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A day-ahead power spot market clearing model considering incentive-based demand response

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A day-ahead power spot market clearing model considering incentive-based demand response

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Abstract. It is a gradual evolution path and the most common practice in the initial stage of power spot market construction in China to start with bidding without price on the demand side, which lead to a question of how to solve the demand respond (DR) in day-ahead power spot market. To this end, a day-ahead power market clearing model considering incentive-based demand response (IBDR) is proposed. The IBDR is mainly aimed at large users with certain load elasticity, which can adjust their production schedules and change their electricity load curve to obtain certain cost incentives. This clearing method can optimize the spot market clearing result to maximize the social benefit by coordinating the electricity purchase cost and DR incentive cost. In this process, large users can obtain certain economic compensation by providing DR and help the dispatching mechanism to solve the operation problems such as power grid congestion, which could improve the operation efficiency of thermal power units. Finally, a case study based on the IEEE-30 buses system is used to verify the effectiveness of the proposed method.

1. Introduction

With the deepening of power market reform in China, power spot market has become an important part of power market construction. At present, the first pilot batches including Shandong province have entered the trial operation stage successively and will turn into the official operation stage soon. According to the mechanism design of each pilot region, the transaction mode with bidding without price on the demand side has become a common mechanism design pattern of power spot market in China. The main reason is that users' awareness and ability to participate in power market transactions still need to be cultivated at the initial stage of power spot market construction [1-2]. In such an environment, it has become an important issue of power spot market mechanism design how to consider demand response to enable users to participate in power spot market transactions more fully.

A demand response method for power spot market in bidding mode without price on user side is proposed in ref. [3]. This method expects to motivate users to adjust their power consumption behavior by releasing the day-ahead nodal marginal price, which essentially belongs to the category of price-based demand response. A virtual power plant operation mechanism considering demand response is proposed in ref. [4], which can realize the interaction and cooperation between power users and large power grid based on the optimization control inside virtual power plant. The long-term revenue of e-commerce sellers is taken into account to formulate the demand response strategy, which could ensure that e-commerce sellers can obtain long-term and stable revenue in the spot power market [5].

It could be seen that current studies tend to focus on the price-based demand response, in which it is assumed that power users will change their electricity consumption behavior after receiving the power price signal which means that they will participate in demand response initiatively. However, the above research ideas have the following problems in the initial stage of power spot market construction [6-7]: (1) demand response is seldom applied in practice in China which causes the response characteristics of power consumer electricity price are lack of reliable data support; (2) The efficient and smooth information transfer mechanism has not been established which is crucial for the price-based demand respond; (3) the benefits of power consumers participating in demand response are not direct enough, especially in the current power spot market, as the node marginal price mode is not adopted in demand side, resulting in their participation motivation is difficult to evaluate.
To this end, this paper will propose a power spot market clearing model considering the incentive-based demand response. Firstly, the basic concept of incentive-based demand response is introduced and the market potential of incentive-based demand response is illustrated based on the reality of Shandong province. On this basis, a day-ahead clearing model considering incentive-based demand response is proposed for the power spot market. Finally, a case study based on an IEEE-30 buses system is used to verify the effectiveness of the proposed method.

2. Basic concepts and market potential of IBDR

2.1. Basic concept

The energy department of the United States defines demand response as a change in the pattern of electricity consumption by the user in response to a real-time change of electricity price, or a change in the form of electricity consumption by the user in response to an economic incentive for high electricity prices or a threat to system reliability. As shown in figure 1, the federal energy regulatory commission divides demand response into two categories: price-based demand response and incentive-based demand response [8-9]. Among them, incentive-based demand response refers to the user's behavior of adjusting its production schedule to change the power consumption curve according to the market transaction result or scheduling instructions. Meanwhile, users who provide incentive-based demand responses would receive direct economic compensation or discounts on electricity power costs. From the perspective of market operation, the main difference between the two types of demand responses is that price-based demand response relies on the user-initiated price response mechanism and is not mandatory. However, if electricity user fails to provide the relevant demand response, it would be punished according to their incentive-based demand response contract. Therefore, incentive-based demand response is mandatory to some extent.
According to the fact that power market operation agency can control user's electrical equipment directly, IBDR can be further divided into the scheduled type and the market one. Centrally controlled air-conditioning equipment is the representative of scheduled IBDR. Power dispatch agency can adjust the operation state of air-conditioning equipment directly to provide emergency load support and other services for power grid operation. As for the market IBDR, users would change their production schedules according to the market clearing results to provide a power consumption curve which meets the market clearing result. The scheduled IBDR has a high technical requirement for real-time operation control, while the market one has a relatively low technical requirement, which is more suitable for the demand side to participate in the initial stage of power spot market in China. The market IBDR is also the focus of this paper.

