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Deviation Power Pricing Mechanism Based on Blockchain Technology for Cross-regional Energy Trading

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ABSTRACT. *More trading entities have participated in the electricity market owing to the electricity market reform. The pricing and settlement methods of the deviation power will affect the fairness of the transaction and the enthusiasm of the trading entities. The establishment of a reasonable deviation power settlement method is a key step to ensure the power market transaction. As an emerging distributed data storage technology and distributed accounting technology, blockchain technology has great application prospects in power market transactions and energy Internet. Therefore, the research on the application of blockchain technology to the settlement of deviation power not only contributes to the advancement of power market reform, but also has positive significance for the application of blockchain technology in the power field. In this paper, the concept of the deviation power, the measurement method and the existing settlement methods are briefly introduced. Then, the application of blockchain technology and the cross-regional energy trading based on this are analyzed. Finally, some transaction entities of China Southern Power Grid are taken as an example. The impact of different price and settlement ratios on the economic benefits and behavior of each transaction subject in terms of deviation power indicates how the blockchain technology can be applied to the settlement of deviation power in cross-regional power transactions.*

KEYWORDS: *deviation power; smart contract; blockchain technology; pricing mechanism*

1. Introduction

Cross-regional energy trading refers to power companies conducting power trading with power companies outside the region. Cross-provincial power trading has great economic benefits, can optimize the allocation of resources, and accelerate economic development. It not only allows the power purchaser's continuous increase in power consumption to be satisfied, but also promotes the power seller to convert natural resource advantages into economic advantages. Due to the increasing number of participating trading entities, the model tends to be complex and

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changeable. The original transaction settlement model can no longer meet the needs of the development in the current situation, especially for the deviation power from the contract power. There is an urgent need to study a set of reasonable offset electricity pricing and settlement methods in order to maintain the core interests of the transaction entity and improve the efficiency of the electricity market operation.

In traditional electricity trading, a trading center and centralized trading and settlement will be established. There are disadvantages to this method of relying on the central institution:1) The database of the central institution needs to be collated frequently with other databases, and the operation and maintenance costs are relatively high;2) Transaction information data is stored too centrally, and once maliciously attacked by a virus, data will be lost or tampered with;3) Information exchange is asymmetric, and there may be transaction entities that use information advantages to infringe on the interests of other transaction entities. In view of the above problems, blockchain technology[1], weakly centralized ideas, and smart contract mechanisms are introduced into power transactions, and on this basis, deviation power is settled to ensure the safe and efficient operation of power transactions.

In the settlement of cross-provincial power transactions, the settlement of deviations from the contracted amount of electricity is a key issue. For the treatment of deviation power, Article [2] gives real-time price attributes of the deviating power and separate pricing and settlement, reflecting the difference from the contract power. For deviation power settlement method: First, from the perspective of the electricity sales company, find a suitable method to reduce the additional cost of its own due to the deviation of the power assessment; The second is to start from the power trading center and consider formulating a fair pricing and settlement method to ensure the fairness of all trading entities in the power market. Article [3] from the perspective of the electricity retail company, an interruptible load purchase model was used to design the optimal operation strategy under the deviation assessment mechanism; Article [4] compared several types of foreign power markets with regard to the deviation power settlement mechanism, and made recommendations for the transaction settlement mechanism in China's power market, but did not establish specific operating methods. Therefore, it is necessary to construct a new model, which can not only divide the responsibility attribution of the deviation power fairly, but also reflect the difference between the deviation power and the contract electricity through the settlement price difference.

Scholars have done a lot of research on blockchain technology and its applications. Article [5] introduced an electric energy trading system based on blockchain technology that has been put into operation in New York, USA. In the application of blockchain technology in the non-energy field; Article [6] introduced the prospect of the application of blockchain technology in the medical field. For the application of blockchain technology in the field of energy internet and electricity; Article [7] proposed to use bitcoin as electronic money for energy transactions in the power grid, and use smart meters to record energy consumption over a period of time. After the parties negotiated and confirmed the validity, the information was recorded in the blockchain. In China, article [8] applied blockchain technology to

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the microgrid, and designed a scheme in the microgrid energy management system to improve the confidentiality of data transmission; Article [9] analyzed the power grid security management and transmission network congestion management scheme with the help of weakly centralized management of power trading methods in the blockchain technology; Article [10] introduced the application of blockchain technology in the field of power auxiliary services, and compared and analyzed the key technologies and their limitations.

