New Energy and Future Energy Systems
G.L. Kyriakopoulos (Ed.)

doi:10.3233/AERD220021

Comparison and Analysis of Virtual Power Plant and Peer-to-Peer Transaction Applied to Distributed Generation Market Transaction in China

Guodong JIANG[a,1], Tao HAN[a], Hongwei DU[a], Xiaojun NIU[b], Xueqiong WU[a], Rongqiang FENG[a], Dong XIA[a] and Yuhang LI[a]

[a]*NARI-TECH Nanjing Control Systems Ltd., No.19 of Chengxin Avenue, Jiangning District, Nanjing 211106, China*
[b]*State Grid Panzhihua power supply company No. 5, Xinyuan Road, Panzhihua City, Sichuan, 617000, China*

Abstract. firstly, this paper analyzes the necessity of market transaction of distributed generation, and summarizes the current situation of distributed generation transaction in the world. Then it discusses and analyzes the relevant policies of the Chinese government for distributed generation transaction, including photovoltaic subsidy policies, support policies for virtual power plants to participate in power trading, and support policies for distributed generation transaction pilot projects. According to China's current electricity market rules and distributed generation transaction support policies, a distributed generation transaction platform system suitable for Chinese electricity market is designed based on blockchain technology. This paper compares and analyzes the two modes of virtual power plant and peer-to-peer transaction from the aspects of DG investor's revenue and trading model. Finally, for the development of distributed generation trading in China, we draw conclusions and suggestions, and put forward the problems to be solved in the next step.

Keywords. Distributed generation transaction, subsidy, virtual power plant, peer-to-peer, revenue analysis, trading model, transaction platform

1. Background

In recent years, with the development of technology and the support of governments around the world, renewable energy represented by wind power and photovoltaic has developed rapidly. Among them, distributed generation (DG), represented by distributed photovoltaic, is highly penetrative in the power system because of its flexible access, high energy efficiency, small network loss and good economy. In 2021, the cumulative installed capacity of global wind power was 837GW, with an increase of 107GW [1]. In 2021, the cumulative installed capacity of global PV is expected to be about 930GW,

[1] Corresponding author, Guodong Jiang, NARI-TECH Nanjing Control Systems Ltd., No.19 of Chengxin Avenue, Jiangning District, Nanjing 211106, China; E-mail: jiangguodong@sgepri.sgcc.com.cn.
This work was supported by NARI-TECH Nanjing Control Systems Ltd. (No. 524609210159).

and the new installed capacity of global PV will reach 170GW [2]. According to the data from the National Energy Administration, the cumulative installed capacity of wind power in China was 328.5GW in 2021, with an increase of 54.86GW. The cumulative installed capacity of PV in China was about 306GW, of which 107.5GW was distributed PV, accounting for 35.1%. The newly installed capacity of PV in China was about 54.88GW, including 29.27GW of distributed PV, accounting for 53.33%.

With the rapid increase of distributed generation, the constraints of the power industry, such as low degree of marketization and imperfect management system, have gradually emerged. A large number of power consumers, after having distributed photovoltaic and other power generation resources, consume electricity and produce electricity at the same time, becoming prosumers. Due to the large number of prosumers, the contradiction between the uncertainty of new energy output and the mismatch of source load will become more and more prominent. Due to the limitation of renewable energy accommodation of distribution power system, a large number of "surplus power" will appear. The traditional modes of "full access to grid" and "self-use and surplus electricity access to the Internet" can not adapt to the current market situation, affecting the accommodation of renewable energy [3].

Distributed generation market transaction refers to the power transaction between distributed generation plants and one or more nearby power consumers in the distribution network who meet the transaction conditions (such as it can accommodate all their power access in grid), and the power grid utility is taken as the transmission service party to sign a three-party power supply and consumption contract, specifying the transaction period, transaction power, settlement electricity price, network fee standard and liability for breach of contract. Distributed generation market transaction has the following main characteristics.

- As close as possible. The distributed power shall, as far as possible, conduct power transactions with consumers within the same power supply voltage level under the same grid access point, so as to realize the nearby accommodation. This reflects the actual situation of the production and consumption of distributed power, and will bring benefits to both parties of the transaction and promote the development and consumption of distributed power.
- Direct transaction between the supplier and the consumer. Distributed generation transaction empowers both the supplier and the consumer the right of choice. The supplier can give priority to transactions with consumers who are more suitable for him. Consumers can also choose one or more suitable suppliers according to their own power demand.
- The participants are more diversified. After implement of real-time distributed generation transactions, on the one hand, the end consumers on the load side can no longer passively accept electric energy, and may be energy consumers with their own power generation equipment; on the other hand. Traditional power market participants, including power grid, power plants and power sale companies, will play new roles.

In order to reconcile the interests of these various types of power market participants and realize power grid regulation, various countries have established a number of distributed generation trading pilot projects based on different trading technologies, mainly in two ways, peer-to-peer (P2P) and virtual power plant (VPP) [4].

