Mechanism Design for Participation of Demand Response in China Power Market

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Abstract. At present, with the rapid development of demand response in China, various market players such as electric vehicles, energy storage, virtual power plants, and load aggregators are constantly enriched. However, due to the imperfect market-oriented trading mechanism, the potential and enthusiasm of demand response have not been fully released. With the accelerated construction of China's power market, various trading mechanisms such as spot market and ancillary services market have gradually improved. Based on the development of China's power market, this paper designs a market-based transaction mechanism for demand response, and proposes a future development path for demand response. In the end, the subsidy for demand response development in China is estimated, which supports the market-oriented participation path of demand response in China’s power market.

1. Concept and Definition of Demand Response

Influenced by price or incentive signals, users' reactions in changing normal power consumption patterns are defined as demand response. As an effective method to ensure power balance, demand response aims at achieving simultaneous optimization of power consumption and resources allocation [1]. According to international experience of demand response application in Europe and America, demand response can be divided into two categories, i.e. price-based demand response (PBDR) and incentive-based demand response (IBDR). PBDR refers to users’ response to the change of electricity retail prices and corresponding adjustment of power consumption, including time-of-use prices, real-time prices, peak prices, and peak real-time prices etc. IBDR refers to the development of incentive policies to encourage users to adjust power demand when the system requires, including direct load control, interruptible load, demand-side bidding, emergency demand response, capacity market [2].

Demand Response Adjustable Resources

- Milliseconds level: Captive power plant, Energy storage system
- Seconds level: Electric heat storage, Ice storage
- Minutes level: Industrial production, Air conditioner
- Hours level: Smart house, Electric vehicles

Fig.1 Adjustable load categories based on response time scale

Based on the adjustable capability of different electricity loads, the main resources involved in demand response include nine categories: industrial production, air-conditioning load, user-side energy storage, electric vehicles, smart homes, combined thermal power plant, captive power plant,
electric heat storage, and ice storage. According to different response time, it can be further divided into milliseconds (within 1 second), seconds (within 1 minute), minutes (within 60 minutes), hours (within 4 hours) and other categories. The typical adjustable load resources on each response time scale are shown in Fig.1 [3].

2. Progress and Challenge of Demand Response in China
Starting in 2014, demand response has achieved considerable progress in accordance with the change of situation in power supply and demand as well as the rapid development of renewable energy in recent years. As a vital foundation, a coordinated demand response policy system between national and provincial levels has taken shape. Combined with the provincial situation of social and economic development, each province has formulated a demand response program in line with the conditions of the power grid, which has distinct local characteristics. The demand response mechanism is also actively innovated, exploring market-oriented trading mechanism and price formation mechanism, and constantly expanding the source of subsidy funds as well.

2.1. Significance of demand response development
The development of demand response in China has four significances.
(a) To satisfy peak load requirement and improve the security of power system.
(b) To alleviate difficulty in renewable energy consumption and improve the utilization of renewable energy.
(c) To enhance the flexibility of power grid and the ability of peak-shaving.
(d) To improve the efficiency of power market and realize interaction between resource, grid, and load.

2.2. Challenges for demand response development
Confined by current situations, the development of demand response in China encountered four challenges.
(a) The construction of China power market lags behind, and the market mechanism as well as rule system need to be further improved.
(b) Demand response has not formulated a unified technical standard, and technical support capacity is inadequate at present.
(c) The business model of demand response is relatively unitary and the subsidy fund is insufficient.
(d) The market awareness of user needs to be cultivated and the willingness to participate in the demand response requires further guidance.

3. Market-Oriented Mechanism Design of Demand Response
Since the start of new round reform of China power market in 2015, the construction of spot market and ancillary service market are advancing rapidly. 8 provincial spot markets including Shanxi, Shandong, Zhejiang, etc. have started trial operation. 11 ancillary service market including North China, Northeast China, Fujian, etc. have started full operation. However, the mechanisms of spot market and ancillary service market haven’t considered the participation of demand response at the first time. To encourage the establishment of market-oriented mechanism of demand response, the participation mechanisms of demand response in spot market and ancillary service market are respectively designed as follows.

3.1. Participation mechanism of demand response in ancillary service market
Currently, demand response is mainly involved in peak shaving ancillary services. In the future, with the gradual improvement of spot market, demand response will mainly participate in the reserve capacity market.

Large industrial power users who meet capacity requirements can directly participate in demand response, while small and medium-sized power users can participate in demand response through load
aggregators and virtual power plant. The main method for demand response to participate in peak shaving ancillary service is to increase the load demand during the response period by means of incentives, i.e. to play the role of valley filling through deployment of resources. Three specific measures may be conducted. ① Increasing adjustable load in response period through price or compensation incentive; ② Transferring time-shiftable load from other peak periods to response period; ③ Charging energy storage system and pumped power stations.