Above all, the current results are more comprehensive in the study of deviations in power transactions, but there is a lack of research on contract execution and fairness in the settlement process. With its own advantages, blockchain technology can use smart contracts to serve the execution of transaction contracts and transaction settlement. This article applies the blockchain technology to the settlement of deviation power, and uses a pricing model of deviation power to analyze the impact of the settlement method of this model on the economic benefits of various trading entities in the power market in different situations.

2. Transaction structure and deviation power pricing model

2.1 Transaction structure

In power trading, a platform is required as the center to enable multiple trading entities to conduct power transactions across regions, and to be responsible for the exchange and transfer of energy flow, information flow, and fee flow. The energy flow is transmitted through the power grid, and the information flow and fee flow are based on blockchain technology, using the electricity trading system structure that relies on smart contracts. The power trading system structure consists of a transaction layer, an extension layer, and a blockchain layer.

The transaction layer includes power plants, electricity vendors, distributed power sources, etc., which are connected through the power grid. Each transaction entity initiates and completes power transactions at the transaction layer. The transaction data is transmitted to the expansion layer and forms smart contracts. Related condition-constrained transactions, data is stored on the blockchain layer.

The extension layer has two main functions: smart contracts and weakly centralized management. The transaction entity negotiates to reach a transaction intention and forms a smart contract. The contract is broadcast to each node of the blockchain via a peer to peer (P2P) network. When the execution condition of the contract is triggered, the contract is automatically executed. Electricity must rely on the transmission network to achieve real-time production and sales balance. There must be a schedule center to grasp the entire network information and coordinate it to ensure the physical and safe operation of the power grid. Reliance on smart contracts to enforce the automatic execution cannot cause failure special circumstances ensure the operation of the trading system. Therefore, compared with the traditional centralized power trading center, the concept of "weak centralization" is adopted to allow the schedule center to ensure the safe operation of the trading

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system on the premise of having limited rights.

The blockchain layer is the underlying technology foundation, including P2P networks and blockchain storage devices. At the blockchain layer, there are a large number of network nodes that serve as the storage points of the blockchain. These nodes have storage capabilities, equal status, flat topology, and mutual interaction to form a P2P network. The role of the blockchain layer is to use distributed data blocks to store information to form a distributed accounting system, so it does not completely rely on traditional central institutions to solve the trust problem in transactions. All transaction data is stored in a distributed network. If the data is changed, it needs to be confirmed by each node in the blockchain network, and cryptographic protocols further ensure that the data is difficult to tamper with.

2.2 Deviation power pricing model

Deviation power is power other than contract power, and its pricing method should consider the cost of power generation at different load levels. If the difference in the cost of power generation is not considered, the electricity seller can arbitrage it through manual operation and damage the interests of other transaction entities. When the load level in the area where the electricity seller is located is high, the cost of power generation is correspondingly higher and higher than the contract price. At this time, the electricity seller tends to sell electricity to users in the region during peak hours and reduce the transmission of electricity to the cross-region electricity transaction entities with which it has signed contracts, so as to obtain profits by artificially forming negative deviation electricity; When the load level in the area where the electricity seller is located is low, the cost of power generation is also lower and lower than the contract price. At this time, the seller tends to send out energy across regions during the valley period, and artificially forms a positive deviation of electricity. The rolling method is used to settle the deviation of electricity. Although the total amount of contract electricity is guaranteed to be constant, the transmission power curve may have great volatility, which exacerbates the peak-to-valley difference and power imbalance.

When setting the price, first determine the load level in the area, determine whether it is in the peak period or the valley period, and then refer to the standard electricity price to set the deviation electricity price and settle it separately from the contract electricity price.

First determine the load level L:

$$L=\frac{L_t-L_{\min}}{L_{\max}-L_{\min}}$$

L_t , $L_{\min}$ and $L_{\max}$ represent the average load, minimum load, and maximum load of the study period.

