Virtual Power Plants (VPPs): Market Mechanisms and Applications in China

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Abstract—Growing penetration rate of renewable energy in China's electricity system results in the decrease of grid flexibility. And virtual power plant (VPP) as a promising solution is drawing growing attention. However, as VPP is in the early development stage in China, the mechanisms that VPPs can apply are yet limited. This paper reviews the current market mechanisms for VPP to participate in China, and investigates several application cases with different proceeding emphasis, and concludes that ancillary service market is a more effective way to promote VPP development at current stage.

Keywords: virtual power plant; demand response; peak regulation ancillary service market; frequency regulation ancillary service market

1 Introduction

To face the challenges of climate change, energy structure transformation has been carried out in China for years. And as an important part, renewable energies have contributed significantly to the transformation and are still developing with great growing potential, which however brings new challenge. High penetration rate of renewable energies connecting into the grid significantly lower the grid's stability and flexibility levels. On the other hand, the distributed energy resources (DER) such as distributed PVs, energy storage and CHPs connected to the distribution grid are considered to be with great potential to contribute to mitigating the problem when aggregated by the formation of virtual power plant (VPP)[1].

The concept of VPP was first brought up in 1997, and although there is still no uniform definition[2], it is widely accepted in China that VPP is a power management system empowered by advanced information and communication technologies and software systems to realize the aggregation and coordination optimization of various DERs including distributed generators (DGs), energy storage systems, adjustable loads, EVs etc., and can participate in the power market and grid operation as a special power plant[3]. theoretically and practically speaking, VPPs can provide ancillary services including peak regulation, frequency regulation, voltage regulation, backup and congestion elimination for the grid and obtain profits in various

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market transactions. However, VPPs' development in China is still in early stage and yet facing technical, operational and market challenges.

2 Market mechanisms of VPPs

2.1 Market mechanisms worldwide

Several studies have researched on the cases that VPPs participate in different types of electricity markets worldwide, including futures and forward market, day-ahead market, ancillary services market, reserve market, intraday market and real-time market, etc[4]. While most DERs have difficulties to access electricity markets for having small capacities, VPPs help these DERs to participate more actively in different ways.

Table 1 Stages of VPP development in China

	Stage 1	Stage 2	Stage 3
Type	Invitational	Market oriented	Autonomous
Function	Peak shaving and valley filling	Electricity system balance	The same as physical power plant
Mechanism	Demand response	Electricity market	Various
Dominant sector	Government and grid dispatch	Trading institution	VPP operating organization
Source of income	Financial incentive	Trading revenue	Operating revenue

Originally VPPs mainly participate in the day-ahead market and real-time balancing market. With the rising penetration rate of RES, the grids' demand for flexibility rises simultaneously, which has created more opportunities for VPPs to participate in ancillary services markets and sign bilateral contracts.

2.2 Market mechanisms of VPPs in China

VPPs have explored a different developing pathway in China. Early stage of VPPs participation in the electricity system in China is functional by invitation to demand response (DR). With the development of electricity market in China, at the next stage VPPs can trade through different trading varieties in the market. And it is expected that VPPs can be fully autonomous and function as physical power plants in the future. And the way that VPPs gain profit will transform from governmental financial incentive to trading revenue and operating revenue. Table1. shows the 3 stages.

Nowadays, the main mechanisms that VPPs operate in China are DR and ancillary services in the electricity market which include peak regulation and frequency control ancillary services. Pilot and demonstration projects have been carried out in several regional, provincial and municipal markets. It can be concluded that VPPs in China are in the transition from stage 1 to stage 2.

2.2.1 Demand response (DR)

DR is an effective way to face the power shortage period. It is usually organized by local governments or grid dispatch departments[5]. When there is predictable power shortage (sometimes over supply) the organizers mentioned above send participation invitation to VPPs as well as issuing financial incentives. VPPs with adjustable loads can choose to change their electricity consumption from normal patterns to response to the incentive payments. This is the first and most widely applied pattern that VPP projects were put into practice in China. As mentioned above, the profits that VPPs gain in DR are mainly government subsidies, which normally have fixed rates. When the incentive payments cannot compensate the loss of production reduction due to electricity consumption cut, it is hard to drive the adjustable loads to response.

2.2.2 Ancillary Service Market

2.2.2.1 Peak regulation

Peak load regulation services aim to mitigate the trend of unbalance between power supply and demand. VPPS participating in the peak regulation ancillary service market adjust their power load curve after receiving a dispatch order [6], and it can be effective both as peak-shaving and as valley-filling. The main difference between peak regulation services and demand response is the degree of marketization and the associated revenue streams for VPP operators, as VPPs participating in the ancillary services market offer quotations which are normally below certain price caps and payments are shared by certain members of the electricity market.

Several regional, provincial and city grids including North China grid, Central China grid, Shandong province, Zhejiang province, Gansu province and Shanghai have allowed VPPs' participation in peak regulation with differed conditions of market access and price caps as shown in Table 2.

