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Trade based on alliance chain in energy from distributed photovoltaic grids

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Abstract: With the rapid development of distributed photovoltaic grids, more and more users join the power sales side, and the traditional power grid operation mode is no longer applicable. This paper analyzes the characteristics of the distributed photovoltaic grid under overload conditions, and further summarizes the problems that the distributed photovoltaic grid will face under these conditions. To solve these problems, the alliance chain technology was introduced into the distributed photovoltaic grid. At the same time, this paper establishes a photovoltaic pricing strategy that considers power transmission loss. Finally, the feasibility of the theory is verified by constructing a virtual model.

Key words: alliance chain, distributed photovoltaic grid, power transmission loss, pricing strategy

1. Introduction

With the rapid development of the economy, the global fossil energy is gradually exhausted, and the environmental consequences are increasingly more daunting [1, 2]. In addition, the invention and use of a large number of electrical equipment has led to a rapid increase in global demand for electricity. Traditional centralized power generation technology [3] and high-voltage transmission technology [4] are difficult to meet the needs of users for the diversity of power consumption. Compared with traditional thermal power generation systems, photovoltaic generation systems have the advantages of safety, reliability, no exhaustion risk, no restriction on resource distribution, and a short construction period, which are in line with future development needs [5–7].

In order to promote the development of the domestic photovoltaic industry, the State Council of China promulgated the "Several Opinions of the State Council on Promoting the Healthy Development of the Photovoltaic Industry" [8], which clearly pointed out that distributed photovoltaic generation technology will be vigorously developed. At the same time, the relevant management departments have clearly proposed to open up the electricity sales business to social capitals, and cultivate a variety of market competition entities on the power-selling side in multiple channels to provide more and better choices for power users. Under the encouragement of the government, in 2018, China's new installed capacity of distributed photovoltaics accounted for about half of the total installed capacity [9]. However, at present, most of China's distributed photovoltaic grids are built in rural areas or other remote areas. They are basically in the stage of demonstration engineering, and there are problems such as the surge in the number of users and the difficulty of settlement in the process of power trading. Moreover, the power grid equipment will produce a large amount of data in the process of operation [10], and higher reactive power management complexity is caused by the access of distributed power [11]. In summary, China's distributed photovoltaic grid trading mechanism is not perfect. If we plan to introduce distributed photovoltaic generation networks into cities to achieve the goal of replacing traditional power grids, it is necessary to establish reasonable operational and competitive mechanisms.

At present, relevant scholars have done some research on distributed power trading mechanisms. Yang Xuanzhong *et al*. [12] constructed a mechanism and model for distributed power trading, considering security constraints based on shortcomings of the traditional power trading mode, such as high maintenance cost, low processing efficiency and delayed fund settlement. The example shows that the method has certain practical value; Yan Yanfang [13] summarized the existing trading models and proposed the distributed energy trading price mechanism, balance mechanism and supervision mechanism. At the same time, the realization path of the distributed energy transaction mode is proposed, which provides a research basis for the transaction risk assessment of distributed energy. Hou Jianchao *et al*. [14] designed a distributed energy Internet transaction mechanism. The data calculation results show that the trading mechanism has good practical value. Harinder Pal Singh *et al*. [15] proposed a fair calculation approach for a multi-objective load dispatch problem. Qi Bing *et al*. [16] proposed a block chain based photovoltaic trading mechanism aimed at resolving the delayed replenishment, consumer surge and settlement difficulty issues. Then proved its pragmatic function through simulation.

In summary, some results of the distributed photovoltaic grid trading mechanism have been obtained by relevant scholars, but there are still some shortcomings, mainly reflected in the following two points:

1) in the case of the proliferation of users of distributed photovoltaic grids, the power system needs to deal with huge interactive data [17];
2) the current photovoltaic grid pricing mechanism is too unidimensional [18], it cannot stimulate transactions between neighboring users.

