Study on the Application of Demand-Side Resources to Participate in the Electricity Ancillary Services Market

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Abstract--As the scope of pilot power auxiliary services continues to expand, major provincial power companies are clarifying the main status of demand-side response resources and energy storage resources as market participants one after another. Electricity auxiliary services are developing towards diversification, and a fair, transparent, competitive and orderly market mechanism for sharing auxiliary services is taking shape. The active participation of energy storage devices, demand-side resourcesand third parties in electricity market services will promote the development of new industries such as new energy consumption, electricity market transactions and virtual power plants. This paper summaries the participation patterns and trading mechanisms of demand-side resources in domestic and international markets, analyses how domestic demand response resources can be used to participate in the ancillary services market, and makes corresponding suggestions for the development of the ancillary services market in the domestic power industry.

1.Introduction

In recent years, China's power supply structure has undergone significant changes, with the continuous expansion of the scale of installed power and the rapid development of clean energy. If the cost of auxiliary services for the entire system is borne by the power generation side alone, the demand generated by a large number of connected renewable energy sources in the system cannot be met, and the construction of the auxiliary power service market has ushered in a new round of challenges[1]. It is the goal of the national electricity market reform and development to break up monopolies, gradually introduce competitive mechanisms, optimise the allocation of electricity resources and improve the operational efficiency of the electricity market.

In the revised Regulation on Electricity Ancillary Services in 2021, it is proposed to establish a new and improved sharing mechanism, improve the ability to regulate demand through the market, improve the new market-based pricing mechanism, reduce the cost of system support for ancillary services and better utilize the decisive role of the market in demand-side resource allocation[2]. Allowing demand-side resources to provide ancillary services will allow generators to operate more efficiently and reduce pollution[3]. This not only increases power system flexibility, but also encourages retail-side customers to participate in the management of their electricity consumption, thereby improving the overall efficiency of the system. The increased responsiveness of electricity demand to market prices will both meet the same level of supply reliability and reduce overall supply costs, while maintaining security of supply. In addition to this it also reduces spot price levels and price volatility during peak demand periods on the grid, with significant overall benefits to market and grid operations.

2.Demand-side resources participate in the electricity market

As electricity market reform continues to advance, new types of demand-side load regulation mechanisms have emerged in China, including demand response and peaking auxiliary services. In the process of participating in the operation of these markets, both the supply and demand sides can maximize the demand-side load regulation potential through joint management of physical capacity and economic and financial complementarity, creating conditions for demand-side resources to participate in the electricity market in various ways[4].

2.1.demand-side resource participation in electricity market models

Electricity demand-side users need to allocate their resources wisely and consider the conditions and benefits of various market participation in order to maximise market benefits. In addition to demand response and ancillary services trading, users can also take advantage of the flexibility of demand-side resources and the interaction between supply and demand in order to exploit the full potential of the market[5]. The transaction model is shown in Table 1.

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Table1. Demand-side resource participation in electricity market trading models

Mode	Features	Sources of benefits	Applicable conditions
Ancillary Services Peaking	Easy access, market base	Power plant share	Inadequate peaking capacity and large peak-to-valley differences
Demand Response Market	High compensation prices and good returns	Government subsidies	
Curve tracing for low valley abandonment	Curve tracing	Abandoned electricity tariff reduction, time-of-use tariff	New energy rich and flexible users
New energy and user deviation substitution	Suppressing volatility, reducing bias	New energy subsidies	
Distributed energy storage	Value added service model	Time Difference	Spot Trading
Medium and long-term power trading with curves that take into account spot	Building a flexible and interactive value system	Value of electricity + value of power	Future electricity market

A number of regions such as Northwest, Northeast, North and East China have issued a number of relevant documents for demand-side participation in auxiliary services. Relevant policies are becoming increasingly mature, and China has promoted and carried out pilot practices in demand-side participation in demand response in a number of regions, and relevant response technologies have achieved significant results, but further in-depth research is needed on policy issues such as the strength of subsidies for demand response and the issuing body. For example, the medium and long-term curve trading of electricity taking into account spot is an electricity market that China is actively building and is committed to improving policy maturity as well as technical maturity[2]. The main technical challenges are: market bidding, clearing, security calibration and assessment and settlement.

