Influence of guaranteed power supply service on competitive power market and compensation mechanism design

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Abstract. In the modern power market system, it is necessary to establish a mature power supply guarantee service mechanism to protect the rights and interests of all users, realize the reasonable allocation of power resources and achieve the “Pareto improvement” of social welfare. Based on a broader definition of guaranteed power supply service, this paper clarifies the scope and mode of guaranteed power supply service, calculates the power supply cost and market clearing electricity of guaranteed power supply service, and designs a corresponding compensation mechanism system to promote the sustainable development of guaranteed power supply service. In the long run, guaranteed power supply service should return to the market mechanism, pricing based on “power supply cost + reasonable profit”, and become an essential part of the competitive power market.

1. Introduction
With the continuous promotion of electricity marketization reform, a competitive electricity market will gradually formed on the electricity selling side. Electricity users have the “free choice of electricity consumption”. They can freely choose and change the selling e-commerce in the market electricity trading based on the principle of utility maximization or cost minimization. However, if the demand for non-marketized users and marketized users delisted under abnormal conditions cannot be guaranteed, the power market will not realize the effective allocation of resources. The phenomenon of “market failure” may damage the overall level of social welfare. Under the background of the marketization reform of the electricity selling side, it is urgent to establish a mature guaranteed power supply services (GPSS) mechanism to protect the rights and interests of all users and realize the rational allocation of power resources.

2. The connotation and pricing mechanism of GPSS

2.1. Definition and related groups of GPSS
As a critical link in the mature and standardized competitive power system, GPSS is the power supply guarantee provided by the power supply enterprises designated by the government to specific users. Although there is no official definition of GPSS, through reviewing the related literature and policy documents, we have constructed a broader definition framework: GPSS refers to when the user need not or cannot gain power from electric power market services (including the user is not included in the scope of market-oriented trading, the user waives the right to choose, the original power sales...
company terminates operations or cannot find the power supply supplier for various reasons, etc.), A main power supplier should assume the obligation to meet the demand of users.

At the present stage, the service objects of guaranteed power supply mainly include four types of users: (i) Non-market electricity users. Mainly refers to the power users who are not temporarily involved in market transactions as required by the government, including residents who have no bargaining power and do not participate in direct power purchase transactions, agriculture, critical public utilities, small commercial users, and public service users. (ii) Electricity users who are qualified for market transactions but choose not to participate in market transactions. Mainly include users who meet the market access conditions but have not chosen to participate in direct transactions or purchase electricity from electricity sales companies. (iii) Power users who have participated in market-oriented transactions and opted out. The electricity price level is differentiated from the second type of user. (iv) Users whose original electricity sales company is unable to perform the contract. Mainly denote users who are unable to obtain adequate power supply due to the discontinuation of the electricity sales company or the inability to provide electricity sales services. However, the relevant documents of the current power system reform include residents, agriculture, and other security users into the main scope of guaranteed users. Nevertheless, in the long run, the direction of power system reform should continue to expand the scope of market entities. The direction of market development should also gradually incorporate qualified and guaranteed users into the market-oriented transaction system.

With the issuance of relevant policy documents on power system reform, the providers of GPSS and their obligations have gradually become clear. The providers of the guarantee service obligation are the enterprise that owns the distribution network, and the ultimate provider of the obligation is the grid company. The distribution network has the characteristic of natural monopoly, so it is reasonable to assume the obligation of protecting the electricity demand of the users in the responsible region. The specific obligations of market entities with distribution networks mainly include the following four aspects: first, provide safe and reliable power supply based on national power industry standards; second, perform universal power supply service obligations; third, charge electricity fees to electricity users in accordance with relevant government pricing rules; fourth, preferential purchase of electricity from power generation enterprises according to government pricing. Obviously, in the current electricity market reform process, the cost and price of guaranteed services are still subject to government control.