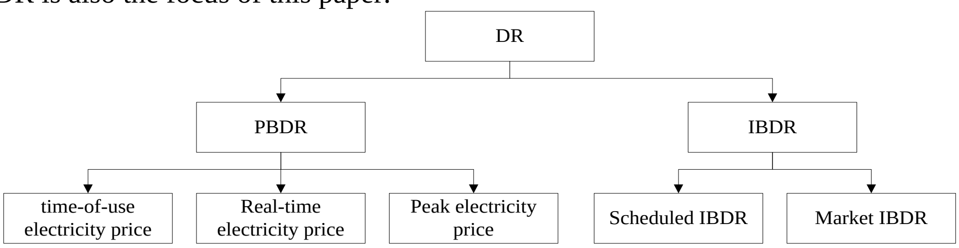

Figure 1. A classification for DR.

2.2. Market potential

Power spot market is an important market mechanism to promote the development of demand side response, energy storage and other new forms of energy. Considering that power spot market in China is still in the initial construction stage, IBDR should meet the following basic conditions when participating in the spot power market:

(1) a certain load elasticity, which means users can adjust their electricity load. This is also the basic condition for power users to participate in power spot market as a DR provider;

(2) a certain electricity consumption scale, which requires that their electricity consumption, electricity load or other indicators must meet a certain access condition, which is determined by the initial market construction technical conditions;

(3) electricity consumption historical data to avoid the impact of virtual bidding on the normal operation of the initial power market.

As one of the first pilot batch areas of power spot market in China, Shandong province has taken the lead in considering the problem of stimulating DR to participate in power spot market.

According to statistics, more than 30% of the current market users meet the above conditions which are concentrated in chemical industry, building materials and other related industries.

2.3. Model formula

In order to regulate the behavior of DR in power spot market, the IBDR model proposed in this paper includes two key point, namely load curve and cost compensation.

(1) load curve

In this model, power users need to declare their load curve after participating in DR. Figure 3 shows the normal load curve and the DR load curve of a chemical enterprise in Shandong power grid. The basic load curve is the normal load curve when power user does not participate in power spot market DR transaction. The DR load curve is declared by power user when participating in the DR transaction according to the DR transaction information. The user's normal production period is from 8:30 to 20:30 in a day. In order to reduce the power load in the daytime, it adjusts its production time into two parts, including 6:00 to 10:00 and 16:00 to 22:00.

It is specified that $d_{dr,t}^{1}$ represents the normal power load of DR user dr at the time period t; $d_{dr,t}^{2}$ represents the declared power load of DR user dr at the same time. A state variable u_{dr} is used to represent the DR clearing result. It indicates that it would not provide DR service when u_{dr} is equal to “0”, while providing DR service when u_{dr} is equal to “1”.

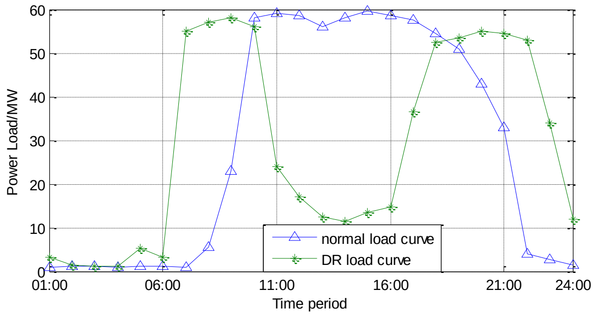

Figure 2. DR load curve.

(2) cost compensation

It is stipulated that the call order of IBDR is determined according to the declaration price, and the declaration price of large users is specified as F_{dr} .

3. Day-ahead clearing model

Clearing model is the core technology of IBDR participating in power spot market. In this paper, the objectives and constraints of model optimization will be introduced.

3.1. Objective

The traditional power spot market clearing model focuses on the coal-fired units cost, including their operation cost and start-stop cost. When IBDR participates in power market transactions, the optimization objective should also take their invocation compensation costs into consideration. The optimization objective can be expressed as:

$$\min_{u,uu,p} \quad C = \sum_{g=1}^{N_G}\sum_{t=1}^{T}[u_{g,t}F(p_{g,t}) + uu_{g,t}^{1}F_g] + \sum_{dr=1}^{N_{DR}} u_{dr}F_{dr} \tag{1}$$

where C is the total cost of power spot market considering IBDR. N_G , T and N_{DR} respectively devotes to the number of coal-fired units, the optimization period number in a single day and the IBDR users' number which declared to participate in the power spot market transaction. $u_{g,t}$ and $uu_{g,t}^{1}$ respectively represent the operation state variables and starting state variables of coal-fired unit g at the time period t . $p_{g,t}$ and F_g are respectively the active generation power at the time period t and the start-up cost of coal-fired unit g . $F(\square)$ is the operation cost function of coal-fired unit.