3.Demand measurement resources participate in the ancillary services market

3.1.demand response

The concept of demand response was first proposed by David Robinson, a senior researcher at the Energy Institute of Oxford University in the US, and refers to the voluntary, temporary measures taken by customers to change their original electricity consumption patterns and therefore receive financial rewards such as financial incentives or tariff concessions. in early 2000, China introduced the concept of demand response, which, according to the relevant national standards, is defined as an electricity customer's response to a price According to the relevant standards, demand response is defined as an act of participation in which electricity consumers respond to price signals or incentives issued by the implementing agency and change their electricity consumption patterns[6].

The types of demand response are mainly divided into two categories: price-based and incentive-based. Price-based demand response refers to customers adjusting their electricity demand based on tariff information and is generally divided into three types: time-of-day, real-time and peak tariffs. Incentive-based demand response refers to the reduction of electricity demand during times of electricity stress, where customers can receive direct preferential tariffs or compensation. As shown in table 2.

Table2. Demand response classification

Price-based demand response	Time-sharing pricing Real Time Tariff Spike Pricing
Incentive-based demand response	Direct load control Interruptible load Emergency demand response Demand-side bidding

3.2.participation in peaking support services

Each region gives strong support for demand-side resources to participate in electricity ancillary services trading, with compensation paid by the new energy manufacturers and demand-side aggregators receiving compensation fees for ancillary services. The market trading prices for ancillary services in each region are shown in the table3.

Table3. Ancillary services market transaction prices

Region	Real-time deep peaking	Interruptible load peaking	Electricity storage and peaking
East China	First tier: cap of RMB 0.3/ kWh Tranches 2 to 5: upper limit 0.4/0.6/0.8/ (yuan/kWh)		
North East	First tier: 0~0.4 RMB/kWh Second tier: \$0.4 to \$1/kW	Lower limit of quotation: 0.1 RMB/kWh Quotation limit: 0.2 RMB/kWh	Lower limit of quotation: 0.1 RMB/kWh Quotation limit: 0.2 RMB/kWh
North China	First tier: 0~0.3 RMB/kWh Second tier: RMB 0~0.4/kWh		
Northwest	First tier: 0~0.4 RMB/kWh	Lower limit of quotation:	

	Second tier: RMB 0.4~1/kWh	0.1 RMB/kWh Quotation limit: 0.2 RMB/kWh	Lower limit of quotation: 0.1 RMB/kWh Quotation limit: 0.2 RMB/kWh
South China Network	First tier: capped at RMB0.2/kWh Tranches 2 to 5: Upper limit 0.4/0.6/0.8/1 (yuan/kWh)		

Participation in the ancillary services market mainly includes the steps of market information reporting, bidding and trading, clearing and settlement, etc. Demand-side market players need to report key information on ancillary services such as adjustable capacity range, time period and market. Different demand-side market players have different reporting contents, for example, energy storage, electric vehicles, etc. need to report the maximum charging and discharging power, while buildings, base stations, etc. only need to report charging power[3].

4.Electric vehicle participation in demand response

Electric vehicles have highly flexible characteristics and can be used as a charging and discharging resource to regulate the electric load, consume renewable energy, etc.4 They can also improve the quality of power supply and are a power resource with great development potential[7]. Electric vehicles, a new type of flexible resource on the load side, participate in the operation of the power system through the peak-valley price differential of the catalogue tariff, power demand response and peak regulation auxiliary services[8]. Table 4 shows the mechanisms and functions of electric vehicles.Among the pilot cities for demand response, Shanghai's work on vehicle-grid interaction is of significant demonstration significance.

