Research on electricity market operation mechanism and its benefit of demand side participation

HAN Shuai, YAN Xu, QIN Li-juan, LIN Xi-qiao, ZENG Bo

Electric Power Research Institute of Guangxi Power Grid Co., Ltd, Nanning530002, China

Abstract: Demand response plays an important role in maintaining the economic stability of the system, and has the characteristics of high efficiency, low cost, fast response, good environmental benefits and so on. Demand side resource is an important part of electricity market. The research of demand side resources in our country is still in the initial stage, but the opening of the electricity sales side provides a broad prospect for the development of electricity market. This paper summarizes the main types of demand side resources in our country, analyzes the economic principle of demand response from the micro perspective, puts forward some suggestions on the operation mechanism of China's demand side resources participating in the electricity market under the condition of electricity sales side opening, analyzes the current situation of pricing in the electricity wholesale market and sets up the pricing strategy of the centralized wholesale market with the demand side power supply participating in quotation, which makes the social and economic benefits reach the maximum.

1 Introduction

Demand response broadly refers to introducing competition in the electricity sales segment of electricity market. In the general commodity market, the commodity buyer chooses the manufacturer (Supplier) to participate directly in the market pricing, promoting the price and quality competition among the producers. Because of the characteristics of the production, transmission and use of electric energy, it is almost impossible for power users to select power plants to participate in market pricing in the case of centralized wholesale market. This determines the particularity of the electricity wholesale market pricing. The research on power demand side resources has been carried out in China for many years, and the research focus is what the influence on the optimal operation of power system it may have. But the actual application of demand side response is still confined to the projects of orderly use of electricity, peak valley TOU price and step price, the reform of the electricity market and the opening of the electricity sales side provide a new opportunity and a broad prospect for the development of the demand side resources in our country.

This paper introduces several main demand side resources, analyzes the current situation of the wholesale electricity market pricing, and the pricing strategy of the centralized wholesale market with the demand side power supply participating in quotation is proposed. It provides a new reference for the demand side to participate in the electricity market bidding in the background of electricity market reform.
2 Introduction of Main Demand Side Resources

Demand side resources are mainly divided into two categories: one is reduced load resources; the other is transferable load resources. Through the price signal and incentive mechanism, the demand side resources can play a role in supporting the supply and demand balance of system. First, for the reduced load resources, the demand response can reduce the total power demand to achieve saving electricity. Second, for the transferable load resources, system can transfer a part of the electricity load from short supply period to oversupply period.

2.1 Reduced load resources

The reduced load resources mainly means that the demand side resources can play a certain role in supporting the supply and demand balance of system through price signals and incentive mechanism. Such as through setting the peak valley price, according to the time distribution and operation cost of peaks and troughs of system, carry out different electricity prices on different time of user's electricity, guide the user in the peak period to reduce electricity consumption and encourage them to increase electricity during the trough through the price effect. For the large users which short-term power outages do not affect the normal work, such as large cold storage and so on, the implementation of peak averting power measures is used to reduce the power demands of the system peak time or the system failure time.

2.2 Transferable load resources

The transferable load resource refers to the system can transfer part of the electricity load in short supply period to the supply exceeding demand period. The electrification of cars means the shift of the vehicle's power source and the transfer of the entire energy transfer process, which is from the dependence on traditional fossil fuels to the demand for electricity. Electric energy expands the choice range of the initial energy source of electric vehicles and gets rid of the unfavorable situation of traditional internal combustion car dependent on crude oil as secondary energy. According to the estimation of vehicle every day about 80% more time is in a quiescent state, so we can assume that use electricity of electric cars in the power grid load tension to meet the power demand and feed electricity to electric cars to reach the role of “peak clipping and valley filling” in power grid load while in power grid trough. The biggest difference between ordinary electric cars and electric load characteristics is its flexible and reverse power characteristics, which determines that the demand side management of net in electric vehicle is different from the traditional demand side management method.

