Practice Exploration and Prospect Analysis of Virtual Power Plant in Shanghai

Jianli Zhao[1](✉), Jia'ni Xiang[1], Zhuofan Tang[1], Lei Qi[2], Qian Ai[2](✉), Di Wang[2], and Shuangrui Yin[2]

[1] State Grid Shanghai Municipal Electric Power Company, Shanghai 200122, China
[2] School of Electric Information and Electrical Engineering, Shanghai Jiaotong University, Shanghai 200030, China
aiqian@163.com

Abstract. Under the background of new power system construction, Shanghai power grid is faced with problems such as high pressure of new energy consumption and lack of flexible adjustment means. Therefore, Shanghai Electric Power Company carried out the demonstration project of virtual power plant, explored innovative applications in the field of virtual power plant, and realized the leap from theory to technology. First of all, according to the technical route of "Resource exploration - Market transaction - Operation dispatching", this paper introduced the preliminary exploration work and innovative application of Shanghai virtual power plants. Subsequently, Construction mode of Shanghai virtual power plants was promoted. Finally, this paper looks forward to the development prospects of Shanghai virtual power plants from three aspects: distributed resource expansion, diversified market transactions, and cloud edge collaborative control.

Keywords: Virtual power plant · Commercial building virtual power plant · Electric vehicle · Electricity market · Cloud side collaboration

1 Introduction

With the aggravation of environmental pollution and energy shortage, traditional fossil energy gradually exits the operation of power system, and massive distributed renewable new energy is connected to the power grid to make up the energy shortage. However, distributed resources have the characteristics of small individual capacity and decentralized geographical location, which make it difficult to schedule in the traditional centralized way. As an effective management means, virtual power plant technology uses advanced control and communication technologies to aggregate, coordinate and optimize distributed energy sources such as distributed power generation, energy storage and demand side resources, which can absorb the fluctuation of distributed resource output and reduce the access and control costs of distributed energy sources.

The research on theory has made a lot of progress. In terms of uncertainty factors, some research methods such as information gap decision theory [1], fuzzy programming

S. Kadry et al. (Eds.): BDEIM 2022, AEBMR 233, pp. 678–688, 2023.
https://doi.org/10.2991/978-94-6463-124-1_77

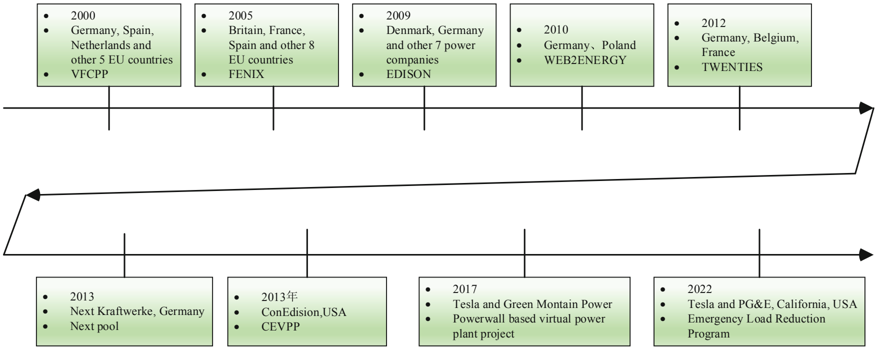

Fig. 1. Development history of virtual power plants

[2], random optimization [3], robust optimization [4] and chance constrained programming [5] are used to ensure the reliability of the transaction scheduling optimization process of virtual power plants. Focusing on the "shared energy storage" business model, reference [6–10] studied the configuration strategy and control method of virtual power plant and energy storage joint operation, and used the flexibility of energy storage to balance the output of wind and solar fluctuating resources. At the same time, in the context of decentralized blockchain transactions, reference [11–13] analyzes the differences between electric energy based on P2P transaction mode and other economic commodities, and adds network security constraints to the transaction management scheme to eliminate the emergence of power flow out of limit, network congestion and other situations.

On the basis of theoretical research, virtual power plant projects have also been carried out. As can be seen from Fig. 1, virtual power plants in European and American countries started earlier. European countries have a high level of development in the field of new energy, and vigorously limit the output of coal resources. Therefore, European virtual power plants focus on the power supply side and participate in power market transactions and power system operation by aggregating renewable new energy. The United States chose the demand side as the starting point for the construction of virtual power plants, and listed the load side into adjustable resources to relieve the peak pressure of power supply by implementing demand response.