Determine whether the load level is at a peak or a valley according to the load

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level cutoff L_0: when $0 \le L \le L_0$, the load level was considered to be at a valley; when $L_0 < L \le 1$, the load level was considered to be at a peak. L_0 should be based on historical operating data and operating experience.

As to the formulation of the reference standard electricity price, the generation cost in the area at different load levels can be selected as a reference, and its price can be compared with the contract electricity price to finally determine the deviation electricity price for the settlement of deviation electricity.

When the load level is low, the power output is borne by the base load unit, such as nuclear power, large thermal power units, etc., and the cost of power generation is low; When the load level is high, the load of the base load unit is not enough to maintain the power demand of the system. The peak shaving unit participates in power generation to bear the peak load, such as natural gas generating units and oil generating units. Therefore, the cost of power generation will change with the load level. The factors that affect the deviation of power prices mainly include the supply and demand relationship and the cost of power generation. The cost of power generation is the most direct manifestation and the easiest indicator to quantify.

Calculate the peak electricity price C_1 and the normal electricity price C_2 in the area where the electricity seller is located:

$$\begin{cases} C_1 = \dfrac{\sum_{i=1}^{m} c_i}{L_{\max}} \cdot \alpha_1 \\ C_2 = \dfrac{\sum_{i=1}^{m} c_i}{L_0 (L_{\max} - L_{\min}) + L_{\min}} \cdot \alpha_2 \end{cases}$$

m is the number of generating units selected for the price in the area where the electricity seller is located. The selection principle should include as many different types of generating units as possible to participate in power generation to reflect the changing characteristics of prices; c_i is the power generation cost of each selected generator set, the value indicates the total cost of the generator to generate electricity. $\sum_{i=1}^{m} c_i$ is the total cost of generating units consumed during peak hours to meet load demand, the ratio of its value to the maximum load level $L_{\max}$ indicates the average cost of power generation to meet unit power demand during peak load hours, and provides a reference for pricing. Also in the calculation formula of the reference electricity price C_2 in the ordinary period, $\sum_{i=1}^{m} c_i$ is the total cost of the units that are involved in generating electricity to meet load demand during ordinary times. α_1 and α_2 are adjustment factors, the power trading center can make appropriate

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adjustments to the reference price adjustment coefficient according to the actual operating conditions.

The determination of the deviation electricity price C_{de} needs to be compared with the reference electricity price C_1, C_2 and the contract electricity price C_c.

If positive deviations are generated during peak hours: $C_{de} = \min\{C_1, C_c\}$

If negative deviations are generated during peak hours: $C_{de} = \max\{C_1, C_c\}$

If positive deviations are generated during valley hours: $C_{de} = \min\{C_2, C_c\}$

If negative deviations are generated during valley hours: $C_{de} = \max\{C_2, C_c\}$

The selection of deviation power price follows the principle of preventing arbitrage. When a positive deviation electricity quantity is generated, a lower price is selected for settlement; when a negative deviation electricity quantity is generated, a higher price is selected for settlement.

3. Example and analysis

3.1 data

The calculation and analysis are performed using data from the China Southern Power Grid's daily cross-regional energy trading contract. The transaction entity includes 3 hydropower stations, 1 thermal power station and 4 regional power grids. The contract power and actual power are shown in Table 1.

Tab. 1 Data of China Southern Power Grid cross-regional power trading (MW·h)

transaction entity	contract power/price		deviation power/price	
	To Guangdong Power Grid	To Guangxi Power Grid	value	percent
Guizhou Power Grid	64259/330	0	-1712	-2.66%
Yunnan Power Grid	132472/323	0	-369	-0.28%
Tianyi Hydropower	4617/284	1874/288	-129	-1.99%
Tianer Hydropower	6180/307	5562/307	-275	-2.35%
Longtan Hydropower	7743/310	7582/295	+331	+0.55%
Xingyi Thermal Power	0	11025/355	-494	-4.48%

3.2 Analysis of calculation results

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According to the above formula, the results of dividing the typical daily load level by the hour and the reference electricity price calculation results are shown in Table 2.