By the end of 2019, the cumulative promotion of new energy vehicles in Shanghai has reached 300,000 units, with an actual ownership of around 260,000 units. The current number of charging piles in Shanghai is over 280,000, ranking first in the country, with a vehicle-pile ratio close to 1:1, of which 190,000 are private charging piles and 50,000 and 40,000 are public and dedicated piles respectively.

Table4.Electric vehicle demand response market mechanisms and enabling functions

Electric Vehicles ⟹	Demand response	Energy Market	Safeguarding the safety of the electricity supply
			Improving the quality of electricity supply
		Ancillary Services Market	Relieving grid congestion
			Deferring power investment
		Capacity Market	Consumption of renewable energy
			Improving system efficiency

4.1.analysis of effects

This chapter collates and compares the operational effectiveness of private charging posts, dedicated office charging posts and battery exchange stations participating in demand response based on the Shanghai Demand Response Report document.

Demand response economics calculations[5]

$$NPV = \sum_{t=1}^{T} \frac{CFt}{(1+IRR)t} - C_0 = 0 \quad (1)$$

NPV:Net Present Value of the project
CFt :Net cash flow for project year t
IRR: Internal Rate of Return
C0 : Initial project investment costs
T: Project operating cycle

$$CF_{t,sc} = R_{dr} - C_{dr} \quad (2)$$

$$R_{DR} = f \times p_{dr} \times P_{EV} \times (1-\alpha) \quad (3)$$

$CF_{t,sc}$:Net cash flow from participation in demand response in year t
R_{dr}: Annual demand response benefit
C_{dr}: Annual demand response O&M costs
f: Frequency of electric vehicle participation in demand response per year
p_{dr}: Unit price of compensation
P_{EV}: Electric vehicle charging power
α: Share of proceeds for organisers
Comparative analysis

Table5 Analysis of results

Economic analysis of the demand response of private charging posts to fill the valley			
Fixed investment by aggregators ($)	500	Single response time (hours)	3
Single vehicle charging power (kW)	7	Responsiveness	24 hours in advance
Response Type	Filling the Valley	Response unit price	0.96
Response rate	5.3%		
Number of	3	5	10

responses (times/year)			
Average annual earnings ($/year)	42	71	141
Internal rate of return (%)	<0	9%	27%

Economic analysis of peak-shaving demand response of dedicated charging posts			
Fixed investment by aggregators ($)	500	Single response time (hours)	2
Single vehicle charging power (kW)	7	Responsiveness	24 hours in advance
Response Type	peak shaving	Response unit price	2.4
Response rate	75%		
Number of responses (times/year)	3	5	10
Average annual earnings ($/year)	70	118	235
Internal rate of return (%)	9%	21%	47%

Economic analysis of peak-shaving demand response in switching stations			
Fixed investment by aggregators ($)	2500	Single response time (hours)	1
Single station charging power (kW)	60-120	Responsiveness	30 minutes in advance
Response Type	peak shaving	Response unit price	6
Response rate	81.2%		
Number of responses (times/year)	3	5	10
Average annual earnings ($/year)	1512	2520	5040
Internal rate of return (%)	60%	101%	202%

Looking at the results of the pilot in Table 5, the overall response rate of private charging posts is low. With a large number of charging posts and long vehicle access times, the potential for private charging post demand response is still large. The number of changeover stations is low and is influenced by the intensity of the changeover service on the one hand, therefore the changeover stations have the highest response cost and the overall response scale is limited in relative terms. In terms of revenue levels and the current operating intensity of Shanghai's electricity exchange network, among the various types of charging piles involved in demand response, the highest rate of return is achieved by exchange stations participating in demand response. The yields for dedicated charging posts and private charging posts are 21% and 9% respectively, which are relatively low.

Although Shanghai is on a unified power exchange platform, the ability of various types of charging facilities to participate in power demand response varies. Electric vehicles are usually connected to private charging piles in the evening to early morning hours and are more appropriately involved in load filling. In contrast, dedicated posts and exchange stations have a higher degree of regulatory flexibility. The pilot results show that dedicated piles and exchange stations can be managed relatively centrally and have a higher response rate to dispatch commands. Private piles and dedicated piles have greater scale potential in terms of the amount of demand response resources, and incentives can be designed in advance to increase the resource potential of private and dedicated piles. Although the exchange stations currently have some regulation potential, with the increasing demand for electricity exchange, their ability to participate in demand response during the day depends on the comprehensive control capacity of the exchange stations.