As one of the super large cities in China, how to combine the local characteristics of Shanghai and give consideration to those two models above is the key point of development. From the perspective of energy structure characteristics, the installed capacity of wind power and photovoltaic in Shanghai will account for about 40% by 2021. In Europe, the proportion of new energy installed capacity is expected to reach 45% by 2030. Therefore, the power generation structure in Shanghai is similar to that in Europe. However, Shanghai virtual power plants do not simply copy the European model, but consider how to tap and integrate demand side resources in Shanghai when the proportion of industrial and commercial power consumption is very high. From the perspective of the characteristics of the market mechanism, due to the characteristics of the system, the United States has mature market trading experience, allowing all entities to conduct free trading in the market. However, China's power market is still in its infancy, so in the initial construction period of virtual power plants in Shanghai, the invitation system is still the main form. However, with the introduction of relevant policies, the construction of power market has begun to take shape, and Shanghai's virtual power plants are also moving towards the stage of independent trading.

At this stage, Shanghai has achieved initial success in the pilot project, so it is necessary to carry out phased summary work. On the one hand, it can provide reference and construction experience for other provinces and cities to carry out virtual power plant projects. On the other hand, it can also help optimize and improve their own project construction, and provide a solid foundation for the subsequent large-scale and normalized operation of virtual power plants.

2 Technical Route for the Development of Shanghai Virtual Power Plant

Shanghai's adjustable load resources exceed 8760 MW, including 1230 MW industrial load, 2160 MW commercial load, 1000 MW electric vehicle load, etc. In order to give full play to the resource advantages, Shanghai virtual power plant project focuses on demand response resources, guides the energy demand of power users, and realizes the identity transformation of power users from power consumers to power producers and consumers.

2.1 Resource Excavation

(1) Shanghai Huangpu District Commercial Building Virtual Power Plant Demonstration Project
Huangpu District, as a densely populated area of commercial buildings in Shanghai, has more than 200 large commercial buildings, equipped with energy consumption monitoring devices in the original buildings, and has complete basic conditions to implement demand response projects. Based on the above conditions, Shanghai launched the construction of the national demand management demonstration project "Shanghai Huangpu District Commercial Building Virtual Power Plant Demonstration Project" in 2016. The implementation of the project provides guarantee for the safe operation of the power system, effectively improves the consumption level of renewable new energy, and fully reflects the concept of green energy conservation.

At present, about 50% of the commercial buildings in Huangpu District are connected to the virtual power plant platform. The project adopts the method of resource audit registration, annual capacity verification and rolling sustainable development to carry out the sustainable construction of resource capacity. At the same time, according to the participation of users, we will carry out automatic demand transformation for high-quality resources, and adopt automatic demand response technology to achieve the control of user side equipment. Compared with traditional passive demand response, automatic demand response can adjust the running state of equipment more timely, ensuring the flexibility and efficiency of demand response. Up to now, 20% of automatic resource demand response transformation has been completed.

(2) Shanghai Jiading District ubiquitous power Internet of Things smart charging and discharging pilot project

The smart charging and discharging business of electric vehicles carried out by Jiading Power Supply Company is integrated with the concept of shared charging, and the orderly charging of electric vehicles is realized through the regulation of smart energy system platform. The smart charging and discharging business adopts the mode of online and offline combination to establish the overall system architecture of "cloud tube end". At the user end level, the energy router realizes plug and play, data sensing, acquisition and control of new energy consuming devices such as electric vehicles, energy storage, distributed power generation, micro grid, and thermal storage electric heating. As the intelligent management unit of the distribution transformer substation area, the energy controller realizes the load data collection in the substation area and the intelligent control of the customer side equipment in the substation area. The cloud platform is responsible for balancing the power grid and user needs, realizing load dispatching of the whole network, and providing customers with high-quality services.

The smart charging and discharging project solved the problem of difficult charging in residential areas. By formulating charging network planning in residential areas, developing universal standardized equipment, solving construction problems in a unified and coordinated manner, reducing the number of piles, solving pile construction problems, reducing charging costs and avoiding disordered construction, sporadic access and repeated construction based on orderly charging, adjacent parking space sharing and other business methods. The smart and orderly charging construction reduces the peak load of the distribution transformer by more than 30% through flexible guidance and active regulation of the user's charging behavior and energy consumption behavior, optimizes and adjusts 80% of the charging capacity to the low load period of the distribution transformer, improves the capacity of the distribution transformer to accept charging piles by four times, significantly improves the utilization rate of the distribution grid resources, and realizes peak load cutting and valley filling.

