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Electricity market transaction model design combining blockchain and machine learning

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***Abstract*—With the deteriorating environment and the issuance of various national policies, green energy has begun to rise and become an important part of the energy market. The traditional energy trading model is a centralized management model, and new energy is not suitable for the current situation due to its wide distribution. Some traditional transaction models, so we use blockchain technology to solve this problem. Aiming at the problems of transaction methods, energy price competition and how to implement the blockchain in energy transactions, the K-nearest neighbor algorithm in machine learning is used to realize the automatic auction at the same time, and the ACO algorithm competition based on multiple time scales is studied. The game realizes the legality of using smart contracts to restrict market transactions, solves the problem of distributed green energy grid connection, and combines with appropriate incentive mechanisms to increase the utilization rate of green energy and promote the rational development of ecology and human life.**

Keywords- Blockchain; Energy Trading System; Ant Colony Algorithm; Machine learning; KNN

I. INTRODUCT

With the development of the energy Internet, renewable energy such as solar energy, wind energy, and water energy is an energy source that does not emit pollutants and can be directly used for production and life, and has high energy conversion rate, high operational reliability, and equipment Distributed energy with the advantages of simple and convenient installation. On September 20, 2019, Li Fulong, Director of the Development Planning Department of the National Energy Administration, said that he is studying the "14th Five-Year" energy development plan and will continue to strengthen the development of clean energy. Under the national environment, distributed clean energy participation will be encouraged. The trend of market transactions is becoming more and more urgent. At the same time, the liberalization of the power sales side [1] makes the types of competition subjects in the market more flexible, and the boundaries between producers and consumers are gradually blurred [2], and the types of power transactions and management models show a diversified trend [3].

In the traditional energy trading market, most of the transactions are carried out in a centralized mode: State Grid sends the power generation data to the system, and at the same time collects user data and uploads it to the grid management system, to adapt to users through centralized matching or optimization methods. When purchasing electricity and transacting with the generator, it must go through the grid management system. The advantages of the centralized transaction model are unified management and unified standards, which have played a key role in the stable operation of my country's power system. However, with the continuous emergence of distributed renewable energy, centralized and unified transactions have exposed many problems: the first is to respond to electricity. Measurement and accounting are not transparent enough. Secondly, it is difficult to form a reasonable market supervision mechanism. Finally, the market mechanism is not flexible enough, and the price of electricity cannot fluctuate with market demand.

In order to solve the above problems, a new management system is needed to adapt to this diversified energy transaction. The demand response transaction model based on the blockchain has the characteristics of decentralization, traceability, transaction transparency, and non-tampering, which is completely compatible with the solution. The technical structure, bidding mechanism and trust supervision of multi-agent market transactions [4-6]. The blockchain is essentially a decentralized database, similar to a well-designed distributed database system. These characteristics of the blockchain can meet the requirements of electricity transactions.

In recent years, some scholars have begun to use blockchain technology to integrate microgrid resources and have some research and corresponding results. Literature [7] uses blockchain incentives to realize energy and electricity the supply-demand network coordinates the independent grid-connected behavior of distributed energy sources. On this basis, the collaborative co-evolutionary algorithm (CCEA) is used to establish a power model through objective functions such as the lowest operating cost and the lowest active power loss; literature [8] uses blockchain technology The management platform obtains relevant data and information, combined with the model prediction algorithm (MPC) method, to optimize the dispatch of distributed energy. The above is the use of blockchain technology to integrate information such as distributed energy generation status and the load status of various entities in the grid, and the feedback of this information is used to control the grid connection of distributed energy. For the literature [9], a non-cooperative game multi-dimensional grid transaction model and solution process was established between the microgrid and the distribution network, and the conditions and influencing factors of the transaction between the microgrid and the distribution network were explained. Literature [10] used a multi-agent dynamic game model in a

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microgrid with storage energy units to solve the problem of competition and game between distributed energy sources in the microgrid system under island operation. At the same time, there are also some research and application systems for the development of blockchain transactions at home and abroad. For example, the distributed photovoltaic power sales blockchain platform Transactive Grid jointly established by the US energy company LO3 and the Bitcoin development company Consensus Systems developed the world's first energy source the blockchain market [11] combines green clean energy with blockchain technology, and users can feed back excess clean energy to the grid. The Energo project builds a decentralized autonomous energy community (DAE) decentralized system, establishes an automatic energy trading platform based on the Qtum- quantum chain, and uses the digital currency TSL to realize the clean energy measurement, registration, management, and management of micro-grids, trading and settlement [12].