2. Development Status of Distributed Generation Transaction

Virtual power plants can be used for distributed generation transactions. They have entered the commercial stage in Germany, the Netherlands, the United States and other countries, and some countries are in the demonstration stage. At present, ABB, Siemens, Ge, AGL energy, Cisco, IBM and other companies provide virtual power plant systems in the world [5]. In 2008, as part of Germany's e-energy plan, RegModHarz virtual power plant project was launched in Hartz and completed in October 2012. The project uses advanced information and communication technology to aggregate photovoltaic, wind power, biogas cogeneration and pumped storage [6]. Next Kraftwerke is a large-scale virtual power plant operator in Germany. It operates a diverse portfolio of power plants, with a large number of independent renewable energy power producers or small and medium-sized power plants. It participates in the power wholesale market and the power auxiliary service market. It also provides software services to other virtual power plant operators, including forecasting, scheduling, real-time data communication, asset control and other functions. In the Netherlands, Autogrid systems company cooperates with Eneco, a Dutch power and natural gas supplier, to establish a virtual power plant for Eneco, integrate a variety of distributed energy resources, and add up to 100MW of schedulable resources to the product portfolio, including cogeneration and industrial demand response [7].

The peer-to-peer transaction method has been applied to distributed generation transactions, and there have been some projects in countries around the world, such as Enyway and Lition in Germany, Piclo in the UK, etc.

Enyway is the largest commercial peer-to-peer energy trading online platform in Germany, which was founded in 2017. Its foundation is a blockchain system, which is composed of a multi-token model and a digital identity register. The multi-token model enables the redesign of public exchange relations and value storage, while the register of digital identity ensures the authenticity and integrity of participants and assets in the blockchain system. At the beginning of 2020, about 35 power producers, with a total of about 20MW, used the Enyway platform to sell their power directly to power consumers [8].

Lition is a P2P energy trading platform in Germany and a blockchain trading platform. The company released DAPP (decentralized APP) for energy trading in April.2018, and now provides services for consumers in more than 100 cities of Germany. The Lition platform deploys smart contract based on blockchain and smart meter, Internet of Things technology, enabling consumers to directly obtain energy services according to cost, production mode and real-time consumption pricing, allowing direct transactions between consumers and producers through smart contracts [7]. Currently, Lition is still running on the open source Ethereum blockchain, but is currently developing its own blockchain software with SAP [9].

Piclo, a P2P trading platform in the UK, is an online trading market platform for clean electricity. Piclo collects the real-time tradable electric energy of each distributed generator and the consumer's electricity demand within 30 minutes reflected by the smart meter. According to the distance between the trading parties, the electric energy price and the trading preference, Piclo uses a proprietary P2P matching algorithm to match the optimal distributed generator for consumers. If a single distributed generator or a certain distributed resource cannot meet the power demand of consumers, Piclo will select another distributed energy resource to supplement the power supply. In terms of transaction contracts, Piclo will customize the power purchase agreement (PPA)

according to the power generation scale, technology and power generation level of each generator owned by the power producer, and even in combination with the on grid electricity price subsidies enjoyed by the power producer. The contract will specify the transaction details such as electricity price and quality level [10].

In China, the application of virtual power plants includes projects in Shanghai, North of Hebei and Nanjing. In 2017, the Shanghai Huangpu District virtual power plant project realized the aggregation of load side resources through virtual power plants and provided demand response services such as peak shaving. In August, 2017, the largest scale trial operation of the Huangpu District virtual power plant involved more than 50 buildings, reducing the load by about 10MW. In December,2019, the demonstration project of Hebei power Internet of Things virtual power plant was officially launched. The first phase of the project has real-time access and control of regenerative electric heating, which can adjust 11 types of 19 adjustable resources, including industry and commercial loads, intelligent buildings, smart homes, energy storage, electric vehicle charging stations, distributed photovoltaic, with a capacity of about 160MW, covering Zhangjiakou, Qinhuangdao and Langfang. The pilot project of applying blockchain technology to distributed generation transaction has not been reported in China yet.

3. Supporting Policies for Distributed Generation Transaction in China

At present, in China, distributed generation cannot directly trade with power consumers in the power market. Due to the increasing penetration of distributed generation in the power grid, it is difficult to accommodate it. At the same time, the cost of distributed PV is getting lower and lower, which also makes the transaction between distributed PV and consumers profitable. Therefore, the Chinese government has started the pilot construction of direct transaction of distributed generation. In October, 2017, the National Development and Reform Commission and the National Energy Administration issued FGNY [2017] No. 1901 'The Notice on the pilot of market transaction of distributed generation' (Hereinafter referred to as 'The Notice'). In January,2018, the National Energy Administration issued FGBNY [2017] No. 2150 'The supplementary notice on the pilot of market transaction of distributed generation' (Hereinafter referred to as 'The Supplementary Notice') [11]. Since then, China has started the pilot project of market transaction of distributed generation. This chapter will interpret and analyze Chinese distributed generation transaction policy from various aspects.

3.1. The Subsidy Policies for Distributed Photovoltaic

Chinese government began to provide subsidies for distributed PV in 2013. In 2013, the National Development and Reform Commission issued 'The Notice of the national development and Reform Commission on giving full play to the role of price leverage to promote the healthy development of the photovoltaic industry' (FGJG [2013] No. 1638), providing a subsidy of 0.42 RMB per KWh for distributed PV for 20 years.