2.2 Market Transaction

(1) Introduction to Policies and Rules

In September 2018, the East China Energy Regulatory Bureau issued the Notice on Printing and Distributing the Pilot Scheme for the East China Power Peak shaving Auxiliary Service Market and the Operating Rules for the East China Power Peak shaving Auxiliary Service Market (Trial). The East China Power Peak shaving Auxiliary Service Market was put into simulation operation at the end of September 2018 and officially put into operation from January 1, 2019. The rules clearly stipulate that the main market sellers are coal-fired units with peak shaving capacity of no less than 300000 kilowatts and above, pumped storage units with newly put into operation electricity price marketization, etc., and consider expanding gradually to other power generation resources with specified peak shaving capacity in due time. In April 2020, the East China Energy Regulatory Bureau issued the Shanghai Electric Power Peak shaving Auxiliary Service Operation Rules (Trial), which clearly stipulates that the Shanghai electric power peak shaving auxiliary service market includes the virtual power plant peak shaving transaction. Since then, the virtual power plant can officially participate in the peak shaving market as an independent market entity to provide auxiliary services.

According to the operation rules of Shanghai electric power peak shaving auxiliary service, the market types are divided into day ahead market, day market and real-time market according to the time type. The day ahead market corresponds to the peak shaving demand launched 24 h in advance, the day in market corresponds to the peak shaving demand launched 3 and 4 h in advance, and the real-time market corresponds to the peak shaving demand launched in the next 15 min.

In the Shanghai electric power peak shaving auxiliary service market, in order to ensure that the virtual power plants participating in the transaction can provide reliable peak shaving capacity, the peak shaving capacity of the virtual power plants participating in the market is set to be no less than 1 MW · h, and the power consumption information collection time cycle in the virtual power plants is required to be less than 15 min, the response time is required to be no more than 15 min, and the response duration is required to be no less than 30 min.

At the time of settlement, because the market is in the early stage of construction, in order to maintain the enthusiasm of market players and encourage more players to participate in market peak shaving, the trading rules do not specify the detailed rules of assessment standards, that is, the settlement is based on the actual output, without considering the deviation between the actual output and the planned output.

(2) Design of market-based transaction mechanism of Shanghai virtual power plant

The market-based transaction of virtual power plants is based on the controllable and adjustable resource characteristics of virtual power plants, and the ecological model of virtual power plants is constructed through market means to optimize the operation characteristics of power grids. According to different application scenarios and time dimensions, four transaction varieties are designed. From the time dimension, it can be divided into medium and long-term transactions and short-term transactions (Table 1).

For different transaction varieties, Shanghai Electric Power Company has made detailed mechanism design from the aspects of access mechanism, transaction clearing, etc.

1. Access mechanism

In order to ensure that the subjects of virtual power plants can successfully participate in market-oriented transactions, they are required to meet the requirements of market information interaction, market measurement cycle and accuracy. At the same time, in order to adapt to the rules of the peak shaving market, the minimum regulated power of the virtual power plant is required to be no less than 1 MW. At the initial stage of market establishment, the requirements of technical indicators such as response time and climbing rate match the existing capacity of the pilot units.

2. Transaction declaration

For medium - and long-term transactions, the virtual power plant can declare and adjust the capacity and price in different periods; For short-term transactions, it is necessary to determine the replacement peak shaving curve (every 15 min) or deviation regulation curve (every 5 min) of virtual power plants and the price sharing ratio.

3. Transaction settlement

Table 1. Transaction type

	Medium and long term transactions		Short term transactions	
Transaction type	Medium and long-term standby transaction	Medium and long-term peak shaving transaction	New energy power generation curve regulation transaction	Alternative peak shaving transaction
Transaction object	Spare capacity that can be called in 10 min at peak period of the next month	Available peak shaving capacity at peak period of the next month	Deviation of power generation curve generated by new energy enterprises on day D-2	Additional peak shaving capacity required for thermal power plants on day D-2
Transaction mode	Unilateral bidding	Unilateral bidding	Bilateral consultations	Bilateral consultations
Transaction cycle	Monthly transaction	Monthly transaction	Irregular trading within a month	Irregular trading within a month

In the transaction clearing stage, response speed, regulation speed, sustainable time, transaction execution degree and other performance indicators are used to correct the declared price, so as to promote the virtual power plant to actively improve its own technical indicators.