This paper proposes a distributed photovoltaic grid trading mechanism based on alliance chain technology, which is used to solve the management difficulties caused by the surge of users. A distributed photovoltaic grid pricing strategy considering power transmission loss is proposed to promote the transactions between neighboring users. Finally, the paper analyzes the practicability of the theory by establishing a virtual model.

2. Characteristics and problems of distributed power grid

Distributed photovoltaic grids are economical, environmentally friendly, widely distributed, and diverse in form.

2.1. Economic and environmental protecting

Distributed photovoltaic generation is a form of photovoltaic generation. Photovoltaic generation has significant energy, environmental protection and economic benefits and is one of the best green energy sources. Under the average sunshine conditions in China [19], a 1 kW photovoltaic generation system can be installed, which can emit 1200 kWh per year, which can reduce the use of coal (standard coal) by about 400 kg and reduce carbon dioxide emissions by about 1 ton. From the perspective of reducing carbon dioxide emissions, each installed 1 square meter photovoltaic generation system is equivalent to the afforestation of 100 square meters. In summary, the distributed photovoltaic grid has economic and environmental characteristics.

2.2. Wide distribution range

A photovoltaic power generation system is a device that converts solar energy into electric energy. Its distribution characteristics are closely related to the distribution characteristics of solar radiation quantity. Therefore, the distributed characteristics of the distributed photovoltaic grid can be studied in combination with the distribution characteristics of solar radiation quantity. China's total solar radiation resources are abundant, and the overall distribution characteristics are "plateaus are larger than plains, the western dry areas are larger than the eastern humid areas". Among them, the Qinghai-Tibet Plateau is the most abundant, with an annual total radiation of more than 1800 kWh/mm^2, and some areas even exceeding 2 000 kWh/mm^2. The resources in the Sichuan Basin are relatively low, and the minimum radiation is less than 1 000 kWh/mm^2 [20]. In summary, most of China's solar radiation resources are abundant. If large-scale construction of distributed photovoltaic grids is implemented, it will have a wide distribution.

2.3. Various forms

Distributed photovoltaic generation includes grid-connected, off-grid and multi-functional complementary microgrids [21]. Urban and rural building roofs, enterprise buildings, agricultural greenhouses and public facilities can be built into grid-connected or multi-functional complementary microgrid-type photovoltaic grids. In remote agricultural and pastoral areas, islands and other areas, off-grid or multi-functional complementary microgrid photovoltaic grids can be built. Therefore, if a large-scale distributed photovoltaic grid is built in the future, it will have various forms of characteristics.

This paper combines the basic characteristics of distributed photovoltaic grids, and specifically analyzes two basic problems that will be faced after the widespread application of distributed photovoltaic grids.

3. Topology of distributed photovoltaic grid based on alliance chain

The topology of the distributed photovoltaic grid connected system based on an alliance chain is shown in Fig. 1, which is mainly composed of a physical layer, blockchain network layer, drive layer and application layer.

