralized infrastructure and distributed computing paradigm that utilizes encrypted chain block structure to verify and store data, uses distributed node consensus algorithm to generate and update data, and utilizes automated script code (i.e., smart contract) to program and manipulate data [13-14].

The structure of blockchain is shown in Figure 1. Each block consists of two parts: the block header and the block body. The block header mainly includes the hash value of the previous block, the hash value of the current block, the timestamp, the Merkle root value, the random number, etc. The block body includes the detailed data information of the block, which is combined with the hash value of the previous block and the random number to obtain the hash value of the block through the hash algorithm. If the data information in the block body changes, the hash value of the corresponding block body also changes, which can effectively prevent data tampering and realize authenticity, credibility and traceability of the data [15-16].

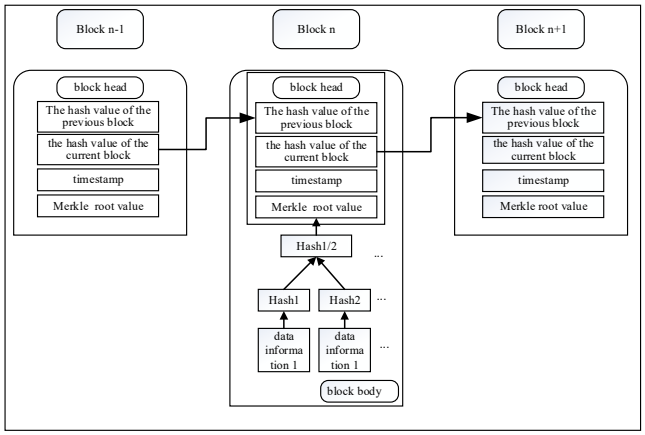

Figure 1. Blockchain Structure Diagram

b. Core Technologies of Blockchain

1) Distributed ledger. Distributed ledger is a distributed database that is independently stored and updated by each participant and each node in the network. The distributed record of ledger in the blockchain is no longer the traditional centralized communication with each node, but the independent peer-to-peer communication between each node. Each node in the network can handle its own transactions independently and share data with any other node. The architecture and characteristics of distributed ledgers can effectively reduce the cost of trust.

2) Asymmetric encryption. Asymmetric encryption refers to using a secret key to encrypt and decrypt, the keys for encryption and decryption are different and cannot be calculated between each other. In an unsafe environment, the security of asymmetric encryption key is higher, so the blockchain network transactions mostly use asymmetric encryption technology, common asymmetric encryption algorithms include RSA and ECC.

3) Consensus mechanism. Consensus mechanism is a blockchain management system. It is a set of methods designed by combining economics, game theory and other disciplines to ensure that each node in the blockchain can actively maintain the blockchain system. It is the core to ensure safe and stable operation of the blockchain. By applying the consensus mechanism, the consensus of all participating nodes can guarantee the correctness of the transaction. At present, the mainstream consensus algorithms include PoW, PoS, DPoS, PBFT and so on.

4) Smart contracts. A smart contract is an executable program that can be triggered to complete a predetermined transaction. A smart contract is a digital contract that only operates if the requirements are met, otherwise it will not produce results. When the written smart contract is stored in the blockchain network, the blockchain gives the smart contract immutability [17].

B. Distributed Power Trading

a. Mechanism of trading

Distributed generation refers to the small and medium-sized power generation facilities, which are connected to the distribution network and consumed nearby. Distributed

generation projects can be built in a complementary manner with multiple energy sources, and energy storage facilities are encouraged to be installed in distributed generation projects to enhance the flexibility and stability of power supply. Projects participating in the market trading of distributed generation shall meet the following requirements: projects with a grid connection voltage level of 35 KV or below shall have a single capacity of not more than 20 MW (for those that have their own electricity consumption, not more than 20 MW after deducting the maximum annual electricity load). The capacity of a single project should be more than 20 MW but not more than 50 MW, and the grid voltage level is not more than 110 KV and is absorbed within the range of this voltage level [18].