At that time, the price of PV modules was too high, and the market was in the embryonic stage. The subsidy of 0.42 RMB per KWh was not high relative to the construction cost of PV power stations, so this subsidy policy lasted for 4 years. By December.19,2017, the distributed photovoltaic subsidy had been reduced for the first time, by 0.05 RMB per KWh to 0.37 RMB per kWh, and then decreased year by year. In 2021, the national development and Reform Commission announced that in 2022, the

government will no longer subsidize the new distributed PV, and encourage and support grid parity for PV. See Table 1 for specific policy changes.

Table 1. The Table of Chinese distributed photovoltaic subsidy policy.

Document No.	Release date	Subsidy content
FGJG [2013] No.1638	August 26, 2013	distributed photovoltaic power: 0.42 RMB (0.063 USD) per KWh (tax included)
FGJGG [2017] No.2196	December 19, 2017	distributed photovoltaic power: 0.37 RMB (0.055 USD) per KWh (tax included)
FGNY [2018] No.823	May 31,2018	distributed photovoltaic power: 0.32 RMB (0.048 USD) per KWh (tax included)
FGJG [2019] No.882	April 28, 2019	household distributed photovoltaic power:0.18 RMB (0.027 USD) per KWh Industrial and commercial distributed photovoltaic: 0.12 RMB (0.018 USD) per KWh (tax included)
FGJG [2020] No.511	April 2, 2020	household distributed photovoltaic power:0.08 RMB (0.012 USD) per KWh, Industrial and commercial distributed photovoltaic: 0.05 RMB (0.0075 USD) per KWh (tax included)
FGJG [2021] No.833	June 7, 2021	household distributed photovoltaic power: 0.03 RMB (0.0045 USD) per KWh (tax included). No subsidy from 2022.

3.2. Policy of Virtual Power Plant Participating in Power Transaction

In July, 2021, Guangzhou Municipal Bureau of industry and information technology issued 'The Implementation Rules of Guangzhou Virtual Power Plant', which will guide power consumers to actively reduce peak load by implementing the demand response via virtual power plants.

In August, 2021, the National Energy Administration issued 'The Administrative Measures for Auxiliary Services of Power System', which brought the adjustable loads be capable of responding to dispatching instructions (including the adjustable loads aggregated through aggregators and virtual power plants) and energy storage into the scope of providing auxiliary services.

In April, 2022, Guangdong Province Government issued 'The Detailed Rules For The Implementation of Market-oriented Demand Response in Guangdong Province'. Virtual power plants can participate in the power demand response market.

Through these policies, the Chinese government has given virtual power plants the right to independently participate in power system auxiliary services in Guangdong Province. However, it has not allowed for virtual power plants to participate in power transactions as independent entities until now.

3.3. Supporting Policies for Market Transaction of Distributed Generation

The following results can be obtained through the interpretation of the two documents 'The Notice' and 'The Supplementary Notice'.

According to 'The Notice', the projects participating in the market transaction of distributed generation are mainly divided into two categories:

- The unit capacity shall not exceed 20MW, and the network voltage grade shall be 35kV or below;
- The unit capacity is between 20~50MW, the network voltage level is not more than 110KV, and the nearby accommodation is realized within the voltage level range.

According to 'The Notice', the transaction modes of distributed generation are divided into three categories:

- Distributed generation projects directly sell electricity to power consumers and pay the network fee;
- The distributed generation project entrusts the power grid to sell electricity, and the power grid will transfer the electricity fee to the distributed generator according to the comprehensive electricity selling price deduct the network fee price;
- The power grid purchases electricity according to the on-grid electricity price of various power generation benchmarks approved by the state, and shall deduct the transmission and distribution tariff corresponding to the consumers with the highest voltage level in the distribution network area.

There are two forms of distributed generation transaction organization mode.

- Establish a market trading platform for distributed generation, and rely on the provincial trading center to set up sub modules of distributed generation trading platform in the city and county-level power grid platform.
- The distributed generation projects that meet the access conditions shall be filed with the local energy authority, and after the technical review by the power trading agency, energy trading contracts shall be signed with the nearby power consumers on a monthly or annual basis.

Charging standard of network fee:

- The transmission and distribution tariff of the highest voltage level involved in the market transaction of distributed generation shall be deducted from the transmission and distribution tariff of the public network of the provincial power grid corresponding to the access voltage level of the power user (including policy cross subsidies),then is network fee, before the verification, which shall be formulated by the provincial (District, city) price authority in accordance with the relevant provisions of the national transmission and distribution tariff reform;
- When the total installed capacity of the distributed generation project is less than the average power load of the previous year within the power supply range, the network fee shall be subject to the network fee standard within the current voltage level. In case of exceeding the limit, the network fee standard of the upper voltage level shall be implemented.

