Practice and Enlightenment of Australian Virtual Power Plant Participating in Market Operation

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Abstract. Under the new power system, the proportion of new energy and new entities continues to grow, new business users are diversified, and the power supply and demand sides exhibit a "double randomness" characteristic. Faced with such challenges, VPP (Virtual Power Plant), as source network load storage integrators that aggregate multiple distributed resources, provide the possibility for the supply-demand balance of the power system. At present, there is no mature operation mode for VPP in China, and they still rely mainly on aggregating load side resources for demand response. This article analyses Australia's participation, trading patterns, and profitability in the electricity market and ancillary services market, summarizes the profit and risk points of VPP in Australia, and proposes relevant suggestions for improving the business model of VPP and promoting their entry into the market in China based on the actual situation.

1 Introduction

In 1997, Shimon Awerbuch first proposed the concept of VPP. VPP consists of independent, and market driven flexible cooperative entities that do not have to own corresponding assets to provide efficient power supply services to consumers [1]. At present, the mainstream view is unanimous that VPP itself does not generate electricity but integrates many scattered and adjustable power loads in the power grid, joins the power grid scheduling, achieves effective peak shaving and valley filling, and can also provide auxiliary power services such as frequency regulation and backup, enhancing the security of the power grid.

Thanks to the flexible and open electricity market mechanism and dispatching operation rules, VPP theory and practice have developed relatively mature in countries such as Europe and America. NextKraftwerke, a German company, provides European grid balancing services and participates in short-term market transactions through the aggregation of distributed energy, with an aggregate capacity of 10.836 GW [2]. Piclohe Company in the UK [3] and Sonnen Company in Germany [4] have both conducted virtual power plant commercial practices, verifying the necessity of adjustable resources participating in grid operation and market operation in mature market environments. California Independent System Operator (CAISO) has implemented smart energy management for distributed energy in California, participating in the electricity market through distributed energy resource providers (DERPs) [5]. The main goal of constructing VPP in Australia is to reduce electricity costs and provide frequency regulation auxiliary services for the power grid. Australian Energy Market Operator (AEMO) and Tesla Corporation in the United States jointly launched a virtual power plant project, which aggregates distributed photovoltaic and energy storage systems to participate in the Australian electricity market and conducts emergency frequency response tests [6].

Under the "dual carbon" goal, with the rapid growth of distributed wind and solar power generation, energy storage systems, and controllable loads, virtual power plant technology, which integrates distributed resources and actively participates in system regulation, has emerged in China. At present, the application of VPP in China is still in the stage of concept validation and pilot. Jiangsu, Shanghai, Hebei, Anhui, Guangdong, and other regions in China have also successively carried out VPP pilot projects. The pilot projects are mostly contract based demand response projects that do not directly participate in the market and are focused on industrial and commercial users by aggregating resources, with buildings and parks mainly experiencing interruptible loads.

To gain a deeper understanding of the business models of VPPs that have been put into operation abroad, this article analyses the trial operation overview of VPPs in Australia, including the aggregated resources, participating varieties, participation models, and revenue in the electricity and auxiliary service markets of VPP. Based on the profit and risk points of VPPs in Australia, targeted suggestions are proposed for the further development of virtual power plant commerce in China.

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2 Trial operation analysis

2.1 Background

From July 2019 to January 2021, led by AEMO, Australia conducted a nationwide trial operation of VPP to accumulate experience in formulating rules and technical requirements for incorporating VPP into the electricity market system [7-10].

2.2 Participating variety

During the trial operation, VPP can participate in the energy market and the emergency FCAS market (emergency frequency control ancillary services).

a) Energy market. VPP participating in the real-time electricity market belongs to non-direct controlled VPP, which accept real-time energy prices and do not require bidding for online access. AEMO predicts its electricity generation and consumption based on the operational data uploaded by VPP and uses it as the boundary condition for electricity supply and demand balance. Whether it is a VPP signed with a power selling company or a VPP owned by the power selling company, several users are packaged for settlement based on the power selling company. During the period when VPP inputs electricity to the grid, the selling company receives a "negative" electricity fee.

b) emergency FCAS: VPP has two response frequency offset methods. ①Adjust according to proportion, that is, the output/load adjustment is proportional to the frequency offset amplitude. ②By switching on or off, such as shutting down or turning on electrical equipment.

