The Enlightenment of US Demand Side Response Participating in PJM Market Trading Mechanism for China

Jian Zuo[1(✉)], Bo Bao[1], Xiangzhen He[1], Yun Yang[1], Lian Tu[1], Shuiping Zhang[1], Minjing Yang[1], Yixing Chen[1], Yulin Dong[2(✉)], and Xuanli Lan[2(✉)]

[1] Southern Power Grid, Power Dispatch and Control Center of Guangdong Power Grid Co., Ltd, Guangzhou 510600, China
zuojian@alumni.hust.edu.cn
[2] Beijing Tsintergy Technology Co., Ltd, Beijing 100089, China
dongyl@tsintergy.com.cn, lanxl@tsintergy.com

Abstract. The basic idea of demand response originates from comprehensive resource planning, which equates the controllable energy demand on the user side with the supply side resources, and integrates it into the category of resource planning and utilization. It enhances the energy utilization efficiency, improves the adjustment ability of supply and demand balance, and improves the comprehensive optimal allocation level of resources. In order to solve the problem of power balance in real-time operation, reduce power consumption and improve economy, the United States completely solves it through a perfect electricity market model. However, Chinese electricity market is in a market mode of transition from medium-and long-term electricity market to medium-and long-term trading and spot trading. In view of the above situation, this paper combs the mechanisms and methods of demand response to participate in electric energy, reserve and FM auxiliary services, and capacity market trading in the American PJM market environment, analyzes the principles, and combines the actual situation of the construction of China's spot market. This paper analyzes the enlightenment of the application of the demand response market mechanism in the United States, and puts forward some suggestions on the demand response mechanism suitable for China, so as to provide reference for the research and application of user-side participation in market transactions under the spot market framework.

Keywords: Demand-side response · power balance · spot market

1 Introduction

The traditional power balance makes overall allocation across regions and seasons through the allocation of electric energy formed by primary power generation such as water, coal, wind and so on. Under the background of the new power system, the proportion of new loads of electric vehicles and distributed power sources with the ability of two-way interaction with the power grid is increasing, and some traditional

loads can also adjust their own electricity demand according to incentives or electricity prices. With adjustable characteristics, thus showing the characteristics of demand-side response. Demand response technology is one of the core technologies of smart grid [1–3]. The application of demand response technology can fully tap the load-side resources and realize the comprehensive optimal allocation of resources. The American electricity market has formed a relatively perfect demand response market system, which is mainly concentrated in the energy, capacity or auxiliary service market. From the classification of demand response, the market subject on the user side participates in the electricity market transaction in the way of quantity quotation, and the "electricity demand-price" curve submitted in each period reflects the characteristics of load changing with the price. To a certain extent, achieve a better effect of optimal allocation of resources, while reducing the market price risk [4–8].

In addition, demand response participation in the power wholesale market is a means for system operators to carry out effective economic dispatching; demand response participation in bidding in the auxiliary service market effectively taps the potential of the load side to provide auxiliary service resources such as frequency modulation and reserve. With the help of the mature conditions of electricity market, capacity market and auxiliary service market, there are various forms of demand response projects and flexible control strategies in the American market environment, according to the specific ways of demand response to participate in market transactions, it is also divided into emergency demand response, economic demand response and demand-side auxiliary services.

The foreign demand response mechanism depends on the mature power market system, which is not fully applicable to the immature electricity market environment in China, but its perfect management model is worth learning from the domestic power market. Therefore, by analyzing and drawing lessons from the mechanisms and methods of American demand response to participate in the market, this paper puts forward some corresponding suggestions on the demand side mechanism in the Chinese market environment.