Relevant policy support for market transaction of distributed generation includes:

- In addition to charging network fees, other services include electricity metering, collecting electricity fees, etc. the power grid does not charge any service fees for distributed generation project units;

- Subsidy of Photovoltaic power generation is moderately reduced on the basis of the standard subsidy of local government file;
- If the unit capacity does not exceed 20MW, the reduction rate of subsidy shall not be less than 10%;
- If the unit capacity is between 20~50MW, the reduction rate of subsidy shall not be less than 20%;
- The renewable energy electricity volume of the distributed generation market transaction is regarded as the renewable energy electricity consumption in the electricity consumption of the power purchaser, and the corresponding energy saving amount is included in the power purchaser. When the renewable energy power quota system is implemented, the renewable energy power transmitted and traded through the power grid is included in the completion of the renewable energy power quota of the local power grid;
- The National Development and Reform Commission and the National Energy Administration determine the total construction scale and annual new construction scale of the pilot areas by the end of 2020. The newly-built wind power and photovoltaic power station projects below 50MW in the pilot area are constructed according to the market transaction mode.

This policy limits the maximum power input to the grid by projects participating in the market transaction of distributed generation, as shown in Table 2.

Table 2. Table of limit requirements of maximum power into grid.

category	Voltage Level	maximum power into grid
1	≤35KV	≤20MW
2	66KV or 110KV	20MW≤P≤50MW
3	≥110KV	No admits

According to the proposal of the National Energy Administration, the forms of distributed power generation participating in market transactions shall include: distributed photovoltaic power plants for "self-use and surplus power on the grid", decentralized photovoltaic power plants and wind farms, and distributed power generation projects connected to the distribution network and meeting the grid voltage level and consumed nearby.

To summarize, Chinese current policy supports the pilot construction of direct trading of distributed generation, but it has not been fully carried out. Moreover, for the pilot project of market transaction of distributed generation, there are restrictions of voltage range, control mode, capacity and others.

4. Design of Distributed Generation Trading System

The current power market in China can be divided into power wholesale market and power retail market. Power wholesale market refers to the market where power generation enterprises conduct power transactions with power sale companies or large power consumers. The power wholesale market adopts the market structure of Electricity Market + Auxiliary Service Market. Electricity market includes medium and long-term electricity market, day ahead electricity market and real-time electricity spot market. The medium and long-term electricity market realizes flexible trading through bilateral

negotiation, centralized competition, listing and other means. The day ahead electricity market and the real-time electricity spot market conduct full electricity bidding to form the spot market prices on both sides of power generation and consumption based on the node marginal electricity price. The auxiliary service market includes frequency modulation, standby and other services, forming a market-oriented auxiliary service call and price mechanism.

Electricity retail market refers to the market in which electricity trading is conducted between power sale companies and electricity consumers. In the power retail market, the power sale company and the power consumers independently sign the retail contract and establish the retail relationship, and make settlement according to the price agreed in the contract. In order to promote orderly competition in the retail market, the upper limit of retail market share of power sale company is set.

The market transaction of distributed generation in the pilot project is carried out in the power retail market. In the microgrid or regional power grid, electricity sale company can directly sell electricity to consumers in the form of virtual power plants. A single distributed generation can directly sell electricity to consumers through peer-to-peer transaction. In theory, peer-to-peer transactions can cross over transformers.

According to the interpretation of the distributed generation market trading rules by the National Energy Administration, the distributed generation market trading platform shall have the following technical requirements and conditions.

- Distributed power transaction information management system. The trading platform shall have the following main functions: apply for participating in distributed power trading, submit bilateral power trading contracts, and accept the online trading power forecast of distributed power sellers. The trading platform is responsible for reviewing the qualifications of both parties to the transaction, and measuring and settling the trading electricity.
- Distributed power supply and demand balance management. Distributed generation (especially photovoltaic and wind power) is not required to balance on-grid power of the seller and the power load of the buyer in real time. The supply and demand contract between distributed generation enterprises and users is the electricity trading contract. The real-time power supply and deviation electricity are automatically organized by the dispatching organization to realize the power and electricity balance. The dispatching organization (generally undertaken by the local dispatching organization or the incremental distribution network dispatching organization) is responsible for establishing a distributed generation (electricity) transaction settlement system to balance and settle the purchase and sale of electricity on a monthly basis.

According to the policies and rules and based on the blockchain technology, we have designed the flow chart of market transactions in the peer-to-peer transaction mode, as shown in Figure 1.

