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CONSTRUCTION OF A POWER MARKET TRADING PLATFORM BASED ON REGIONAL BLOCKCHAIN TECHNOLOGY

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Abstract. In order to solve the problems of traditional centralized trading platforms being difficult to handle rapidly increasing transaction data, achieving cross regional information sharing and resource unified optimization configuration, the author proposes the construction of a power market trading platform based on regional blockchain technology. This technology is based on the regional power energy trading architecture, designs a decentralized cloud energy storage blockchain trading model, and further refines the three-layer technical architecture of the business layer, middleware, and open license chain, thereby ensuring effective collaboration between the client and the distributed backend. In order to further improve the computational efficiency of the system, the author proposes a consensus algorithm optimization scheme based on transaction credit evaluation. The evaluation of blockchain nodes is achieved through the joint evaluation of multidimensional indicators, and the credit ranking of nodes is completed based on the defined transaction priority weight. The experimental results indicate that: Compared with the comparison algorithm, the clustering accuracy obtained by the proposed algorithm is higher, with a maximum value of 91.56%, indicating that the proposed algorithm correctly clusters more electricity sales information. The algorithm proposed by the author can reduce the probability of malicious transactions compared to existing algorithms, while improving the processing power and response speed of the trading system.

Key words: Blockchain, Electric energy, Credit evaluation, Consensus algorithm

1. Introduction. In a narrow sense, the electricity market refers to the mechanism by which electricity producers and users determine prices and quantities through competition. The construction of the electricity market and the establishment of trading platforms are of utmost importance in the reform of the electricity system, and are also key factors in the success or failure of the reform [1]. The electricity market trading platform is a technical support system that serves market operations. The power trading platform is one of the key components of the national power market trading operation system, which contains a wide range of information types and involves a wide range of aspects. Therefore, it has received high attention from the state, regulatory authorities, and various sectors of society. The rapid increase in electricity trading information poses great challenges to the processing and application of electricity trading information [2]. As a distributed shared database technology, blockchain technology has the characteristics of decentralization, transparency, fairness and other characteristics consistent with the concept of the energy Internet. It can be a pattern and mode under the Internet, operate efficiently under the premise of ensuring trust, promoting transactions, achieving authentication and other advantages, and make up for the shortcomings of high transaction costs, asymmetric transaction information, low transaction data efficiency and data security in the traditional power trading mechanism, laying the foundation for building a multi-agent form of energy interconnection, information and physical integration of power trading platform [3].

With the continuous deepening of electricity reform, the market operation will become more complex and variable. In order to better avoid risks, it is important to comprehensively grasp the information trading business of the electricity market, analyze the operation of the electricity market, and timely predict market trends in future electricity trading work. The strengthening of electricity trading market analysis business is conducive to improving service quality and meeting the needs of the company's business development [4]. By collecting

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real-time data information, analyzing big data, and monitoring trading business throughout the process, we can grasp market dynamics, conduct early warning analysis, and ensure the healthy and orderly operation of the trading market. Therefore, the reconstruction design of the four major applications of commodity trading, market settlement, market services, and market analysis is of great significance, which can effectively avoid affecting the normal operation of other applications when one application malfunctions. In this way, the stability and security of the trading platform system will be greatly improved [5]. In recent years, the energy Internet, which is highly integrated with new energy power generation and information technology, has provided possible solutions for large-scale utilization and flexible access of all kinds of energy [6]. More and more market entities are transforming from traditional single energy consumers or producers to electricity producers and consumers with independent decision-making abilities, participating in electricity market competition in a more flexible and diverse way. In this new situation, how to build a reasonable and effective distribution side electricity market trading platform, fully guarantee the different interests of various market entities and the effective allocation of energy resources, is currently a key issue that urgently needs to be solved.