For the existing research situation, most of the research is to use the blockchain technology to integrate information resources to rationally dispatch distributed energy or the game competition between the power generation side and the supply side, and it has not yet involved the diversified competition game among the various entities in the power grid.

This article combines the research at home and abroad, based on the blockchain-based distributed energy trading program, first, the application of blockchain technology in the smart grid is introduced. The consensus algorithm and cryptography principles ensure the transparency, security and non-tampering of power transaction data. Secondly, based on the blockchain technology, the power transaction model is proposed, the smart contract for demand response is designed, and then the mathematical model of the demand of each subject in the power market environment is designed. At the same time, starting from each subject in the power grid, it is established based on microgrid companies, energy bureaus and general User and other multi-agent diversified non-cooperative game model, using ant colony algorithm (ACO) to solve the above game model, realize the method of peer-to-peer (P2P) transaction, automatic auction based on K-nearest neighbor algorithm, and finally analyze through simulation experiments to verify the model and algorithm The feasibility.

II. Methods and Conclusions

A. Blockchain-based transaction model

Taking into account the characteristics of power transactions, a typical blockchain system is divided into six levels of business, from bottom to top, data layer, network layer, consensus layer, incentive layer, contract layer and application layer. The data layer encapsulates the underlying data organization and representation, related timestamps and data encryption technology, etc.; the network layer logically organizes physical nodes into a point-to-point network, including point-to-point networking mechanisms, data dissemination mechanisms, and data verification mechanisms; consensus layer in a highly decentralized system, coordinate all parties to reach consensus and complete tasks such as transactions. This layer completes various consensus algorithms that encapsulate network nodes; the incentive layer contract layer mainly encapsulates various agreements, algorithms, and contracts as programs that can trigger execution (Smart contract) is the basis of the programmable features of the blockchain; the application layer implements application scenarios and specific cases based on the services provided by the bottom layer.

