International Journal of Computer Science and Information Technology
ISSN: 3005-9682 (Print), ISSN: 3005-7140 (Online) | Volume 3, Number 3, Year 2024
DOI: https://doi.org/10.62051/ijcsit.v3n3.23
Journal homepage: https://wepub.org/index.php/IJCSIT/index

Research on the Application of Blockchain in Integrated Energy Systems

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ABSTRACT

In the low-carbon background, the synergistic development of multiple energy flows has become an important development direction for the reform of the energy system, and the blockchain technology itself has features that can greatly empower the integrated energy system. This paper firstly introduces blockchain theory, characteristics. Secondly, by analyzing the characteristics between blockchain and comprehensive energy system, the fit between the two is further analyzed, and the current status of energy blockchain technology research is sorted out and summarized. Finally, it looks forward to the development prospect of energy blockchain, and puts forward relevant suggestions on the development direction and requirements of energy blockchain technology in the future in view of the problems existing in the existing research.

KEYWORDS

Blockchain; Integrated energy system; Energy blockchain

1. INTRODUCTION

As global environmental awareness grows stronger, the contradiction between energy consumption and environmental protection is becoming more and more prominent, and improving energy efficiency and finding clean and low-carbon alternative energy sources have become important measures to help the energy system complete its reform. Since the introduction of the "3060 Goal", the State has been continuously stepping up its efforts to promote the transformation of the energy system into a low-carbon one. In order to ensure the realization of this goal, the state strongly supports research on the synergy and complementarity between heterogeneous energy sources. The integrated energy system converts heterogeneous energy sources into energy sources that can be directly consumed by users, such as electricity, heat, cold and natural gas, through the coupling element, and realizes the coordination and synergistic optimization of the production, transmission, conversion, storage and consumption of energy sources in the region or across the region. Blockchain technology's features of de-trusting, decentralization, transparency, data encryption, fairness, and distribution coincide with the characteristics of the integrated energy system and its development needs, and will become an important support for China's development of the integrated energy system. The combination of comprehensive energy and blockchain technology will show great vitality, and the application of energy blockchain technology will help create a decentralized energy market and promote the development of comprehensive energy systems.

2. BLOCKCHAIN BASIC THEORY AND TECHNICAL CHARACTERISTICS

A decentralized crypto digital currency supported by blockchain technology as the underlying layer was known in 2018, and because of this the technology of blockchain stepped into people's view. Blockchain is a distributed shared ledger and database with the characteristics of decentralization, de-trust, openness and transparency, traceability, and non-tampering. At present, according to different degrees of openness blockchain can be divided into private chain, public chain, and alliance chain.

(1) Public Chain: Public blockchain is open to everyone, anyone can participate in the blockchain network, such as Bitcoin, Ether, etc.. The public chain is completely open, there is no entry threshold standard, everyone can access the blockchain, participate in transactions, and all the information and data on the blockchain are open and transparent. This type of blockchain with the highest degree of decentralization is characterized by transparency, openness and security.

(2) Private Chain: A blockchain network that only specific people or organizations have access to, such as an internal enterprise blockchain or a federation chain. The private blockchain is partially public, set up with access standards that specify who can access and write to the blockchain. It is mainly open and transparent to a small number of institutions or individuals within the scope of permitted access, and the degree of decentralization is the lowest among the three types, but the transaction speed is faster and the security is higher, which is suitable for some scenarios with higher privacy requirements.

(3) Coalition chain: a type of blockchain between public chain and private chain, with access permission restricted to a specific institution or organization, slightly larger than the scope of private chain. A federated chain is also partially public and transparent only to those who are licensed to access it. It combines the partially decentralized nature of a public chain with the high security of a private chain, and is suitable for scenarios where multiple parties are involved but there is some need for privacy.

The following are the main features of blockchain technology:

(1) Decentralization: one of the core features of blockchain technology is decentralization. It does not require a centralized institution or server to manage and control the data. Instead, the data is maintained by numerous nodes in the network that are distributed across the globe and work together to verify and record transactions. This decentralized structure reduces the risk of a single point of failure and improves the robustness and security of the system.

(2) Non-tamperability: Blockchain technology utilizes cryptographic principles to ensure that data, once written, cannot be modified. This is because each block generates a unique hash value through the hash algorithm, and each block not only includes the information of this block, but also contains the hash value of the previous block. This linking mechanism makes any tampering with the data immediately recognized by other nodes in the network. Therefore, blockchain provides a highly reliable data storage and transmission mechanism.