The institution of distributed power generation project conducts power trading with the nearest power users within the distribution network who meet the transaction conditions, and signs a tripartite power supply and consumption contract with the power grid enterprise, who serves as the transmission service party. The contract stipulates the transaction term, transaction quantity, settlement price, "network crossing fee" standard and liability for breach of contract. The institution of distributed power generation project firstly conducts transactions with power users who can absorb all their on-grid electricity. Power grid enterprises undertake the power transmission of distributed generation, cooperate with relevant power trading institutions to organize distributed generation market-based transactions, and collect "network passing fees" according to the standards approved by the government.

b. Mode of trading

The characteristics of distributed power generation is that the power generation is connected to the distribution network and consumed in the nearby distribution network. At the same time, it needs to meet the requirements of energy efficiency, environmental protection and safety. Trading modes are mainly divided into three categories [19] :

1) Direct trading mode. Direct transaction mode is the main mode of distributed generation transaction marketization. In this mode, distributed generation project trades directly with power users, power grid enterprises provide power transmission services, and the three parties need to sign a supply and power supply contract to determine the transaction term, transaction quantity, settlement method, settlement price, network fee standard and liability for breach of contract.

2) Entrust the power grid enterprise to sell electricity. This mode is a trading mode that power grid enterprises sell electricity on commission. Power grid enterprises supply electricity to users in a unified manner according to the electricity supply of the distributed generation project and the comprehensive electricity sale price, and deliver the electricity sale income to the distributed generation project provider after deducting the network fee. The distributed generation project needs to sign a contract with the power grid enterprise to determine the term of cooperation, the amount of traded electricity and the settlement method, etc.

3) Power grid enterprises make the purchase according to the benchmark price. Power grid enterprises are regarded as power purchasers of distributed power generation projects and purchased according to the benchmark price. Power grid enterprises make the purchase of distributed power generation projects who do not participate in market transactions uniformly according to the benchmark price. Countries should provide subsidies per KWH that deduct the transmission and distribution price of users with the highest voltage level in the region to power grid enterprises according to the policy.

C. Compatibility Analysis of Blockchain Technology and Distributed power trading

Blockchain technology has the technical characteristics of "decentralization, transaction immutability, traceability, transaction transparency, interconnection and sharing", and distributed power trading mode has the technical requirements of "subject equality, intelligent mutual trust, fairness and justice, information sharing". This indicates that blockchain technology has a high compatibility with distributed power trading [20] :

1)Blockchain is jointly maintained by the whole network nodes in a decentralized way, and there is no central organization, which is in line with the attributes of distributed power tradings:autonomous and spontaneous;

2) Blockchain guarantees the fairness, notarization and openness of transactions with the principle of cryptography, which could meet the demand of market fairness for distributed power tradings;

3) Blockchain data is traceable. Once a transaction is recorded, it will be automatically executed and cannot be tampered, which could ensure the execution of the distributed power tradings.

The compatibility analysis of blockchain technology and distributed power trading is shown in Table 1.

TABLE I. COMPATIBILITY ANALYSIS OF BLOCKCHAIN TECHNOLOGY AND DISTRIBUTED POWER TRADING

Technical characteristics of blockchain	Technical requirements of distributed power trading	Compatibility Analysis	The advantages of the combination
Decentralization	Subject equality	Blockchain has the characteristics of decentralization, and the status of each participating node is the same, which is compatible with the equality and decentralization of each subject of distributed power trading.	Reduce trading cost
Immutability & Traceability	Intelligent mutual trust	Blockchain provides each node with equal rights to read and write information. The information cannot be tampered with and can be traced back, which is compatible with the requirements of distributed power trading for the authenticity and reliability	Reduce credit cost

Technical characteristics of blockchain	Technical requirements of distributed power trading	Compatibility Analysis	The advantages of the combination
		of the whole process of power trading information.	
Transaction transparency	Fairness and justice	The consensus mechanism of blockchain platform and the operation rules of smart contracts are open and transparent, which is compatible with the requirements of distributed power trading for fairness and justice.	Improve transaction credibility
Interconnection and sharing	Information sharing	The information of each node of the blockchain platform is not restricted by access, and it can master the changes of relevant information in the transaction process, which is compatible with the realization of full information sharing and quick transaction matching among the subjects of distributed power trading.	Improve trading efficiency