Electric energy use is evolving from one-way transmission to two-way interaction. Electric vehicles have the dual attributes of load and empowerment, and are mobile energy storage units with a high degree of flexibility. A market-based mechanism to guide electric vehicles to participate in demand-side response to electricity makes the possibility of two-way interaction richer in the long run, and deeply integrates into the demand-side response to electricity city and the green trading market.

5.China's current demand-side resources to participate in the challenges facing demand response

5.1.market environment

Electricity demand response, which relies on market instruments, is far from being developed in China to the stage where market prices are used to influence the timing and level of demand. As shown in table 6.

Table 6 Summary of impact factors by region

Conditions	Europe	United States	China
Environment	The design of electricity markets in some regions hinders the development of demand response	Market-based demand response products that take advantage of superior electricity market conditions	A unified management model for grid companies to facilit ate the roll-out of new dema nd response technologies and solutions
Policy	Strong government support	Relatively well developed policies	In the stage of building a system and actively improving it
Projects	Concentration for interruptible load and time-of-use tariffs	Demand response projects are numerous and varied	Less demand-responsive project formats
User	Early start and high user acceptance of DR	The earliest start, usersare mo tivated to participate	Late start and limited understanding of DR by users
Technology	1.High penetration of smart meters, mature and widely used load control technology and communication technology 2. Established industry technical standards	1. A large number of advanced technologies are promoted and used 2. A dedicated technology development facilities and numerous technology suppliers	1. Time-sharing meters and load control devices are fitted in some customers 2. National Grid widely used electric load management system
Potential	The potential for future DR in European countries remains high	Demand response measures could cut peak loads by up to 20% in the future and could absorb the growth in electricity demand across the US over a 10-year period	Various industries have the potential to cut peaks to varying degrees, especially the building materials and machinery manufacturing industries have great potential

In market segments that are not yet truly market-based and competitive in China, the application of demand response measures is largely determined by policy guidance and is a mandatory tool in the event of unexpected system failures or capacity shortages[9]. Traditionally, ancillary services are provided by the generation side, which must always meet customer demand. In order to optimise the allocation of resources and improve the efficiency of electricity consumption, the ability of the load side to participate in the provision of ancillary services should be explored, allowing customers to voluntarily participate in the ancillary services market and consciously improve their electricity consumption characteristics to achieve optimal system operation.

5.2.users and technology

Different types of business enterprises have different production utilisation load patterns and a wide range of equipment makes and models, which makes it difficult to collect and track information on users' equipment and related parameters[10]. In addition, the analysis of the users' regulation potential is not very accurately foreseen, and the control of equipment risks increases. Demand-side resources involved in ancillary services may participate in both the energy and capacity markets. Therefore, demand-side technologies need to be able to mature and effectively overcome the constraints of load participation in multiple market transactions. On the other hand, ancillary services markets place very stringent requirements on the users involved, such as the obligation to have a certain level of upward and downward regulation and to provide ancillary services with capacity that can be sustained over a certain period of time. Even in the US, where electricity markets and demand response mechanisms are well developed and the business and financial environment is mature, demand-side participation in the ancillary services market is very limited[11]. In general, loads must be able to provide specific response information to determine the level of response under different conditions.

5.3.ancillary services market pricing mechanism

The generation-side dominated market pricing mechanism for ancillary services is based on opportunity costs. As demand-side resources have complex opportunity cost calculations in such a market rule and are highly dependent on investment costs, it is difficult to accurately assess the cost effectiveness of ancillary service provision and to create a fair and equitable competitive market environment. The current lack of clarity in local electricity markets regarding the pricing mechanisms for different resources to participate in the market makes it difficult for demand-side flexibility resources to participate in ancillary markets to generate revenue to cover the cost of gap assessment, and does not provide an effective incentive for them to participate in the market[12]. Demand-side flexibility resources are suitable for a wide range of application scenarios and there is some variation in the market participation capacity of different resources.