2.2. Pricing mechanism for GPSS
In essence, GPSS is a guarantee measure to meet the electricity demand of market-oriented entities when the market mechanism fails. Since the guarantee service mainly occurs when the market cannot function effectively, the design of the relevant pricing mechanism needs to consider the possible changes in the power supply cost under the guarantee state and the impact on the competitive power market. The design of the mechanism should be dedicated to providing incentives for users who can participate in market transactions, so that they can involve in market transactions as much as possible.

As a unique power supply service temporarily started under certain conditions, the guaranteed power supply has the characteristics of partial relief, temporary and transitional nature. Depending on the service subject, and the conditions of occurrence, the corresponding pricing mechanism for GPSS should also be different. First, the situation of users who have not yet been market-oriented and do not participate in direct power purchase transactions. At this time, the status quo of the power grid companies selling electricity to them according to the government’s pricing is still maintained, and the “catalogue price” set by the government is implemented. Second, there is a situation in the retail electricity market where users meet market access conditions but choose to withdraw from the market voluntarily. A punitive electricity price can be set for guaranteed service users. That is, the price can be added to a certain percentage of the standard power supply cost. The State of Texas in the United States stipulated that GPSS providers can charge at 130%-135% of the monthly wholesale electricity
market price. Third, there are situations in which retailers go bankrupt and exit the market, and there are no other suitable retailers to undertake power supply services. Power users are forced to withdraw from the market. At this time, in order to maintain the competitiveness of the market, a transition period needs to be set. When the transition period is over, continue to let users participate in market transactions. Therefore, after the end of the transition period, if there are still other electricity retailers in the market, and users still choose to enjoy the guarantee service, the same treatment should be adopted as when users voluntarily withdraw from the market. And if there are still no new retailers on the market, the transition period for guaranteed power supply needs to be extended. Fourth, in the event of force majeure, such as natural disasters that cause retailers or the distribution network to be unable to provide power supply services, power users will naturally turn into guaranteed users. At this time, if the retailer or the distribution network has the ability to continue to operate, the additional cost of the guarantee service should be borne by the retailer or the distribution network. Moreover, if the retailer or the distribution network cannot continue to operate, it can refer to the retailer’s exit from the market and adopt the model of setting a transition period.

3. Impact of GPSS on the competitive power market

When a distribution network enterprise or a grid company fulfills the obligation of guaranteeing the power supply, due to the changes in user demand, additional power supply costs are required, which in turn affects the price and electricity consumption in equilibrium. With reference to the design ideas of the two-part electricity price, this article builds a mid-to-long-term power supply cost model for guaranteed minimum users based on the research of Wu and Lin [1], and analyses the changes in power supply costs under the guaranteed minimum state, and further studies the impact of guaranteed minimum pricing on the competitive power market.

3.1. Power supply cost and power demand model

Price and electricity consumption are the core indicators of a competitive electricity market. By calculating the power supply cost in the guaranteed state, it is helpful to determine the electricity price and the level of electricity consumption in the state of market clearing. Wu and Lin [1] calculated the mid-to-long-term power supply cost based on data from a provincial power grid. Following this research, combined with the idea of setting prices for the two parts, we decompose the unit power supply cost of the terminal into three parts: electricity purchase cost, capacity cost, and line loss:

\[ EC_t = EC_{feedin} + EC_{cap} + EC_{loss} \]  \hspace{1cm} (1)

Where \( EC_t \) is the total power supply cost. \( EC_{feedin} \) represents the cost of electricity purchase, where is represented by the average feed-in price. \( EC_{cap} \) means the capacity cost, and the cost of transmission and distribution is also included. \( EC_{loss} \) denotes line loss cost.

Power purchase cost and line loss cost can be calculated according to the amount of electricity purchased. The line loss cost can be calculated based on the line loss rate and the average on-grid electricity price, which is shown in equation (2).

\[ EC_{loss} = \eta / (1 + \eta) \times EC_{feedin} \]  \hspace{1cm} (2)

The capacity cost can be calculated based on the total capacity and the gaps between purchase and sale price.

\[ EC_{cap} = (ER - EP - EL) / Cap \]  \hspace{1cm} (3)

Where \( ER \) represents electricity sales revenue. \( EP \) denotes the cost of electricity purchase. \( EL \) is the cost of line loss. \( Cap \) refers to installed capacity.