2   Specific Forms of Demand Response Under PJM Market Conditions

In the American PJM electricity market, medium-and long-term trading contracts are mainly signed in the form of over-the-counter transactions, most of which are contracts for difference, defining the total amount of electricity, prices, delivery nodes and decomposition curves of buyers and sellers [9]. In the day-ahead market, the market participants, including demand response resources, submit the quantity and price declaration information of electric energy and operation reserve, and through the joint clearance of electric energy and operation reserve service, the next day generation plan and operation reserve plan that meet the requirements are obtained, and the node marginal price (LMP) is taken as the day-ahead market clearing price, and the unified clearing pricing (MCP) method is adopted to price the day-ahead reserve [10–13]. The market entities who have not won the bid in the market a few days ago can submit the quantity and price information of electric energy, synchronous reserve and FM auxiliary services in the real-time

market declaration stage, according to the boundary conditions such as load forecasting, frequency modulation and reserve demand in the real-time operation stage, the winning results of real-time generation planning, synchronous reserve and FM auxiliary services are determined by the joint clearance of electric energy and auxiliary services, and the node marginal price of the real-time electric energy market is determined. The mileage clearing price and capacity clearing price of the FM market, as well as the clearing price of the synchronous reserve market. In addition, planned or commissioned generation capacity, user-side adjustable load resources can participate in the PJM capacity market transaction to meet the system's capacity demand during peak hours in the next three years.

3   The Mechanism and Method of Demand Response Participating in American PJM MarketTest

3.1   The Mechanism and Method of Demand Response Participating in Electric Energy Market

(1) Clearing Mechanism of spot Electric Energy Market

DR quotation as a virtual unit to participate in the competition of electric energy trading, from the principle of analysis to meet the bidding principle of the centralized spot market. In the clearing phase of the day-ahead and real-time electric energy market, although the qualified DR users have submitted a segmented supply curve that competes with the generating units, based on the market clearing principle of maximizing net social benefits, PJM market operators need to compare the net benefit price (NetBenefitPrice, hereinafter referred to as NBP) calculated by the net benefit test (NetBenefitTest) with the LMP of this period. To decide whether to introduce DR and the bidding of the generator set [14–16] during this period of time, as shown in Fig. 1. When NBP is less than LMP, the segmented supply curve submitted by DR during this period will be included in the market clearing, and the response capacity of the time period will be issued to the users who win the DR and settled according to the node marginal price of that period. Otherwise, even if the DR user submits a lower bid than LMP, it will not be notified of winning the bid, and the actual power reduction will not be accepted.

The market operator carries out the net benefit test according to the quotation on the generation side of last month, and the net benefit testing mechanism has a clear meaning. Specifically, the synthetic quotation curve of the generation side is drawn in logarithmic coordinates, and the rate of increase of the declared price of the generation side / the increase rate of the declared capacity of the generation side is the "generation side bidding elasticity coefficient", and the generation side quotation corresponding to the point where the coefficient is equal to 1 is NBP. The meaning of the net benefit balance point is that after exceeding the price, the bidding elasticity of the generation side is more than 1, indicating that it is no longer economical to continue to increase the supply of the generation side, instead of introducing the response resources of the user side to replace this part of the power generation resources. The concept of "generation side bidding elasticity" introduced in the net benefit test is similar to the meaning of
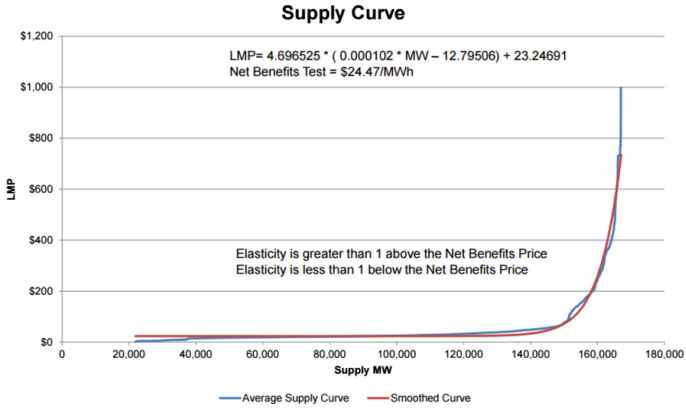
Supply Curve

