Optimization of Bidding Mode for Capacity Market Considering The Participation of New Energy

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Abstract

One of the construction purposes of the capacity market is to solve the problem of fixed cost recovery of power sources in the pure energy market based on variable cost bidding. With the continuous deepening of the construction of new power systems, more new energy entities will participate in providing capacity resources. If the capacity market lacks consideration for the differences in power cost structure, it will be difficult to meet the different cost recovery demands of various power sources, which will affect the accurate generation of investment incentive signals. This article analyzes the capacity market construction problem under the current differentiated power supply cost structure, proposes a capacity market mechanism design scheme for differentiated power supply cost structure, and verifies it through numerical examples.

Keywords

New Energy, Capacity Market, Bidding Mode, Power Cost.

1. Qualitative Analysis of Capacity Market Issues under Differentiated Power Supply Cost Structure

The capacity market incentivizes power investment by providing capacity compensation for capacity resources, especially flexible power sources such as thermal power, to ensure system adequacy and flexibility in the energy transition process. However, there is a phenomenon of new energy "hitchhiking" in the current capacity market mechanism, which may cause new energy to obtain excess profits through the capacity market, further squeezing the profit space of flexible power sources and violating the original intention of capacity market construction[1]. The phenomenon of new energy "hitchhiking" in the capacity market is described in detail as follows.

When both new energy and conventional fossil energy participate in the electricity spot market, based on the node electricity price theory, after sorting in order of price from low to high, the last thermal power unit that meets the power supply requirements will usually be regarded as the marginal unit, and its marginal cost is set as the market clearing price (as shown in Figure 1). In this situation, new energy has a high profit margin due to its low power generation cost. In addition, new energy can receive additional subsidies in green certificate trading. Therefore, the power generation benefits of new energy can almost cover all costs or exceed costs.

In the capacity market, capacity resources are quoted based on the cost shortfall, that is, the unrecovered costs are reported. For new energy, although the investment cost is higher than conventional fossil fuels, it can be declared at a lower price in the capacity market due to its high profit potential in the spot market[2]. According to the principle of supply and demand matching, usually high priced units (such as gas) become marginal units, and their capacity quotation is set at the market clearing price (as shown in Figure 2). Therefore, the demand for cost recovery in the capacity market for new energy is not high, but it obtains excess profits through "hitchhiking", resulting in excessive compensation costs in the capacity market[3]. And due to excessive subsidies for new energy, it is not conducive to guiding the smooth transformation of the power structure, which affects the real utility of the capacity market. Although there are actual markets that have reduced the revenue space of new energy by calculating equivalent reliable capacity, it is still impossible to avoid new energy units that have already achieved profitability in the electricity market from obtaining additional capacity revenue in the capacity market[4]. Moreover, it is difficult to provide accurate and effective price signals for two types of goods with significant cost structure differences through a single bidding platform.

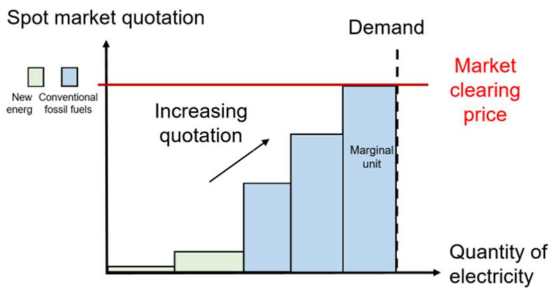

Figure 1. Schematic diagram of the formation mechanism of clearing electricity prices in the spot electricity market

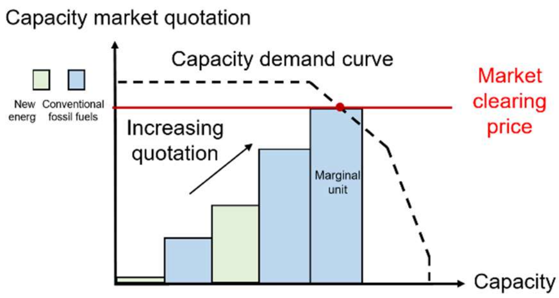

Figure 2. Schematic diagram of the formation mechanism of clearing electricity prices in the capacity market

2. Quantitative Analysis of Capacity Market Issues under Differentiated Power Supply Cost Structure

To further demonstrate the existence of "hitchhiking" phenomenon in the capacity market, a simple mathematical model of the current market was established based on reasonable assumptions and derived for analysis. Assuming there are two types of power sources in the system: new energy sources such as wind power and flexible power sources such as thermal power.The annualized fixed costs per unit capacity for new energy and flexible power sources are I_r and I_f , the ratio is K , The marginal generation costs are M_r and M_f 。 We will now analyze the revenue and expenditure situation of a new energy unit G_r with capacity Q_r and a flexible power unit G_f with capacity Q_f in the system.Among them, assuming the hourly output of the new energy unit is χQ_r , the capacity credibility in the corresponding capacity market is set as χ 。 It should be noted that when assuming that the output of new energy remains consistent, the setting of capacity credibility can be considered accurate, and this study is mainly based on the analysis of the overall returns of power sources in the energy market and capacity market. The volatility of new energy output has little impact on the analysis of the results, and this assumption is reasonable.