2.2.2.2 Frequency regulation

Frequency regulation refers to the refers to the service provided by the grid-connected entities to actively adjust their power output by means of speed regulation system and automatic power control to reduce the frequency deviation when the frequency of the power system deviates from target frequency. The time delay requirement of frequency regulation service is significantly higher than peak regulation and other forms of VPP function[7], and higher requirement mainly lay in higher level of system control and communication networks.

At present, Zhejiang and Jiangsu province have issued policies to make it clear that VPPs can participate in the frequency regulation ancillary service market. VPPs in Jiangsu can take part in primary frequency regulations while VPPs in Zhejiang can participate in both primary and secondary frequency regulations.

2.2.3 Electricity market

With the development of electricity market in China, participation of VPPs in the electricity market is encouraged at the national level, and policy implementations of different regions are yet to be expected which might diverse from each

Table 2 Peak regulation service mechanism of different regions

Region	Market access	Quotation cap
North China grid	Stable regulative capacity and quantity no less than 10MW and 30MWh	Cap price: 600 RMB/MWh
Central China grid	Single adjust capacity and quantity over 5MW and 2.5MWh	Bottome price:0.12RMB/kWh; VPPs can participate in both provincial and inter provincial markets
Shandong province	Capacity over 10MW; continuous response time over 4hrs	Cap price: 400RMB/MHh
Zhejiang province	Adjust capacity and quantity over 5MW and 2.5MWh; continuous response time over 1hr	Cap prices: 320RMB/MWh with valley filling and 1000RMB/MWh with peak shaving
Shanghai	Capacity over 1MW; response time<15min	Cap price: 100RMB/MWh with day-ahead market, 400RMB/MWh with real-time market
Gansu province	Encourage customer-side energy storage systems and DGs to form VPPs in order to cut abandon of wind and solar power as well as participate peak regulation	Cap prices: 0.5 RMB/kWh with spot goods and 0.3RMB/kWh with non-spot goods

other as the market development levels diverse. Ningxia Hui Autonomous Region has recently given permission that VPPs can participate in electricity market as well as ancillary service market and DRs, and no repeated charges shall be paid to the same regulatory action. Before the establishment of electricity spot market in Ningxia, VPPs can first make medium and long-term transactions. And the market mechanisms are designed for VPPs to gain long-term stable profits in the electricity market meanwhile profits that reflect their values of flexible and regulative services can be gained in the ancillary service market.

3 Typical architecture of VPP platform

VPP projects in China are typically operating with a four-part architecture of cloud, communication networks, edge servers and terminal devices, as shown in Fig.1. The cloud computing refers to management and control platform of VPPs, which interacts with grid operators, electricity trading platforms and edge servers to support resource management, plan implementation and operational trading. The communication network can be either private or public and are designed to ensure the security, accuracy and timeliness of information interaction. The edge servers aim to aggregate and analyze information, and are endowed with local autonomy or able to generate regulatory strategies based on command from superior platform. The terminal devices refer to terminal monitoring and control devices which are equipped for collecting electrical, thermal and environmental parameters from various DERs, and performing corresponding adjustment and control operations.

4 Application cases in China

VPPs operation have taken place in a few areas in China with different focuses, types of DERs aggregated, mechanisms and scales to face different challenges.

4.1 Jiangsu Province

The concept of VPP in China was first put into practice in 2016 in Jiangsu province through demand side management, where the world's largest scale demand response of the day was carried out. And from 2020 VPPs have been allowed to

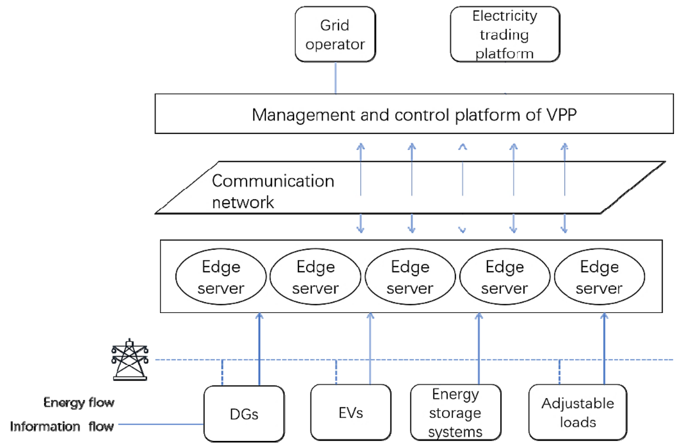

Figure 1. Typical architecture of a VPP platform

participate in the ancillary service market in Jiangsu province. For the frequency regulation service, it operates in the order of, firstly, a weekly quotation, followed by the day-ahead pre-clearance and ultimately the intraday service invocation. The types of DERs with access to the ancillary service market are till limited though, and only storage system with the capacity higher than 10MW and discharge time over 2 hours are permitted to registered as market members. However so far there hasn't been any realized case of VPP providing ancillary services in Jiangsu.