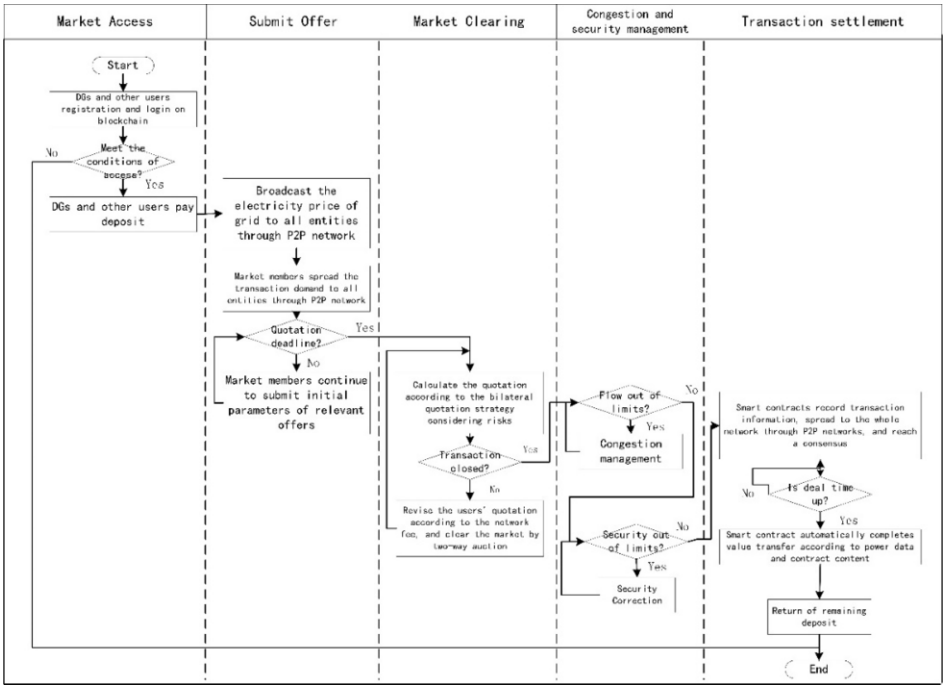

Figure 1. Peer-to-Peer Transaction Flow Chart.

The process of peer-to-peer power transaction includes five stages: market access, submit offer, market clearing, congestion and security management, and transaction settlement. This transaction mode is based on blockchain technology [12].

Due to the randomness and fluctuation of the output of distributed photovoltaic power stations and the electricity consumption behavior of users, the power balance and electricity balance cannot be achieved during the execution of peer-to-peer electricity trading, and there will be deviations [13]. At this time, the third party needs to provide balance services to eliminate the deviations. In the electricity market environment, the balancing service is provided by the units participating in the balancing service and settled according to the spot price in the real-time balancing service market [14]. At present, for the rules of the distributed generation market transaction pilot project, both parties to the transaction do not need to bear this responsibility, and the distribution network operator provides this service [15].

The distributed generation trading system platform preliminarily designed by us consists of four functional modules: system management, transaction management, settlement management and transaction monitoring. The system platform is designed for the actual functional requirements such as user management, quotation and bidding, settlement and clearing, and transaction monitoring, and realizes the following functions [16].

- System management: System management mainly realizes basic functions such as platform initialization, role management, authority management, device management, user management, etc. Device management refers to the unified management of the accessed external terminals. The platform can safely and effectively read the terminal information and data. Before the terminal is

connected to the system, it needs to complete the binding with the user, form a unique and effective identification, and grant the platform access to the terminal.

- Transaction management: Transaction management includes transaction publishing, transaction matching, transaction execution and other functions.
- Settlement management: Settlement management includes settlement details, data verification and transaction settlement.
- Transaction monitoring: Transaction monitoring includes transaction monitoring and system monitoring functions. It can monitor the release, delisting, verification, confirmation, execution, settlement, etc. of various transactions, as well as the operation of the system. It supports historical registration, login, operation and other queries according to the time dimension.

5. Comparison and Analysis of Various Transaction Modes

At present, there are four modes for distributed generation to participate in market transaction in China, including the three modes proposed in 'The Notice' and the virtual power plant mode. According to the current policies and market conditions in China, we compare and analyze the benefits of distributed generators under these four modes.

For the network fee, take a province in Eastern China as an example, and its transmission and distribution tariff are shown in Table 2.

Table 2. Table of transmission and distribution tariff in a province of Eastern China.

Category	Electricity Price (RMB/KWH)			Network Fee (RMB/KWH)
	10KV	35KV	110KV	
Ordinary industry and Commerce	0.3745 (0.05584 USD)	0.3595 (0.0536 USD)	/	0.015(10KV-35KV) (0.0022 USD)
Large-scale industry	0.213 (0.03176 USD)	0.198 (0.02952 USD)	0.183 (0.02729 USD)	0.015(10KV-35KV) (0.0022 USD) 0.03(10KV-110KV) (0.0045 USD)

According to 'The Notice',

Network Fee= Transmission and distribution tariff corresponding to power user access voltage level - Transmission and distribution tariff of the highest voltage level involved in the transaction

If both parties of the transaction are at the same level, the network fee is zero.

Therefore, for large-scale industry users, the calculation shows that:

10kV-35kV, network fee is 0.015 RMB/KWh;

10kV-110kV, network fee is 0.03 RMB/KWh.

There is a distributed photovoltaic power station in this province, with a total capacity of 1MW, connected to a 35KV transformer station, with an average daily power generation of 3000kwh. Peak, normal and valley electricity is account for 50%, 45% and 5% respectively. It supplies power to 10kV ordinary industrial power users. The peak electricity price is 1.3388 RMB/KWh, the normal electricity price is 0.8033 RMB/KWh, and the valley electricity price is 0.3678 RMB/KWh. The subsidy for per kilowatt-hour is 0.42 RMB/KWh. At the same time, according to Chinese regulations, the subsidies for distributed PV will be reduced or cancelled after it participates in market transaction. Therefore, we set the state subsidy to be reduced by 50% after participating in market transaction.