LMP= 4.696525 * (0.000102 * MW – 12.79506) + 23.24691
Net Benefits Test = $24.47/MWh

Elasticity is greater than 1 above the Net Benefits Price
Elasticity is less than 1 below the Net Benefits Price

Average Supply Curve   Smoothed Curve

Fig. 1. Net benefit test calculation of unit quote fitting curve

"user price elasticity coefficient". Through the application of this net benefit testing mechanism, it is helpful to enhance the economy of market clearing.

(2) DR participates in the settlement Mechanism of spot Electric Energy transaction.

Under the PJM centralized spot market mode, the electricity plan actually implemented by the market subject only needs to be settled according to the deviation of the spot clearing price, and there is no need to charge additional assessment fees. After DR participates in the clearing of electric energy and replaces part of the power generation resources, DR actually participates in the market transaction as an equivalent virtual unit. If it is completely settled in accordance with the deviation settlement of the spot electric energy market without assessment requirements, there will be a large amount of DR winning the bid and the actual unimplemented, which will lead to an increase in the risk of active power shortage in the system. In view of the above considerations, for the DR resources that have won the bid in the day-ahead and real-time energy market in the PJM power market, in addition to the settlement of the deviation according to the spot energy price, the actual response capacity is more than $\pm 20\%$ of the day-ahead and real-time bid-winning capacity. This part of the deviation is assessed with reference to the price of the intra-day reserve market [17–19]. Set 20% as the threshold of punitive assessment, its original intention is similar to the non-stop assessment of the unit, and ensure the reliability of power grid operation within the scope of system reserve capacity.

3.2 The Mechanism and Method of Demand Response Participating in Auxiliary Service Market

(1) DR Mechanism of standby Auxiliary Service Market.

On the basis of meeting the access conditions of electric energy trading, the DR resources participating in PJM capacity market trading and spot electric energy trading, the market entities whose time frequency of load measurement is 1min and the deviation rate of measurement accuracy is less than 2% can also participate in the transaction of backup auxiliary services on the time scale of the day. There are two types of synchronous reserve resources in PJM reserve system, among which class T1 refers to the reserve

resources provided by units that meet the principle of economic dispatching (without considering opportunity cost) and have the ability to respond to 10min, while class T2 mainly refers to units used for synchronous and phase-adjustable operation of power grid, and its response rate should reach the expected target within 10min [20]. DR resources admitted to standby auxiliary service transactions are regarded as class T2 synchronous reserve resources, and participate in the joint clearance of electric energy, reserve and FM auxiliary services on the time scale of the day, but the demand response capacity of providing synchronous reserve in the clearing result cannot exceed 33% of the total synchronous reserve capacity. DR resources should complete the declaration of the maximum and minimum response capacity and price of standby auxiliary services by 14:15 before the day.

(2) Authentication method for DR to provide backup Auxiliary Service.

Due to the high clearing and calling frequency of T2 type synchronous reserve, the baseline load calculation with the frequency of 1 h can not effectively evaluate the spare capacity provided by the DR resource, so it is necessary to record the actual load of DR users according to the frequency of 1min. The synchronous reserve capacity provided by DR is calculated on the basis of the difference between the load value at the beginning of the response and the load value after the response start 10min. Considering the influence of factors such as measurement data deviation at a single time, the maximum values of the measurement values of the response start time and the front and back 1min are selected as the load at the response start time; similarly, the minimum value of the measurement values from 9 to 11 min after the start of the response is selected as the load of the 10min after the start of the response [21, 22].