2. Literature Review. With the development of digitalization, networking, and information technology, as well as the expansion of the number of users on electricity market trading platforms, there are also higher requirements in terms of computing [7]. The power trading platform, based on the "cloud" technology architecture and utilizing big data to analyze basic business and expand service channels through mobile applications, has emerged in response to the trend [8]. Cloud services have high security, and transaction rules in different regions can be subdivided into various "transaction microservices" according to their respective situations. When rules change, only small-scale upgrades and adjustments to microservices can quickly adapt to the rapid development needs of the market. In the future, network technology will continue to mature, and cloud based trading platforms can be continuously upgraded to quickly expand the demand for software and hardware resources, improve the stability, reliability, and efficiency of trading platforms, and ensure that all types of market members can participate in market transactions fairly [9].

Yang et al. introduced an assessment framework for gauging the maturity of blockchain technology applications. This system encompasses five primary indicators: critical application prerequisites, data safeguarding measures, process intricacies, ecosystem coherence, and technical performance benchmarks, each accompanied by relevant secondary indicators [10]. Afzal, M. et al. categorized blockchain technology, consensus algorithms, and smart contract varieties within the context of peer-to-peer energy markets. Their work offers insights into how blockchain can revolutionize conventional markets into advanced iterations. Furthermore, they compiled a range of objective functions and strategies utilized to attain optimal objectives in electricity trading markets, serving as valuable references for researchers delving into blockchain applications in energy market trading [11]. Chen et al. argue that power energy systems are evolving towards greater decentralization, posing challenges to centralized management due to the potential absence or lack of trust in central institutions. They contend that blockchain technology presents a viable solution to this issue by facilitating trusted collaboration among stakeholders without relying on a central authority [12]. Hasan, M. et al. outlined the primary security concerns addressable by big data and blockchain technologies within smart grid contexts. Subsequently, they conducted a comprehensive review of recent blockchain-focused research across diverse literature sources, analyzing their implications for enhancing the security of smart grid systems [13].

The author combines the blockchain distributed accounting framework with the smart contract model for electricity trading to establish an electricity trading platform in a distribution side trading framework with multiple market entities. On the basis of meeting the interests of various trading entities, build a peer-to-peer distributed sharing network architecture to achieve trust and security in transactions. The effectiveness of the proposed power trading platform has been verified through examples, which can provide reference for the application of blockchain technology in the construction of a distribution side power market trading platform.

3. Method.

3.1. System Model. The regional coordination of power supply and demand is constrained by various supply and demand relationships, including policy guidance, institutional construction, platform support, and safety assurance [14]. The architecture of the regional power energy cloud storage trading system is shown in Figure 3.1.

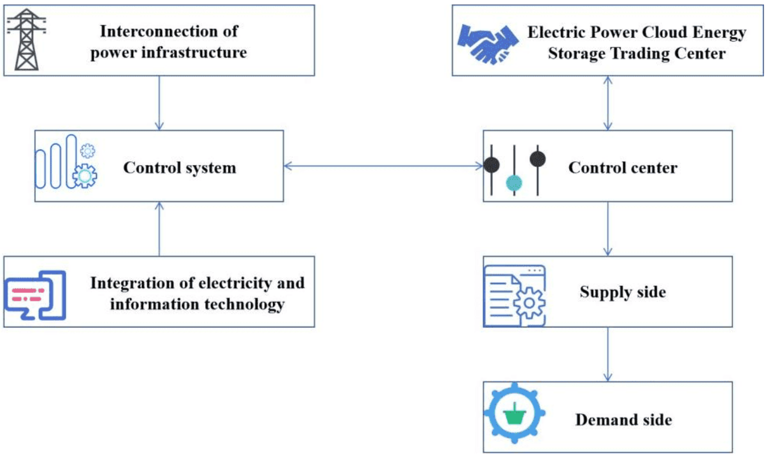


Fig. 3.1: Architecture of Regional Power Energy Cloud Storage Trading System

The power control center is the dispatch center of the entire system, which interacts with the power control system and the power cloud energy storage trading center. The control system is mainly responsible for receiving power infrastructure interconnection information, achieving the integration of power and information technology, and completing the construction of the power dispatch basic platform. The power cloud energy storage trading center is responsible for completing the transaction scheduling of online power storage units, and sending the transaction information and scheduling data to the control center, which then centrally schedules resources, and then transmits them to the power demand side through the power resource supply side.