6.Conclusion

The cost of ancillary services in China was previously based on an apportioned compensation mechanism with a low degree of marketisation.An appropriate compensation mechanism should guide market behaviour so that the unpowered and user sides involved in the market can all be motivated. By actively participating in the market to make their own value increase, in order to ensure the security of power supply, should be done by the power supply, grid and demand side in collaboration. Incorporating demand-side resources into the electricity auxiliary services market can improve system reliability and flexibility, optimise resource allocation and improve electricity efficiency, with significant social benefits.The flexible regulation of demand-side resources on a permanent basis will be a key means of ensuring a reliable, stable and low-cost supply of electricity for the new power system. China should accelerate the construction of facilities, related research and the marketisation process on the electricity consumption side, promote the process of appropriate pricing for ancillary services and the development of corresponding rules and standards, and facilitate the application and development of demand-side management in China's ancillary services market.

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References

1. H.L.Wang , J.L.Yang , J.J.Gao,Y.H. Li , J.X.Xiao, B.Y.Xu Bing. A multi-entity trading strategy for distribution networks considering demand response potential[J]. Power Demand Side Management,2023,25(02):50-56.
2. W.J.Cheng, J.S.Liu, , Zhu, Kevin, J.F.Zhang, Z.X.Chen, ,Z.K.Li. Network-source-load intelligent interaction risk control strategy with demand response[J]. Journal of Nanjing University of Technology,2022,46(06):763-770.
3. H.M.Wang. Electric vehicle charging load zoning prediction with demand response [D]. Nanjing University of Posts and Telecommunications, 2022.
4. G.X.Xu , H.Deng , L.Fang , K.Gong , X.Wang , C.W.Jiang . A review of domestic and international research on market mechanisms for electricity auxiliary services considering demand-side flexibility resources participation[J]. Zhejiang Electric Power,2022,41(09):3-13.
5. Li Feng, Yao Yun, Zhang Huijuan, Luo Kaiyan, He Rui. Study on the economics and price mechanism of new energy storage [J]. Price Theory and Practice,2022(04):66-70+204.
6. J.Zhou, J.Geng, L.Tang, Y.Y.Zhao, S.Zhang . Analysis and reflection on the rules of participation of adjustable load resources in the electricity auxiliary service market [J]. Power Automation Equipment,2022,42(07):120-127.
7. H.L.Zhou, Y.B.Liu , Y.G.Chen , Z.Wang . S.P.Qu , K.He, and S.Y.Bao. A feasible domain aggregation method fordemand-side resources considering flexibility gains[J]. ChinaElectric Power,2022,55(09):56-63+155.
8. W.S.Chen.Electric vehicle charging load demand responsemodel and application benefit analysis[J].Mass Electricity,2022,37(11):34-35.
9. W.Zhang, E.S.Zhang, Guo, Ma, K.X.Zhang. Optimal oper-ation of integrated energy system considering integrated demand response and "double carbon" mechanism[J]. Power S-ystem Protection and Control,2022,50(22):11-19.
10. C.X.Wang, Z.Y.Shi, Z.F.Liang, Q.M.Li, B.B.Huang, L.P.Jiang. Key technologies and prospects for demand-side resource utilization of new energy-based power systems [J]. Power System Automation,2021,45(16):37-48.
11. B.Li,J.Zhang, B.Qi ,D.Z.Li, K.Shi ,G.Y.Cui. Blockchain:A supporting technology for demand-side resource participation in grid interaction[J]. Power Construction,2017,38(03):1-8.
12. Z.Chen, L.H.Wang, M.Zeng, Y.H.Song . Electricity demand-side management in the context of domestic and international electricity sales side reform[J]. Electricity demand-sidemanagement,2016,18(03):62-64.