(3) Transparency and traceability: Transaction information on the blockchain is public to the nodes participating in the network, which means that anyone who has access to the network can view the transaction records on the chain. This transparency helps to increase trust, reduce fraud, and facilitate compliance. However, some blockchain designs also offer privacy-preserving features, such as the use of technologies such as zero-knowledge proofs to hide transaction details, thus enabling transparency while protecting user privacy.

(4) Security: Blockchain technology employs a range of cryptographic algorithms and security protocols to secure data. Through the encryption mechanism of private and public keys, users can securely conduct transactions and access their assets. In addition, consensus mechanisms (e.g., proof of workload, proof of equity, etc.) ensure that nodes in the network agree when adding new blocks, thus preventing double-flush attacks and other potential security risks.

(5) Smart Contract: Smart contract is one of the core technologies of blockchain, which is to digitize the contracts in daily life, and when certain conditions are met, they will automatically perform the corresponding operations. This feature makes blockchain able to support more complex business logic and automated processes, improving the efficiency and reliability of transactions.

In summary, the decentralization, tamperability, transparency, security and smart contracts of blockchain technology together constitute its unique value and application potential. These features make blockchain have a wide range of application prospects in many fields.

However, it is also important to note that blockchain technology still faces a number of challenges in terms of scalability, privacy protection and other aspects, which need to be continuously developed and improved.

3. THE FIT BETWEEN BLOCKCHAIN AND INTEGRATED ENERGY SYSTEMS

The fit between blockchain technology and comprehensive energy system is reflected in several aspects, which helps to improve the efficiency, security and transparency of the energy system.

(1) The decentralized characteristics of blockchain technology fit with the distributed nature of integrated energy systems. An integrated energy system usually consists of multiple energy types, including renewable energy and traditional energy, which are distributed in different geographic locations and connected and coordinated through a network. Blockchain technology enables decentralized data storage and validation through a distributed ledger and a network of nodes, thus avoiding the risk of a single point of failure and data tampering. This enables blockchain technology to support the distributed management and coordination of integrated energy systems and improve system flexibility and reliability.

(2) The data immutability of blockchain technology helps ensure the security and integrity of data in integrated energy systems. In energy transactions, the accuracy and trustworthiness of data is crucial. Blockchain technology uses the principle of cryptography to connect each block with the hash value of the previous block, forming a tamper-proof data chain. This provides strong protection for the data in the integrated energy system and ensures the authenticity and trustworthiness of the data.

(3) The open and transparent characteristics of the blockchain also help to improve the transparency of the integrated energy system. Transaction records on the blockchain are publicly visible and can be viewed and verified by anyone with access to the network. This makes energy transactions and flows in an integrated energy system more transparent and helps to increase trust and cooperation among all parties. At the same time, transparency also helps to detect and prevent fraudulent behavior in energy transactions and improve the security of the system.

(4) Smart contract mechanism. A smart contract is a self-executing digital protocol that can automatically perform corresponding operations when certain conditions are met. In the integrated energy system, smart contracts can be used to automate energy transactions, optimize energy allocation and scheduling and other tasks, improving the operational efficiency and intelligence of the system.

From the above, it is easy to see that the fit between blockchain technology and integrated energy system is reflected in various aspects such as decentralization, non-tamperability, transparency and smart contracts. This fit helps to improve the efficiency, security and transparency of the comprehensive energy system and promote the sustainable development of the energy industry.

4. RESEARCH STATUS OF BLOCKCHAIN TECHNOLOGY IN ENERGY SYSTEM

Under the characteristics of energy system presenting distributed and multi-energy flow synergy, blockchain technology serves as one of the core technologies to realize reliable operation, security and transparency, and decentralization of integrated energy system. There have been studies on the combination of blockchain and integrated energy system, the content is roughly divided into three categories, the following will be summarized in the literature research.

