Mechanism Design of China Ancillary Service Market Considering Provincial and Inter-Provincial Market Characteristics

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Abstract. With the future large-scale access of renewable energy, the electric power system will accelerate the development in the direction of clean and low carbon, especially under a high proportion of renewable energy electric power system, the structure and layout of China's electric power production has been deeply adjusted. Thus, the balance situation of the power quantity is more complex, the risk of failure chain reaction caused by the simple accident increases greatly. Moreover, with the increase demand for flexible resources in power system, the importance of thermal power plant as well as ancillary service market is highlighted. Considering the difference between provincial and inter-provincial market, an overall mechanism design of China ancillary service market is put forward

1. Introduction

Since the beginning of power sector reform in 2003, the construction of China ancillary service market is put on the agenda simultaneously. Constrained by the reality of power sector before 2002, the ancillary service market started with central optimization by power dispatch center without extra compensation. Later, after the separation of power plant and power grid, ancillary service market evolves into compensation by schedule [1]. However, with the large-scale utilization of renewable energy resources, the problem of insufficient ancillary resources is becoming more and more prominent. The original compensation mode and strength of ancillary service plan can't meet the needs of power grid operation. Thus, the construction of ancillary service market is urgently needed.

2. Evaluation of ancillary service market around the world

From the perspective of the world, the United States of America, Europe and Australia have carried out the construction of ancillary service market with their own national characteristics [2].

2.1 Ancillary service market in Australia

Along with the construction of power market, the National Electricity Market (NEM) of Australia built up an ancillary service market at the same time. Aimed at increasing operation security of power system, the trading product of ancillary service market in Australia includes Frequency Control Ancillary Services (FCAS), Network Support Control Ancillary (NSCA) and System Restart Ancillary Service (SRAS). According to the difference in effectiveness and response time, FCAS could be categorized into regulation and contingency as demonstrated in Table 1.

Table 1. Different categories of FCAS

Category	Transactions	Effect	Response time
regulation	up-regulation	slight decrease in frequency correction	4 seconds
	down-regulation	slight increase in frequency correction	4 seconds
contingency	rapid upward recovery	to avoid massive frequency decrease in emergency	6 seconds
	rapid downward recovery	to avoid massive frequency increase in emergency	6 seconds
	slow upward recovery	to stabilize frequency after massive decrease	60 seconds
	slow downward recovery	to stabilize frequency after massive increase	60 seconds

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delayed upward recovery	to restore frequency to normal range after massive decrease	5 minutes
delayed downward recovery	to restore frequency to normal range after massive increase	5 minutes

In accordance with power market, the ancillary service market of NEM is also operated by Australian Energy Market Operator (AEMO), who is responsible for the optimization and centralized clearance of ancillary service market. Besides, the purchase cost of ancillary service is calculated by AEMO as well, which is allocated to customer sides through electricity prices.

2.2 Ancillary service market in PJM

According to the Order 888 issued by Federal Energy Regulatory Commission (FERC) in 1996, PJM established ancillary service market in 1997, which contained 2 categories at first time. With the change in the needs of system operation, 3 more categories were gradually introduced into PJM ancillary service market since 2000. At present, PJM ancillary service market contains frequency adjustment, reserve, black-start, voltage control and balancing service [3].

Based on the centralized optimization mode PJM power market, the frequency adjustment and reserve ancillary services in PJM are jointly optimized and cleared with the power market, which ensures the minimum system operation cost in total. As for the black-start ancillary service, a medium and long-term bilateral negotiation trading mode is adopted. The voltage control and balancing services are uniformly arranged and scheduled by PJM according to the market rules, and the compensation is settled according to the fixed price. Similar with NEM in Australia, the independent system operator of PJM is responsible for the operation and settlement of ancillary service market. On behalf of all customers in PJM, the independent system operator purchases different ancillary services in terms of system operation requirement. The total cost of ancillary service is distributed to customers through electricity prices.

2.3 Ancillary service market in Europe

In Europe, despite of power market integration since 2014, the ancillary service market in Europe is mostly conducted in national level. Under the guidance of European Network of Transmission System Operators for Electricity (ENTSO-E), almost every national ancillary service market is standardized designed into 3 categories, i.e. Frequency Control Reserve (FCR), Fast Restore Reserve (FRR) and Replace Reserve (RR). The difference of ancillary service categories are compared in Table 2 as follows.

Table 2. Different categories of ancillary service in Europe

Category	Dimension	Effect	Response time
FCR	ordinary	to adjust frequency in the range of 49.9-50.1Hz	2-3 minutes
	disturbance	to adjust frequency in the range of 49.5-49.9 and 50.1-50.5 Hz	30 seconds
FRR	automatic	automatically restore frequency back to 50 Hz	15 minutes
	manual	manually restore frequency back to 50 Hz	15 minutes
RR	/	stabilize frequency after massive change	30 minutes

Unlike the centralized optimization mode in Australia and United States, the power market in Europe is designed into decentralized mode. Under this market design, ancillary service market is normally operated by national system operator. Among the different trading categories, FRR and RR are usually traded through annual and monthly negotiation, while FCR is bidding and optimized in day-ahead level [4].