3.2. Cloud energy storage transaction blockchain technology architecture. The transaction of the power cloud energy storage trading center needs to ensure the security of the power system, consider the convenience of transactions, and also consider the credibility of the platform. Based on this, the author proposes a blockchain based regional power energy cloud storage trading technology. Blockchain is a decentralized distributed ledger technology that has the characteristics of decentralization and immutability [15]. The overall architecture of power energy trading based on blockchain technology is shown in Figure 3.2.

The blockchain architecture adopted by the author is shown in Figure 3.3, which is mainly divided into three modules: business layer, middleware, and open license chain [16]. Among them, the business layer includes business systems, HSM services, and browsers; Middleware is mainly divided into Application Programming Interface (API), Message Queuing, and Data Processing modules; The open license chain includes communication modules, consensus modules, encryption and signature verification modules, smart contracts, and blockchain data ledgers.

The block structure adopted by the author is shown in Figure 3.3, which mainly includes two parts: Block head and block body. Different blocks can be connected together to form a blockchain.

The block header is mainly responsible for storing connection information between blocks, that is, storing the block number, the parent hash hash value of the block, the hash hash value, timestamp, difficulty target, and random number of the block. The information stored in the block header is used to ensure that the blocks can be orderly connected to the blockchain. The block body stores a large amount of transaction information, and each block is independent, and due to the association of storage parameters with the preceding and following blocks. Therefore, traceability can be carried out and the immutability of block information can be ensured [17].

3.3. Blockchain Cloud Energy Storage Transaction Consensus Technology. The use of blockchain architecture in power energy trading requires ensuring the accuracy and credibility of the entire transaction data. Therefore, it is necessary to use reasonable and efficient consensus algorithms to ensure the ecological balance of system consistency, availability, and partition tolerance. On the basis of practical Byzantine algorithms, the