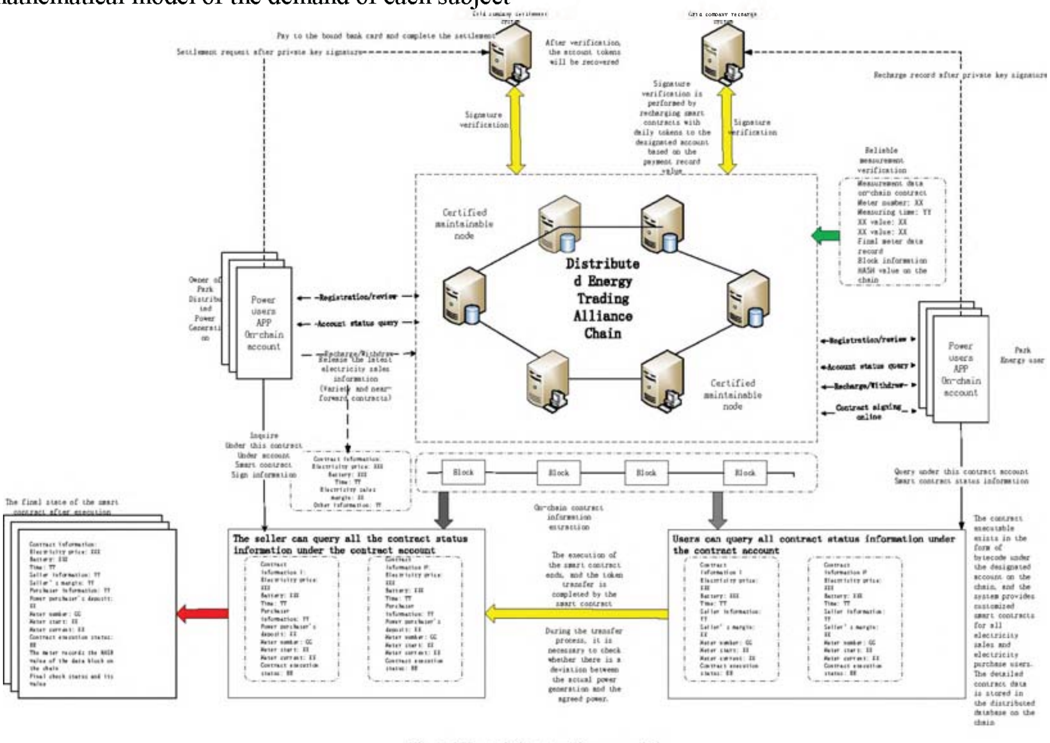

Fig.1 Electricity trading model

The model design based on the blockchain power transaction studied in this paper is shown in Figure 1. The balance model of Ethereum is used as the account model. The account includes the electricity sales account and the electricity purchase account; at the same time, due to the special nature of the distributed energy market in energy transactions the consortium chain is selected as the blockchain model [13]. The consortium chain has the characteristics of auditing participating nodes, and each participating node needs to be audited. This model uses the PBFT (Practical Byzantine Fault Tolerance) consensus algorithm to improve the efficiency and safety of the overall system. This consensus algorithm uses mathematical calculations to quickly distribute the accounting rights, without the need to compete in computing power, reduce power consumption, and achieve a consensus in the shortest time [15].

The main bodies of the distributed energy market mainly include microgrid companies, energy bureaus, and ordinary users. All entities in the distributed energy market hope that their rights and interests are maximized. It can be seen from Figure 1 that micro-grid companies and energy bureaus are the main producers of energy. Micro-grid companies mainly focus on green and clean energy such as wind power generation and solar power generation. Under the condition of meeting their own load, they will store the excess energy for supply. The Energy Bureau or user groups sell it. If the microgrid company lacks energy, it can purchase energy from the Energy Bureau; the Energy Bureau mainly uses nuclear power and thermal power generation in a centralized power generation mode. The Energy Bureau is ensuring the safety of the entire system load. Under the circumstances, the energy generated by the microgrid company is merged into the main grid to reduce its own power generation and resource loss. At the same time, the Energy Bureau can also purchase the excess energy generated by the microgrid and sell it to the user group, earning money through the price difference. Take profits; user groups only consider meeting their own electricity needs with the smallest cost.

The distributed energy framework design mainly includes smart meters, central management systems, and smart routing. In this framework, every producer and consumer install a smart meter, which collects and records the production and consumption of energy at all times, and transmits the situation to the central management system and uploads to the block, from the block in real time Read the information to monitor the status of each node at all times. The legality of the transaction is determined by the smart contract in the blockchain and the Energy Bureau. If any violation is found, it will be directly recorded in the credit report of the block and account. The system provides reliable measurement authentication technology, and all measurement data is on the chain to further ensure the reliability and traceability of measurement data. Smart contracts ensure the fairness of all market participants.

B. The Mathematical Model of the Demand of Power Transaction

Blockchain-based power trading is a power trading model that considers microgrid companies, energy bureaus, ordinary users, etc., and is also a multi-time-scale demand response bidding for "day-ahead-intraday-real-time" rolling dispatch between transaction subjects' resources Mechanism, that is, the supply and demand information issued by each subject and the signed supply and demand contract do not need to be authenticated by an intermediate authority. The system guarantees that the transaction data has the properties of tamper-proof and non-repudiation. The cryptography principle of the blockchain can ensure that the transaction information has the above properties. The principle and technology of traceability, tamper-proof and smart contract based on blockchain can support the establishment of a transparent and efficient power supply and demand transaction model [16].

In order to maximize their own interests, the microgrid companies, energy bureaus, and ordinary users participating in the market game will influence market changes by formulating different strategies for purchasing and selling electricity at different stages. Therefore, how to obtain excess profits through competition and game in the market conditions supported by blockchain technology is the most concerned issue of all players. In addition, the power purchase subsidy for micro-grid companies and ordinary users will be added to the system to promote the prosperity of the electricity market.

