The fifth anniversary of China's new electricity market reform: an overview and enlightenment of subsidy mechanism for high-cost units

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Abstract. With the continuous deepening of China's electricity market reform, the problem that units with different costs compete in the same plat has become increasingly prominent. In the transitional period of market reform without capacity market, it is urgent to design a reasonable and effective subsidy mechanism for high-cost units to ensure their survival. This paper first summarizes the common subsidy mechanisms in China, and then introduces the design of subsidy mechanism for high-cost unit participation in the market in Guangdong, Zhejiang and Yunnan provinces. Finally, comparing the advantages and disadvantages of the above three subsidy mechanisms, the design idea of participating in market competition for high-cost units is given.

1. Introduction

Under the background of power industry regulation, the unit income is mainly based on the benchmark grid price. The Chinese government has formulated an annual power generation plan for different units and has approved the corresponding electricity price. This mechanism has played a positive role in promoting investment in the generation and ensuring power supply, but it also has a serious negative effect: lack of competitiveness. After the marketization of electric power, different cost units should compete on the same platform in essence, so that low-cost units can be cleared first, so as to maximize social welfare. However, China is still in the primary stage of power market construction lacking of capacity incentive mechanism, where competition of units with different costs on the same platform will make it difficult for high-cost units to recover stranded costs. Therefore, in the transition period of power industry reform, it is urgent to design a reasonable subsidy mechanism for high-cost units to help them adapt to market competition and ensure the safe and stable operation of power system.

At present, scholars at home and abroad have conducted extensive research on subsidy mechanism, but they mainly focus on renewable energy[1-3] and distributed generation[4-5]. In addition, there are a few literatures on the subsidy of other types of generation[6].

Meanwhile, subsidies, as a financial method by the government, are widely applied in many countries, especially in developing countries. In the field of power generation, common subsidy mechanisms include feed-in tariff, premium system, renewable portfolio standard, contract for difference authorized by government, tax exemptions, carbon tax and carbon trading, etc. For example, the United States has adopted Favorable Tax Treatment to support some energy sources, including the...
Production Tax Credit for the wind energy and the Investment Tax Credit for the solar energy. Besides the UK introduced contract for difference authorized by government for renewable energy units to ensure that low-carbon power producers can obtain stable operating income encouraging the capital flow to low-carbon power sources. Ontario of Canada signed a Clean Energy Supply Contract (CES) with gas-fired units[7], implementing the estimated revenue method to ensure the income of gas-fired units and guide them to quote based on their marginal cost.

In fact, there are few researches on subsidies for high-cost units. This paper is divided into four parts. The first part is introduction and literature review. The second part summarizes the common subsidy mechanisms in China. The third part studies the subsidy mechanisms design of Guangdong, Zhejiang and Yunnan provinces for high-cost units to participate in the electricity market, analysing their advantages and disadvantages. The fourth part is our conclusion.

2. Overview

2.1. Types of subsidies
A subsidy can be defined as any form of preferred treatment granted to consumers or producers by a government, which mainly provided through direct or indirect support from the government[8]. Nowadays, many countries divide subsidy mechanism into four types: Direct and Indirect Transfer of Funds and Liabilities, Government Revenue Foregone, Provision of Goods or Services and Income or Price Support. Among them, the Direct and Indirect Transfer of Funds and Liabilities mainly include government loans and guarantees, while the Government Revenue Foregone refers to tax incentives and production tax credit. The Provision of Goods or Services includes facilities and technical assistance provided by government. And the Income or Price Support refers to feed-in tariffs and premiums etc.

According to different subsidy objects, subsidy types can be divided into R&D subsidy, investment subsidy, generation subsidy, consumption subsidy, decommissioning subsidy and throughout subsidy. The subsidy discussed in this paper is the generation subsidy in Income or Price Support.

2.2. Common subsidy mechanisms in China
In the process of China's power market reform, the following subsidies are generally adopted for high-cost units: Kilowatt-hour Subsidies, Contract for Difference Authorized by Government and Price Adjustment Subsidy.

Kilowatt-hour Subsidy (KS), one of the premium mechanism, is a method based on the actual generation amount. According to the comprehensive cost of high-cost units, the actual on grid electricity of is subsidized after deducting the base amount of electricity. The amount of subsidy is the same for each kilowatt-hour of the high-cost unit, so the more power generation, the more subsidy.