3.3 The Mechanism and Method of Demand Response Participating in Capacity Market Transaction

The emergency DR resources involved in the capacity market transaction include different project subtypes, which are different in the period of time for providing capacity, the number of calls, the maximum response time and so on, and organize bidding transactions respectively. Currently, there are three subtypes of capacity market transactions that emergency DR participates in in the PJM market, as shown in Table 1–5. Through the setting of different DR varieties, it can meet the capacity requirements of the whole PJM network in different periods and different periods, and improve the adaptability between all kinds of DR response characteristics and power grid operation.

The emergency DR projects involved in capacity market transactions include direct load control (DLC), fixed level power consumption (FSL) and defined capacity reduction (GLD). In the stage of market registration, it is necessary for the distribution company (EDC) to determine the peak load contribution value and network loss coefficient of the user, which is used to evaluate the actual response capacity of DR resources in the year of capacity delivery. The response capacity needs to be determined according to the difference between the user's baseline load and the actual load, as well as the difference between the peak load contribution value and the actual load. Among them, the actual reduction of the emergency response of DLC type can be determined according to the load reduction directly called after the event starts, while the actual reduction of emergency response of FSL type needs to be calculated according to the deviation between the peak

load contribution factor PLC and the actual load value. For the actual reduction of GLD type, the reduction calculated by the baseline load and the peak load contribution factor PLC should be taken into account.

The reduced capacity calculated by the above method is the actual subscribed capacity (ICAP) and needs to be converted into generation-side trusted capacity (UCAP) for settlement. UCAP is a general concept in the PJM capacity market. After the DR response capacity call is completed in the capacity delivery year, it needs to be converted to UCAP according to ICAP. If the UCAP calculated by the actual response of DR users is lower than the bid-winning capacity, it will be assessed by the vacancy capacity. The method of converting the user's actual subscribed capacity (ICAP) to the generation-side trusted capacity (UCAP) is as follows: generation-side trusted capacity (UCAP) = actual subscribed capacity (ICAP) × DR factor × (1 + PJM forced outage rate), where the DR factor is a coefficient evaluated based on the historical performance of emergency response resources, which is between 0 and 1. Since the emergency demand response resource provides part of the capacity, it is considered to be equivalent to providing the unblocked output of the unit (the forced outage rate is 0), so the forced outage rate coefficient should be considered when converting to UCAP.

4   The Inspiration of American Demand Response Mechanism to China's Power Market

With the advance of the construction of the spot market, on the basis of taking into account the quotation of the main body of the market on the user side, we can consider the feasibility of taking the demand response as a virtual unit to participate in the quotation of the quoted quantity on the generation side, as a mechanism to improve the market price in extreme scenarios. The mode of user-side quotation itself can improve the elasticity of market demand and enhance the effect of resource allocation, but its implementation is relatively complex due to the combination of planning and market and the accuracy of busbar load forecasting. In some provinces or regions where power supply and demand are tight, some demand-side response resources such as adjustable load and energy storage are introduced as virtual units to participate in the competition in the spot power market as the main body of the generation-side market. According to the quotation, clearing and actual implementation of the day-ahead and real-time spot energy market, the deviation settlement is carried out for the load reduction provided by the demand-side response resources. It will help to improve the problem of channelling subsidy funds that need to be solved by means of pilot subsidy funds.

4.1   Typical Provincial Peak Shaving Auxiliary Service Transaction Model in China

Some provinces and regions in China have established a normal peak regulation market trading mechanism. As one of the most basic peak regulation market trading varieties, deep peak regulation takes the initiative to reduce the output of the units connected to the grid during the day when the load rate is less than the paid peak regulation benchmark

(50%). The target transaction is the unit output reduction. At present, the sellers of peak-shaving auxiliary service transactions are mainly coal-fired thermal power units (a small number of nuclear power units), and the buyer is the power generation enterprises in the province and outside the province. When the shortage of negative reserve caused by new energy consumption and power balance is considered, the deep peak regulation market mechanism will be triggered, and the coal-fired thermal power units will be cleared according to the load rate. According to the principle of "day-ahead quotation, real-time clearing", in the real-time stage, in accordance with the system requirements, in the process of system load decline, priority is given to reducing the output of units with low quotation; in the process of rising system load, priority is given to increasing the output of units with high quotations. In terms of cost sharing, the cost of deep peak regulation service is shared by thermal power units, wind turbines, photovoltaic units, hydropower units and some non-provincial units transmitted by tie lines, which are operated during the deep peak regulation trading period in the market, according to the ratio of online electricity in the billing cycle.