2.3 Economic principles of demand response

Figure 1 gives a schematic diagram of the economic using the theory of supply and demand in microeconomics to analyze demand response. In the figure, P axis represents price, Q axis represents demand. Suppose the supply curve of normal operation in power market is S1, if the market does not introduce competition in the electricity sales segment, then the demand curve D1 in the market is approximately perpendicular to the Q axis, the supply and demand curves intersect at point C, at this time, if the supplier exercises market power to make the supply curve be S2, it will cause the market price spikes P1+ ΔP, but due to lack of demand elasticity, the demand is reduced from Q3 to Q2, almost unchanged. The D2 curve in Figure 1 represents the demand curve after the introduction of demand response through market adjustment, at this time, quantity demanded reduce P1+ΔP, and the price spike also greatly reduce the T, in Figure 1, the area of triangle ABC represents the net income which is caused by introducing demand response in electricity market.
3 Bilateral Mutual Pricing of Forward Wholesale Market

3.1 Centralized wholesale market pricing without demand side bidding
Forward wholesale market refers that electricity purchasing party puts forward the established total amount of wholesale electricity of some day in the future and auction to the power producers through the power load forecasting. It can be divided into two kinds of different auction behavior: demand side without quotation and demand side declared price.

According to the game theory of micro economics, each power producer in order to meet the needs of society and the production of electricity, at the same time, it also will pursue the maximum profit, so it is always trying to raise the price and get more profits in the market competition. However, the expectation will be affected by other power producers and electricity purchasing party, because the demand of electricity purchasing party is constant and it seeks to make the minimum purchase cost. The market electrovalence is determined by the market behavior of electricity purchasing party and each power plant (unit). Assume that the total demand power in a certain period of time of someday in the future (length usually is half an hour or an hour) is $S$, unit time generation power of $n$ internet power plants (unit) are $W_1, \ldots, W_i, \ldots, W_n$ respectively. Power plant cost curves are $C_1(W_1), \ldots, C_i(W_i), \ldots, C_n(W_n)$, respectively, then the total power $S=W_1+\cdots+W_i+\cdots+W_n=\sum_{i=1}^{n}W_i$, market price $P(s)=P(\sum_{i=1}^{n}W_i)$. For a single power plant (unit), the profit maximization problem can be expressed as

$$\max \pi_i(S,W_i) = P(s)\cdot W_i - C_i(W_i) \quad (1)$$

The maximum condition of power generation is

$$P(s)[1+\frac{\alpha_i}{\varepsilon}] = C'(W_i) \quad (2)$$

In formula, $\varepsilon = P(s) / P'(s) \cdot s$ is the price elasticity of total electricity demand, it represents the demand side to participate in the wholesale market price; $P'(s)$ is the marginal price of the system; $\alpha_i$ is the share of total demand in the first ith power plants. The formula (2) shows that the profit maximization of each power plant is restricted by the market price and the demand side which responses to electricity price. At the same time, its quoted price also affects the entire market price.

The condition of profit maximization which meets $n$ power plants (unit) is

$$nP(s) + P'(s) \cdot s = \sum_{i=1}^{n} C_i(W_i) \quad (3)$$
Unified wholesale electricity price is calculated according to the following formula

$$P(s)[1 + \frac{\alpha_s}{\varepsilon}] = \frac{1}{n} \sum_{i=1}^{n} C(W_i)$$

(4)

That is, the wholesale price of electricity market is determined by the average marginal cost of each power plant and the price elasticity of the demand side. In the competitive market, the power plant will not give the power generation cost function curve, but it can only profit based on the marginal cost or the quoted price of the total cost plus the appropriate profit. Therefore, the market price can be calculated according to the following formula

$$P(s)[1 + \frac{1}{\varepsilon n}] = \frac{1}{n} \sum_{i=1}^{n} P_{bi}$$

(5)

In the formula, $P_{bi}$ is the quoted price of the first i power plant (unit).

3.2 Price elasticity of power demand

The price elasticity of electricity demand is the response of the total demand side to the market price in the system, which represents the adjustment of electricity purchasing party to the power plant (unit) quotation. It is defined as

$$\varepsilon = \frac{\Delta S / S}{\Delta P / P}$$

(6)

In the formula, $\Delta S$ is the increment of system electrical quantity; $\Delta P$ is the increment of system electricity price. The differential form of $\varepsilon$ here is $\varepsilon = P(s) / P'(s) \cdot s$ in the formula (2).

The electricity user's response to the market price is lagging behind when the electricity price information is not smooth. In recent years, the emergence of reasonable industrial users who are inefficient and use more electricity is the performance of encouraging user to use electricity at low price that leads to the price elasticity of electricity demand lagging. If the elasticity of electricity demand is low, the electricity market will have two undesirable consequences, that is: the market price spikes can be seen in many electric power markets; power producers use market control force to raise wholesale electricity price. In the electricity market, $\varepsilon$ is negative value, $|\varepsilon|$ can be chosen between 0.5 and 5.