The overall process of demand response participation in peak shaving ancillary service includes five steps: ① Electric corporation estimates peak shaving quantity requirements. ② Participators submit quantity-price bidding information to market operator. ③ Market operator conducts optimization to minimize social cost. ④ Participators execute demand response portfolio according to clearing results. ⑤ Market operator conducts financial settlement.

For the price mechanism of demand response, fixed-rate price compensation can be used in the initial stage of the market, and the marginal peak-shaving compensation price can be collected and settled by auction during the market maturity period. The profit of demand response in participation of ancillary service market could be defined as equation (1), where $Q_1$ and $P_1$ represent the quantity and price of demand response in ancillary service market respectively. By introducing reference load, the actual load curtailment or increasing value of demand response could be defined as equation (2), Where $P_{a,t}$ and $P_r$ represent the actual load and the reference load of demand response. The reference load value $P_r$ could be calculated based on the historical load data of demand response as defined in equation (3), where $T$ represents the time interval of history data. In terms of compensation funding resources, government subsidies are suggested to support at the beginning of the market. With the maturity of the market, the subsidy cost could be allocated to the profitable market players [4].

3.2. Participation mechanism of demand response in spot market
Market participants of demand response in spot market are consistent with ancillary service market. Large industrial power users are allowed to participate directly, while small and medium power users need to be aggregated by virtual power plants.

Demand response has two power characteristics in spot market. One is to reduce load requirement as a "positive power plant", which is equivalent to a power plant increasing the power supply during the bidding period. The other is increasing load demand as a "negative power plant", which is equivalent to decrease power output during the bidding period.

The participation process for demand response in spot market is consistent with other market participators. ① Electric corporation forecasts load demand. ② Participators submit quantity-price bidding information to market operator. ③ Market operator conducts optimization to minimize social cost. ④ Participators execute demand response portfolio according to clearing results. ⑤ Market operator conducts financial settlement.

For price mechanism, the profit of demand response is determined by spot market clearing results as well as actual response quantity. Based on different clearing mechanism, the clearing results of spot market could be locational marginal price (LMP) or system marginal price (SMP), etc. The deviation between the actual response quantity of demand response and the accepted bidding quantity shall be settled according to the spot market rules. The profit or cost of demand response in spot market could be defined as equation (4).

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M_s = \sum_t (Q_{d,t}P_{d,t} + Q_{l,t}P_{l,t})
\]

$Q_{d,t}$ and $Q_{l,t}$ represent the actual load of demand response in day-ahead market and real-time market respectively. $P_{d,t}$ and $P_{l,t}$ represent the clearing price of day-ahead market and real-time
market respectively. Through the guide of price signals in spot market, demand response could optimize the load portfolio itself in order to minimize economic cost [5].

4. Future Development Path for Demand Response in China

According to the construction progress of China's spot market and ancillary service market, it can be divided into four typical stages as illustrated in Fig.2.

![Fig.2 development path design for demand response](image)

4.1. Ancillary service market and spot market have not been established
Demand response at this stage mainly participates in "peak shaving and valley filling" by means of agreement. The electric corporation signs a bilateral agreement with demand response resources, and executes a certain amount of demand response within the agreed period. Compensation prices are mainly based on fixed rates. When the ancillary service market is initially established, it can enter next stage.

4.2. Ancillary service market is initially established
Demand response in this stage mainly participates in peak-shaving ancillary services through bidding. By centralized bidding and clearing, the market clearing price and quantity of ancillary service market are formed. Each market participant performs demand response based on the results of the clearance. When spot market is initially established, it can enter stage next stage.

4.3. Ancillary service market and spot market are initially established
Demand response at this stage mainly participates in spot market through bidding. By centralized bidding and clearing, the clearing price and power output of spot market are formed, and each market participant performs demand response based on the clearing results. After the rules system and operation mechanism of the electricity market are relatively complete, it can enter stage the final stage.

4.4. Ancillary service market and spot market are completely established
At this stage, demand response mainly participates in spot market and reserve capacity market through bidding. By joint optimization of spot market and reserve capacity market, the power output and reserve capacity of demand response are determined simultaneously. After the execution of demand response, financial settlement is performed according to the market clearing price.

5. Case Study and Conclusions

Based on the estimated simulation, demand response capacity of China is around 45GW, which accounts for 5% of China’s maximum load [6]. The applicable hour of demand response is 20 hours on average. In addition, the subsidy standards are also different in China, to simplify simulation, five regional subsidy standards are put forward representing the typical situation of the region. For example, in Eastern China, the subsidy standard of Shanghai ¥3/kWh is applied for calculation, while in Central China, the standard of Henan ¥6/kWh is treated as a representative. After the calculation, the total subsidy required for demand response in China is nearly ¥1.65 billion, while the applicable subsidy fund provided by China government is only ¥0.1 billion, which leads to a funding gap of ¥1.55 billion. Although facing difficulty in providing enough subsidy for demand response, the social and economic profit brought by demand response is far beyond the monetary expense. Thus, to promote the application and development of demand response and increase the flexibility and security of power grid, the market-oriented participation mechanism of demand response is essential and vital.
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