We calculate the electricity revenue of distributed photovoltaic power stations under four modes.

- Mode 1: direct transaction

Revenue = electricity sales income + subsidy income - network fee

Consumers are given preferential treatment. Each kilowatt-hour of electricity is 0.4 RMB/KWh cheaper than the peak and normal electricity prices. There is no preferential treatment for valley time electricity prices.

The subsidy income is reduced by 50% and the network fee is about 0.015 RMB/KWh.

Then the electricity sales revenue is:

3000*0.5*(1.3388-0.4)+3000*0.45*(0.8033-0.4)+3000*0.05*0.3678=2007.83RMB

Subsidy income is:

3000*0.42*0.5=630RMB

Network Fee is

3000*0.015=45RMB

Therefore, the total income today is:

2007.83+630-45=2592.83RMB

- Mode 2: entrusted power grid to sell electricity

Revenue = power sales income - network fee - line loss fee

The power cost of network loss is calculated as 1%. The weighted average peak valley electricity price of 10kV general industrial and commercial industries is 0.8366 RMB/KWh. Assuming that the electricity price is 0.3 RMB/KWh cheaper on this basis, the total income today under Mode 2 is:

3000*(0.8366-0.3-0.015-0.8366*0.01)=1539.7RMB

- Mode 3: direct acquisition by power grid

Revenue=Income based on PV benchmark ongrid price - transmission and distribution tariff

The photovoltaic benchmark ongrid price is calculated as 0.85 RMB/KWh, the transmission and distribution tariff are the highest voltage level transmission and distribution tariff, and the 35kV is about 0.3595 RMB/KWh.

Then the total income today is:

3000*0.85-3000*0.3595=1471.5RMB

- Mode 4: virtual power plant mode

Revenue=electricity sales income + subsidy - network fee

The operator of the virtual power plant has reached a long-term agreement with the distributed power plant, which is set at 0.43 RMB/KWh according to the market situation.

The subsidy income is reduced by 50%, and the network fee is about 0.015 yuan / kWh

Then the total income today is:

3000*0.43+3000*0.42*0.5-3000*0.015=1875RMB

For the four modes, the income comparison is shown in table 3.

Table 3. Revenue comparison of four modes.

Item	Mode1	Mode2	Mode3	Mode4
Total Revenue daily (RMB)	2592.83	1539.7	1471.5	1875
Average price per kilowatt-hour (RMB/KWh)	0.864	0.513	0.491	0.625

From the calculation results, the daily total income of mode 1 is the highest, mode 4 is the second highest, and mode 3 is much lower than mode 2. The average sale price per kilowatthour is, Mode1 is 0.864 RMB/KWh, 0.513 RMB/KWh for mode2 and 0.491 RMB/KWh for mode3, Mode4 is 0.625 RMB/KWh. This price is higher than the LCOE of photovoltaic power generation. Through the analysis, the factors that have a great impact on the profitability of market transaction of distributed generation are: the time distribution of power load, government subsidies, network fees and network loss fees.

At present, there are mainly two modes for China to do distributed market trading pilot projects: virtual power plant and peer-to-peer mode. However, there are many differences between the two models in terms of information flow, cash flow and the relationship between the participants. The following is an analysis.

Under the mode of virtual power plant, the virtual power plant is composed of three types of distributed resources: distributed generation, prosumers, and consumers. Distributed generation is transmitted to the distribution network, which supplies power to consumers, and the energy flows between prosumers and the distribution network in two directions. Distributed generation, prosumers and consumers all interact with the virtual power plant platform. In order to regulate the distribution network, distributed generators and prosumers interact with the distribution network operation center, while consumers do not interact with the distribution network operation center. The trading center interacts with the distribution network operation center and the virtual power plant platform in terms of information flow, while the distributed power generation, prosumers and consumers do not interact with the trading center. The trading center directly makes cash settlement with the virtual power plant platform and the distribution network operation center, and the virtual power plant platform makes cash settlement with its internal entities. As shown in Figure 2.

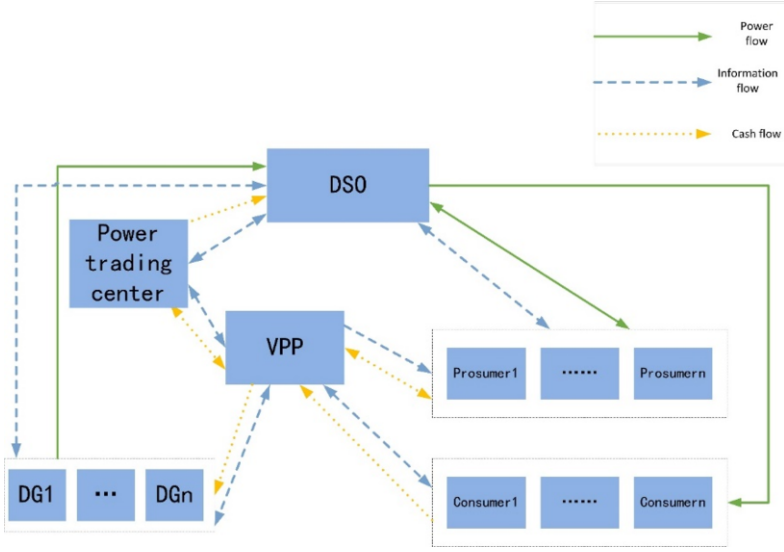

Figure 2. Trading Model for Virtual Power Plant.