Choose the smaller $|\varepsilon|$ value in peak load to reduce the risk of generating electricity and promote users off-peak power consumption; choose the larger $|\varepsilon|$ value in the trough to encourage users to use electricity at low ebb so as to improve the utilization rate of power generation.

3.3 Centralized wholesale market pricing of demand side supply electricity quotation

The power supply company puts forward the local load of a certain period of time in the future and the corresponding expected price. Power Grid Corp collect the load of the power supply companies to form a total market demand, and purchase electricity from power plants (units) uniformly, which is called centralized wholesale market of demand side supply electricity quotation.

(1) Expected market power price on demand side

The user uses electrical energy to produce some economic benefits, and strive to maximize economic benefits.

Assume that m power supply companies declare the power of a period of time are $S_j, \ldots, S_j, \ldots, S_m$, the electricity benefit of corresponding regional are $u(S_j), \ldots, u(S_j), \ldots, u(S_m)$, then $S = \sum_{j=1}^{m} S_j$, expected market price on demand side is

$$P(s) = P(\sum_{j=1}^{m} S_j)$$
The problem of maximizing the electricity consumption benefit in the whole electricity market can be expressed as:

$$\max \pi(S, P) = \sum_{j=1}^{m} u(S_j) - \sum_{j=1}^{m} P(s)S_j$$ \hfill (7)

The condition of maximizing the power consumption in the whole electricity market is

$$mP(s) + P'(s) \cdot S = \sum_{i=1}^{m} u'(S_j)$$ \hfill (8)

In the formula, \(u'(S_j)\) is the marginal benefit of electricity consumption in the first \(j\) power supply area.

The expected market power price of the whole market demand side is calculated according to the following formula

$$P(s)[1 + \frac{1}{\varepsilon m}] = \frac{1}{m} \sum_{i=1}^{m} u'(S_j)$$ \hfill (9)

The market mechanism will promote the power supply enterprises to declare the expected price \(P_{dj}\) based on marginal benefit. Then the expected market power price \(P_d(s)\) on the demand side can be rewritten as

$$P_d(s)[1 + \frac{1}{\varepsilon m}] = \frac{1}{m} \sum_{i=1}^{m} P_{dj}$$ \hfill (10)

(2) Negotiated pricing in wholesale market

According to formula (5) and formula (10), the expected price of generation side and demand side in electricity market can be calculated respectively. In general, the expected power price of electricity generation side and the demand side of the expected market price is inconsistent. According to the principle of competition in the commodity market, the price can be negotiated by the two sides agreed when the bidding price and tender price are inconsistent. The same price is called the negotiated price. Based on the characteristics of the electricity market, the wholesale market price can be determined according to the following formula

$$P_s(s) = \frac{[P_g(s) + P_d(s)]}{2}$$ \hfill (11)

The most effective electricity price is the market price that is obtained from the sum of the marginal cost of the generating side equaling the sum of marginal benefit of demand side. This price will produce the greatest social and economic benefits.

4 Conclusion and Suggestion

Demand side participating in the pricing of the two-sided market has the following characteristics:
(1) The forward wholesale market adopts the two-sided interactive pricing method to determine the market power price, demand side can use demand price elasticity or expected power price on demand side to participate in market power price adjustment effectively.
(2) Real time market uses the weighted average method of electricity quotation and the market price is determined by the common market behavior of each power plant (unit) to promote the competition of power generation side more effective.
(3) Both bilateral interactive pricing method and weighted balance method of electricity quotation can be used in the electricity market and ancillary services market.

Based on the analysis of the experience of our country’s electricity market and the central wholesale market design, this paper presents the “demand side participating in the wholesale market power price mechanism” is a more effective centralized wholesale market power price mechanism, which can avoid the market problem caused by unilateral pricing methods such as system marginal price and so on. It is suggested that the bilateral wholesale market model of demand side participating in pricing should be adopted in our country’s regional electricity wholesale market.
Acknowledgement
This work is supported by science and technology project of Guangxi Power Grid Co., Ltd (GKKJXM20151002).

References
[1] Zhou Ming. Study on some problems of power demand side market operation [D]. North China Electric Power University (Hebei), 2006.
[2] Zhu Jingchun. Research and application of competitive electricity market based on demand side participation [D]. North China Electric Power University (Beijing), North China Electric Power University, 2011.
[3] Wang Yuliang, Study on Day-ahead Market Trade Considering Demand-Side Bidding [D]. Beijing Jiaotong University, 2009.
[4] Li Haiying. Model and algorithm of demand side participation in transmission congestion management [D]. Shanghai Univer, 2007.