1) Microgrid company needs

For micro-grid companies, due to the uncontrollability of the energy produced by the environment, it cannot guarantee that the energy produced will be in balance with its own load. There will be a lack of electricity or excess electricity, and the lack of energy requires the purchase of energy. Excess energy can be released to participate in the auction.

$$PT_{sell}^{green}(t) = P_{sell}^{GtoU}(t)Q_{Sell}^{GtoU}(t) + P_{sell}^{GtoC}(t)Q_{Sell}^{GtoC}(t) \quad (1)$$

$$SL_{buy}^{green}(t) = P_{buy}^{CtoG}(t)Q_{buy}^{CtoG}(t) \quad (2)$$

$$SE_{get}^{green}(t) = 0.05 \bullet Q_{Sell}^{CtoG}(t)P_{buy}^{CtoG}(t)^2 \quad (3)$$

$PT_{sell}^{green}(t)$ represents the benefits of green energy, $SL_{buy}^{green}(t)$ is the micro-grid company sells surplus energy to ordinary users or sells energy to the energy bureau. When there is a shortage of power, the micro-grid company will purchase energy from the energy bureau. $SE_{get}^{green}(t)$ is subsidies for power purchase by microgrid companies. $P_{sell}^{GtoU}(t)$ indicates the price of electricity sold by the microgrid company to ordinary users at time t. $Q_{Sell}^{GtoU}(t)$ indicates the amount of electricity sold by the microgrid company to ordinary users at time t. The same goes for other representations. G stands for microgrid companies, U stands for ordinary users, and C stands for Energy Bureau.

2) Demand from Energy Bureau

As the largest producer, the Bureau of Energy can continuously generate energy to satisfy the perfect operation of the overall system. Of course, the Bureau of Energy can also purchase excess energy from micro-grid companies at a low price and auction it out. In this system, the energy bureau does not need load.

$$PT_{sell}^{Country}(t) = P_{sell}^{CtoU}(t)Q_{Sell}^{CtoU}(t) + P_{sell}^{CtoG}(t)Q_{Sell}^{CtoG}(t) \tag{4}$$

$$SL_{buy}^{Country}(t) = P_{buy}^{GtoC}(t)Q_{buy}^{GtoC}(t) \tag{5}$$

$$SE^{Country}(t) = 0.05\mathrm{Q}_{\mathrm{Sell}}^{\mathrm{CtoU}}(\mathrm{t})\mathrm{P}_{\mathrm{sell}}^{\mathrm{CtoU}}(\mathrm{t})^2 + 0.05\mathrm{Q}_{\mathrm{Sell}}^{\mathrm{CtoG}}(\mathrm{t})\mathrm{P}_{\mathrm{sell}}^{\mathrm{CtoG}}(\mathrm{t})^2 \tag{6}$$

$PT_{sell}^{Country}(t)$ is revenue of the Energy Administration, the source of the energy bureau's income is mainly the demand for energy load of ordinary users and the cost of energy purchase by microgrid companies in the case of power shortage. $SL_{buy}^{Country}(t)$ is the cost of purchasing the excess electricity generated by the microgrid company. $SE^{Country}(t)$ is subsidies from the Energy Administration.

3) Ordinary user needs

As the largest energy consumer in this system, it is mainly for getting lower electricity prices to invest in life and production. Ordinary users do not have the ability to generate energy and can only purchase energy.

$$SL_{buy}^{User}(t) = P_{sell}^{CtoU}(t)Q_{Sell}^{CtoU}(t) + P_{sell}^{GtoU}(t)Q_{Sell}^{GtoU}(t) \tag{7}$$

$$SE^{User}(t) = 0.05\mathrm{Q}_{\mathrm{Sell}}^{\mathrm{CtoU}}(\mathrm{t})\mathrm{P}_{\mathrm{sell}}^{\mathrm{CtoU}}(\mathrm{t})^2 \tag{8}$$

$SL_{buy}^{User}(t)$ is the cost of purchasing energy for ordinary users, $SE^{User}(t)$ is ordinary users receive subsidies from the Energy Administration.