In the peer-to-peer trading model, a peer-to-peer trading platform is added between the electricity sale company and the customers. This mode does not change the power supply mode. The peer-to-peer transaction adopts the blockchain technology. The electricity sale company establishes the blockchain system in the regional power grid. Each of the distribution network operation center, distributed generation, consumers and prosumers is one node, and the data is shared openly and transparently in the blockchain. The peer-to-peer transaction adopts the decentralized mode, and the transaction does not go through the power trading center. The P2P platform reports the transaction results to the electricity sale company, and then the electricity sale company reports it to the power trading center. In terms of cash flow, the distribution network operation center, distributed power generation, consumers, prosumers and other market entities automatically settle accounts in the blockchain system without going through the trading center and electricity sale company. As shown in Figure 3.

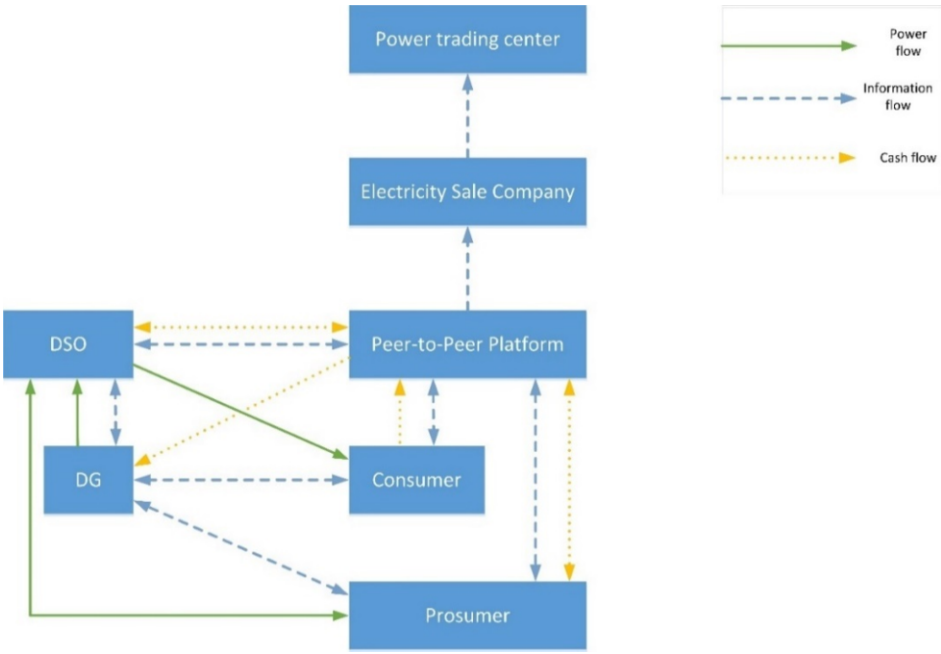

Figure 3. Trading Model for Peer-to Peer.

Based on the above analysis, we compare the characteristics of participating in distributed generation transactions by virtual power plants and point-to-point transactions, as shown in Table 4.

Table 4. Comparison between virtual power plant and peer-to-peer transaction.

Item	virtual power plant	peer-to-peer transaction
Main purpose	It is convenient to manage a large number of distributed resources, mine and make use of the flexibility of distributed resources, and reduce the risk of distributed generation participating in power transactions	Realize direct transactions between customers and power producers to save energy costs
applied technology	Internet of Things, cloud computing, big data, artificial intelligence, blockchain (optional)	Blockchain (mandatory), Internet of Things, big data, artificial intelligence
Is it decentralized?	centralized	decentralized
Revenue of distributed generator	Medium	high
Does the transaction pass through the power trading center?	Yes	No
Do it accept deviation assessment?	accept	Not accept
Participating power market	Both electricity wholesale market and retail market	Only in retail market
Composed entity	Aggregate of multi type distributed energy resources	Single distributed generation

6. Conclusion and Outlook

After the above analysis, we can draw the following conclusions:

First, the Chinese government will quickly promote the market-oriented transaction of distributed power generation, allowing the market to discover the value of distributed new energy. There are three reasons: photovoltaic subsidies have been canceled, and it is necessary to find a new power to promote the development of Distributed Renewable Energy; due to technological progress, the cost and price of photovoltaic and wind power have further decreased, and all social subjects should share the dividends of technological progress; the price of fossil energy has risen rapidly, resulting in a rise in electricity prices. The introduction of distributed power generation for direct electricity sales can reduce the power consumption cost of users.

Second, the market transaction of distributed generation will be operated under the transformer with the highest voltage of 110kV, and the transformer operation entity with the voltage level of 110kV and below will be responsible for establishing the distributed generation transaction platform in the substation area for operation and management. On the one hand, in the regional power grid with the ability of source and load balance, the problems of new energy accommodation and power balance consumption can only be solved by its operating party; On the other hand, because the whole substation area is connected and traded with the superior power grid, it can reduce the pressure of the superior power grid dispatching, power trading center and price management department on the dispatching, trading, price management and accounting of distributed power generation. The transaction results of distributed generation at the transformer level of all voltage levels shall be reported to the provincial power trading center.