Contract for Difference Authorized by Government (CfD) is one of the long-middle term financial contract which is distributed to the high-cost units mandatorily. The amount of the contract is approved by the government. And the contract price is the on grid price determined by the government based on the long-term marginal cost of the unit.

Price Adjustment Subsidy (PAS) is applied in Yunnan Province to encourage thermal power units to actively participate in market-oriented transactions according to electricity demand. In this method, the settlement price of thermal power units is the sum of the market transaction price and their declared adjustment price.

3. Application of subsidy mechanisms in China

3.1. KS in Guangdong electricity market
As a economically developed province, Guangdong’s installed coal-fired units and gas-fired units are the two largest types of generator, whose capacity account for 49.1% and 18.3% respectively. In Guangdong, the operating income for the gas-fired units to recover stranded costs faces two challenges:
one is the high fuel cost[9]; the other is the low electricity price brought by market competition. Although gas-fired units as peak load units can enjoy a certain peak electricity price, due to the high fuel cost, short peak load time, insufficient operating hours and market price cap restrictions, its economic benefits can not reach the expected value. Therefore, Guangdong introduces KS to ensure the survival of gas-fired units.

3.1.1. Basic principles. KS is one of the premium system. The gas-fired units will receive price supports when they produce per unit electric energy. Finally, the revenue of the units will be settled based on the actual generating capacity multiplied by the difference between the unit on grid price and the benchmark on grid price[10].

\[
S_i^t = Q_i^t \times (P_i^{on} - P_i^{on}) \times C
\]  

where \(S_i^t\) represents the subsidy for the unit \(i\) in interval \(t\); \(Q_i^t\) represents the quantity of the unit \(i\) should be subsidized in interval \(t\); \(P_i^{on}\) is the on grid price of the unit \(i\); \(P_i^{on}\) is the benchmark on grid price, representing the feed-in tariff and environmental protection tariff of coal-fired units which is 0.463 CNY/kWh under consideration of desulfurization, denitrification, dust removal and ultra-low emission; \(C\) is an adjustment coefficient.

3.1.2. KS with financial contracts. Actually, most gas-fired units in Guangdong will sign different types of long-middle term financial contract. There are two types of market oriented long-middle term contracts in Guangdong electricity Market: price difference contract and absolute price contract. The price difference contract is used for units to compete on the basis of its on grid price and the market will be cleared according to the price reduction range of each unit based on the approved on grid price. Considering that different units have different on grid price, and the absolute settlement price after conversion is different, which means that the transaction price already contain allowances, the generating capacity of units under this contracts will not be subsidized, while the quantity under the absolute price contracts can receive allowances.

When the clearing quantity of gas-fired units in the spot market is greater than that of price difference contracts, only the differential section will be subsidized.

\[
Q_i^t = Q_i^{spot} - Q_i^{pdc}
\]  

where \(Q_i^{spot}\) represents the clearing capacity of the unit \(i\) in interval \(t\) in the spot market; \(Q_i^{pdc}\) represents quantity of the unit \(i\) in interval \(t\) under the price difference contracts. Here, we ignore the base amount of electricity.

When the clearing quantity of gas-fired units in the spot market is smaller than that of the long-middle term financial contract, only the quantity under the absolute price contracts can be subsidized. Meanwhile, the differential section between quantity in the spot market and that of the long-middle term financial contract will be settled based on 0.463 CNY/kWh (rather than the on grid price of the gas-fired unit which is higher than 0.463 CNY/kWh) subtracting the decrease in unit declaration.

\[
Q_i^t = Q_i^{apc}
\]  

where \(Q_i^{apc}\) represents quantity of the unit \(i\) in interval \(t\) under the absolute price contracts.