In the energy market, assuming the probability of clearing units with new energy as the marginal source throughout the year is p_r, the corresponding clearance price is M_r, at this point, G_r cleared, while G_f failed to clear,the probability of clearing a unit with flexible power supply as the margin is $p_f = 1 - p_r$, the corresponding clearance price is M_f M_f, at this point, both units have achieved clearance.Assuming that both units are cleared according to the reported electricity consumption, i.e. assuming that both units are cleared as non marginal units. Although this assumption cannot cover all situations in the market, it can represent a common scenario that may occur in the actual market.The annual total cost and energy market annual total revenue of Units G_r and G_f are:

$$CT_r = CF_r + CV_r = I_r Q_r + 8760 M_r \chi Q_r$$
$$RE_r = 8760 M_r p_r \chi Q_r + 8760 M_f p_f \chi Q_r$$
$$CT_f = CF_f + CV_f = I_f Q_f + 8760 M_f p_f Q_f$$
$$RE_f = 8760 M_f p_f Q_f$$

In the formula: CT_r and CT_f are the annual total costs of G_r and G_f respectively; CF_r and CF_f is the annual fixed cost of G_r and G_f respectively; CV_r and CV_f are the annual variable costs of G_r and G_f; RE_r and RE_f are the annual energy market returns of G_r and G_f.

If the fixed/variable cost ratios of units G_r and G_f are defined as a_r and a_f, respectively, then:

$$a_r = \frac{CF_r}{CV_r} = \frac{I_r}{8760 M_r \chi}$$
$$a_f = \frac{CF_f}{CV_f} = \frac{I_f}{8760 M_f p_f}$$

In the capacity market, if the unit reports costs that have not been recovered in the energy market, the capacity quotes for G_r and G_f units of capacity are:

$$b_r^C = \frac{CT_r - RE_r}{Q_r} = I_r + 8760 \chi \left[(1 - p_r) M_r - p_f M_f \right]$$
$$b_f^C = \frac{CT_f - RE_f}{Q_f} = I_f$$

When the capacity market fully compensates for the cost of flexible power unit G_f ,the capacity market clearing price is G_f , and the capacity quotation is b_f^C ,The yield of G_f is 1, which happens to achieve breakeven.At this time, the capacity market revenue RC_r and yield η of the corresponding new energy unit A G_r are:

$$RC_r = b_f^C \chi Q_r$$
$$\eta = \frac{RE_r + RC_r}{CT_r}$$

The yield of new energy unit G_r can be obtained as follows:

$$\eta = \frac{K\frac{p_r}{a_r} + \chi(1+\frac{1}{a_f})}{K(1+\frac{1}{a_r})}$$

From the above equation, it can be seen that the relationship between the yield η of unit G_r and the cost structure of the power source(K , a_r , a_f),the credibility of new energy capacity (χ) and the clearing situation of the energy market (p_r) are related.

If the capacity market wants to provide reasonable capacity compensation for both new energy and flexible power sources,the η in the formula should be 1 or close to 1.In the formula, since the value of the credibility χ of new energy is calculated based on the effective capacity of new energy, it cannot be guaranteed that η is 1 or close to 1.This indicates that in the current capacity market of a single bidding platform, even if differentiated settings are made for different power sources by considering the conversion of new energy capacity, it cannot guarantee to simultaneously meet the differentiated capacity compensation needs of various power sources.In fact, the value of η may be greater or less than 1, mainly related to the system load situation.If there is a significant difference between η and 1, it indicates the existence of new energy or flexible power sources,at this point, the capacity market may not compensate adequately for certain types of power supply capacity, or incur higher costs to achieve full cost recovery for all power supplies.

If the value is based on the current system experience, K is taken as 1.5, χ is taken as 0.45, a_r is taken as 3, a_f is taken as 0.25, p_r is taken as 0.65(The corresponding flexible power utilization hours are 3942h),calculated $\eta = 1.2875$. That is to say, when the flexible power source is just balanced in revenue and expenditure, new energy has achieved a net profit of 28.75%. This indicates that there is a phenomenon of new energy "hitchhiking" in the current market environment, and it is necessary to propose strategies to improve the capacity market mechanism.

3. Layered Capacity Market Model for Differentiated Power Supply Cost Structure

Considering that a single bidding platform is difficult to coordinate the differences between two types of power sources, and with the construction of new power systems, the participation of new energy in the capacity market will gradually develop to be consistent with that of flexible power sources[5]. Therefore, this study proposes a capacity market construction concept for new energy and flexible power source sub platform bidding. At the same time, in order to meet the differentiated capacity compensation needs of new energy and flexible power sources, and generate effective differentiated investment incentive signals, effective market parameter coordination is needed[6].