2.4 Enlightenment

Based on the construction and operation experience of ancillary service market around the world, several enlightenments could be concluded as follows.

1) Adapt to the adjustment of energy structure, the categories of ancillary service market need innovation constantly. With the increasing proportion of renewable energy, the requirement for climbing service, system inertia and fast frequency adjustment is sparking.

2) Adapt to technological innovation, the scope of participation of ancillary service market players should be expanded. With the emergence of virtual power plant, micro-grid and load aggregator, new forms of market participators are becoming more and more important. To increase the flexibility of system operation, new forms of market participators should be encouraged and allowed in market competition.

3) Promote the construction of auxiliary service market according to local conditions and strengthen the coordination and connection with the spot market. Based on different power market mode design, ancillary service markets should be independently operated or jointly optimized with power market.

4) Establish and improve the cost allocation and benefit sharing mechanism of the auxiliary service market. All of the typical ancillary service markets have established a cost allocation mechanism to ensure the reasonable allocation of ancillary service market cost. Also, by providing compensation for service providers, more flexible resources are encouraged to participate in the market.

3. Design of ancillary service market in China

3.1 Current situation

Since the first round of power sector reform of China in 2002, the construction of China ancillary service market is simultaneously carried out. To avoid unbalanced

benefit allocation, two regulations are put forward by National Electric Regulatory Commission in 2006, which provides reasonable compensation for service providers according to their contributions. Also, the cost of ancillary services are charged to the power plants, which don't participate in ancillary service market [5].

With the large-scale grid-connection of renewable energy, the problem of insufficient adjustment means of power system is becoming more and more prominent. The original compensation mode and strength of ancillary service plan can no longer meet the needs of power grid operation. Thus, under the guidance of No.9 Document, the ancillary service market of China started to emerge.

In 2021, National Energy Agency put forward "Measures for the Administration of electrical Ancillary Services", which divided ancillary services into 3 main categories as indicated in Table 3.

Table 3. Ancillary service categories for China

Category	Dimension
Active balance	Peak-shaving
	Frequency adjustment
	System inertia
	Reserve service
	Climbing service
Reactive balance	Automatic voltage control
	Condenser operation
Emergency and restoration	Stable disconnection of generators
	Stable disconnection of demand
	Black-start

Ancillary service market is an indispensable part of the electric power market. In the aspects of policy guidance, basic principle and market development goal, it should not only coordinate with the electric energy market, but also according to the particularity of the economy and technology of ancillary service itself, and rely on the development needs of electric power market and electric power system.

At present, an inter-provincial and provincial ancillary service market system with peak-shaving, frequency regulation and reserve has been formed in China as indicated in Fig.1.

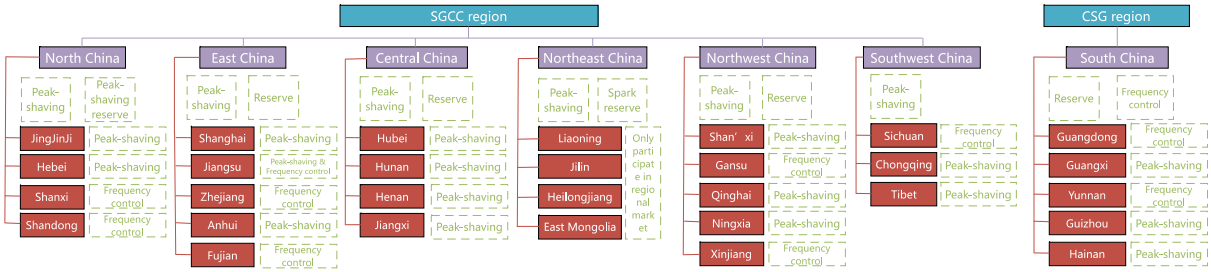

Fig.1 Current ancillary service market in China

From regional perspective, all seven regions have established regional ancillary service market to encourage flexible resources sharing in regional level. However, constrained by the grid connection situation in different regions, peak-shaving service is the most common category in regional level. With the gradual enhancement in grid connection, reserve services are also introduced in Central, East and South China.

From provincial perspective, all provinces have established provincial ancillary service market. The main category of ancillary service is peak-shaving, which could contribute to the renewable energy utilization. However, in spot market pilot provinces, due to the similar function of peak-shaving service and spot market, frequency control is the main category in ancillary service market.

3.2 Construction path design

Combined with the top-level design of China electric power market, based on the actual demand of China electric power system operation and the development trend of ancillary service market, ancillary service market of China can be divided into three construction stages.

1)initial stage (2022-2025)

Provincial and inter-provincial peak-shaving will continue to be the main trading services, and the development of frequency adjustment and reserve markets will be accelerated. In spot market pilot provinces, peak-shaving services would be replaced by spot market, while in other provinces peak-shaving services should be gradually integrated with spot market.