Third, in the early stage of development, the distributed generation market transaction will be mainly operated in the form of virtual power plants. The reasons are

as follows: blockchain technology and other related technical tools required by peer-to-peer exchanges are not yet mature in China; the virtual power plant is centralized, which is convenient for the centralized control center of the power grid to monitor and control the distributed power supply; the functions of virtual power plants are more diversified. They can participate in both the power wholesale market and the power retail market, while point-to-point transactions can only participate in the power retail market.

According to the current situation in China, if the market transaction of distributed generation is implemented, it will face the following systemic problems:

- Under the current legal framework in China, can prosumer be regarded as a trading entity?
- Do consumers need to pay additional electricity tax when purchasing electricity from prosumer?
- If the transaction electricity of distributed power generation purchased by power customers is insufficient, can they purchase additional power from local grid companies?
- How to install smart meters for distributed generation transaction according to Chinese power measurement standards and procedures?
- Who will bear the responsibility for the power imbalance and electricity imbalance caused by the market transaction of distributed generation?

These problems, including law, technology and transaction framework design, will be solved in future practice.

Reference

[1] GWEC, Global Wind Report 2021, https://gwec.net/global-wind-report-2021/, Feb, 2022.

[2] Financial circles, the implementation plan for promoting the high-quality development of new energy in the new era was officially announced, and wind power and photovoltaic industry chain companies are expected to benefit fully, https://baijiahao.baidu.com/s?id=1734267143892184837&wfr=spider&for=pc, May, 2022.

[3] National energy information platform, the rapid rise of producers and consumers represented by distributed photovoltaic will have a far-reaching impact on social economy, https://baijiahao.baidu.com/s?id=1654597701133605204&wfr=spider&for=pc, March, 2020.

[4] Lin L, Xu BQ. Analysis and recommendations of typical market-based distributed generation trading mechanisms. Automation of Electric Power Systems. 2019 Feb; 43 (4): 1-8.

[5] Virtual Power Plant Market 2022 by Companies, Key Applications, Industry Growth, Competitor Analysis, New Technology, Trends and Forecast 2028, https://www.rfdtv.com/story/46574688/virtual-power-plant-market-2022-by-companies-key-applications-industry-growth-competitor-analysis-new-technology-trends-and-forecast-2028, May, 2022.

[6] Hochloff P, Filzek D, Heusel G, Lesch K, Liebelt A, Nicklaus L, Ritter P, Rohrig K, Roehrig C, Schloegl F, Volkert C, Wickert M, Winter M. Regenerative Modelregion Harz– RegModHarz. In Kasseler Symposium Energie-Systemtechnik, Oct. 2011.

[7] Andy Colthorpe, 'Software-defined power plant' to integrate multiple DG sources into Dutch grid, https://www.energy-storage.news/software-defined-power-plant-to-integrate-multiple-dg-sources-into-dutch-grid/, November 23, 2015.

[8] GJETC, Peer-to-Peer (P2P) electricity trading and Power Purchasing Agreements (PPAs), Wuppertal, Tokyo, June 2020.

[9] Lition is The World's First Operational Peer-to-Peer Energy Trading Platfor, https://bitcoinist.com/lition-is-the-worlds-first-operational-peer-to-peer-energy-trading-platform/, 2018.

[10] Mujeeb A, Hong XF, Wang P. Analysis of Peer-to-Peer (P2P) electricity market and Piclo's Local Matching Trading Platform in UK, the 3rd IEEE conference on Energy Internet and Energy System Integration, November 8-10, 2019; Changsha, China.

[11] The National Energy Administration, the person in charge of the new energy department of the National Energy Administration answered the reporter's questions on 'The Notice on the pilot of market

transaction of distributed generation', http://www.nea.gov.cn/2017-12/18/c_136834863.htm, December 2017.
[12] Gao CW, Tong GG. Application analysis of blockchain technology in market-based transaction of distributed generation. Power Demand Side Management. 2018,20(04):1-4+15.
[13] Shen L, Zhou M, Gong X, and Shi Z. Architecture design for market-oriented transaction of distributed generation based on blockchain. 2019 IEEE Sustainable Power and Energy Conference (iSPEC). 2019; 2298-2302.
[14] Ullah MH, and Park JD. Distributed energy trading in smart grid over directed communication network. IEEE Transactions on Smart Grid. 2021 July; 12(4):3669-3672.
[15] Thomas M, Niall F, Sarah JD, Malcolm DM. Using peer-to-peer energy-trading platforms to incentivize prosumers to form federated power plants. Nature Energy, 2018 Feb; 3:94-101.
[16] Jiang GD, Xie ZX, Han T. Virtual power plant platform for demand response based on microservice architecture. In: Antonio JTB editor. Frontiers in Artificial Intelligence and Applications, IOS Publishing; 2021. p.102-117.