# Participation of Digital Twin Virtual Power Plants in Power Market Trading Model

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**Abstract:** With the proposal of the national "carbon peaking and carbon neutrality" and "building a new power system with new energy as the main body" and other goals, cleaning and digitization have become an urgent need for power systems. Based on advanced control, metering, communication and other technologies, the virtual power plant aggregates massive multi-distributed resources on the demand side, which can provide the necessary flexibility support for the power system through diversified means of saving, and at the same time help renewable energy consumption. The digital twin technology uses big data, cloud computing, artificial intelligence and other digital technologies to virtually model the characteristics, behavior, processes and performance of the physical entities of distributed resources, which is an ideal way to achieve virtual power plant operation optimization. This paper illustrates the basic definition and system construction of digital twin virtual power plants, and analyzes the participation of virtual power plants in the multi-level market models of auxiliary services, medium and long-term, and spot, so as to provide reference for the construction and development of China's digital twin virtual power plants participating in the power market.

**Keywords:** digital twin, virtual power plant, power market, trading model

## 1. Introduction

In recent years, the new round of power market reform and the promotion of new Internet technology, communication technology and intelligent power technology have enabled virtual power plant technology to provide new ideas for the consumption of multiple DERs and digital transformation of the power system on the demand side. Through the aggregation and regulation of a large number of diversified DERs, virtual power plants have the characteristics of stable power output and bulk power sales of traditional power plants, but also have better flexibility to enhance the revenue of DERs while providing management and auxiliary services for transmission and distribution networks[1]. By empowering virtual power plants through digital means, the transmission and distribution network can continuously improve the holographic sensing ability and flexible control ability of massive and diversified DERs on the demand side, build a new business model for virtual power plants to participate in the power market, and provide flexible regulation means for smooth operation of the power grid from the demand side[2]. The fidelity, real-time and closed-loop characteristics of digital twin technology make it particularly suitable for complex systems with asset-intensive and high-reliability requirements, while virtual power plants are comprehensive and complex systems incorporating massive and multiple DERs on the demand side, which are highly compatible with the application areas of digital twin technology [3].

Traditional demand-side resources such as retailers, power-generating entities and load aggregators are gradually transforming to the virtual power plant concept, and virtual power plants are widely recognized by the society in providing grid auxiliary services and participating in power market transactions [4]. In terms of virtual power plant participation in market trading model, the German virtual power plant flexibility resource utilization model provides a reference for virtual power plant participation in market trading construction [5]. In terms of interactive information technology, the differences between virtual power plants and microgrids in promoting distributed energy forms and groupings are analyzed in comparison in terms of control, data metering and communication technologies [6]. Other scholars have analyzed the control mode of virtual power plants in the consumption of new energy and given directions for the utilization of new energy[7]. In addition, the key technologies of Shanghai virtual power plants in aggregation, interaction and platform construction are studied, and typical European virtual power plant cases are analyzed in terms of information and communication, optimal control and safe operation [8].

Based on the common features of virtual power plants and digital twins, this paper constructs the system architecture of digital twin virtual power plants and designs the participation mode of digital twin virtual power plants in power market transactions, laying the theoretical foundation for the application of digital twin virtual power plants in power market transactions.

## 2. Digital twin virtual power plant

### 2.1 Definition

The digital twin virtual power plant [9] is a developmental form in which the physical space entity and the information dimension virtual power plant intermingle and coexist. By accepting various types of information from physical DERs entities, environment, market, etc., the digital space creates a virtual space that matches and corresponds to the physical virtual power plant and evolves synchronously with the physical virtual power plant, reflecting the state of the virtual power plant in the real environment in the form of holographic simulation, dynamic monitoring, real-time diagnosis, accurate prediction, etc., thus promoting the digitization of all elements of the virtual power plant, real-time visualization of the whole state, multi-level operation and management collaboration and intelligence, realize comprehensive and accurate monitoring of the physical virtual power plant, interact with the virtual space, and feed back the analysis results of diagnosis, prediction, participation in the power market and dispatch control to the physical entity of the virtual power plant. By combining the virtual power plant decision system with the digital twin, it forms an intelligent decision support system that can continuously learn and evolve to improve the efficiency of the allocation of demand-side material, intellectual and information resources, thus promoting the overall optimal operation of the virtual power plant.As a closed-loop empowerment system connecting massive multi-DERs and transmission and distribution network data resources, the digital twin virtual power plant will open up a new mode of digital smart grid construction and operation management through resource-wide identification, accurate state perception, real-time data analysis, model scientific decision-making, and intelligent and accurate execution.