2)development stage (2025-2030)

Promote the integration of peak-shaving service and power spot market, explore the sharing and mutual relief of ancillary service resources in a larger scope, introduce new ancillary service market trading varieties such as climbing and inertia at the right time, explore the introduction of multiple types of power supply and emerging market players to participate in the ancillary service market.

3)mutual stage (after 2030)

Under the framework of the national unified electricity market, the ancillary service market has been gradually improved, and the trading varieties of ancillary services, such as frequency modulation, reserve,

climbing and inertia, have been carried out in a steady and orderly manner at all levels of the market according to local conditions.

4. Case study

Based on the proposed design of ancillary service market, a case study for ancillary service demand and cost analysis have been conducted based on realistic operation statistics in China pilot provinces.

4.1 Ancillary service demand forecast method

To evaluate the demand for frequency adjustment, a mathematical method is introduced. Based on the historical load data of typical provinces and the actual output curves of wind power, photovoltaic and other renewable energy resources, the maximum change rate of net load curve of typical provinces was statistically analyzed in accordance with the statistical period of 5 minutes and the daily cycle, and combined with the load growth rate and installed growth rate of renewable energy of typical provinces, the demand for frequency adjustment ancillary service in the future was reasonably estimated.

$$J_0(t) = L_0(t) - W_0(t) - P_0(t) \quad (1)$$

Where $J_0(t)$ represents the net demand. $L_0(t)$、$W_0(t)$ and $P_0(t)$ represents the historical load and the realistic output of wind and photovoltaic respectively. *t* refers to time duration. The net demand curve of typical provinces after *n* years could be calculated as equation (2).

$$J_n(t) = L_0(t) \times \eta_l^n - W_0(t) \times \eta_w^n - P_0(t) \times \eta_p^n \quad (2)$$

Where η_l^n, η_w^n and η_p^n represent the forecast increase rate of load, wind output and photovoltaic output respectively. Thus, the demand for frequency adjustment of the typical provinces could be calculated as equation (3).

$$\Delta J_n(t) = J_n(t+5) - J_n(t) \quad (3)$$

According to the calculated net load changes, the maximum value of positive/negative frequency adjustment demand in day d could be calculated as follows.

$$\Delta J_n^{+/-}(d) = max\left\{\Delta J_n^{+/-}(t)\right\}, \mathrm{t} = 1,2 \cdots 288 \quad (4)$$

And finally, the frequency adjustment demand of the typical provinces in year n could be calculated as follows.

$$\Delta J_n^{+/-} = max\left\{\Delta J_n^{+/-}(d)\right\}, \mathrm{d} = 1,2 \cdots 365 \quad (5)$$

4.2 Ancillary service demand calculation

Take a typical spot market pilot province in China as an example, the realistic load and output of wind and photovoltaic are used as basic situation, while the increase rates of load, wind output and photovoltaic output are assumed 12%, 42%, 84% respectively. Based on the method in 4.1, the demand for frequency adjustment service is forecasted as Fig.2.

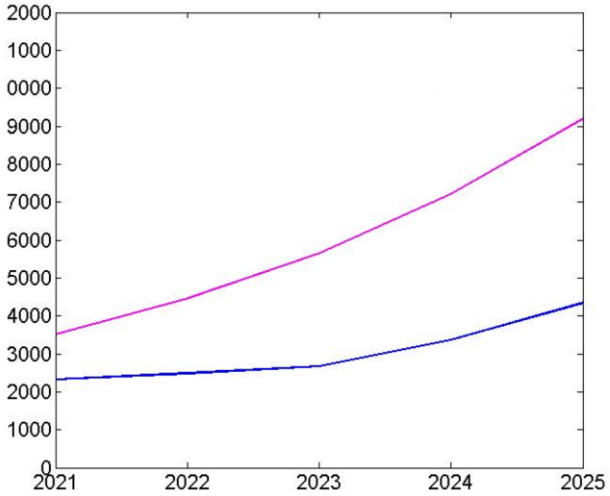

Fig.2 Frequency adjustment forecast

As indicated in Fig.2, the maximum positive and negative frequency adjustment demand in 2021 are 2325.6MW and 3516.4MW respectively while in 2025, the demand are increased to 4350.4M and 9188.7MW respectively. Also, due to the high proportion of renewable energy installation, the demand for negative frequency adjustment grows far more quickly than positive frequency adjustment.

5. Conclusions

Based on the proposed ancillary service market design for China, the key objectives and core targets of ancillary service market could be drawn in three suggestions.

1)To facilitate the construction of new power system, a coordination between ancillary service market and power market should be built. Based on the different modes of power market, ancillary service market could either independently operate or jointly optimize with power market.

2) To satisfy the need of power system operation, several new trading categories of ancillary service could be introduced. With the integration of renewable energy in power system, frequency adjustment, reserves as well as rapid climbing services will be gradually introduced into the market.

3) To encourage the participation of flexible resources, a cost allocation and benefit distribution mechanism should be built. The cost of ancillary service market should be allocated to customer side according to the consumption value of power, while compensation should also be distributed to flexible resources based on their contribution.

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