C. Design of multi-time scale demand response bidding mechanism based on blockchain

In order to maintain the balance of the entire system and the stability of the market, this system uses the ACO algorithm competition game based on multiple time scales in order to prevent any one of the energy bureau, micro-grid companies, and ordinary users from gaining the most benefits. According to the ACO (Ant Colony Algorithm) algorithm, the hourly best bid price is obtained and displayed to the users participating in the bidding and publishing bids for reference. The main participants in the optimization are the Energy Bureau, micro-grid companies, and ordinary users.

The supply and demand parties release power supply and demand information, and comprehensively consider the form of energy, time scale ("day-ahead-intraday-real time"), electricity, policies, etc. during the game. Factors, to achieve the balance of supply and demand income, to reach power supply transactions, and to provide a basis for optimal power dispatch.

1) The main body of the algorithm A

The main body of the algorithm model of the distributed energy trading system studied in this system is mainly N micro-grid companies, M energy bureaus, and K ordinary users at time t.

$$A = \{G_1, G_2, G_3, \ldots, G_N, C_1, C_2, \ldots, C_M, U_1, U_2, U_3, \ldots, U_K\} \tag{9}$$

2) Algorithm strategy

The algorithm strategy of this system is to maximize the revenue of the Energy Bureau and the micro-grid company by changing the price of electricity sold by each subject, and minimize the cost of ordinary users.

3) The objective function of the algorithm

a) The objective function of the microgrid company:

$$\max \mathrm{H}_{Get}^{green} = \sum_{i=o}^{t} \left(\begin{array}{c} P_{sell}^{CtoU}(t_i)Q_{Sell}^{CtoU}(t_i) + P_{sell}^{CtoG}(t_i)Q_{Sell}^{CtoG}(t_i) \\ - \\ P_{buy}^{GtoC}(t_i)Q_{buy}^{GtoC}(t_i)) + 0.05 \bullet Q_{Sell}^{CtoU}(t_i)P_{buy}^{GtoC}(t_i)^2 \end{array} \right) \tag{10}$$

b) The objective function of the Energy Administration:

$$\max H_{Get}^{Country} = \sum_{i=o}^{t} \left(\begin{array}{c} P_{sell}^{CtoU}(t_i)Q_{Sell}^{CtoU}(t_i) + P_{sell}^{CtoG}(t_i)Q_{Sell}^{CtoG}(t_i) \\ - \\ P_{buy}^{GtoC}(t_i)Q_{buy}^{GtoC}(t_i)) - 0.1 \bullet Q_{Sell}^{CtoG}(t_i)P_{sell}^{CtoG}(t_i)^2 \end{array} \right) \tag{11}$$

c) The objective function of ordinary users:

$$\min R_{out}^{User} = \sum_{i=o}^{t} \left(P_{sell}^{CtoU}(t_i)Q_{Sell}^{CtoU}(t_i) + P_{sell}^{GtoU}(t_i)Q_{Sell}^{GtoU}(t_i) - 0.05 \bullet Q_{Sell}^{GtoU}(t_i)P_{sell}^{GtoU}(t_i)^2 \right) \tag{12}$$

In formulas (10), (11), (12), t_i is in which time period.

4) Constraints of ACO algorithm

$$P_{MIN}(\mathrm{t}) \le \left\{ P_{sell}^{CtoG}(t), P_{sell}^{GtoU}(t), P_{sell}^{CtoU}(t), P_{sell}^{GtoC}(t) \right\} \le P_{MAX}(\mathrm{t}) \tag{13}$$

5) Adaptive pheromone volatilization factor in ACO algorithm

The information volatilization factor ρ in the ant colony algorithm, 1-ρ represents the residual factor. When ρ is too small, the residual information factors on each path are not much different, which will cause invalid paths to be searched continuously, which affects the optimal algorithm. The convergence speed of the solution; when ρ is too large, some effective paths will be ignored, which affects the optimal solution of the algorithm to be ignored.