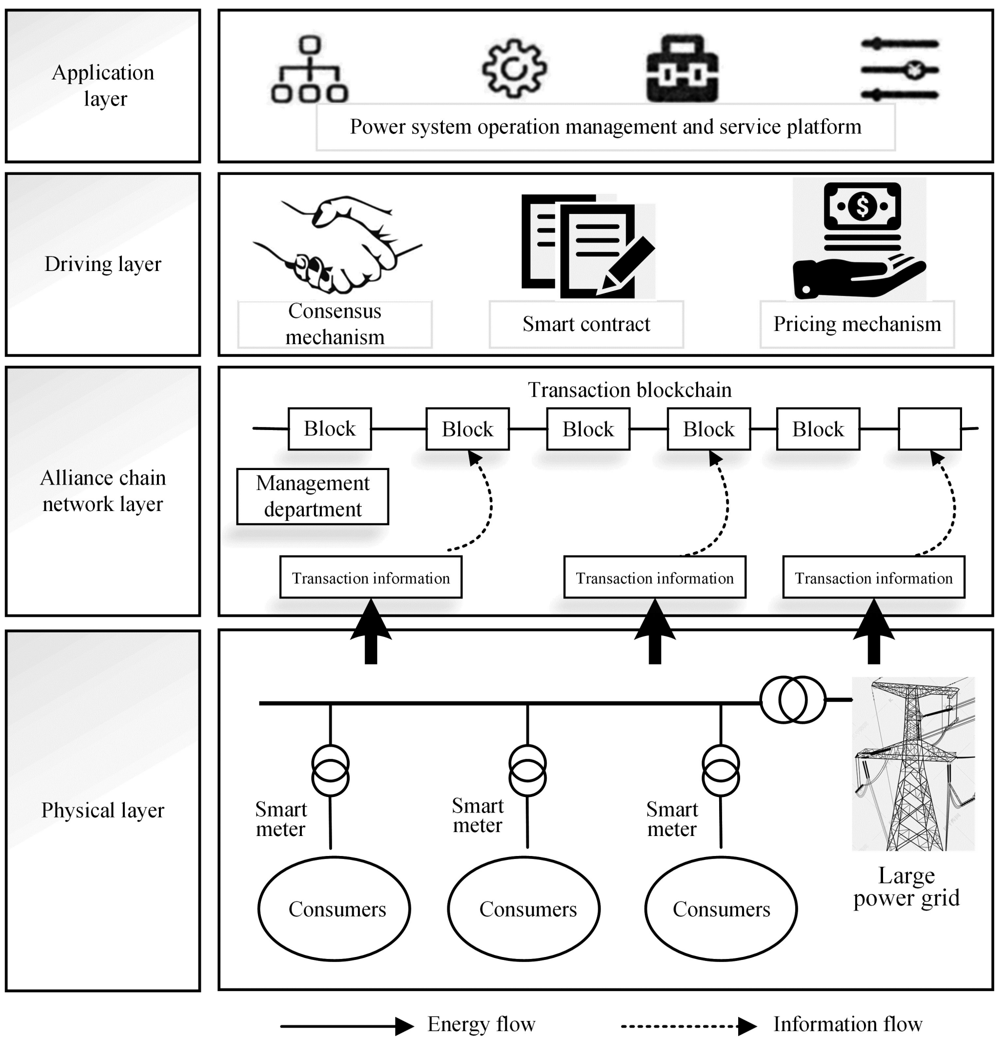

Fig. 1. Topology structure diagram of distributed photovoltaic grid based on alliance chain

Among them, the physical layer is the energy node connection diagram; the blockchain network layer is the decentralized network generated by the energy node mapping to drive the operation of the blockchain architecture; the driving layer includes a smart contract, consensus mechanism and incentive mechanism; the application layer is the actual power application. The specific functions of each layer are as follows:

1. Physical layer
   The physical layer includes the physical information and equipment information related to distributed generation, such as power users, power suppliers, power suppliers and large power grids. In the power operation and trading network system based on an alliance chain, it is embodied in each energy node. Starting from the large power grid, the physical layer connects multiple power trading blocks. The energy between blocks can flow with each other, the smart meter records the input and output of node electric energy.
2. Alliance chain network layer
   The network layer of a blockchain is a decentralized network generated by energy node mapping, including two aspects of a P2P protocol and signaling characteristics of blockchain technology. A blockchain network is essentially a P2P (peer-to-peer) network, each node not only receives information, but also generates information. Nodes maintain communication by maintaining a common blockchain. The network layer of a blockchain is the network guarantee of communication, transaction and consensus between nodes. To join the network, new nodes need to be certified by the management department to ensure the network security.
3. Driving layer
   The driving layer includes a consensus mechanism, smart contract and incentive mechanism, which is the core layer to realize power system operation and transaction. After the participants form a transaction through game, they automatically generate a smart contract. The smart contract has the attributes of an ID user, transaction price, transaction time and energy source type of both parties. Then both parties sign with a private key to ensure the reliability of the data of the power chain and broadcast all over the network.
4. Application layer
   The application layer encapsulates various application scenarios and cases of blockchains, integrates the power transaction, power system operation management application and service platform, mainly including blockchain user clients, various cryptocurrencies, such as Ethereum wallet and bitcoin, to realize transfer and bookkeeping functions.