### 2.2 System construction

The construction of the digital twin virtual power plant should be synchronized with the planning of the physical entity of the virtual power plant and the digital twin virtual space, and the data center should be built from the modeling stage to form a static attribute database[10]; at the same time, the simulation, knowledge, application and other related models and management data should be continuously imported into the virtual space during the operation process to continuously improve the data center database;and the decision support and optimization management of the virtual power plant should be achieved in the operation stage by relying on the intelligent analysis platform. For DERs that have been built and put into operation, they are integrated into the digital twin virtual power plant system through digital modeling and deployment of IoT facilities, and the information hub data center is supplemented and improved through intelligent sensing and data collection. In terms of optimized operation, the virtual twin space and the physical entity achieve twin parallelism and virtual-real interaction through efficient connection and real-time transmission.Through the Internet of Things intelligent sensing and real-time information collection technology to achieve "from real into virtual"; virtual power plant physical entities and virtual space through the feedback mechanism to achieve virtual-real iteration, and through the support of intelligent decision-making platform and real-time optimization of operational control to achieve "from virtual to real".

In response to the above requirements for building a digital twin virtual power plant, this paper proposes a digital twin virtual power plant system (DTVPPS) containing physical entities, digital twins, twin data, connections, and intelligent applications with reference to the five-dimensional model of the digital twin in industry. The overall architecture of DTVPPS is shown in Figure 1, PVPP digitally describes the characteristics, behavior, formation process and performance of physical objects such as DERs and markets through digital technologies such as intelligent sensors and IoT, and builds historical and real-time operational databases; VVPP uses data integration and simulation to form a complete digital twin mapping, and realizes the evolution and prediction of the future state of the virtual power plant through real-time simulation, and visualizes it to the user, supporting the safe and stable operation of the virtual power plant while providing DT&S for safety warning and fault diagnosis. Finally, through efficient connection and real-time transmission, it achieves collaborative interaction of all parts, feedback control of physical entities and iterative growth of simulation models in VVPP.

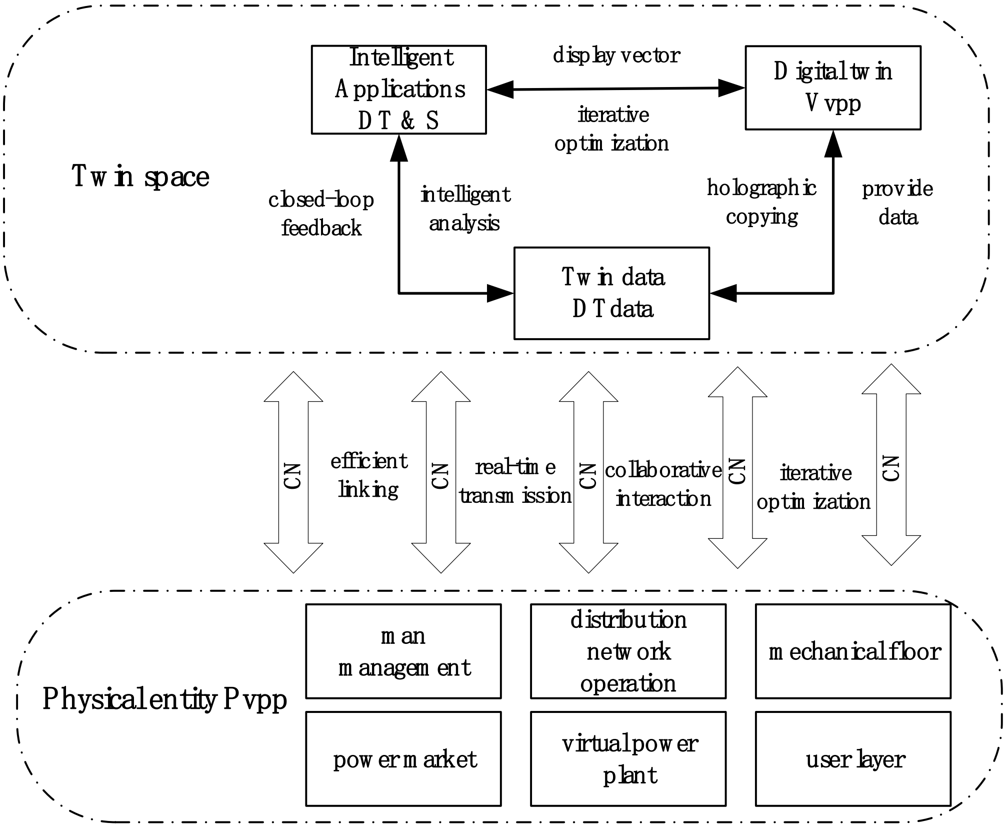


**Figure 1 System architecture diagram**

## 3. Electricity market trading model design

### 3.1 Participation in the ancillary services market

Virtual power plants with mainly adjustable loads or energy storage can respond to system regulation needs in system operation through market-based approaches. Virtual power plants are mainly involved in power regulation market transactions in the near future, and can gradually participate in medium and long-term, spot and other power markets and auxiliary service markets with higher technical requirements in the future, as shown in Table 1.