Blockchain's distributed energy transactions, blockchain technology can realize direct energy transactions between participants, remove the intermediaries of traditional energy transactions, and greatly improve transaction efficiency and security. Literature [1] constructs an energy system infrastructure supported by blockchain technology, divides energy Internet users into six kinds of participant subjects, and realizes an energy security transaction system scheme with the characteristics of tampering and decentralization of transactions. Literature [2], based on game theory, takes the maximization of benefits of energy trading as the objective function, constructs a game model of multi-energy trading strategies, provides new solutions for solving the problems of energy trading security, efficiency and fairness brought about by the large-scale influx of users, and provides price references for the trading mechanism. Literature [3] adopts blockchain technology to design a secure energy trading model supporting decentralized data control mechanism, which ensures the reliability of the transaction, and at the same time effectively copes with the future large-scale data influx. Literature [4] used a heterogeneous energy blockchain structure model to propose a transaction model based on blockchain technology, designed an auction mechanism conditioned on price constraints and matched by smart contracts, which guarantees the priority of clean energy users, and used a double authentication mechanism to guarantee the security of the transaction. Literature [5] on the basis of smart contract technology, constructed for the microgrid peer-to-peer energy trading model with the producer and consumer as the research object, to improve the proportion of renewable energy consumption at the same time, the user benefit can be increased. Literature [6] proposes an integrated energy system optimization model containing cross-chain trading of green certificates, breaking the barriers of value and data in the traditional green certificate market. Literature [7] designs a multi-chain structural support environment model that integrates consensus and contract mechanisms to meet the requirements of energy blockchain transactions, in view of the characteristics of the participation of multiple subjects. Literature [8] in response to the blockchain in distributed energy systems, there are heterogeneous inter-blockchain communication difficulties, poor scalability, the paper proposes a heterogeneous energy blockchain multi-energy complementary security transaction model to achieve secure cross-energy synergy. Literature [9] proposes an integrated energy management system framework based on blockchain technology and designs a special zero-knowledge proof authentication method to guarantee the privacy of energy users in the transaction process. In addition, considering the regional energy trading system compared to the distributed energy trading system, there are many problems such as low efficiency, high consumption cost, and security cannot be guaranteed. Literature [10] constructs a regional energy transaction model based on blockchain technology, completes the automatic execution of transactions through smart contracts, and provides a reference direction for the further application of blockchain technology in the energy system in the future. Literature [11] designed an energy market model in which energy merchants and users can conduct two-way transactions. As an important aspect of regional energy trading, the prospect of integrating blockchain technology into the direct power purchase system for large users is promising. Literature [12] combines the characteristics of large-user direct power purchase, cites the framework of large-user direct power purchase transaction, analyzes the many challenges that will be faced after the combination of blockchain technology and large-user direct power purchase, and gives reasonable measures to solve the problems. Literature [13] considers the impact of energy transactions on the operation of the power system, constructs a transaction architecture integrating

blockchain, calculates the overall probability of each attack to assess the security level of different transaction frameworks.

Blockchain-based energy system scheduling. Traditional centralized scheduling in a unified center requires rapid collection of comprehensive data information and processing of all decision-making variables, which results in high pressure on IES data transmission, high security risks, and inefficient operation; in addition, each participating subject in the energy system tends to retain the right of autonomous scheduling, aiming to defend its own rights and interests and data security. In order to achieve the goal of autonomous operation and cooperative scheduling of each subject, the introduction of blockchain technology can be considered. Literature [14] constructed a general architecture for optimal dispatching of integrated energy systems, which makes the blockchain network become the information interaction and data storage center of the energy system, and retains part of the guiding role of the dispatching center to ensure the safe and stable operation of the power grid. Literature [15] utilizes the characteristics of decentralized scheduling methods and blockchain technology to propose an IES scheduling architecture that can operate effectively based on a small amount of data. In addition, China's power grid spans a large area, and irrational power scheduling can cause high power consumption. Literature [16] constructs a shared energy storage scheduling model for microgrids based on energy blockchain network, which effectively reduces the power consumption and improves the energy storage scheduling capability of microgrids.