4. Transaction Execution

After the dispatching center completes the pre call plan of the virtual power plant on the next day, the virtual power plant determines the call capacity of various aggregated resources on the next day according to the plan to form a call scheme. The next day, the dispatching center calls the virtual power plant in real time.

5. Deviation implementation

The deviation amount shall be determined by the marketing department by comparing the baseline of the virtual power plant with the transaction execution amount. When the adjustment capacity and response time of the virtual power plant fail to meet the call requirements, the virtual power plant will be assessed. At the time of settlement, the power trading center shall calculate the compensation fees, deviation assessment fees and other information of the virtual power plant, and issue settlement vouchers.

2.3 Operation Dispatching

The operation architecture of a complete virtual power plant can be divided into three layers: resource layer, aggregation layer and platform layer. The resource layer is mainly composed of adjustable resources of different types of user response terminals, including distributed power generation, small thermal power, new energy, conventional user load, energy storage facilities, electric vehicles, charging piles, etc. The aggregation layer gathers and optimizes the adjustable resources with small monomer capacity, large resource quantity and rich variety through the virtual power plant side systems of different types and regions. The platform layer includes dispatching platform, power trading

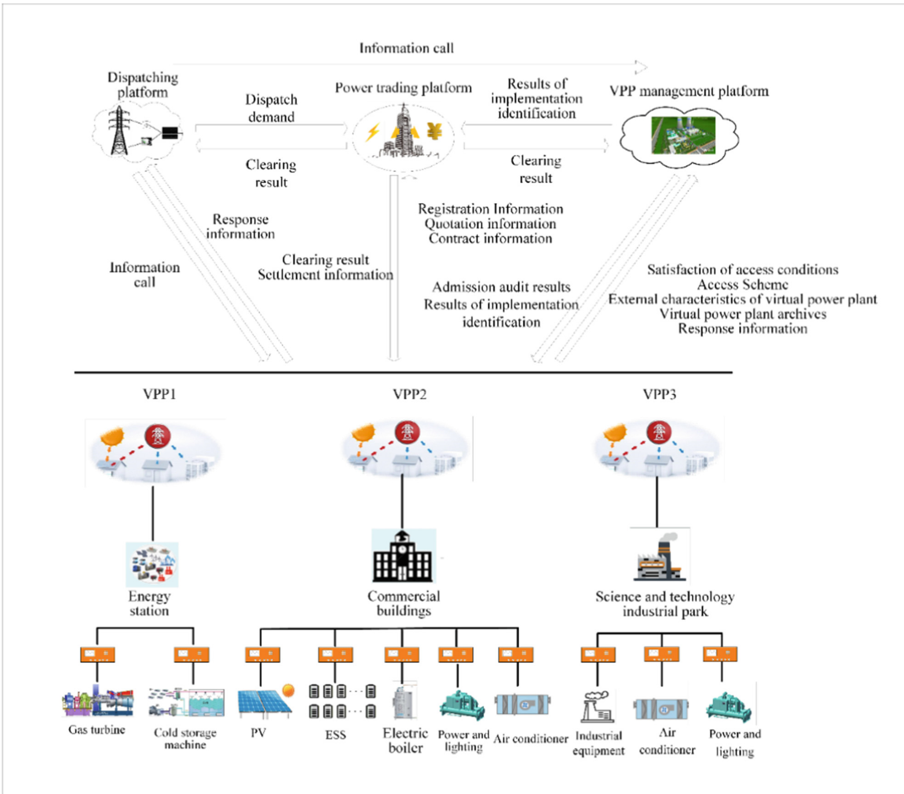

Fig. 2. Virtual power plant operation architecture

platform and virtual power plant management platform. The whole process management of registration, transaction, operation and settlement of the virtual power plant is realized through the coordination and cooperation of various platforms. The following Fig. 2 shows the operation architecture of the virtual power plant.

The virtual power plant operation management and monitoring platform realizes the unified management and dispatching of all virtual power plant resources in Shanghai. The target platform has access to 12 virtual power plants, including industrial and commercial buildings, triple supply, electric vehicles, tower base stations, etc. There are 10078 virtual generator units, with peak shaving capacity of 107310 kW and valley filling capacity of 79300 kW.