III. PDISTRIBUTED POWER TRADING ARCHITECTURE BASED ON BLOCKCHAIN ASYNCHRONOUS CONSENSUS

A. Design of asynchronous consensus mechanism

In order to adapt to the large-scale distributed power trading scenario and improve the throughput rate of the blockchain system, the sharding technology is adopted to disperse the data to different chains or regions for decentralized processing, which is helpful to increase the parallelism of the blockchain system and improve the throughput rate of the system. The basic idea of blockchain sharding is to divide the nodes in the blockchain network into several relatively independent sharding. A single sharding processes small transactions or stores part of the network state. If multiple sharding processes transactions in parallel, the throughput of the whole network will be improved. Blockchain sharding strategy mainly includes network sharding, transaction sharding and state sharding. Network sharding is the basis of transaction and state sharding. Transaction sharding determines the processing model of blockchain transactions, in which including the way to partition transactions into shards and the way to confirm transaction consistency. State sharding separates the storage of the system, each shard is only responsible for hosting the data of its own shard, and does not store the complete state of the blockchain.

In this scheme, a sharding asynchronous consensus mechanism suitable for distributed power trading is established. The sharding blockchain is jointly maintained through the scenarios involved in the distributed power trading mode, such as micro-grid, comprehensive energy, virtual power plant, power users, etc., and the verification node, consensus node and management node are dynamically updated by election every other cycle in combination with node credit.

1) When sharding starts to operate, the common nodes in each dynamic cycle sharding region will make a consensus, and the verification node with the worst performance in the current slice will be elected and replaced. The verification node will carry out consistency check on the transactions in the shard through consensus;

2) If the result of consistency check is consistent, the transaction information will be packaged into a block and submitted to the consensus node or management node, and the consensus node or management node participates in the the consensus process of partitioning again through the consensus agreement; If it is inconsistent, for example, when achieving transaction processing, sharding consensus may contain a variety of transactions with a large probability distribution in different slices. Therefore, cross-slice transaction processing should be considered in sharding consensus.

3) During cross-chip transaction processing, a master node is randomly selected from the verification nodes in each dynamic cycle, and number of master nodes of shards are randomly selected to form an asynchronous consensus group with the master nodes of this shard. After asynchronous consistency verification, each master node among the consensus groups will pack the transaction information into blocks.

The sharded asynchronous consensus mechanism is applied in distributed power trading scenarios to ensure the security and credibility of the system, improve the transaction throughput rate, reduce transaction delay of the system, and thus improve the reliability, security and consensus efficiency of the system consensus to meet the needs of large-scale power trading scenarios. A schematic of the asynchronous consensus mechanism is shown in Figure 2.

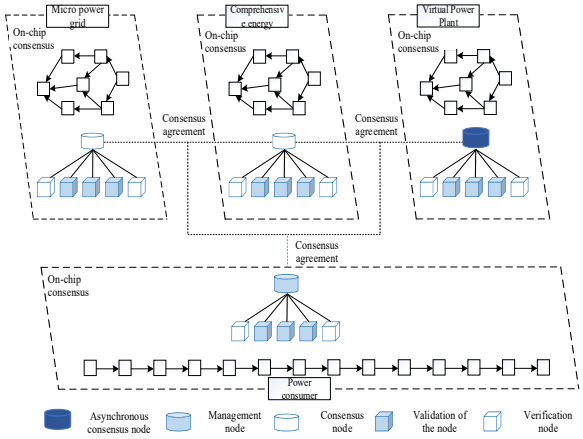

Figure 2. Blockchain Asynchronous Consensus Mechanism

B. System architecture

Considering the intelligent mutual trust and information sharing in the distributed power trading process, in order to realize the information interaction between market entities and regulators, the distributed power trading system based on blockchain is divided into infrastructure layer, platform layer, service layer, application layer, access layer, security protection, operation and maintenance management and other parts in this paper. The architecture diagram of distributed power trading system based on blockchain is shown in Figure 3.