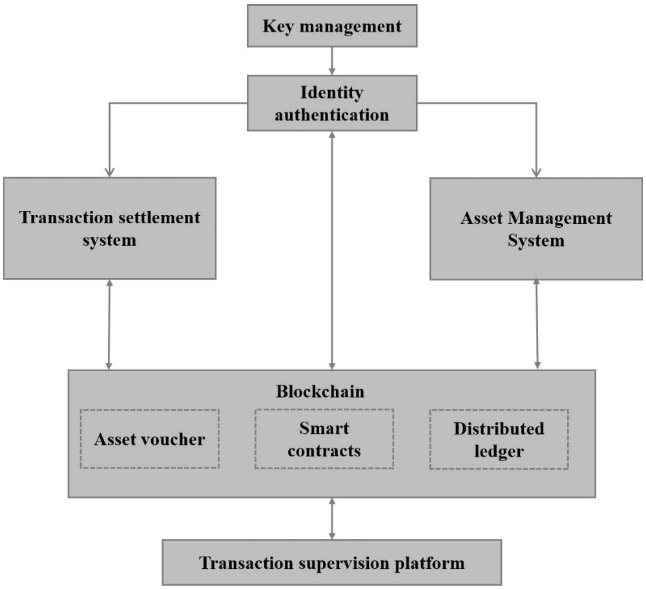


Fig. 3.2: Blockchain Power Cloud Energy Storage Trading Model

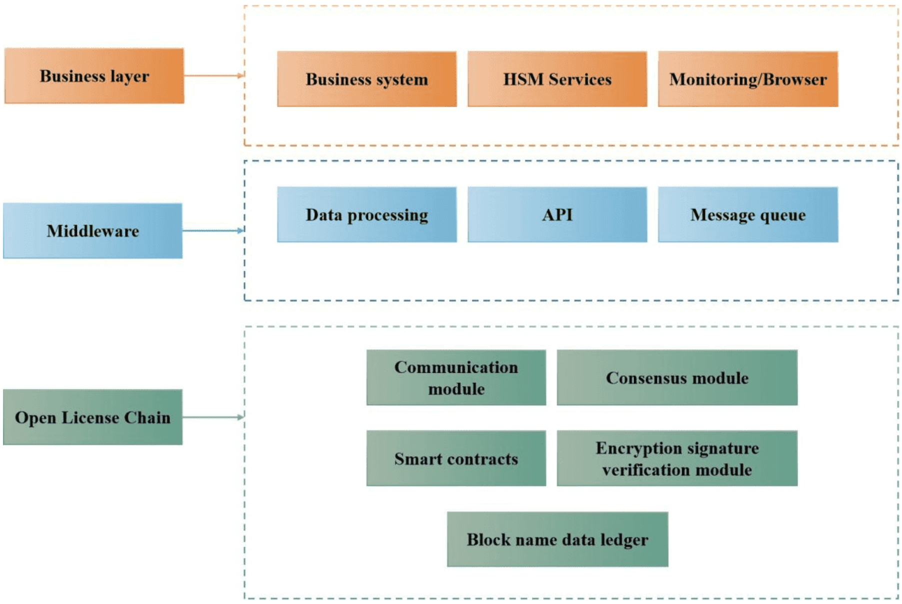


Fig. 3.3: Blockchain Power Cloud Energy Storage Trading Technology Architecture

author evaluates transaction behavior to further suppress malicious nodes and reduce computational power loss, enabling the system to quickly complete information synchronization and reach consensus. The consensus optimization algorithm process based on transaction credit evaluation is shown in Figure 3.5.

The smart contract model for electricity energy trading defined in the article is:

$$B_E = (S, B, C_E, SC, T, \mu) \tag{3.1}$$

In the formula, S represents the power supply side set, B represents the demand side set, C_E represents