2.3 Participation mode

AEMO stipulates three ways for VPP to participate in market trial operation, as shown in figure1, figure 2, and figure 3. Mode I is through cooperation between VPP and electricity sales companies, which can simultaneously participate in the emergency FCAS market and the real-time electricity market. VPP signs an agreement with the power selling company, and VPP does not need to register. The trading institution settles with the power selling company; Mode II is for the power selling company to register its own VPP and participate in both the emergency FCAS market and real-time power market transactions simultaneously; Mode III is that VPP can be registered separately but can only participate in the emergency FCAS market.

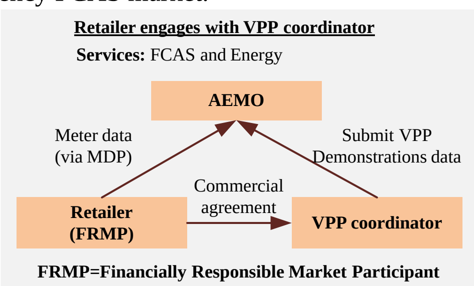

Figure 1. Mode I

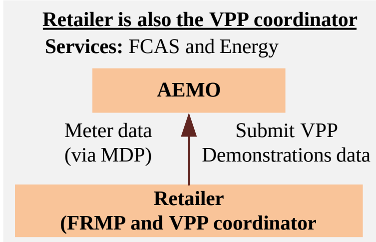

Figure 2. Mode II

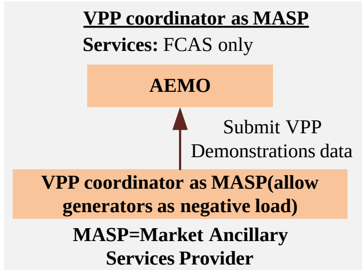

Figure 3. Mode III

2.4 Participant

As of July 2021, a total of eight entities from seven companies have participated in this VPP trial operation, as shown in table 1. Among them, the largest is the SA VPP, which is jointly participated by Tesla and energy retailer Energy Locals.

The technical equipment participating in the pilot operation of VPPs are all "photovoltaic+energy storage batteries", with a total capacity of 31 megawatts, of which 87% of VPPs are distributed in South Australia. Approximately 7150 users signed up to participate in the pilot VPP project, accounting for almost 1/4 of the installed energy storage battery users.

Table 1. VPP participant summary table

	SA VPP	AGL	Simply Energy	son nen	Shine -Hub	Member Energy	Hydro Tas
Area	SA	SA	SA	NSW	SA	Vic and NSW	ALD
Type	MP	MP	MP	MASP	MASP	MP	MASP
Mode	I	III	III	III	III	II	III
Size	16MW	6MW	4MW	1MW	1MW	2MW	1MW
Control	①	①	①	①	②	①	①

3 SA VPP Profit analysis

To gain a clearer understanding of the revenue situation of the VPP project in Australia, the SA VPP with the largest scale and highest market share is selected here to analyse its revenue in the energy market and emergency FCAS market. SA VPP adopts a PPP model, with investment capital sourced from government agencies SA, the Australian Renewable Energy Agency, the Commonwealth Scientific and Industrial Research Organization of Australia, and private capital Tesla. The SA VPP battery has a scale of 5MW and a user base of 1000 residential users.

3.1 SA VPP Total Revenue Analysis

From September 2019 to January 2021, SA VPP cooperated for approximately 18 months with a total revenue of approximately $2443872, with energy market revenue accounting for approximately 10% and emergency FCAS market revenue accounting for approximately 90%, as shown in figure 4.

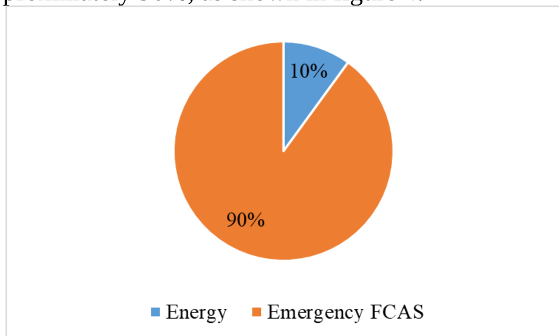

Figure 4. SA VPP Revenue Distribution Chart from September 2019 to January 2021

The proportion of emergency FCAS market revenue for each month during the trial operation period is shown in the table 2 and table 3.