4.2 The Mode of Demand Side Participating in Peak Shaving Market

In order to coordinate with the current peak regulation auxiliary service transaction model, the increase of electricity consumption on the load side during the trough period can be considered as the relevant suggestions to participate in the peak regulation market. In fact, the energy storage and peak regulation mentioned in the peak regulation rules of some provinces and regions is the above-mentioned mode.

1. Market access conditions: allow charging piles, electric energy storage devices, industrial and commercial users whose electricity consumption scale reaches a certain level and access voltage to reach a certain level, and can upload real-time electricity information to the dispatching organization, and accept the dispatching agency's centralized unified dispatching command to participate in peak regulation auxiliary service transactions.
2. Market participation mode: when the demand side participates in the peak regulation auxiliary service, it is necessary to combine the conditions such as its own charging (discharging) power and the growth (reduction) rate of electricity load, when the market of deep peak regulation auxiliary service market starts before the day, declare the quantity-price curve with 15 min as the billing cycle. According to the demand forecast of peak regulation the next day, the declaration of coal-fired thermal power units and their application information, the dispatching agencies respectively put out the peak regulation transaction of clear thermal power units and the peak regulation transaction on the demand side, and complete the safety check.
3. transfer mode: according to the principle of "call on demand, call in order", during the period of large wind power photovoltaic generation and peak regulation demand, the dispatching organization will give priority to calling the cleared coal-fired thermal power unit peak regulation resources, and then transfer the demand side resources. The demand-side resources shall be carried out in accordance with the peak shaving auxiliary service transaction cleared a few days ago.
4. settlement method: the settlement method of peak regulation auxiliary service for demand-side resources is the same as that of thermal power deep peak regulation

service charge for coal-fired units, which is the product of the amount of deep peak regulation in the unit billing cycle and the clearing price in the corresponding time (load rate range).

5. cost sharing method: the demand-side peak regulation auxiliary service fee is uniformly incorporated into the total plate of deep peak regulation service fee, and the proportion of power consumption of each grid unit in the unit billing cycle is apportioned according to the current allocation method.

5   Conclusion

With the promotion of the construction of power market reform, the development of demand response can be guided by the market mechanism, which can give full play to the role of demand-side resources in the optimal allocation of power resources and ensure the safe and economic operation of power grid. it is also an indispensable content in the formation of a relatively complete and mature power market system.

This paper introduces the mechanism and method of demand response participating in electric energy market, auxiliary service market and capacity market under the environment of American spot market, analyzes the principle, and combines the present situation of electricity market in our country. This paper puts forward the market model of demand-side participation and peak shaving, and puts forward relevant suggestions for the demand response mechanism under the condition of China's spot market. It is hoped that it can provide reference for the research of electricity market trading mechanism and policy formulation.

References

1. Bitaraf H, Rahman S. (2018) Reducing curtailed wind energy through energy storage and demand response[J]. IEEE Transactions on Sustainable Energy, 9(1): 228-236.
2. Adams J, O'Malley M, Hanson K. (2010) Flexibility requirements and potential metrics for variable generation: implications for system planning studies[M]. Princeton, NJ: NERC, 14-17.
3. Capasso A, Falvo M C, Lamedica R, et al. (2005) A new methodology for power systems flexibility evaluation[C]Proceedings of the Power Technology. Russia: IEEE, 27–30.
4. Chen Zhe, Zhang Yining, Huang Gang, et al. (2019) A Chance Constrained Optimal Wind Power Consumption Model Considering Random Line Faults [J]. Grid Technology, 43 (2): 363-370.
5. North American Electric Reliability Cooperation. Special report: accommodating high levels of variable generation [R]. North American Electric Reliability Cooperation, 2009.
6. Cui Jianlei, Wen Yunfeng, Guo Xin, et al. (2013) Power grid security risk management and control system for dispatching operation (2) risk index system, evaluation method and application strategy [J]. Power system Automation, 37 (10): 92-96.