KS is a simple and easy method to ensure the stable revenue of the high-cost units. But obviously, there are two main weaknesses. One is that if want a higher marginal income, the gas-fired units must obtain more cleared electricity in the spot market when the medium and the long-middle term financial contracts have been fixed. The other is that if want to get more cleared electricity, the units must lower the quotation to participate in the spot market. The subsidy-based quotation broadens the range of price cuts for gas-fired units. When the subsidy amount is greater than the cost difference between the high-cost units and the low-cost units, high cost units will be cleared first in the spot market, leading to a distorted market environment and causing an inefficient allocation of market resources.
At present, the average on grid price of gas-fired units in Guangdong is 0.665 CNY/kWh, while the feed-in tariff and environmental protection tariff of coal-fired units is 0.463 CNY/kWh. The government needs to subsidize gas-fired units by 0.202 CNY/kWh according to the KS. In order to get more subsidies, the gas-fired units will reduce the quotation to 0.463 CNY/kWh to gain more volume in the market. When the marginal cost of coal-fired units is greater than 0.463 CNY/kWh, the market will give priority to clearing gas-fired units whose quotation are smaller. Guangdong electricity spot market was operated in 2018 and several settlement trial operations were conducted in May, June and October 2019. During the trial settlement in May, the average quotation of coal-fired units was 0.315 CNY/kWh while that of gas-fired units was 0.504 CNY/kWh, which basically reflects the marginal cost of various units. However, the difference between the average quotations of the two types of units is 0.189 CNY/kWh which is smaller than 0.202 CNY/kWh. If the price of gas-fired units is further reduced, the power generation space of coal-fired units will be squeezed. The subsidies for high-cost units during the three trial runs are shown in the Figure 1. The total amount of subsidy accounts for about 6% of power generation revenue. From a long-term perspective, the subsidies costs will be paid by users, which will increase the cost of electricity purchase.

Figure 1. Subsidy amount for high-cost units during the three trial runs.

3.2. CfD in Zhejiang electricity market
Zhejiang electricity market adopted the Contract for Difference Authorized by Government to promote the transition from plan to market and help gas-fired units to achieve risk aversion and hedging. As a kind of financial contract, the CfD can help the participants to determine the revenue in advance, which does not involve the actual delivery of electricity. The electricity covered by the contract shall be settled according to the contract price, and the part exceeding or lower than the contract power shall be settled according to the spot clearing price. The contract settlement method as follows:

$$R_{i,t}^{\text{CfD}} = (P_{i,t}^{\text{CfD}} - P_t^b) \times Q_{i,t}^{\text{CfD}}$$

(4)

where $R_{i,t}^{\text{CfD}}$ is the contract revenue for the unit $i$ in interval $t$th; $P_{i,t}^{\text{CfD}}$ and $Q_{i,t}^{\text{CfD}}$ represents the price and the amount of the CfD for the the unit $i$ in interval $t$th respectively; $P_t^b$ represents the benchmark price of the contract. It is not difficult to find that the three factors affecting the contract revenue include contract price, contract amount and benchmark price. Generally, $P_{i,t}^{\text{CfD}}$ will be set to the on grid price of the unit $i$, and the $P_t^b$ will be set to the clearing price in the spot market.

The total revenue of gas-fired units includes spot market revenue and CfD revenue.
\[
R_i = \sum_{t \in T} \left[ (Q_{i,t}^{\text{spot}} \times P_t^{\text{spot}}) + \left( P_{i,t}^{\text{CfD}} - P_t^{\text{spot}} \right) \times Q_{i,t}^{\text{CfD}} \right] \\
= \sum_{t \in T} \left[ (Q_{i,t}^{\text{spot}} - Q_{i,t}^{\text{CfD}}) \times P_t^{\text{spot}} + P_{i,t}^{\text{CfD}} \times Q_{i,t}^{\text{CfD}} \right]
\] 

(5)

where \( R_i \) represents the total revenue of unit \( i \); \( Q_{i,t}^{\text{spot}} \) and \( P_t^{\text{spot}} \) is the clearing capacity of the unit \( i \) and the clearing price in the spot market in interval \( t \)th respectively; \( T \) represents the time period collection.