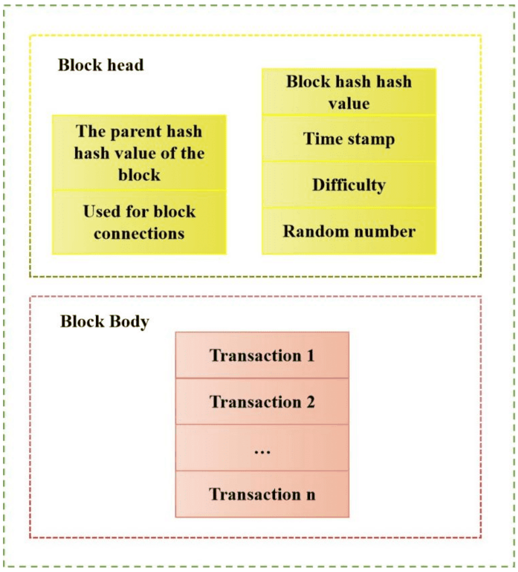


Fig. 3.4: Blockchain Block Structure

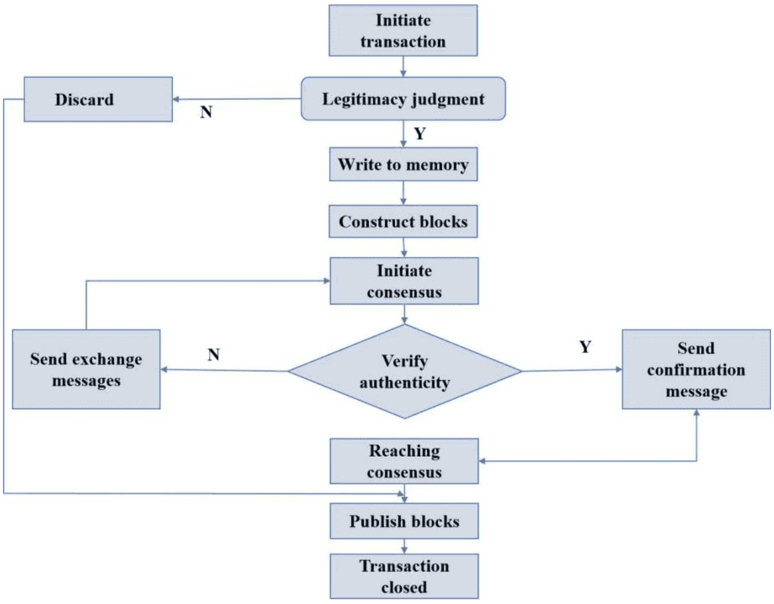


Fig. 3.5: Consensus Optimization Algorithm Process

the transaction blockchain, and SC represents the smart contract, μ represents the mapping between T and C_E. $T = \{t_k | k \in S \times B\}$ represents the set of transactions, and S×B represents the Cartesian product.

The definition of power energy trading blockchain is:

$$C_E = (C_0, C_{0a}) \tag{3.2}$$

Among them, C_0 represents the initial blockchain, and C_{0a} represents the consensus optimization algorithm. The consensus optimization algorithm based on credit evaluation proposed by the author evaluates the accuracy of electricity energy transactions, and its indicators mainly include:

1. C_1: Integrity of power energy dispatch information, including information on the demand side and supply side of power energy, electricity consumption and unit price, etc;
2. C_2: Verify the authenticity of information on the power energy supply side and verify whether the supply side truly exists;
3. C_3: Reasonability of power energy trading time, verified based on timestamp information;
4. C_4: The authenticity of information on the demand side of electricity energy;
5. C_5: Adequacy of funds on the demand side of electricity energy, which can meet the electricity resources required for payment;
6. C_6: Random number matching of transaction information.

In summary, the accuracy evaluation results of electricity energy trading can be expressed as:

$$T_K^n = \prod_{i=1}^{6} C_i \tag{3.3}$$

In the formula, T_K^n represents the accuracy of the transaction, K represents the blockchain number, n represents the transaction number, C_i represents the evaluation indicator, and its quantification is defined as:

$$\begin{cases} C = \{C_i | i = 1,2,3,4,5,6\} \\ C_i = 0, false \\ C_i = 1, true \end{cases} \tag{3.4}$$

There are:

$$\begin{cases} T_K^n = 0, invalid \\ T_K^n = 1, effective \end{cases} \tag{3.5}$$

If the transaction is invalid, it indicates that there is an error in the transaction information record. This transaction is illegal and there may be a risk of malicious tampering with transaction information, so blockchain information synchronization should not be carried out.

In order to evaluate the accuracy of node transaction information records, credit value AA is defined as a representation:

$$e_N^l = \frac{\sum_{n=1}^{N_K} T_K^n}{N_K} \tag{3.6}$$

Among them, N_K represents the number of transactions in block K.

In the power trading blockchain, nodes collect transaction information and calculate random number solutions that comply with the blockchain hash function. The solution of this function can be expressed as:

$$H(M,S) \leqslant T_a \times e_N^l = 2^{n-t} e_N^l \tag{3.7}$$

Among them, M represents the Merkle root of the node, S represents the random value of the node's forward solution, and T_a is the system difficulty coefficient.

After hashing the forward solved random numbers and mapping them with a mapping interval of $0 \sim 2^{n-1}$, the probability of obtaining a random number that meets the requirements in a single solution is:

$$P_i^l = \frac{T_a \times e_N^l}{2^n} = \frac{2^{n-t} e_N^l}{2^n} = \lambda e_N^l \tag{3.8}$$

Among them, n represents the mapping space range, t represents the difficulty coefficient, and $\lambda = 2^{-t}$ represents the probability difficulty constant.

Assuming that the computing power of nodes in the blockchain is the same, the transaction credit values of different nodes are different. The probability of node competition winning transaction accounting rights in blockchain can be expressed as:

$$P = \frac{P_i^l}{\sum_{j=1}^{L} P_i^l} = \frac{e_N^l}{\sum_{j=1}^{L} e_N^l} \tag{3.9}$$

In the formula, L represents the number of nodes.