Suppose the initial value of ρ is ρ(0)=1. When the ACO algorithm cannot obtain the optimal solution or the optimal solution cannot be improved, ρ will be adjusted according to the following formula (14):

$$\rho(t) = \begin{cases} 0.8\rho(t-1) & 0.8\rho(t-1) \ge \rho_{min} \\ \rho_{min} & 0.8\rho(t-1) < \rho_{min} \end{cases} \tag{14}$$

6) The probability of ACO algorithm calculates the position of the next moment:

$$X(t+1)=\begin{cases} X(t)+rand\times\lambda, p_i<p_0 \\ X(t)+rand\times\dfrac{(upper-lower)}{2}, p_i\ge p_0 \end{cases}$$

$$X(t+1)=X(t)+rand\times\frac{(upper-lower)}{2} \tag{15}$$

In formula (15), rand is a random number with a value range of [-1,1], p_0 is a transition probability constant, where λ will decrease as the number of iterations increases. For $p_i < p_0$ time, $X(t+1)=X(t)+rand\times\lambda$ is a local Search; For $p_i \ge p_0$, $X(t+1)=X(t)+rand\times\frac{(upper-lower)}{2}$ was a global search.

7) The steps of the algorithm:

Step1: First calculate the income and expenses of micro-grid companies, energy bureaus, and ordinary users before the current time, and then generate a set of initialization ants according to the given price range, according to the predicted value of green energy production at the next time and each object Predict the load value, initialize a set of data, and record the current global optimal position.

Step2: According to the setting, 35 groups of ants are generated and start to explore the optimal solution.

Step3: The choice of ant's path is related to the intensity of information. Initially, the pheromone is set to be equal, and the pheromone is proportional to the quality of the solution.

Step4: When 35 groups of ants search once, it is iterated once. After each iteration, pheromone updates will be performed on all the plans, and then the ants participating in the next iteration will make new explorations based on the last pheromone.

Step5: When the predetermined number of iterations (such as the 200 iterations of this algorithm) is reached, the type of ant will no longer change (that is, the value of the array contained in the ant will no longer change), the algorithm will end, and the final data is the Excellent solution about the current problem.

8) k-nearest neighbor algorithm

This system uses the k-nearest neighbor algorithm in machine learning to realize automatic trading. The system automatically collects each user's quotation, constructs the data set generated by the user's quotation into a kd-Trees, and then generates it according to the above ACO algorithm the best value is regarded as the target value X, and then the leaf node containing the target value X is found in kd-Trees. This leaf node is the best quote among many users' quotes. If no leaf node is found, the nearest leaf node is found as the best offer. This offer satisfies the strategy of the game algorithm. The system will automatically generate orders and smart contracts to monitor the execution of transactions.

D. Simulation experiment and result analysis

The test environment of this algorithm is Python software. In order to simplify the complexity of the test, the algorithm uses a micro-grid company, an energy bureau and two ordinary users to participate in the algorithm test. This article also stipulates that the excess electricity produced by the micro-grid company should be sold first. For ordinary users, if it is redundant to sell to ordinary users, then sell to the Energy Bureau, and ordinary users only buy electricity but not sell electricity, further reducing the calculation dimension of the algorithm. The bidding space of microgrid companies is 0.5-0.7 yuan/(kw*h); the bidding space of the Energy Bureau is 0.4-0.6 yuan/(kw*h); the bidding space of ordinary users is 0.4-0.6 yuan/(kw*h).

The verification data of this algorithm includes a photovoltaic power generation system with an installed capacity of 800KW and a wind power generation system with an installed capacity of 800KWd. The following figures shows the real and predicted values of the 24-hour wind power generation system and photovoltaic power generation system, and Figure 2 shows the real and predicted values of the load demand of ordinary users and micro-grid companies in 24 hours.

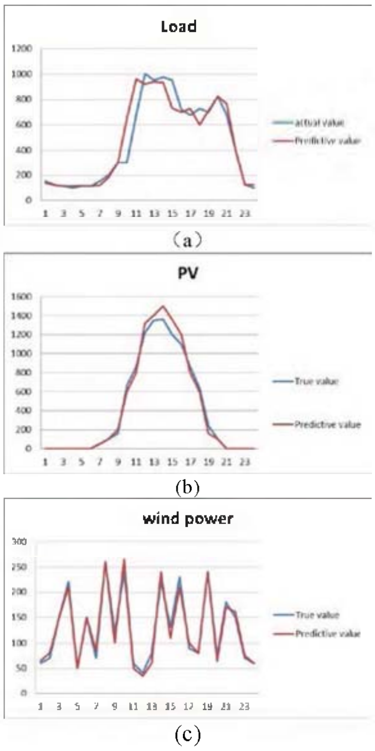

Fig.2 Load true value and predicted value

Figure 5 is the best value of the ACO algorithm obtained from the 24-hour compilation and running of the system, Figure 3 is the 24-hour saleable electricity generated by the micro-grid company and the Energy Bureau, and Figure 4 is the effective filter of the system according to the specific sales situation in Figure 5 value. In the figure, G->U refers to the micro-grid company selling electricity to ordinary users, G->C refers to the micro-grid company selling electricity to the