Table 2. Share of SA VPP Emergency FCAS Market Revenue from 2019 to 2021($)

	2019		2020		2021	
Jan	Emergency FCAS	Energy	Emergency FCAS	Energy	Emergency FCAS	Energy
Feb	Not started	Not started	113962	55000	47009	-2000
Mar	Not started	Not started	1173560	25000	End	End
Aqr	Not started	Not started	181557	27000	End	End
May	Not started	Not started	29967	4500	End	End
Jun	Not started	1000	30472	3000	End	End
Jul	Not started	4500	29590	7000	End	End
Aug	Not started	12000	35425	8500	End	End
Sep	29414	16000	41487	7000	End	End
Oct	33068	22000	57131	-4500	End	End
Nov	138577	13000	98757	9000	End	End
Dec	19951	43000	67748	8500	End	End

Table 3. Share of SA VPP Emergency FCAS Market Revenue from 2019 to 2021(%)

	2019	2020	2021
Jan	-	67.45	(Energy market revenue is negative)
Feb	-	97.91	-
Mar	-	87.05	-
Aqr	-	86.94	-
May	-	91.04	-
Jun	0	80.87	-
Jul	0	80.65	-
Aug	0	85.56	-
Sep	64.77	(Energy market revenue is negative)	-
Oct	60.05	91.65	-
Nov	91.42	88.85	-
Dec	31.69	(Energy market revenue is negative)	-

3.2 SA VPP Energy Market Revenue Analysis

During the trial operation period, VPP's participation in the real-time electricity market is a non directly controlled resource that accepts real-time energy prices and does not require bidding for online access. However, the pricing entities participating in the Australian energy market are often natural gas units with higher marginal costs, which makes the energy market revenue of VPP highly correlated with natural gas prices during the trial operation period.

The revenue generated by SA VPP in the energy market from 2019 to 2021 is shown in figure 5.

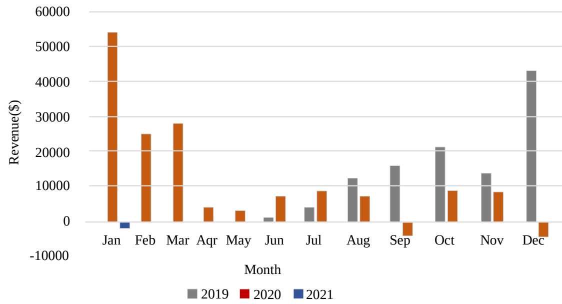

Figure 5. Revenue from SA VPP in the energy market from 2019 to 2021

From the perspective of the energy market, the charging and discharging behaviour of VPP participating in the energy market is not highly sensitive to electricity price signals. VPP's focus is on optimizing user electricity consumption, reducing user energy costs, and meeting user electricity quality requirements. Therefore, VPP's market strategy is not to profit through real-time market price gaming. The behaviour of VPP has not significantly changed within the normal electricity price range (0-300 $/MWh). Even in extreme situations where real-time prices are above 10000 $/MWh and below -500 $/MWh, there is no convergence behaviour in the response of VPP. When real-time prices are extremely high, only three VPPs respond in 39% of the time. When many negative real-time prices appear, there is VPP charging, but these periods basically coincide with the daily noon charging time of VPP. During other negative price periods, VPP charging is very limited. This is because due to user agreement constraints, VPP is unlikely to recharge at a negative electricity price outside of the set charging time. Therefore, the weak correlation between VPP market behaviour and electricity price signals reflects that the power generation and consumption decisions of VPP largely depend on non-price factors such as user agreements and predesigned charging and discharging control algorithms.