The price elasticity of electricity demand is the key to measuring the minimum electricity demand of users. The price elasticity of electricity demand refers to the corresponding change in the amount of electricity demand caused by the change in the electricity price, that is, the ratio of the percentage of the change in electricity consumption to the percentage of the corresponding price change in a certain period. The price elasticity of electricity demand \( \varepsilon \) can be expressed by equation (4):
\[
\varepsilon = \frac{\Delta Q}{Q} / \frac{\Delta p}{p}
\]

(4)

Where \( q \) refers to electricity demand. \( p \) represents the electricity price.

We use a fixed substitution elastic demand function to describe the changes in power demand, and the power demand function is as follows:

\[
Q = Q_0 p^n
\]

(5)

When the price of electricity changes from \( P_1 \) to \( P_2 \), the change in electricity demand is shown in equation (6):

\[
Q_2 / Q_1 = (P_2 / P_1)^\varepsilon
\]

(6)

3.2. Power supply cost and market cleared electricity under GPSS

Due to the data availability, the data year estimated in this paper is 2017. On-grid electricity price, sales electricity price, line loss can be obtained from the National Energy Administration’s “2017 National Electricity Price Regulatory Bulletin”. The installed capacity and power consumption are derived from the “2018 China Electric Power Yearbook”. The elasticity of electricity demand is based on the calculation results of He et al. [2] and Yu and Xin [3].

Table 1 shows the power supply cost and cross-subsidy scale of various industries. Rural residents’ electricity has the highest power supply cost of 1.036 yuan/kWh. It exceeds the cost of urban residents’ domestic electricity and primary industry electricity, which are 0.905 yuan/kWh and 0.689 yuan/kWh, respectively. However, the three enjoy the lowest electricity price of 0.533 yuan/kWh, and the price gap is mainly made up by the cross-subsidy of industrial users in the secondary industry. According to the results, the scale of cross-subsidy for the secondary industry is 355 billion yuan.

| Industry                  | Power supply cost (Yuan/kWh) | Electricity price (Yuan/kWh) | Cross subsidy (Yuan/kWh) | Power consumption (100 million kWh) | Cross subsidy scale (100 million Yuan) |
|---------------------------|-----------------------------|------------------------------|-------------------------|-------------------------------------|----------------------------------------|
| Primary industry          | 0.68932                     | 0.53311                      | 0.15621                 | 1175.12                             | 183.56                                 |
| Secondary industry        | 0.52104                     | 0.60008                      | -0.07904                | 44922.24                            | -3550.62                               |
| Tertiary Industry         | 0.68536                     | 0.72632                      | -0.04096                | 8825.22                             | -361.51                                |
| Electricity consumption for urban residents | 0.90531                     | 0.53311                      | 0.37220                 | 4961.81                             | 1846.81                                |
| Electricity consumption for rural residents | 1.03616                     | 0.53311                      | 0.50305                 | 3740.73                             | 1881.76                                |

The results prove the economic reality that guaranteed users receive a large number of cross-subsidies [4]. For guaranteed users such as residents, the government’s priority is to ensure the supply of electricity, so it cannot increase the cost excessively. Simultaneously, due to residents’ high sensitivity to electricity prices, adopting a market-based pricing mechanism for them in the short term will arouse users’ resentment and may cause social conflicts. Therefore, although the current guaranteed power supply prices for residents, agriculture, and other users are significantly lower than their power supply costs, the corresponding funding gap is compensated by cross-subsidizing prices for industrial and commercial users. From an economic point of view, this kind of cross-subsidy will cause unnecessary loss, which is not conducive to the reasonable allocation of power resources and the improvement of the overall welfare of society [5].