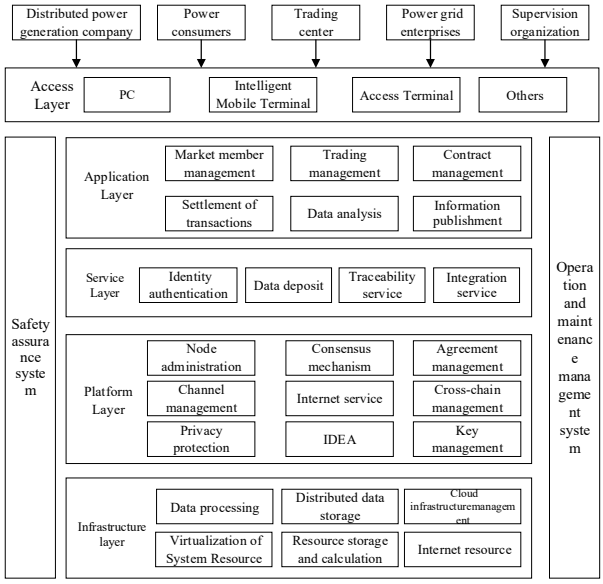

Figure 3. Blockchain Distributed Power Trading System Architecture

1) Infrastructure layer. Through the construction of basic environment, hardware and software infrastructure, network and data storage and other aspects, this layer could help to meet the requirements of physical resources in the operation and application process of various businesses in the blockchain distributed power trading system.

2) Platform layer. This layer is the core technology layer of blockchain distributed power trading system, which mainly provides the core technical support of blockchain, such as node management, consensus mechanism, encryption algorithm and smart contract.

3) Service layer. The function of this layer is to achieve the blockchain identity authentication service, data storage service, traceability service, integration service and other functions.

4) Application layer. This layer could support the application of distributed electricity transaction, the main functions of this layer include market member management, transaction management, contract management, transaction settlement, data analysis, information release and others.

5)Access Layer. This layer provides the required user access service entry for the blockchain distributed power trading system. It could help to offer a full range of intelligent services for distributed power generation companies, power users, trading centers, power grid enterprises, regulators and other parties.

6) Safety assurance system. This system provides information security protection for the blockchain distributed power trading system, strengthens access control and operation internally, prevents illegal intrusion and malicious damage externally, and ensures the overall security of the whole system.

7) Operation and maintenance management system. It provides a guarantee for the operation and maintenance of the blockchain distributed power trading system, meets the real-time monitoring of the running state of the power trading system, and ensures the efficient and stable operation of the trading system.

C. Transaction process

Blockchain-based distributed power trading process mainly includes market access, demand and quotation submission, transaction matching, security check and blocking management, transaction settlement and others. The transaction process is shown in Figure 4.

1) Market access: distributed generation companies and power users need to register in the blockchain transaction system, and determine whether the relevant subject members meet the access conditions according to the market access rules. After passing the audit, each subject will log in the transaction system to participate in the electricity transaction.

2) Demand and quotation submission: Distributed generation companies and power users submit the electricity price and quantity of the next trading cycle to the trading system according to their own forecast about electricity generation and consumption. According to the relevant information received, the smart contract of blockchain is used to calculate the quotation of each principal member and to broadcast to all nodes of the whole network through P2P network.

3) Transaction matchmaking: Blockchain transaction system matches the prices of distributed power generation companies and power users to form reservation orders. If the conditions of smart contract matchmaking are not met, each subject will resubmit the offer for matchmaking until the transaction is successful. The transaction quantity, transaction price and identity information of each subject involved in the whole process of transaction are stored in the blockchain system to prevent malicious changes to relevant information.

4) Security checking and blocking management: According to the results of the matchmaking, security checking and blocking management are carried out. If the trend does not exceed the limit, the security checking is passed and the transaction settlement process is transferred. If the security checking is not passed, the transaction volume is automatically adjusted through the smart contract of blocking management.