3.3 SA VPP Emergency FCAS Revenue Analysis

From September 2019 to January 2020, SA VPP achieved a total revenue of $224926 in the emergency FCAS market, with no significant difference in the proportion of raise/lower emergency FCAS revenue, as shown in table 4. From a market perspective, raise6sec has the highest revenue, accounting for 28.6%, and has the lowest revenue. From the perspective of the call time of emergency FCAS, SA VPP was called 70% of the time during the entire trial operation period. This is because during the trial operation, to verify the fast frequency regulation ability of VPP, AEMO will prioritize calling VPP for emergency FCAS.

Table 4. Analysis of SA VPP's Revenue in the Six Categories of Emergency FCAS Market from September 2019 to January 2020

	Lower contingency FCAS			Raise contingency FCAS		
Trading variety	Lower 5min	Lower 60sec	Lower 6sec	Raise 5min	Raise 60sec	Raise 6sec
Total	$224926					
Total across the 6 contingency FCAS markets	$4226	$5988 6	$6208 0	$4057	$3035 9	$6431 9
Sum of Lower/Raise services	$125958			$125958		
Lower/Raise portion of total	56%			44%		
Amount of time the VPP was enabled per contingency FCAS market	73%	73%	73%	70%	71%	71%
Average amount of energy enabled per contingency FCAS market (MW)	1.1	1.1	1.1	1.2	1.3	1.3

From September 2019 to August 2021, SA VPP achieved a total revenue of $2189372 in the emergency FCAS market, with R6 accounting for 38%, L60 accounting for 23%, and R60 accounting for 22%, which is basically in line with the six categories of emergency FCAS market revenue in table 4. From figure 6, SA VPP has the highest revenue in the emergency FCAS market in February 2020 and March 2021, with revenue of $1173560 and $800000, respectively. Both months have seen extreme power system events in South Australia that disconnected from the national power market.

As of the end of January 2021, SA VPP accounted for almost all emergency FCAS revenue of Australian VPP. At the same time, it can be seen that in February 2020, SA experienced extreme emergency FCAS prices. In this month, SA VPP's emergency FCAS revenue exceeded the total of 16 months from Sep 2019 to Jan 2021.

By comparing energy market revenue and emergency FCAS revenue, it is found that in a relatively short period of time, the profit opportunities of emergency FCAS are higher than those of the energy market, and the profits obtained are also greater (except for December 2019), as shown in figure7. As more resources enter the emergency FCAS market, the profit gap between the two markets may narrow.

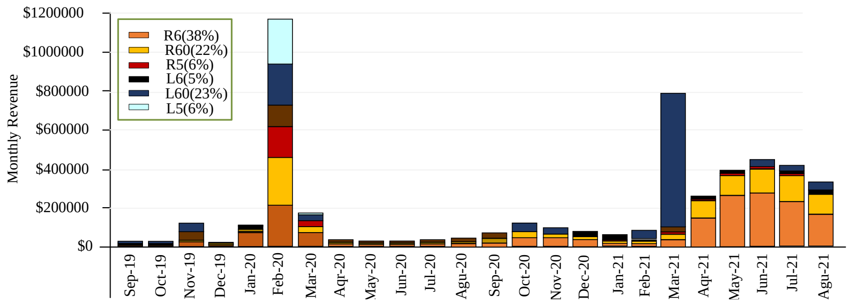

Figure 6. Monthly revenue share of SA VPP in the six types of emergency FCAS market from Sep 2019 to Aug 2021