3.2. Operation constraint
The constraint conditions to be considered include power balance constraint, operation reserve constraint, operation section constraint and unit operation constraint.
(1) power balance constraint
The constraint requires that the power balance condition must be satisfied at any time, which can be expressed as:

$$\sum_{g=1}^{N_G} p_{g,t} = \sum_{b=1}^{N_B} d_{b,t} + \sum_{dr=1}^{N_{DR}}[(1-u_{dr})d_{dr,t}^{1} + u_{dr}d_{dr,t}^{2}] \tag{2}$$

where N_B represent the bus number in the power grid and $d_{b,t}$ devotes to the power load of bus b at the time period t , which does not contain power load of IBDR users.
(2) operation reserve constraint
This constraint requires that the maximum generation capacity should meet the system operation reserve requirements, which could be expressed as:

$$\sum_{g=1}^{N_G} u_{g,t}p_g^{up} \geq (1+r)D_t \tag{3}$$

where p_g^{up} is the maximum generation capacity of coal-fired unit g . r represents the operation reserve rate of power system. D_t is the total power load at the time period t , which could be expressed as:

$$D_t = \sum_{b=1}^{N_B} d_{b,t} + \sum_{dr=1}^{N_{DR}}[(1-u_{dr})d_{dr,t}^{1} + u_{dr}d_{dr,t}^{2}] \tag{4}$$

(3) operation section constraint
This constraint requires that the operation section power flow should be within its limitation at any time, which can be expressed as:

$$-F_l \leq \sum_{g=1}^{N_G} T_{l,g}p_{g,t} - \sum_{b=1}^{N_B} T_{l,b}d_{b,t} - \sum_{dr=1}^{N_{DR}} T_{l,dr}[(1-u_{dr})d_{dr,t}^{1} + u_{dr}d_{dr,t}^{2}] \leq F_l \tag{5}$$

where F_l and $-F_l$ respectively represents the maximum and minimum permissible limitation of operation section l . $T_{l,g}$, $T_{l,b}$ and $T_{l,dr}$ respectively represents the power transfer distribution factor between power flow of operation section l and the power generation or power load of coal-fired unit g , bus b and IBDR dr .
(4) unit operation constraint
The constraints include output range constraints, climbing capacity constraints and start-stop state constraints, which could be expressed as:

$$u_{g,t}p_g^{down} \leq p_{g,t} \leq u_{g,t}p_g^{up} \tag{6}$$

$$p_{g,t} - p_{g,t-1} \le R_g^{up} u_{g,t-1} \tag{7}$$

$$p_{g,t-1} - p_{g,t} \le R_g^{down} u_{g,t} \tag{8}$$

$$u_{g,\tau} \ge u_{g,t} - u_{g,t-1} \qquad \forall t \le \tau \le \min(T, t + T_g^{on} - 1) \tag{9}$$

$$u_{g,\tau} \ge 1 - (u_{g,t-1} - u_{g,t}) \qquad \forall t \le \tau \le \min(T, t + T_g^{off} - 1) \tag{10}$$

$$uu_{g,t}^1 - uu_{g,t}^2 = u_{g,t} - u_{g,t-1} \tag{11}$$

where p_g^{up} and p_g^{down} respectively represents the maximum and minimum generation capacity of coal-fired unit g . R_g^{up} and R_g^{down} respectively represents the maximum and minimum generation climbing capacity of coal-fired unit g . T_g^{on} and T_g^{off} respectively represents the minimum operation time and off-operation time of coal-fired unit g . $uu_{g,t}^2$ is stopping state variables of coal-fired unit g at the time period t .

4. Case study

4.1. Basic data

In order to verify the effectiveness of the proposed method, a case study is constructed based on IEEE-30 buses system. The IEEE-30 buses system is shown in figure 3.

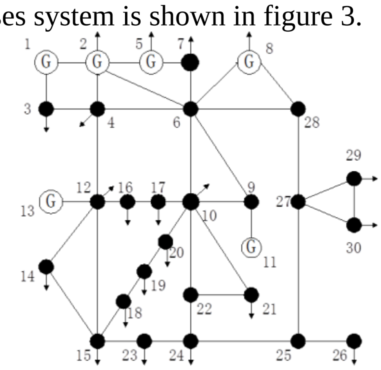

Figure 3. IEEE-30 buses system.