5) Transaction settlement: The transaction information recorded by the blockchain system is broadcast to the whole network through the P2P network in combination with the data of power generation and consumption and settlement rules of distributed power generation companies. The final transaction documents are generated and the transaction settlement is completed according to the intelligent and automatic execution.

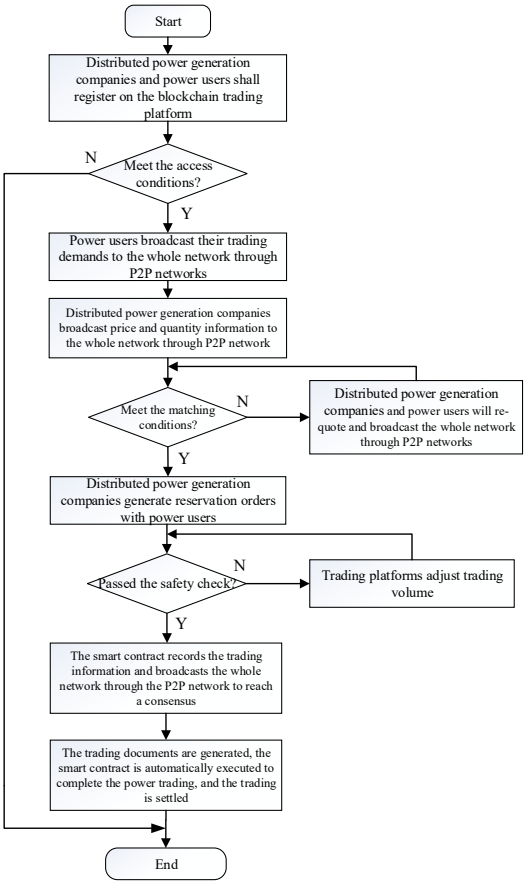

Figure 4. Transaction Process

IV. PILOT APPLICATION

In combination with the demand of blockchain technology and the requirement of distributed power trading, the application scenarios of distributed power supply, virtual power plant, micro grid, integrated energy in Ningxia, Shanxi, Qinghai and other places are selected to carry out the deployment and verification of distributed power trading system based on asynchronous consensus mechanism. From the test results and application effects, the system establishes an equal and credible decentralized trading network among multiple subjects including source network, load and storage, and achieves a fair, point-to-point, real-time and mutual trust transaction between users, which can achieve fairness, impartiality and reduce the uncertainty of the transaction. Up to now, it has served thousands of various transaction subjects, matched more than 100 transaction subjects, optimized the distributed electricity transaction process, improved the efficiency of electricity transaction, increased the efficiency of segmented consensus by 8%, met the needs of distributed electricity transaction, ensured the whole process of distributed electricity transaction is open and transparent, promoted the enthusiasm of transaction subjects to participate in the transaction, activated the development of new energy industry, and promoted the improvement of the consumption level of new energy.

V. CONCLUSION

In order to adapt to large-scale distributed power trading scenarios, this paper carries out compatibility analysis of blockchain technology and distributed power trading technology according to the technical characteristics of them, studies how to apply blockchain shard technology and cross-chip asynchronous consensus mechanism to distributed power trading field, designs distributed power trading system architecture and trading process based on blockchain asynchronous consensus mechanism, and selects Ningxia, Shanxi, Qinghai and other places for pilot application. The series of research effectively verifies the effectiveness of the application of blockchain asynchronous consensus mechanism in distributed power trading system, achieves good application effect to solve the trust problem in the process of distributed power trading, ensures the transparency and fairness of the transaction, and has certain reference significance for the application of blockchain in the field of distributed power trading. With the deepening of power system reformation and the continuous development of distributed energy field, new business forms, new transaction modes and service modes will be rapidly developed in future energy internet projects. How to apply blockchain technology to provide support for the new transaction mode will also be the focus of future research.

ACKNOWLEDGMENT

The Science and Technology Foundation of SGCC,Grant no:SGSXXT00JFJS2000206.

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