4. Alliance chain based distributed photovoltaic grid operating principles

The relationship between a network layer and physical layer is as illustrated in the Fig. 2.

In the Fig. 2, solid lines represent energy flows, dotted lines represent information flows. Type A users are distributed nodes whose electricity exhaustion outweighs its electricity generation, consisting mostly of factories and office buildings. Type B users are distributed nodes whose electricity generation outweighs its electricity exhaustion, consisting mostly of farm greenhouses and rural accommodations. Management departments are government facilities in charge of the identification of new nodes joining the distributed power grid, the documentation of power transactions and the supervision of real time power price decisions. The main grid connects to the distributed grid through the grid nodes which are responsible for energy transmission between the distributed grid and the main power grid.

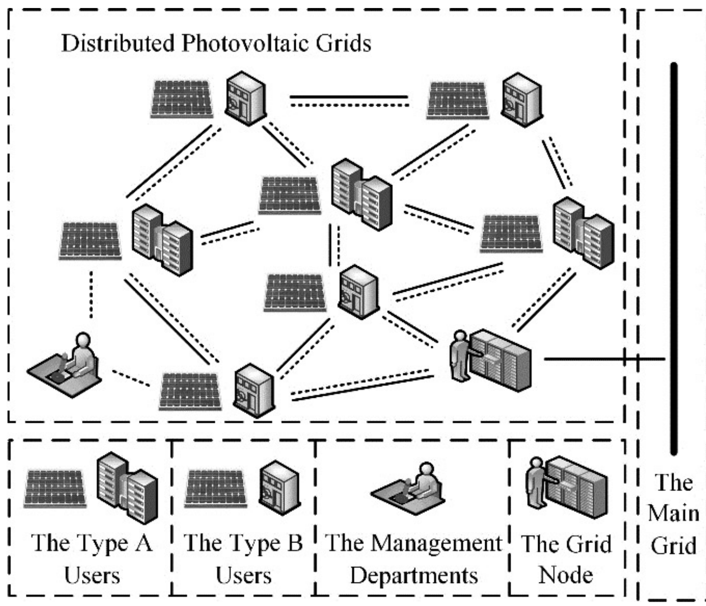

Fig. 2. The relationship between network layer and physical layer

Alliance chain based distributed photovoltaic grid operating principles are as below:

1. The intelligent contract formulated by managing government facilities. The contract should consist of rights and obligations of Type A and B users, for instance, the power-purchasing side should purchase power from the nearest power-selling nodes while taking into consideration the rationality of power prices.
2. When new nodes propose to join the distributed photovoltaic grid, they should acquire qualification from management departments beforehand, management departments should define the user type according to its actual condition and investigate the power purchase and power sales capabilities of the new node. At the same time, they should set a certain limit on the amount of quantity of electricity sold and power purchased, to ensure the fluent operation of the distributed photovoltaic grid.
3. In addition to the certification work of the new node, the government management department also needs to record and supervise the power transaction information in the distributed photovoltaic grid. Once the power transaction exceeds beyond qualification or other violations are found, the node should be immediately dealt with according to relevant legislation.
4. The distributed photovoltaic grid node is responsible for connecting the main power grid to the distributed photovoltaic grid. At the same time, it acts as the power-selling side and

the power-purchasing side participating in the power transaction. When the total power generation fails to outweigh its power exhaustion, the difference is supplemented by the main grid. When the total electricity production exceeds the total demand, the excess is sold to the main grid at a lower price.

The flow chart of the distributed photovoltaic grid transaction based on an alliance chain is illustrated in the Fig. 3. By introducing the alliance chain into the distributed photovoltaic grid, the problem of management difficulties caused by the large-scale application of the distributed photovoltaic grid is solved. Compared with the distributed photovoltaic grid based on the blockchain, the introduction of the management department can conduct the authentication of new users and supervise the daily operation of the system.