Energy Bureau, and C->G refers to the energy bureau selling electricity to the micro-grid company. C->U Energy Bureau sells electricity to ordinary users. Taking 12:00 as an example, the best values obtained by the ACO algorithm are: $p_{C->G} = 0.420585\text{yuan} / (KW \bullet H)$, $p_{C->U} = 0.555435\text{yuan} / (KW \bullet H)$, $p_{G->C} = 0.595725\text{yuan} / (KW \bullet H)$, $p_{G->A} = 0.687799\text{yuan} / (KW \bullet H)$. The above data shows that during the peak period of electricity consumption at 12 o'clock, each object tries its best to meet its own electricity consumption. Sell at a high price to obtain the highest profit. For example, for a micro-grid company, the purchase price of electricity should not be higher than 0.420585 yuan/(KW·H), otherwise the income will be small, and for the Energy Bureau, if the price is lower than this price, no high profit will be obtained. Comparing the prices sold to ordinary users by the Energy Bureau and the Micro-grid Company, it is obvious that the price of electricity sold by the Micro-grid Company is higher than the price of the Energy Bureau. According to the figures, this is because the Micro-grid Company is guaranteeing its own use. In the case of electricity, the amount of electricity sold is smaller than that of the Energy Bureau, so in order to achieve higher profits, a higher price is set.

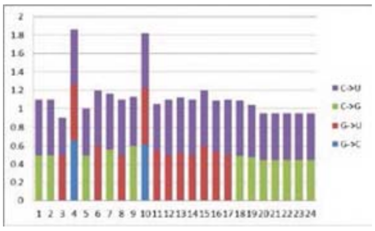

Fig.3 Producer can sell electricity

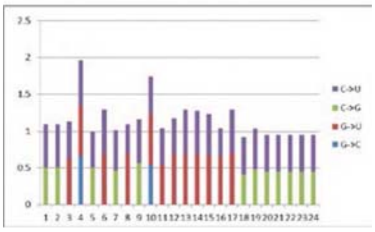

Fig.4 Actual competitive value

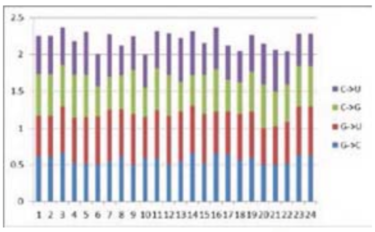

Fig.5 Best bid value of each object

III. CONCLUSION

This paper designs a new energy trading system based on blockchain technology, ACO algorithm and machine learning. According to the cryptographic principles of blockchain, the system can ensure that the transaction data has the properties of tamper-proof and non-repudiation, and fully consider multi-party entities. The competitive relationship between each other and their respective goals establishes a game model for local grid market competition. The advantages of an energy trading system based on blockchain technology are that one is to make energy transactions transparent and open, and the other is that smart contracts in blockchain technology ensure the legitimacy of various energy transactions under decentralized management. For smart contracts, signing smart contracts does not need to be authenticated by an intermediate authority, which ensures that there is no human intervention in the transaction contract. However, due to the immutability of blockchain technology, it needs to be tested repeatedly before entering the market, because smart contracts once deployed, it cannot be modified, and there is a sentence: Code is the law. This sentence vividly describes smart contracts, so the writing and logic of smart contracts need to be very rigorous. This paper also uses the k-nearest neighbor algorithm in machine learning to automatically find the best auction price and automatically sign smart contracts. In the future, the blockchain-based energy trading market may be multi-chain cooperation, which will be combined with carbon emissions, reputation rankings, and energy project capitalization.

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