In the context of large-scale integration of renewable energy systems into the power system, the distribution grid is developing in the direction of more intelligent and flexible, and it needs to be able to monitor the state of the distribution grid in real time, and help the distribution grid realize autonomous coordination and intelligent control. Literature [17] uses Ethernet technology to construct a decentralized distributed distribution network real-time multi-variable transaction mechanism and model, which well meets the needs of decentralized transactions and open and transparent data in distribution networks. Literature [18] constructed a hierarchical architecture model of energy internet based on blockchain technology, and designed an intelligent transaction model and trust mechanism of energy internet with centralized transaction, which fits the characteristics of intelligent management, regulation and control of each node in the power grid. Literature [19] proposes a weakly centralized hierarchical network communication architecture to realize real-time power mutual aid transactions between nodes at all levels of the power system and to guarantee the reliable operation of the power system. Literature [20] proposes a renewable energy power tracking model taking into account the principle of proportional distribution, determines the amount of consumption of the quota theme and carries out the assessment, which effectively promotes the amount of consumption.

Overall, the research on blockchain technology in energy systems aims to improve the efficiency, security and sustainability of energy transactions and promote decentralized control and management of energy. Although there are still some technical and regulatory challenges, the prospect of blockchain application in energy systems is still very promising.

5. CONCLUSION

Nowadays, people's energy load demand is gradually diversified, in the carbon neutral era of development, the development and construction of multi-energy flow synergistic optimization of the integrated energy system has become an inevitable choice for the reform and transformation of the energy system. Comprehensive energy system can realize the complementary mutual aid between heterogeneous energy sources such as electricity, natural gas and cold and heat energy, and guarantee the load demand of energy users. With the large-scale grid integration of renewable energy, the power system presents distributed characteristics and wide range of renewable energy due to its volatility, uncertainty to the safe and reliable operation of the power system has brought challenges, in addition to the face of wind abandonment, abandonment of the phenomenon of serious light. Blockchain

technology provides technical support for solving the problems faced by the integrated energy system due to its decentralized, transparent and traceable, and impartial characteristics. Existing applications of blockchain technology in integrated energy systems mainly involve the fields of energy trading, energy dispatching, and power grid management. With the large-scale construction of the total integrated energy system and the participation of more energy users, blockchain, as an information technology with the advantages of traceability, anti-tampering, high reliability, etc., the application of blockchain in the energy field can accelerate the intelligent transformation and upgrading of energy and electricity, and promote the development of multiple links such as energy production, transmission and distribution, trading, consumption, and regulation in the direction of greater safety, environmental protection, and high efficiency. In addition, it is expected to reshape the operation mode of the energy industry. By realizing the sharing and real-time updating of energy data, energy blockchain will promote the collaborative autonomy of the energy system, enhance the efficiency of energy transactions, and promote the popularization of renewable energy. At the same time, it also helps build a global energy supply network to ensure the security and stability of energy supply.

However, in the case of reverse distribution of energy and load centers, the combination of blockchain and integrated energy systems still has certain deficiencies, and further exploration and research is still needed to solve the challenges of technology, regulations and security in order to achieve a better fit and meet the practical application needs of the energy system. In view of the existing problems of the combination of the two and the future development trend, this paper puts forward the following suggestions:

(1) Strengthen technology research and development innovation. The existing energy blockchain system still has deficiencies in performance, stability, security and other aspects. In the further development of more secure encryption algorithms to improve the security of transaction data and protect the privacy of both parties, it is also necessary to optimize the blockchain consensus mechanism and network architecture to improve the processing capacity.

(2) Accelerate standardization and interoperability. With the large-scale investment and construction of energy systems, energy systems have taken on distributed characteristics, and it is important to promote the standardization of energy blockchain and formulate unified technical standards and data interfaces, so that different blockchain platforms can be docked peer-to-peer with each other. This will help break down barriers between different industries and promote the widespread application of energy blockchain.

(3) Establish sound policies and regulations and implement regulatory mechanisms. The development of energy blockchain needs a good regulatory and policy environment and regulatory system to guarantee it. The government should introduce relevant policies to encourage and support the development of energy blockchain, and at the same time strengthen the supervision of energy blockchain to ensure its compliant operation.

(4) Strengthen talent training and foreign cooperation and exchange. Talents are necessary for the stable and long-term development of anything. The development of energy blockchain needs the support of high-quality professionals. We should strengthen talent cultivation, build a perfect talent cultivation system and introduce efforts to cultivate a group of composite technical talents with knowledge of blockchain technology and the energy industry, so as to inject "fresh blood" into the reform of the energy system. At the same time, we should strengthen the communication and cooperation between relevant organizations and enterprises at home and abroad, and collect the strengths of a hundred schools of thought, so as to jointly promote the technological innovation and application development of energy blockchain.

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