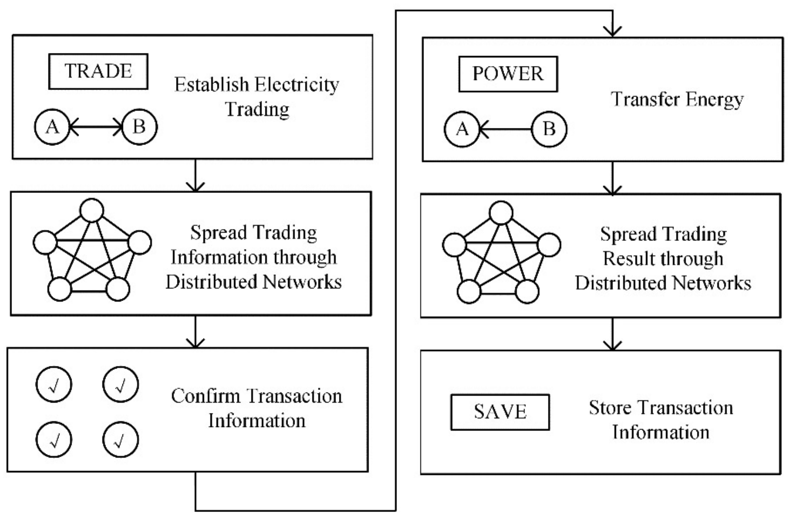

Fig. 3. Flow chart of distributed photovoltaic grid transaction based on alliance chain

5. Photovoltaic power pricing strategy considering power transmission loss

At present, China's distributed photovoltaic grids use the method of "self-sufficient powering, surplus electricity goes to the girds" to sell overflowing electric energy. That is, after users use photovoltaic to meet their own production and living needs, the excess electricity is sold to the local power supply bureau. The power supply bureau then sells it to other power purchasers. In this mode, the price of the photovoltaic sold to the grid is mainly determined by factors such as cost, profit and taxes, and the price difference of users in the same region is not prominent. When distributed photovoltaic generation is widely popularized, the traditional distributed photovoltaic pricing strategy cannot stimulate the enthusiasm of direct power transactions between neighboring users, which is contrary to the original intention of distributed photovoltaic generation. Therefore, a new photovoltaic pricing strategy is needed to facilitate the close proximity of power transaction users with neighboring users, while meeting the demand for power consumption among users.

Combined with the traditional power pricing strategy, a power pricing strategy considering transmission loss is designed in this paper. The power transmission loss constant is introduced on the basis of the traditional power price, and it is mainly related to the length of the transmission distance and the number of nodes the transmission goes through.

The photovoltaic pricing strategy model considering power transmission loss is as follows:

$$P = \omega P_f + L, \tag{1}$$

$$L = \alpha D + \beta N. \tag{2}$$

In the formula above, P is the final price for the purchaser to purchase electricity from the electricity seller, P_f is the local benchmark electricity price, L is the power transmission loss, D is the shortest distance between the seller and the purchaser, N is the smallest number of nodes needed for transmission between the seller and the purchaser, ω, α, β are the coefficients.

We set E_{total} as the total electricity purchased by a certain electricity purchasing user, E_{near} is the electricity purchased by the user from the adjacent generating units, and η represents the proportion of the electricity purchased by the user nearby. The calculation is carried out by Formula 3.

$$\eta = \frac{E_{\text{total}}}{E_{\text{near}}}. \tag{3}$$

In order to encourage the purchase of electricity nearby, η should be set as large as possible under the condition of ensuring the stability of the power grid. At the same time, we can also observe the value of η to judge and adjust the value of ω, α, β. The specific algorithm is shown in Fig. 4.