Define the transaction priority value as:

$$V = \frac{c}{e_N^l} \tag{3.10}$$

Among them, c represents the cost of power supply. The higher the credit value, the higher the transaction priority, and the higher the probability of successful node competition. Correspondingly, malicious nodes with low credit values have a lower probability of successful competition.

3.4. Blockchain distributed ledger design. The author designs a distributed ledger for electricity trading based on blockchain technology, which is a database that is shared, replicated, and synchronized among market entities under the blockchain. The main ledger structure includes an account information layer, a security encryption layer, a consensus mechanism layer, and a transaction incentive layer. Based on real account and address information, each market entity node implements legal accounting through encryption technology and consensus mechanisms, and rewards trading participants, so that each node obtains a unique and authentic copy of the ledger, which is tamper proof and transparent and traceable.

3.4.1. Account Information Layer. Each market entity in the blockchain network has a dedicated public key and private key (hexadecimal string). The public key is bound to the true identity and address of the trader and can be publicly released to users across the network, while the private key is only held by the user themselves. The design of blockchain private keys ensures unique ownership under the corresponding account address, where each account address has and only corresponds to one private key. The use of private keys adopts the Hash algorithm, which maps a string to another fixed length string, and the two are not independent. That is, after a series of encryption operations, the private key can obtain the address, but cannot be inferred from the address.

3.4.2. Security encryption layer. Not only do the public and private keys of the account have an encryption relationship, but the transaction bills under each node are also encrypted, reflected in the digital digest and signature of the trader. Digital summarization is a hash operation performed on digital content to obtain a unique string to refer to the original and complete digital content, ensuring that the original content has not been tampered with; Market entities can use private keys to sign summary information. After the electricity selling entity encrypts the transaction bill with a private key, other users verify the authenticity of the data source by decrypting it based on the electricity selling entity's public key, which can be regarded as the inverse operation of the signature process. If the decryption value is consistent with the digital signature in the original transaction bill, it indicates that the transaction is valid and is allowed to be added to the blockchain ledger [18].

3.4.3. Consensus mechanism layer. Blockchain has the characteristics of distribution, autonomy, openness and free access, so there is no central node to ensure the consistency of accounting among each node. The author adopts a proof of work (PoW) mechanism to ensure consensus on transaction bills for blockchain addition. Each market entity continuously adds random numbers (nonce) to new blocks that have not yet joined the chain for hash operations, in order to compete for unique accounting rights in this round by solving cryptographic problems (i.e. proof of workload). Because only one node in each round can successfully account and add the new block information to the blockchain network, other nodes that fail to compete will stop competing for accounting rights, copy the new block information and add it to their own node database, thereby ensuring the uniqueness and authority of the blockchain ledger, enabling all nodes in the network to reach consensus and share data.

Table 4.1: Clustering accuracy data Table

Number of experiments/time	Accuracy (%)	
	Propose an algorithm	Comparison algorithm
1	89.56	65.41
2	78.93	58.51
3	80.34	55.32
4	91.56	59.13
5	85.57	57.32
6	90.26	60.20
7	85.45	72.08

3.4.4. Transaction incentive layer. As the trading volume increases, in order to avoid too many invalid transactions, the trading network continuously increases the difficulty and cost of reaching consensus, that is, the number of digits starting with 0 calculated by Hash continues to increase. Therefore, a reasonable incentive mechanism can be introduced into the consensus mechanism to promote active participation of traders in the development of blockchain, encourage effective accounting behavior, and align the self-interest behavior of consensus nodes to maximize profits with the overall goal of ensuring the security and effectiveness of decentralized systems. In the PoW mechanism, the trading network adds a transfer transaction as a recognition reward to the node that wins the accounting rights.