Tab. 2 Load level time division by the hour and reference price

transaction entity	seller	buyer
Peak hours	6-11，14-20	8-19
Valley hours	0-5，11-13，21-23	20-23，0-7
Reference price C_1	￥450/ MW·h	￥400/ MW·h
Reference price C_2	￥340/ MW·h	￥320/ MW·h

As can be seen from Table 1, the transaction entities Guizhou Power Grid, Yunnan Power Grid, Tianyi Hydropower, Tianer Hydropower and Xingyi Thermal Power have negative deviations. The settlement deviation of the transaction entity Longtan Hydropower is positive. From the calculation results, settlement according to the deviation of power prices has an impact on the economic benefits of each transaction entity.

Taking the trading entity Guizhou Power Grid as an example. It is reasonable to complete the power transmission task in accordance with the contract in 64,259MWh. Actually, the entity completed 62,547MWh and reduced power transmission by 1,712MWh. Formed negative deviation power. Without taking into account the special attributes of the deviating power price, the settlement will be based on the contract power price, which will reduce the income by RMB 352,800 yuan; and according to the deviation of the power price settlement, reducing the income of RMB 622,200 yuan, that is, the transaction entity Guizhou Power Grid suffered more economic losses due to failure to complete the contract.

The settlement results of the transaction entities Tianyi Hydropower, Tianer Hydropower and Xingyi Thermal Power are similar to those of the Guizhou Power Grid, all of which resulted in negative deviations in electricity generation, reduced economic income, and suffered more economic losses. The transaction entity Longtan Hydropower formed a positive deviation power, and the part that produced the deviation cannot generate more additional income due to default.

3.3 Application of blockchain in transaction settlement

After the transaction is completed, the transaction results will be stored in the blockchain. When using the blockchain to record transaction result information, the transaction record is stored in the block body after verification. In a selected trading period, the settlement related information of each transaction subject is transformed into a Merkle tree after Hash transformation. Merkle tree recorded in the block header.

In the field of smart contracts, the more advanced and well-known technology is Ethereum. Ethereum is based on blockchain technology, with strong sense of value

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and blockchain awareness. The contract contains the basic constructor: the electricity sales function, which provides the amount of electricity that the buyer and seller need to trade; Contract query function. After the automatic execution time of the contract arrives, the transaction entity can query the execution condition of the transaction, the settlement amount and the responsibility for the deviation from the weakly centralized management center.

Taking the transaction entity Guizhou Power Grid as an example, the transaction information needs to be recorded: transaction time; the electronic address of the transaction entity Guizhou power Grid; deviation power -1712 MW·h; contract price ￥330/ MW·h; deviation power price ￥421/ MW·h. transaction time refers to the time when the amount of the main account of the transaction is changed, and it is not necessarily the same as the electricity delivery time. People can choose the transaction time according to the negotiation between the two entities. The purpose of selecting the transaction time is to ensure that the transaction entity has sufficient time to appeal when there is doubt, and to avoid misjudgment due to the enforcement of the smart contract. When all transaction entities recognize the transaction results and there is no default in the smart contract, the smart contract completes the settlement of the deviation settlement amount, changes the account balance of the transaction subject, and a complete transaction process ends.

4. Conclusion

This paper combines the settlement of offset energy in cross-regional energy transactions with blockchain technology, which reflects the advantages of smart contracts based on blockchain technology that can improve security in the field of power transactions, and provides a solution to the problem of transaction settlement.

When establishing the deviation power settlement model, the difference between the deviation power and the contract was considered, and the special attributes of the contract power were clarified. In the settlement, the deviating power is separately priced with the deviating power price. By reducing the economic benefits of the transaction arbitrage of the contract arbitrage, the transaction can be executed in accordance with the contract as much as possible, thereby reducing the generation of deviating power. This settlement method can be applied to other forms of power or energy transactions, providing a new idea for China's power market reform.

Because the blockchain technology is not complete, there are still some parts to be improved in the application of power transaction settlement. Legal and regulatory rules must be mature to ensure the beneficial development of new technologies; The imperfect construction of the power market and the complexity of the power trading model also place higher requirements on the application of new technologies; The combination of different modes of power transaction settlement and blockchain technology still needs to be continuously researched and explored.

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