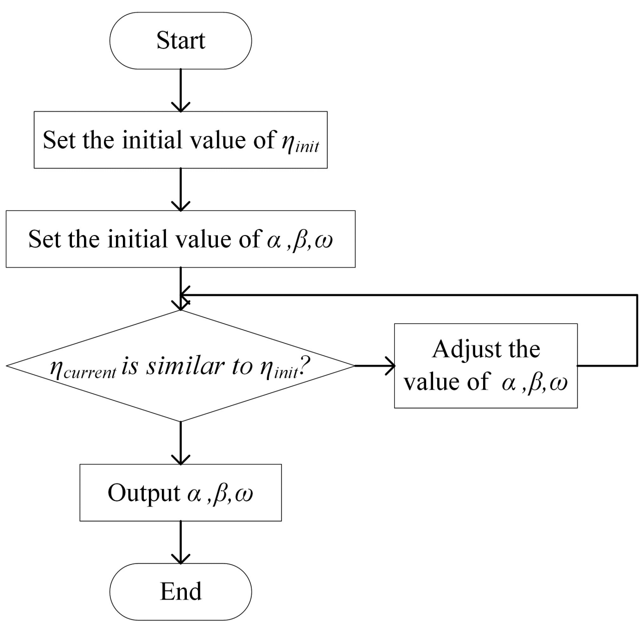

Fig. 4. The calculation method of ω, α, β

In Fig. 4, η_{init} is the preset value of η, and η_{current} is the current value of η. When η_{current} is not similar to η_{init}, adjust ω, α, β until the two are close. Then output ω, α, β.

The Fig. 5 shows the relationship between the power transmission loss L, the shortest transmission distance D, and the minimum number of nodes N when both α and β are 0.5.

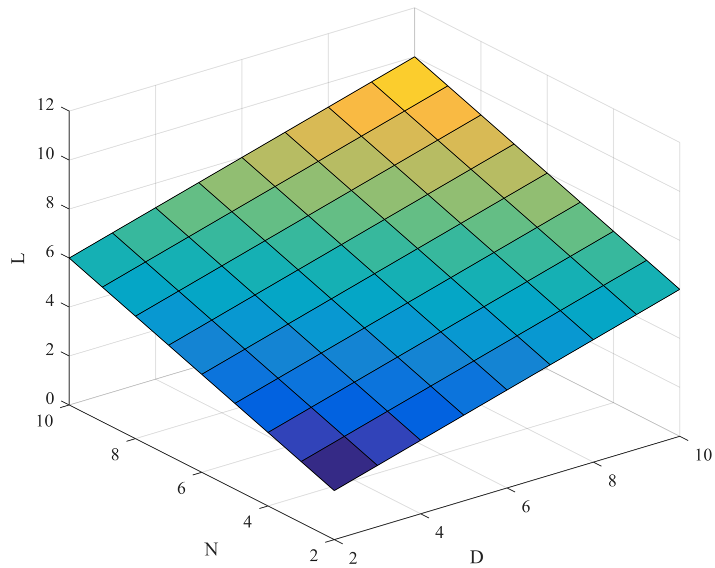

Fig. 5. The relationship between L, N and D

From Fig. 5, we can see that the power transmission loss L gradually increases as the minimum number of nodes N and the shortest transmission distance D increase. Therefore, people will trade electricity with neighboring users for lower electricity prices.

6. Simulation analysis of photovoltaic pricing strategy considering power transmission loss

This paper demonstrates the application value of the photovoltaic pricing strategy through simulation. First, an equivalent model of the distributed photovoltaic grid is instituted. The model is shown in the Fig. 6.

The circle in the figure represents the nodes in the distributed photovoltaic grid. The lateral distance between the nodes is equal, as well as the longitudinal distance, and the nodes are evenly distributed. The A node represents the purchaser, and the B and C nodes represent the electricity seller. By comparing the price of the A node purchasing power from the B and C nodes, the practical value of the photovoltaic pricing strategy considering power transmission loss is analyzed.