7. Ding Huajie, Song Yonghua, Hu Zechun, et al. (2013) Study on probability distribution of day-ahead prediction error based on power characteristics of wind farm [J]. Chinese Proceedings of the CSEE, 33 (34): 136144

8. Chen Zhe, Zhang Yining, Huang Gang, et al. (2019) Chance-constrained optimal wind power absorption model considering line random faults [J]. Grid Technology, 43 (2): 363,370.

9. Han Zifen, Jing Qianming, Zhang Yankai, et al. (2019) Summary of wind power forecasting methods and new trends [J]. Power system Protection and Control,47 (24): 178187.

10. Xu Yibin, Zhang Yu, he Yubin, et al. (2018) Maintenance-operation collaborative optimization model and algorithm considering flexibility [J]. Power system Automation, 42 (11), 31-40

11. Ma Xiyuan, Sun Yuanzhang, Fang Hualiang, et al. (2013) Scenario-base multiobjective decision-making of optimal access point wind power transmission corridor in the load centers [J]. IEEE Transactions on Sustainable Energy, 4 (1): 29,239.

12. Zhou Ming, Xia Shu, Li Gou, et al. (2015) Joint optimal dispatching of monthly unit commitment and maintenance plan in power system with wind power [J]. Chinese Proceedings of the CSEE, 35 (7): 1586-1595

13. Ding Tao, Guo Qinglai, Bai Rui, et al. (2014) Interval economic dispatching model and spatial branch and bound method considering wind power uncertainty [J]. Chinese Proceedings of the CSEE, 34 (22): 3707-3714.

14. Lu Jinling, Zhang Jin, Ding Maosheng. (2016) Economic evaluation of power system dispatching with wind power [J].Grid Technology, 40 (8): 2258–2264.

15. Zhou Ming, Zhai Junyi, Ren Jianwen, et al. (2017) Decentralized and coordinated dispatching method for DC interconnected power grid with wind power grid connection [J]. Grid Technology, 41 (5): 1428-1434.

16. Zhang Qin, Wang Xifan, Wang Jianxue, et al. (2008) Summary of research on demand response in electricity market [J]. Power system Automation, 32 (3): 97,106.

17. Liu Xiaocong, Wang Beibei, Li Yang, et al. (2015) Large-scale wind power consumption stochastic unit combination model considering demand-side resources [J]. Chinese Proceedings of the CSEE, 35 (14): 3714-3723.

18. Chaohong, Hu Guowei, Xie Haipeng, et al. (2014) Optimal dispatching of wind power system considering demand response [J]. Power system Automation, 2014, 38 (13): 115,120.

19. Yu Na, Li Weimeng, Huang Dawei, et al. (2018) Day-ahead scheduling model of wind farm with transferable load [J]. Power system Protection and Control, 46 (17): 61-67.

20. Deng Tingting, Lou Suhua, Tian Xu, et al.(2019) Optimal dispatching of wind power system with thermal power system considering demand response and thermal power deep peak regulation [J]. Power system Automation, 43 (15): 34-40

21. Bitaraf H, Rahman S. (2018) Reducing curtailed wind energy through energy storage and demand response [J]. IEEE Transactions on Sustainable Energy, 9 (1): 228236.

22. Adams J, O'Malley M, Hanson K. (2010) Flexibility requirements and potential metrics for variable generation: implications for system planning studies [M]. Princeton, NJ: NERC, 14-17.