In this case, the declared prices of six generation units are as shown in figure 4. Coal-fired units are declared in three-paragraph form. The maximum declared price is 3 \$/MWh, which is declared by G11, while the minimum declared price is 3 \$/MWh, which are declared by G1, G2 and G5.

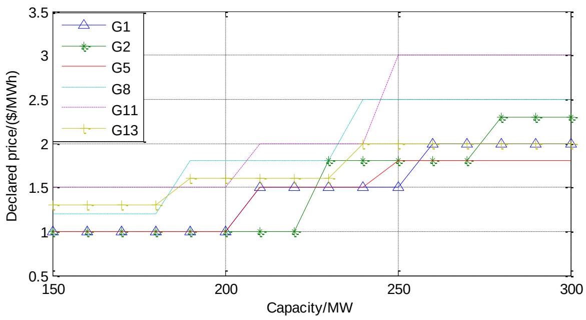

Figure 4. Declared prices.

4.2. Result analysis

The demand-side response user described in figure 2 is introduced to the location of bus 7 in the system. If the declared price is changed, the variation characteristics between the system operation cost and the declared price are shown in figure 5.

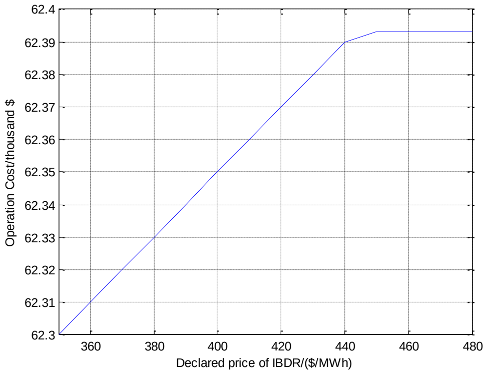

Figure 5. Operation cost change.

When the declared price of IBDR is lower than 446$, IBDR would be selected by the power spot market clearing result. The compensation cost of IBDR is lower than the operation cost of high-priced units. In this process, the system operation cost increases linearly with the declared price of IBDR. However, when demand-side response costs increase further, high-priced coal-fired units are chosen by the clearing model, while IBDR would be abandoned. This result indicates that the proposed method can consider the economy between IBDR and the coal-fired units and provide the optimal operation result for power spot market clearing.

5. Conclusion

In this paper, a day-ahead clearing model of power spot market is proposed, which takes IBDR into account. This model fully considers the ability of market members to participate in market transactions at the initial stage of power spot market construction. The clearing model can give the optimal result of the system operation considering the demand side response cost and can improve the system operation benefit.

6. References

[1] ZHANG Kun, LIU Yingshang, PENG Chaoyi, ZHOU Huafeng, GU Huijie, HU Rong, LIU Kai and LIUQixing 2019 *Southern Power System Technology* Technical Support System for Southern Regional Electricity Spot Market: Market Clearing Module **13** 59-66

[2] MA Hui, CHEN Yuguo, CHEN Ye, et al 2018 *Southern Power System Technology* Mechanism Design of Southern China (Starting from Guangdong Province) Electric Spot Market **12** 42-48

[3] CHEN Yuguo, ZHANG Xuan, LUO Gang, et al 2019 *Automation of Electric Power Systems* Demand Response Mechanism and Approach of Electricity Spot Market in Bidding Mode without Price on User Side **43** 179-186

[4] XU Feng, HE Guangjun, LI Jianbiao, et al 2019 *Power Demand Side Management* Review of research on commercial mechanism for virtual power plant considering demand response **21** 2-6

[5] FENG Xiaofeng, XIE Tiankuo, GAO Ciwei, et al 2019 *Power System Technology* A Demand SideResponse Strategy Considering Long-term Revenue of Electricity Retailer in Electricity Spot Market **43** 2761-2769

[6] HE Dewei, YANG Wei, CHEN Haoyong, et al 2018 *Smart Power* Discussion on Demand Response Under Electricity Market Environment **46** 41-48

[7] DING Yi, HUI Hongxun, LIN Zhenzhi, et al 2017 *Automation of Electric Power Systems* Design ofBusiness Model and Market Framework Oriented to Active Demand Response of Power Demand Side **41** 2-9

[8] WEN Fushuan, LIN Hongji and HU Jiahua 2019 *Power Demand Side Management* A preliminary investigation on commercial mechanism and market framework for demand response **21** 4-9

[9] YANG Xuying, ZHOU Ming and LI Gengyin 2016 *Power System Technology* Survey on Demand Response Mechanism and Modeling in Smart Grid **40** 220-226