There are two main forms of CfD in the electricity market, which can be divided into relative quantity CfD and absolute quantity CfD according to the different methods of contract decomposition. The relative quantity contract gives the contract decomposition curve after the event, which is simple to operate but is not conducive to the realization of unit hedging. The relative quantity contract is decomposed in advance, which is beneficial to encourage the unit to participate in the market, but the contract decomposition is more difficult. The \( Q_{i,t}^{\text{CfD}} \) is closely related to the total amount of contract and the method of contract decomposition. How to determine the size of \( Q_{i,t}^{\text{CfD}} \) is a very difficult problem. The units can realize the perfect risk hedging through the CfD when the \( Q_{i,t}^{\text{spot}} \) is equal to the \( Q_{i,t}^{\text{CfD}} \). However, \( Q_{i,t}^{\text{spot}} \) is generally not equal to \( Q_{i,t}^{\text{CfD}} \) because of the difficulty to forecast load accurately. Besides, if too much electricity is decomposed to gas-fired units in the valley load period, then the units will obtain high-revenue with less electricity because of the high contract price, leading to unfair distribution of social welfare. Particularly, in the peak load period, when the \( P_{i,t}^{\text{CfD}} \) is likely to be lower than the \( P_t^{\text{spot}} \), the gas-fired units may face the risk of negative income if the \( Q_{i,t}^{\text{CfD}} \) is greater than the \( Q_{i,t}^{\text{spot}} \), making the gas-fired units unable to realize the risk hedging through the CfD.

Zhejiang Province classifies CfD into seven categories on the basis of the period and the unit types\[11\], covering base load, waist load, peak load, hydropower, wind power, and solar power, as shown in Table 1, and there are two types of contracts for gas-fired units. The contract decomposition method is based on the typical generation curve of gas-fired unit. And the total amount of contract is determined by the government and decomposed according to the "peak principle". However, it gives the contract decomposition curve after the event, which may lead to the gas-fired units can not completely avoid the risk of spot market price fluctuations.

| Types               | Power Output Characteristics                                      |
|---------------------|------------------------------------------------------------------|
| Base-load           | Nuclear power units & Coal-fired units & Hydropower units        |
|                     | operating during the wet season                                  |
| Waist-load          | Coal-fired units & Hydropower units operating during waist load period |
| Peak-load&Fixed-price| Gas-fired unit invoked during peak power consumption in summer    |
| Peak-load&          | Gas-fired unit invoked during emergency period                    |
| Capped&Fixed-price  |                                                                  |
| Limited-fuel        | Power outside the province invoked during emergency period        |
| Fuel-constrained &  | Hydropower units with uncertain water resources                   |
| Non-water renewable energy | Wind power units & Photovoltaic units                           |

3.3. PAS in Yunnan electricity market

In Yunnan Province, hydropower-based clean energy installed capacity accounts for 83%, and thermal power accounts for 17% approximately. Affected by the water inflow characteristic, the electricity
supply and demand status of Yunnan Province is surplus during the flood season and tight during the dry season when the clean energy can't meet electricity demand, requiring the output of thermal power units. However, the fuel cost determines that the marginal cost of thermal power units is much higher than that of hydropower. Hence, Yunnan Province have applied the PAS to encourage thermal power units to actively participate in market-oriented transactions according to electricity demand.

3.3.1. Basic principles. Both PAS and KS belong to the premium system, but PAS introduces market competition for subsidies. In Yunnan electricity market, the final revenue of thermal power units includes two parts: market-based transaction price and adjustment price that is the subsidy for the units. The revenue formula of thermal power units is as follows:

$$ R_i^\Sigma = R_i^{market} + R_i^{adjust} $$

where $R_i^\Sigma$ denotes the final revenue of unit $i$; $R_i^{market}$ denotes the market-based transaction revenue, which is formed by competition of the thermal power unit and the hydro power unit on the same platform; $R_i^{adjust}$ represents the final adjustment revenue of the thermal power unit $i$.

3.3.2. The process of the PAS. PAS mechanism mainly consists of five steps[12], as shown in Figure 2.

![Figure 2. The process of the PAS.](image)

Firstly, a monthly thermal power generation capacity plan will be formulated and released by the Electric Trading Center (ETC) according to load forecast. Secondly, the thermal power units quote market price, market electricity quantity and adjustment price according to generation cost. $P^{adjust}$ is the adjustment price set; $p_i^{ad}$ is the adjustment price quoted by the thermal power unit $i$.

$$ P^{adjust} = \{ p_1^{ad}, p_2^{ad}, p_3^{ad}, ..., p_i^{ad} \} $$

Thirdly, ETC will check the quoted volume of all thermal power market and the monthly thermal power generation capacity. And then the thermal power units with low quotation are preferentially operated. The equation for the settlement of thermal power unit $i$ is represented as follows:

$$ R_i^{adjust} = p_i^{ad} \times q_i^{ad} $$

where $p_i^{ad}$ denotes the settlement price of the units $i$ winning the bid; $q_i^{ad}$ denotes the settlement electricity of unit $i$.