A capacity market framework based on platform bidding has been proposed in the organizational model of the capacity market. The capacity market for sub platform bidding includes two sub markets: the new energy capacity market and the flexible power capacity market. New energy sources such as wind power and photovoltaics are participating in the new energy capacity market, and credible capacity conversion is not currently considered; The flexible power capacity market currently only considers the participation of conventional energy sources such as coal and gas. After fully considering the characteristics of construction and operation costs, flexible resources such as hydropower and energy storage can be considered to participate in the same flexible power capacity market auction or establish a new bidding platform based on the difference between cost recovery demands and thermal power. Similarly, new energy capacity market bidding platforms can be further divided according to the type of new energy. The two capacity markets are organized by market operating institutions on an annual basis during the same period, and are auctioned according to the capacity demand targets of new energy and flexible power in a future target year. The bidding mechanism adopts a centralized bidding mode, and the settlement is uniformly paid by the market operation agency to the capacity resources for capacity fees, which are ultimately shared among end users.

In terms of market parameter coordination, the method of correcting capacity demand curve parameters based on mechanism utility feedback is applied. By setting appropriate values for capacity demand curve parameters, capacity investment that can meet the capacity needs of both new energy and flexible power sources without causing excessive investment waste is incentivized, achieving coordinated development of new energy and flexible power sources.

4. Case Study Analysis - Validation of Key Boundary Decision Method for Capacity Market Clearance Model

Verify the effectiveness of the key boundary decision-making method for the capacity market clearing model based on the coupling effect of capacity energy market proposed in this chapter on a provincial power system. Based on the 2023 power grid data of a certain province, establish a simplified system model for case analysis. The system considers four main types of power generation resources: coal, gas, wind power, and photovoltaics. The system situation is shown in Table 1. Typical units are used for various types of power sources, with 600MW typical coal-fired units used for coal and 130MW typical gas-fired units used for gas. The relevant technical and economic parameters are shown in Tables 2-4. Select one week each month as a typical scenario to obtain the load and electricity consumption situation, as well as the output of wind and solar power in each typical scenario.

Table 1. System situation

Project	MW
Total coal-fired capacity	65368
Total gas capacity	3560
Total wind power capacity	20095
Total photovoltaic capacity	33045
Annual maximum load	72800

Table 2. Basic Technical Parameters of Thermal Power Units

Unit type	Unit capacity (MW)	Maximum output(MW)	Minimum output(MW)	Climbing rate(MW/h)	Minimum start stop time(h)
Coal fired	600	600	288	180	8
Gas	130	130	97.5	130	8

Table 3. Basic Economic Parameters of Thermal Power Units

Unit type	Investment cost(yuan/kW)	Operation and maintenance cost(yuan/kW.y)	Power generation cost(yuan/MWh)	Start up cost(Ten thousand yuan/time)	Downtime cost(Ten thousand yuan/time)
Coal fired	4000	130	272.3~319.7	60	42
Gas	1270	160	332.1~397.9	14	9.8

Table 4. Basic Economic Parameters of New Energy Units

Unit type	investment cost(yuan/kW)	Operation and maintenance cost(yuan/kW.y)	Power generation cost(yuan/MWh)
Wind power	6000	32	110
Photovoltaics	3420	46	270

The simulation parameters of the system are set as follows:

Table 5. System Simulation Parameters

Parameters	Value taking
System capacity margin	15%
Annual load growth rate	5%
Simulation duration	15 years
The threshold for setting Δ Q	3% Q^{target}
Maximum allowable investment limit	15% system installed capacity

Simulation result analysis: The key boundaries in the capacity market clearing model are set as the benchmark price parameter and benchmark capacity parameter in the capacity demand curve. The iterative simulation results of the capacity demand curve parameters are shown in Figure 3.35. The figure shows the iterative process of the benchmark price parameter and the adjustment coefficient of the benchmark capacity parameter in the capacity demand curve. As the parameter feedback correction strategy proposed in this chapter assumes synchronous changes with the same strategy, it remains consistent with the changes. According to Figure 3.35, after five iterations, the parameter values that meet the convergence requirements are obtained. The difference between the installed capacity of the system under the influence of the capacity market and the capacity target is 1.78%, indicating that the expected investment incentive utility target has been achieved. The value of the adjustment coefficient for the final capacity demand curve is 0.8704, indicating that the benchmark price parameter and benchmark capacity parameter of the capacity demand curve should be 0.8704 times the initial state. This indicates that for the system, the actual investment incentive effect of the capacity demand curve parameters set based on the current planning method is too large. Although it ensures the system's adequacy, it may cause excess capacity compensation. The calculation results show that after the method proposed in this chapter, the key boundary parameter configuration of the capacity market that meets the mechanism utility goal can be obtained, avoiding excessive or insufficient investment incentive effects in the capacity market.

5. Conclusion

This study proposes the concept of capacity market construction for sub-platform bidding of new energy and flexible power sources.In order to meet the differentiated capacity compensation requirements of new energy and flexible power supplies, effective differentiated investment incentive signals are generated.From the results, the method of modifying the parameters of the capacity demand curve based on mechanism utility feedback is applied.By setting the appropriate capacity demand curve parameters, it is possible to stimulate capacity investment that can meet the respective capacity requirements of new energy and flexible power supplies without excessive waste of investment, and ultimately achieve the coordinated development of new energy and flexible power supplies.

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