The dispatching control platform is responsible for proposing market demand according to the grid operation, and has the ability to issue control instructions to the virtual power plant in the long term. For dispatching control technology, Shanghai Electric Power Company has carried out exploratory and standardized design, and put forward specific requirements for dispatching technology, including that the regulation system needs to timely master the user regulation capacity of adjustable resources, supported regulation methods and user response methods.

3 Experience Promotion and Prospect of Shanghai Virtual Power Plant

3.1 Experience Promotion of Shanghai Virtual Power Plant Construction

(1) Operation process
At present, the dispatching resources of virtual power plants in Shanghai are mainly industrial and commercial buildings and electric vehicles. The development goal of the next stage is to aggregate more diversified resource types, give full play to the space-time complementarity of different resources, and improve the overall power supply reliability.

Therefore, it is necessary to comprehensively carry out the current arrangement and planning layout of adjustable resources, master the current scale and distribution of adjustable resources in Shanghai, make a good planning layout of future adjustable resources, further expand the scale of adjustable resources, and realize flexible access, information collection, monitoring and control of various types of adjustable resources according to different grid application scenarios.

(2) Mechanism design
At the initial stage of construction, the virtual power plant is often difficult to start, and may be difficult to meet the high quality requirements of the power grid to maintain stable performance. Therefore, in the design of the trading mechanism of the peak shaving market in Shanghai, the construction of the virtual power plant was fully considered, the deviation assessment mechanism was not designed in detail, and the peak shaving performance of the virtual power plant was not considered in the settlement, but the settlement was only based on the actual implementation amount. At the same time, in terms of access mechanism, only the minimum regulated power is required to be no less than 1 MW, while there are no specific requirements for the other two important indicators (response time and climbing rate).

The above mechanism design has greatly improved the enthusiasm of virtual power plants to participate in market transactions and greatly promoted the rapid development of virtual power plants. However, at the initial stage of the construction of Shanghai virtual power plant, the actual participation of users is insufficient. Therefore, how to attract the enthusiasm of users to participate in the virtual power plant and improve the enthusiasm of users to respond is also the focus and difficulty of the construction. For this reason, the virtual power plant redesigns the profit distribution mechanism, and distributes all the profits from participating in the market exchange to the users participating in the response, while the virtual power plant itself makes profits through other businesses. This profit distribution mechanism can attract many groups to participate in the project at the initial stage, and maintain the loyalty of users through profit sharing among users, which is conducive to expanding the scale of virtual power plant market players.

This mode provides a new idea for other cities to develop virtual power plants, which helps them to quickly stand firm and gradually expand their scale in the initial stage of construction.

3.2 Prospect of Shanghai Virtual Power Plant

(1) Distributed resource expansion

At present, the dispatching resources of virtual power plants in Shanghai are mainly industrial and commercial buildings and electric vehicles. The development goal of the next stage is to aggregate more diversified resource types, give full play to the space-time complementarity of different resources, and improve the overall power supply reliability.

Therefore, it is necessary to comprehensively carry out the current arrangement and planning layout of adjustable resources, master the current scale and distribution of adjustable resources in Shanghai, make a good planning layout of future adjustable resources, further expand the scale of adjustable resources, and realize flexible access, information collection, monitoring and control of various types of adjustable resources according to different grid application scenarios.

(2) Diversified market construction

At present, the peak regulation rules in Shanghai are designed only from the time dimension, without considering the interaction with the provincial power grid. In terms of market electricity price design, the declared price of Shanghai peak shaving market design is only 100 yuan/MWh, which is far less than the price ceiling of the same type of North China electricity market. At the same time, there are also unreasonable price settings in the intra day peak shaving market in Shanghai. The upper limit of peak shaving price in the intra day market is 400 yuan/MWh, while the peak shaving and valley filling price of demand response is 800 yuan/MWh. The irrationality of price setting in the day ahead and day in day market may affect the enthusiasm of virtual power plants to participate in the market.

(3) Cloud Edge Collaborative Scheduling

At this stage, Shanghai Electric Power Company has built a municipal virtual power plant operation management and monitoring platform and dispatching platform, realizing the unified management and dispatching of all virtual power plant resources in Shanghai, which can well adapt to the current initial status of virtual power plant construction. However, with the continuous emergence of massive distributed resources in the future, and with various problems such as different types of resource subjects, decentralized locations, and changing operating environments, the operation of the virtual power plant management and control platform will be difficult to sustain.