Among them, the price cap is set for the settlement price of the bid winner. The equation for the winning bid price is represented as follows:

$$ p_i^{ad} = \min(p_i^{ad}, p^{ben} - \bar{p}) $$

where $p^{ben}$ is the benchmark price of thermal power unit. $\bar{p}$ represents the average market price of the month.

Considering the difference between the actual generating capacity of the unit and the quoted volume, the final settlement adjustment quantity of thermal power unit is the minimum value of the above two. The equation for the settlement volume is represented as follows:

$$ q_i^{ad} = \min(q_i^{ad}, q_i^{act}) $$

where $q_i^{ad}$ denotes the adjustment electricity quoted by the winning unit $i$; $q_i^{act}$ denotes the actual power generation of thermal power unit $i$ in the current month.
Besides, for some thermal power units that must be operated, the adjustment price is approved by ETC, and the price is set to zero when clearing to ensure that these units must be cleared.

PAS introduces bidding mechanism to subsidy price, which can make subsidy closer to market competition and promote the maximization of social welfare. However, for the power market with high concentration of thermal power units, PAS will strengthen the motivation of generating units to exercise market power. In view of the above problem, on the one hand, Yunnan electricity market set a price cap for settlement price, which is 0.1008 CNY/kWh, on the other hand, a random function considering unit energy cost is used to arrange the unit clearing sequence when the adjustment price quoted is the same.

In January 2019, Yunnan's thermal power units declared a generating capacity of 460 million kWh, and the average declared adjusted price was 0.0968 CNY/kWh. After being checked and adjusted, the transaction power generation of thermal power units was 330 million kWh, and the average deal price was 0.0860 CNY/kWh, which is 0.0108 CNY/kWh lower than the declared average price. By introducing competition, the subsidy amount was effectively reduced. The subsidy amount that month was only 28.41 million CNY. And the subsidized generating units are all low-cost units.

4. Conclusions

The advantages and disadvantages of KS, CfD and PAS are shown in the Table 2:

| Subsidy | advantages | disadvantages |
|---------|------------|---------------|
| KS      | Stimulate units’ enthusiasm | Market prices distortion |
|         | Improve units’ utilization | Social welfare loss |
|         | Simple operation | |
| CfD     | Controllable amount of subsidy | Great impact on unit revenue by the decomposition mode of contract capacity |
|         | Controllable market power | |
| PAS     | Stimulate units’ enthusiasm | Uncontrollable market power |
|         | Maximize social welfare | |

The application of market mechanism is to make the market play a decisive role in resource allocation, so as to improve the efficiency of resource allocation. In the transitional period of market construction, we should take into account the interests of different market participants before and after the reform, and take corresponding measures to ensure that their revenue do not change too dramatically. The subsidy mechanism is a financial means adopted by the government to ensure the smooth transition of market construction, which can balance the interests of all parties. But if used improperly, it will be counterproductive.

At present, Guangdong electricity market adopts the KS based on the actual generating capacity for high-cost units. In terms of the feasibility of operation, KS is the simplest. However, this subsidy will affect the bidding strategy of high-cost units, which may cause the quotation of high-cost units to be lower than that of low-cost units that will distort the market price, so that the high-cost units will be cleared first and the efficiency of resource allocation will be reduced. Therefore, it is not suitable to adopt KS under electricity market construction.

In order to ensure the fairness of market construction, we can use the way of initial property rights distribution to balance the interests of different participants, such as the CfD, which can determine part of the participants' revenue in advance and achieve the purpose of market power control. But it has strict requirements on the accuracy of contract decomposition.

PAS divides the market into two parts: one for all units to compete on the same platform, another for high-cost units only. In this way, high-cost units can be fully mobilized to participate in market regulation, but it will also lead to units collusion, which needs a supporting market power control mechanism.
Actually, it is not an ideal method to realize the competition of units with different cost on the same platform through subsidy mechanism. It is necessary to study the establishment of a complete electricity market system including the capacity market as soon as possible to solve the problem that the single energy market cannot reasonably price the value of the high-cost units required by the system.

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