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1 There are currently no public data on the average electricity price of the primary industry. According to the sales electricity price data of the State Grid and China Southern Power Grid, the electricity price for agricultural production is very close to the price for residential electricity. Therefore, the electricity price assumption of the primary industry in the table is the same as that of residential electricity.
Based on the power supply costs of different users, the deviation between the cleared electricity under market equilibrium and the actual electricity consumption can be further measured. The market-clearing price is equal to the cost of the power supply. According to the elasticity of electricity demand of various users, the amount of market cleared electricity of users in different departments can be calculated. As shown in Table 2, the deviation of electricity consumption between urban residents and rural residents reached 109.3 billion kWh and 100.35 billion kWh, respectively. The deviation range also reached 28.26% and 36.66%. In other words, the prosperity of residential electricity consumption caused by low electricity prices has squeezed the development space of industry and commerce. The power consumption deviation of the secondary industry is -537.3 billion kWh. The relatively heavy burden of electricity prices inhibits the power supply-demand of industry and commerce, which is not conducive to the steady development of the real economy. Because the price elasticity of electricity demand in the secondary and tertiary industries is higher than that of residential, price distortions have also led to a lower than the desired level of electricity consumption by -367.648 billion kWh in the whole society. This can also be regarded as the negative economic externality of China’s unstandardized guaranteed power supply system. The current guarantee mechanism cannot balance the benefits of guarantee users with the improvement of overall social welfare [6]. With the rapid growth of the electricity market-oriented transactions and the expansion of market-oriented shares, the problem of incoordination and unsustainability between the guaranteed power supply and power “market-oriented transactions” has become increasingly apparent. After the future power spot market runs, the existing balance of payments model of guaranteed power supply will no longer exist. If there is no corresponding compensation and incentive mechanism, the guaranteed power supply will be difficult to achieve sustainable development.

| Table 2. Results of Market clearing |
|-------------------------------------|
| Price elasticity of demand | Market clearing electricity (100 million kWh) | Electricity consumption deviation (100 million kWh) | Deviation range |
| Primary industry | -0.066 | 1155.36 | 19.76 | 1.71% |
| Secondary industry | -0.8 | 50295.73 | -5373.49 | -10.68% |
| Tertiary Industry | -0.8 | 9244.73 | -419.51 | -4.54% |
| Electricity consumption for urban residents | -0.47 | 3868.56 | 1093.26 | 28.26% |
| Electricity consumption for rural residents | -0.47 | 2737.23 | 1003.50 | 36.66% |

4. Compensation mechanism design for GPSS
As a standard configuration in a competitive power system, GPSS needs to consider the livelihood attributes of power services and the cost-benefit principle in the context of market transactions. A rational competitive market always follows the law of “sell expensive, buy cheap”. If the guaranteed price is very low, the retail company will not be willing to undertake the guaranteed service unless it is compulsorily designated. This will result in a lack of GPSS resources, which leads to the risk of power interruption for users. Conversely, if the guaranteed electricity price is high, many electricity sales companies are willing to undertake the guaranteed business. In the background of incomplete information, users may choose large electricity sales companies based on prudent strategies, which is not conducive to the flexible opening of the electricity sales market.

Therefore, the selling price of guaranteed power supply should be determined on the basis of “reasonable cost + reasonable profit”, which is neither “power supply at a loss” nor “power supply at a punitive price”. The standardization development direction of China’s guaranteed power supply is to gradually reduce the guaranteed power supply objects and determine the guaranteed power supply price based on the cost principle. Under the condition of maintaining stable prices of non-market electricity for residents and agriculture, in order to achieve the financial balance and sustainability of the guaranteed power supply, the following compensation mechanism can be designed according to
the power structure, the proportion of household agricultural electricity, the construction schedule of the power market and other factors:

First, the transmission and distribution prices include “cross-subsidies” from high-income groups to low-income groups. Formulate minimum service rules in line with market mechanisms, and include “cross-subsidies” for the consumer side in the power transmission and distribution prices for market-based transactions. Resident users with various income levels are treated differently. Non-market users such as residents, agricultural, and other non-market users need to pay for the fund gap of guaranteed power supply by high-income groups according to different standards. It can refer to the tiered electricity price system to levy power guaranteed public service funds for different income groups.