**Table 1 Electricity market trading varieties**

| SERIAL NUMBER | TRADING VARIETIES | ADVANTAGES |
|---|---|---|
| 1 | Bilateral trading, centralized trading | Advantages such as complementarity, elimination of volatility, and coordination and optimization |
| 2 | Contractual transfer | Marginal cost advantage over traditional thermal power enterprises;<br>Regulatory and forecasting advantages over new energy power generation enterprises |
| 3 | Spot market | Strong reconciliation capabilities to maximize trading and execution space |
| 4 | Frequency and voltage modulation | Rapid response advantage of multiple participating units can be coordinated |

| | | |
|---|---|---|
| 5 | Green certificates, financial transactions, etc. | Leveraging reconciliation and better predictive capabilities to gain market advantage;<br>Market-based trading using blockchain decentralization, smart contracts, etc. |

**3.2 Participation in the medium and long-term power market**

Virtual power plants participate in medium and long-term transactions as market players, which may include medium and long-term bilateral power transactions, centralized power transactions, power generation rights transactions, capacity (standby) markets, etc.

The medium and long-term transactions that virtual power plants can participate in as power purchase and sales agents include bilateral or centralized power transactions and power generation rights transactions. There are various scenarios for a virtual power plant's generation and consumption needs and roles in the medium and long-term market. If the resources aggregated by the virtual power plant are mainly controllable loads, it is required to conduct power purchase transactions in the medium and long-term market.If the distributed power supply is the main source, then the power sale transaction will be conducted. If the resources aggregated by the virtual power plant are diversified, including distributed power, energy storage and power consumers, it can trade in the market any generation or electricity demand that it still cannot balance after achieving self-generation within the virtual power plant. However, not all diversified resources can be internally self-generated and self-used first, in which case they still need to be traded separately in the market according to the generation and consumption needs of different types of resources.

As a flexible regulating resource, the medium and long-term transactions that virtual power plants can participate in are mainly in the capacity (standby) market.Based on the medium and long-term capacity requirements of the system operation mechanism, capacity standby contracts, including positive and negative standby, are signed in advance with the virtual power plant through competitive bidding or policy provisions. After the contract is signed, the virtual power plant is required to prepare positive and negative reserve capacity as required during a certain period of time, and to reduce output/increase load or increase output/reduce load as required according to the instruction.

Under this approach, the benefits of virtual power plant can be divided into two categories. One is fixed income, that is, as long as the adjustment ability is required, the return can be obtained, even if there is no actual adjustment in the end. The second is the actual adjustment income. On the basis of providing positive and negative reserve on demand, if the system has actual adjustment demand, the system requires adjustment and obtains return according to the adjustment power/electricity.

**3.3 Participation in the spot market**

The participation of virtual power plants in the spot market as a class of market players is similar to the participation of traditional market players. Since virtual power plants have information on the constraints and regulatory performance of the resources they aggregate, they are more rational and optimal in their declared power and tariff strategies, and also have the ability to control and price guide the fine-tuning of power generation and consumption. Therefore, they are more flexible than traditional market players, and thus more able to avoid risks and reap benefits in the spot market.

If the virtual power plant predicts that the spot market price is higher near a certain period of time, the virtual plant offers an adjusted compensatory price internally to induce its aggregated resources to generate more or consume less electricity. If the virtual power plant predicts that the spot market price is low near a certain period of time, the virtual plant offers an adjusted compensatory price internally to induce its aggregated resources to generate less or use more electricity.

## 4. Conclusion

First, the construction of the digital twin virtual power plant will promote the construction of a new power system with new energy as the main body and promote the digital development of the power system, which is the key to the "carbon peaking and carbon neutrality" strategy of the power system. By building a digital twin virtual power plant, creating a flexible and efficient demand-side DERs management and configuration platform, enhancing the holographic perception, flexible control, optimal scheduling, health management and intelligent service capabilities of the virtual power plant, it will support the development of renewable energy, enhance the flexibility adjustment ability of distribution area and promote "clean substitution" and “electric energy substitution".

Second, in conjunction with the construction process of spot energy market and auxiliary services market, policies and rules such as virtual power plant investment management, market access, market participation rules, investment and operation subsidies are introduced.According to the principle of "who benefits, who finances", a reasonable and stable source of incentive funds will be formed. Actively explore the decentralized balance model to achieve balance pressure and decentralized responsibility.

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