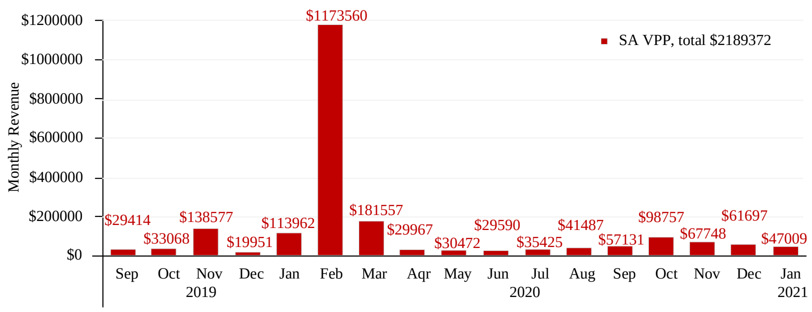

Figure 7. SA VPP Emergency FCAS Market Monthly Total Revenue

4 Main profit factors and enlightenment of SA VPP

4.1 Revenue source

During the trial operation period, the main source of VPP revenue is the extreme high prices brought about by extreme events, and spot income within normal prices only accounts for a small proportion. However, the spot price in Australia is limited to -1000 $/MWh~15500 $/MWh, and within the price range of up to 16500 $/MWh, VPP still cannot generate significant profits in the energy market. The advantage of VPP lies in its fast-tuning performance rather than pure electrical energy output. VPP mainly recovers costs through the FCAS market.

For our country, the FCAS trading varieties have not been subdivided according to the response time, but only quoted and converted based on performance indicators. High performing frequency regulation resources will be prioritized for use. For hourly power regulation, the frequency regulation performance of VPP converted according to the quotation may still be lower than other frequency regulation resources. Therefore, the current mechanism cannot reflect the differentiated value of frequency regulation resources with different timelines, nor is it conducive to the recovery of investment costs by new entities. The domestic power market should streamline the trading mechanism of frequency regulation varieties to allow market prices to reflect the value of different frequency regulation resources, and thus effectively promote the entry of VPP into the market.

4.2 Extreme price event

4.2.1 Extreme high prices in the energy market

Taking January 2020 as an example, analysing the spot price trend of SA VPP participating in energy market transactions, except for the spot price exceeding 800 $/MWh on January 30, 2020, the average spot price fluctuates between 0 and 100 $/MWh at other times. The extreme price event on January 30, 2020, was caused by a large-scale power plant failure, and when supply was in short supply, SA VPP was called up for discharge, resulting in SA VPP earning over $35000 in revenue on that day. As shown in figure 8.

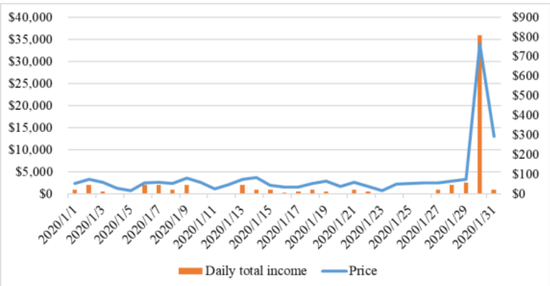

Figure 8. Jan 2020, SA VPP Participation in Energy Market Daily Average Price

China has always been very concerned about extreme prices, and to avoid extreme price phenomena, strict upper and lower price limits have been set. In this case, VPP cannot benefit. In the future, we can gradually consider relaxing the upper and lower limits of prices and introducing new entities such as VPP into the market. On the one hand, we can guide extreme risk control through market mechanisms, and on the other hand, new entities can also make profits.

4.2.2 Extreme high prices in the emergency FCAS market

On November 9, 2019, due to the increased risk of power islanding in South Australia, the Australian Energy Administration called on VPP to participate in emergency FCAS. During this period, there was a shortage of supply in the 60 second FM and 6 second FM markets, resulting in the energy market hitting the price ceiling ($14700 per megawatt hour) in the 85th minute. Through this emergency FCAS incident alone, SA VPP received a daily revenue of $50396.

On November 16, 2019, a fault on the Heywood Interconnector line (one of the high-voltage transmission lines connecting South Australia and Victoria) caused South Australia to be disconnected from other state electricity markets for approximately 5 hours. Therefore, the Australian Energy Authority has called on VPP to participate in emergency FCAS. During this period, due to supply shortages in the lower6sec frequency and raise6sec frequency markets, the price caps were reached in the 100th minute and 65th minute respectively after the market was disconnected. In this emergency FCAS incident, SA VPP received a daily revenue of $59645.

The total revenue from the two major emergency events mentioned above is $110041, accounting for 49% of all emergency FCAS revenue of SA VPP in the four months from September 2019 to October 2021.

The positioning of foreign power markets is that prices can accurately reflect the degree of resource scarcity, allowing market entities to receive high returns when resources are scarce, in order to stimulate private capital investment. For market resources such as energy storage and VPP that require the introduction of private capital for spontaneous investment, the domestic price system should be further rationalized. Only when the upper and lower limits of short-term price regulation are relaxed can long-term investment be guided by price signals.