Second, the implementation of “contracts for difference” settlement to guarantee the financial balance of power supply. When the low-cost power supply is not enough to guarantee the financial balance of guaranteed power supply, for units participating in the spot market competition, the settlement ratio of “partial power is settled at market price and some power is settled at the original government price” to guarantee the financial balance of power supply Control (contract for difference), to realize the sustainability of guaranteed power supply, and also ensure the effective development of power generation competition.

Third, electricity selling companies, non-residents, and non-agricultural users in guaranteed power supply shall bear part of the additional costs for guaranteed power supply. For the supply side, all electricity sales companies are required to pay a guaranteed service fund and grant corresponding fund subsidies to companies that implement GPSS. For the consumption side, the funding gap for low-cost guaranteed power supply for residents, agriculture, etc., is partly borne by non-residents and non-agricultural users in the guaranteed power supply, and serves as an auxiliary subsidy mechanism for the GPSS, thereby effectively promoting relevant subjects to withdraw from the guaranteed power supply and actively participate in the market.

Fourth, improve the reasonable compensation mechanism for companies that bear additional losses due to GPSS. Grid companies that undertake GPSS often increase operating costs and incur additional expenditures due to temporary power sales. Therefore, the government should formulate suitable compensation standards, and provide reasonable compensation for the losses and increased costs suffered due to the start of GPSS. The related expenses can be shared by all power sales companies in the business area that do not undertake the GPSS.

5. Conclusions

The reform of the electric power system is related to the national economy and people’s livelihood, and the relevant guaranteed power supply system is worthy of in-depth study to promote the stable operation of the economy and society. This article first provides a broader definition of GPSS, and then clarifies the scope and mode of GPSS. Based on this theory, the power supply cost of the GPSS and the market cleared electricity are calculated. The relevant results prove that guaranteed users have received a large number of cross-subsidies. The cross-subsidy scale of the secondary industry is 355 billion yuan, which can effectively ensure the basic electricity demand of guaranteed users at the cost of the industry’s welfare losses. The boom in residential electricity consumption due to low electricity prices has squeezed the development space of industry and commerce. The difference in electricity consumption between urban and rural residential electricity consumption reached 109.3 billion kWh and 100.35 billion kWh, respectively. The deviation range also reached 28.26% and 36.66%. The power consumption deviation of the secondary industry is -537.3 billion kWh. The relatively heavy burden of electricity prices inhibits the power supply-demand of industry and commerce, which is not conducive to the steady development of the real economy. The negative economic externalities of China’s unregulated minimum power supply system are becoming increasingly apparent, and targeted compensation and incentive mechanisms are urgently needed to promote the sustainable development of minimum power supply. In order to achieve the financial balance and sustainability of the guaranteed power supply, the government can implement “cross-subsidies” from electricity sales companies to guaranteed service companies, high-income groups to low-income groups, and
implement “contracts for difference” settlement to ensure the guaranteed financial balance of power supply. Also, the policymakers can implement policies to allow non-residents and non-agricultural users in guaranteed power supply to bear the additional costs of guaranteed power supply, and improve the reasonable compensation mechanism for companies that cause additional losses due to GPSS.

In the short term, it is difficult to reduce the scale of cross-subsidies and improve the level of social welfare by substantially raising the price of household electricity. However, in the long run, as the income level of residents rises, the electricity price cross-subsidy that distorts market prices should be gradually eliminated. Corresponding GPSS should also return to the market mechanism, pricing based on “market costs + reasonable profits” to achieve Pareto improvements in social welfare, and become an essential part of the competitive power market.

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