Therefore, Shanghai Electric Power Dispatching Center will deploy a virtual power plant collaborative and interactive regulation system with the architecture of "Cloud side collaboration-Internet of Things technology-Artificial intelligence" to ensure the rationalization of energy allocation, give full play to the flexibility of side resources, and realize the friendly grid connection and flexible support of distributed resources.

4 Conclusion

As one of the super large cities in China, Shanghai is characterized by intensive load, rapid development of new energy and insufficient resource endowment. Therefore, in order to meet the needs of social development and the construction of new power systems, Shanghai is actively building virtual power plant projects.

(1) It introduces the construction of Shanghai virtual power plant, and analyzes the work of Shanghai virtual power plant project in "resource exploration market transaction operation dispatching".

(2) It summarizes the construction mode of Shanghai virtual power plant from the aspects of operation process and mechanism design, and provide reference for other virtual power plant projects.
(3) It looks forward to the development prospect of Shanghai virtual power plant from three aspects: the expansion of distributed resources, diversified market transactions, and cloud edge collaborative control.

Acknowledgments. This work is supported by the China National Key R&D Program (No. 2021YFB2401203) and Science and Technology Project of State Grid Shanghai Municipal Electric Power Company (NO. 52090D21N002).

References

1. Sun Guoqiang, Zhou Yizhou, Wei Zhinong, et al. (2017) Optimization model of virtual power plant scheduling based on hybrid stochastic programming/information gap decision theory. Electric Power Automation Equipment, 37(10):112-118.
2. Duan Pian, Zhu Jianquan, Liu Mingbo. (2016) Optimal dispatch of virtual power plant based on bi-level fuzzy chance constrained programming. Transactions of China Electrotechnical Society, 31(9): 58-67.
3. Zhou BO, Lv Lin, Gao Hongjun, et al. (2018) Optimal bidding strategy based on two-stage stochastic programming for virtual power plant. Electric Power Construction, 39(9): 70-77.
4. Liu Xin, Li Yang, Shi Yunpeng, et al. (2022) Robust optimization model for virtual power plant distribution considering uncertainty of user participation. Electric Power Automation Equipment, 42(7): 84-93.
5. Fan Songli, Ai Qian, He Xing. (2015) Risk Analysis of Virtual Power Plant Scheduling Based on Chance Constrained Programming. Chinese Journal of Electrical Engineering, 16:4025-4034.
6. Wang Xiao, He Yigang, Ma Hengrui, et al. (2022) Distributed optimization control method for virtual energy storage power plants for grid auxiliary services. Automation of Electric Power Systems, 46(10): 181-188.
7. Bai Xueyan, Fan Yanfang, Liu Yujia, et al. (2022) Hierarchical capacity allocation of wind-solar storage virtual power plants considering reliability and flexibility. Power System Protection and Control, 50(8):11-24.
8. D. Wang, K. Meng, X. Gao, J. Qiu, L. L. Lai and Z. Y. Dong, (2018) Coordinated Dispatch of Virtual Energy Storage Systems in LV Grids for Voltage Regulation, IEEE Transactions on Industrial Informatics, 14(6):2452-2462.
9. Yan Tao, Qu Zhanzhan, Hui Dong, etc. (2014) Economic Analysis of Commercial Virtual Power Plants with Large-scale Battery Energy Storage System. Automation of Electric Power Systems, 17: 98-104.
10. Zheng Haowei, Yan Qingyou, Yin Zhe, et al. (2022) VPP operation optimization and double-layer benefit distribution considering day-ahead-real-time trading and shared energy storage. Electric Power Construction, 43(9):34-46.
11. X. Jin et al., (2019) Blockchain-enabled Transactive Method in Distributed Systems Considering Security Constraints, 2019 IEEE Congress on Evolutionary Computation (CEC), pp.1203–1207.

12. Yang Xuanzhong, Zhang Zhebo, Zhao Shenyi, et al. (2019) Blockchain-based distributed power transaction method with security constraints. China Electric Power, 52(10):31-39.
13. Tai Xue, SUN Hongbin, GUO Qinglai. (2016) Electricity transactions and congestion management based on blockchain in energy internet. Power System Technology, 40(12): 3630–3638.