For the convenience of calculation, we assume the unit distance between the nodes is D_{Unit}. It can be seen from the figure that the shortest distance from node A to node B needs to go through

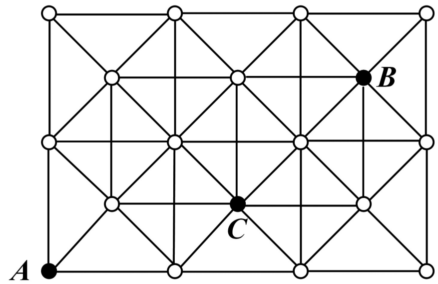

Fig. 6. Equivalent model of the distributed photovoltaic grid

3 nodes, and the shortest distance is $(3 + \sqrt{2})D_{\mathrm{Unit}}$; the shortest distance from node A to node C needs to go through 1 node, and the shortest distance is $(1 + \sqrt{2})D_{\mathrm{Unit}}$. The price at which node A purchases power from node B is:

$$P_{A-B} = \omega P_f + L_{A-B}, \tag{4}$$

$$L_{A-B} = (3 + \sqrt{2})\alpha D_{\mathrm{Unit}} + 3\beta. \tag{5}$$

The price at which node A purchases power from node C is:

$$P_{A-C} = \omega P_f + L_{A-C}, \tag{6}$$

$$L_{A-C} = (1 + \sqrt{2})\alpha D_{\mathrm{Unit}} + \beta. \tag{7}$$

After the three coefficients ω, α, β are determined, it is not difficult to find that $P_{A-B} > P_{A-C}$, meaning the price of the A node purchasing power from the B node is greater than the price at which the A node purchases power from the C node.

Further, we calculate the price at which the A node purchases power from each node when α and β are 0.5. The electricity price chart is shown in Fig. 7.

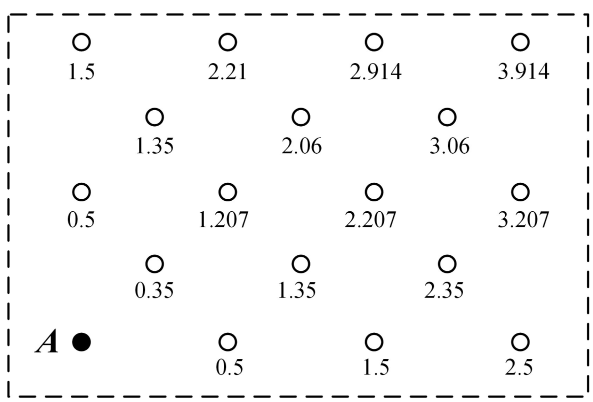

Fig. 7. The electricity price chart

By comparing with Fig. 3, we can know that the price trend of the simulation results is consistent with the theoretical results.

Through the above analysis, we can speculate that as the transmission distance increases and the number of nodes increases, the price of electricity will continue to increase. Therefore, when the values of ω, α, β are reasonable, the purchaser wanting to purchase cheaper power will directly conducts power transactions with neighboring users, thereby achieving the goal of reducing the burden on the grid.

7. Conclusion

Under the condition of a rapid increase in the number of users, the distributed photovoltaic grid has the characteristics of economically efficient, distribution range wide and various in forms. At the same time, distributed photovoltaic grids will face management difficulties and the nonapplicable situation of traditional pricing strategies.

Introducing the alliance chain technology into the distributed photovoltaic grid through the above presented management to carry out new user authentication and power grid transaction process supervision solves the problem of management difficulties faced by the distributed photovoltaic grid under overload conditions. At the same time, the main grid joins the distributed photovoltaic grid as a node, and does not directly participate in the transaction process between other nodes in the distributed photovoltaic grid, which reduces the operational burden of the power grid.

Establishing a photovoltaic pricing strategy that considers power transmission loss, links the price of electricity to the transmission distance and the number of nodes passing through the transmission process. Finally, by constructing a model for simulation, it is verified that the pricing strategy can effectively stimulate direct transactions between neighboring users.

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