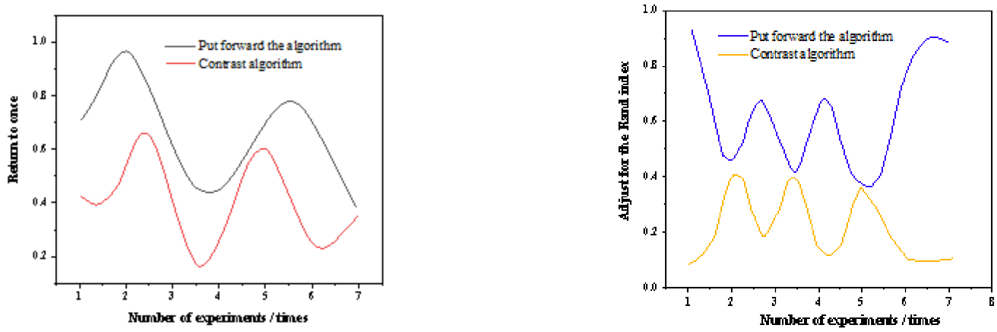
3.5. Experimental Analysis. In order to verify the application performance of the proposed algorithm, a power load data clustering algorithm based on DTW histogram was selected as a comparative algorithm, and a comparative experiment was designed. The specific experimental process is as follows. Selecting the electricity sales information generated by a certain regional electricity trading center as the experimental object, although the selected experimental object is the electricity trading center within a small area, the number of users is still considerable, and the quantity of electricity sales information is still high. For the convenience of conducting experiments, the electricity sales information generated by the electricity trading center in a certain week is used as experimental data to reduce the amount of experimental data and ensure the stability of the experiment [19]. Based on the selected experimental subjects, in order to quantify the clustering effect of the integrated distribution of electricity information, clustering accuracy, normalization degree, and their adjusted Rand index are selected as evaluation indicators. The calculation formula is:

$$\begin{cases} ACC = \frac{N_{cor}}{N} \\ NMI = \frac{2I(X,Y)}{H(X)+H(Y)} \\ ARI = \frac{RI-E[RI]}{MAX[RI]-E[RI]} \end{cases} \tag{3.11}$$

In the formula, ACC, NMI, and ARI represent clustering accuracy, degree of regression, and their adjusted Rand index, respectively; N_{cor} represents the number of correctly clustered electricity sales information; N represents the total number of electricity sales information; I (X, Y) represents the correlation between any two electricity sales information. H(X) and H(Y) represent the maximum entropy of the electricity sales information X and Y, respectively; RI represents clustering coefficient; E [RI] and MAX [RI] represent the clustering coefficient error value and maximum value, respectively.

4. Experimental Results and Discussion. The clustering accuracy data obtained through experiments are shown in Table 4.1. As shown in Table 4.1, compared with the comparative algorithms, the clustering accuracy obtained by the proposed algorithm is higher, with a maximum value of 91.56%, indicating that the proposed algorithm correctly clusters more electricity supply information.

The normalization and adjusted Rand index obtained through experiments are shown in Figure 4.1. As shown in Figure 4.1, compared with the comparison algorithm, the proposed algorithm obtained larger values of normalization and adjusted Rand index, with maximum values reaching 0.98 and 0.92, respectively.



(a) Return to one degree

(b) Adjusting the Rand index

Fig. 4.1: Schematic diagram of normalization and adjustment of Rand index

The clustering accuracy, normalization, and adjusted Rand index obtained by the proposed algorithm are all relatively high, which fully confirms that the integrated clustering effect of the proposed algorithm on electricity sales information is better.

5. Conclusion. The author proposes the construction of a power market trading platform based on regional blockchain technology, conducts in-depth research on blockchain based power energy cloud storage trading technology, designs a blockchain distributed trading architecture, and realizes the module design of four-dimensional integration of trading, scheduling, security, and supervision. In addition, the author further proposed a consensus optimization algorithm based on transaction credit evaluation, which effectively improves system efficiency and fault tolerance. Through multidimensional evaluation and credit ranking, malicious nodes have been effectively suppressed, system processing capabilities have been improved, and response latency has been reduced. Subsequent work can be further optimized to meet the high concurrency requirements of blockchain technology.

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