4.2 State Grid Jibei Electric Power

State Grid Jibei Electric Power offers services covering five cities in the north part of Hebei province. It is the first regional grid to launch VPP project in China. The project can be traced back in 2019 when the proportion of renewable energy capacity in Jibei grid reached 57.3%. In order to promote consumption of renewable energy and relieve the tension of peak-hour electricity demand, Jibei Electric Power established the VPP demonstration project based on ubiquitous electric internet of things (UEIOT), with a tri-layer architecture, i.e. the bottom layer of DERs, the middle layer of intelligent management and control platform of VPPs and the top layer of grid dispatching system. It aggregated 11 types of adjustable resources including distributed photovoltaic power, adjustable industrial and commercial load, smart buildings, smart homes, energy storage, regenerative electric heating, EV charging stations etc.[8]. The VPPs in Jibei grid can participate peak regulation in the North China market and are the most marketized VPPs in China.

In the summer of 2020, the air conditioning load of Jibei Grid reached 6 gigawatt and 10% of which was satisfied by the real-time response of the VPPs. And in winter the VPPs offers electricity to regenerative electric heating through real-time response.

4.3 Shanghai Huangpu District

Huangpu District in Shanghai is a typical central urban district with high density of commercial buildings. When the VPPs project was carried out, the emphasis was naturally focused on connecting these commercial buildings with typical adjustable loads of water chilling units, air-cooled heat pumps, electric boilers, power lightings and charging piles etc. which can register as response resources. Currently, the VPPs work under the mechanism of DR and about 50% of commercial buildings in Huangpu District are connected to the virtual power plant platform with the response capacity of over 60MW.

Initially, the profits generated from market transaction were distributed to the market users in order to increase user engagement and more active response participation. And the VPP operators recover their cost and make profits through other businesses while they are mainly companies providing services of power installation, operation, maintenance or energy saving.

Table 3 Yearly Profits generated in DR in Guangdong

Year	**Trading days**	**Profit of aggregators (million RMB)**	**Profit of market members (million RMB)**
2021	77	240	740
2022	9	39	12.1
2023	0	0	0

4.4 Guangdong province

Guangdong province started DR mechanism in 2021 and instead of financial incentives issued by local government, the DR income for VPPs and aggregators are paid by the market users in the region where DR is carried out. It is a step forward to marketization for DR and VPP operations. Subsequent policies enriched the types of aggregators and raised the bottom level of clearance prices in order to attract more resources to participate. However, sharp drop in profits generated for VPPs and other DR participants in 2022 when compared with 2021, and in 2023 there hasn't been any DR organized in Guangdong (Table 3). This can be mainly attributed to slowdown of economic development followed by electricity demand reduction. Milder temperatures in summer also contributed to less peak demand.

4.5 Shenzhen

Shenzhen power grid has the highest load density in the China, and thus stable power supply faces severe challenges[9]. The city started VPP operations in 2021 and by June 2023, more than 30 VPP aggregators with high variety of aggregated resource types including distributed energy storage, data centers, charging piles, subways, buildings, 5G base stations, distributed photovoltaic, etc. have accessed to the VPP management platform. The total capacity exceeds 1.5GW and the maximum regulative load capacity is over 300MW in real time. These VPPs mainly participate in DR activities. Local

Besides, VPPs in Shenzhen have attempted to offer ancillary services, including frequency regulation and backup services. The first frequency regulation realized by VPP in China took place in Shenzhen with the aid of 5G network slicing technology. And 10 VPPs in Shenzhen have participated in the test run in the interprovincial backup service in China Southern Power Grid and offered 60MW backup capacity in peak load period. Therefore, technically speaking VPPs in Shenzhen are ready to offer ancillary service while the permitting or supporting policies are yet to come.

5 Discussions

It can be concluded from the cases analyzed above that the dominant mechanism is demand response which is with relatively low marketization level and main profits for VPP operators are governmental incentive payments. The key problems are, on the one hand the DR activities are highly influenced by factors as level of economic activities, climate conditions etc. and the demand is quite unstable, and on the other hand, fixed incentive payments sometimes fail to draw participation of DERs. Therefore, the healthy development of VPPs relies on more accesses to electricity market where the price level truly reflects the relation between supply and demand and has stable demands. Consider the level of electricity market establishment in China[10] and the technology level of VPPs, it is not yet economically and technically possible for VPPs to compete with conventional power plants in electricity selling, however ancillary services such as frequency regulation can be more ideal for VPPs to participate as they have comparative advantages in terms of substantial advantages in terms of more efficient transmission facilities and more flexible physical characteristics[11]. And of course, this requires application of improved or innovative technology.

6 Conclusions

This paper reviewed the mechanisms that VPPs are currently participating in China including DR and ancillary services. Case analysis shows that DR is the dominant mechanism to date and followed by peak regulation, while frequency regulation service in two provinces is open to VPP participation however is till lack of practical cases. The paper then discussed the defects of DR which might hinder VPP development. It can be expected that before the VPPs achieve to be autonomous, ancillary services like frequency regulation which offer relatively stable demand and can be satisfied by VPPs with comparative advantage are more ideal mechanisms for VPPs' development.

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