5 Main risk factors and Enlightenment for SA VPP

5.1 Technical defects

During the trial operation of the Australian VPP, the technical equipment of the VPP participating in the pilot operation was all "photovoltaic+energy storage batteries". Once the solar panels were fully charged, it would be impossible to remotely control the VPP to reduce energy output power. This phenomenon occurred when the energy price was negative, and VPP continued to output, resulting in negative monthly energy revenue in September, December 2020, and January 2021.

It can be seen that the low returns of VPP in the spot market are largely due to the inherent physical performance of integrated distributed resources. VPP still have some technical shortcomings, which prevent them from accurately adjusting output based on price signals, which may lead to loss of profits during negative electricity prices. At present, there are few provinces in China that have released negative electricity prices. In the future, the market will be completely discovered by prices. The opportunities and challenges faced by VPP will be greatly changed, and to some extent, VPP improvement technology will be pushed back to improve equipment control accuracy.

5.2 Adjusting accuracy

In the extreme island incident on November 16, 2019, SA VPP was forced to reduce its usage by 1MW, but in reality, SA VPP only achieved the target of 838kW. Although SA

VPP has achieved high returns on this day, if the adjustment accuracy of VPP is improved, SA VPP may obtain higher returns.

For China, there are two ways to improve the VPP response accuracy. First, the centralized dispatching mode is adopted to deploy VPP centrally from the perspective of system efficiency optimization, which also conforms to the traditional dispatching mode of China's power system. Our country is more inclined to adopt centralized scheduling to realize the optimal allocation of resources from the overall perspective. Secondly, scheduling agencies can combine market conditions to increase the technical threshold for VPP participation in the market, filter out technologically outdated VPPs, and achieve the goal of improving regulation accuracy. This can also to some extent promote the development of the VPP industry towards high-precision and cutting-edge industries.

5.3 Power limitation

According to regulations in South Australia, the power output of small users is limited to single-phase 5kW, therefore, the scale formed by Tesla's 1000 users is 5MW. Considering only the energy market revenue, with a scale of 1000 users and a discount rate of 7%, the net present value of SA VPP under different power constraints is shown in table 5. From the table, it can be seen that the higher the power limit threshold, the higher the revenue that SA VPP can achieve. On the premise of keeping the cost unchanged, the larger the NPV (net present value) value, the better the investment efficiency of the project.

Table 5. SA VPP NPV under different power limits

	2kW power limit	5kW power limit	10kW power limit
Cost (by 2030)	0.46	0.46	0.46
Revenue (by 2030)	1.23	2.92	3.18
NPV	0.77	2.46	2.72

When promoting the entry of VPP into the market in China, attention should be paid to the issue of the scale of VPP aggregated resources and access. Under the premise of little change in unit cost, the scale of VPP aggregated resources and access can reach a certain value in order to form an industrial scale effect. Only in the VPP industry can efficient economic efficiency growth space be formed, thereby improving the competitiveness of the entire industry, obtaining greater profits and higher comprehensive revenue.

6 Conclusion

This article systematically introduces the VPP trial operation project carried out by the Australian Energy Authority from 2020 to 2021, and conducts a specific analysis of the SA VPP with the largest market share. Based on the practical experience of SA VPP in the electric energy market and auxiliary service market, the opportunities and challenges faced by the development of VPP are extracted, and the following suggestions are proposed:

a) We need to streamline the trading mechanism of frequency regulation varieties, so that market prices reflect the value of different frequency regulation resources.

b) Foreign VPP recover fixed costs through extreme market prices, while domestic VPP need to be provided with ways to recover capacity costs.

c) The accuracy of VPP regulation is limited, and it is not possible to accurately adjust output based on price signals. In the future, after the release of negative electricity prices, attention should be paid to the profit risks of VPP.

d) The VPP response accuracy can be improved by adopting the centralized dispatching mode and improving the technical threshold for VPP to enter the market.

e) Attention should be paid to the balance between VPP access scale and economic revenue.

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