

Research on the Guidance Mechanism for the Price Signal of Power Grid Connection Service

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Abstract. At present, the utilization hours of thermal power continue to decline, and renewable energy generation also has a serious socket phenomenon, so it is necessary to guide the construction of power side selection points through price signals, so as to promote the smooth integration of more power generation into the grid. This study focuses on the connection services provided by grid enterprises to power side and demand side, analyzes and summarizes the connection charging practices of different countries, designs a shallow connection cost recovery model according to energy strategy and the characteristics of supply and demand side in our country, and puts forward feasible suggestions for renewable energy generation connection charging, in order to promote the investment and construction of grid and the consumption of renewable energy.

Key words: Power grid connection service; price signal; connection cost recovery mechanism.

1. Introduction

In the new round of electric power market system reform, the transmission and distribution price is determined according to the basic principle of allowable cost plus reasonable profit. Compared with the previous method of determining the transmission and distribution price by the difference between the grid sales price and the on-grid price, it has been scientific and reasonable. At the same time, on the basis of the reform of electricity transmission and distribution price in the first two phases, the third supervision cycle has also played a certain role in encouraging and guiding power users by separately listing the electricity charges of pumped storage capacity and line loss costs in the online link besides the electricity transmission and distribution price. However, the grid connection price is an important part of the transmission and distribution price, and the above single line fee is only the first step. It is necessary to further improve the verification method and charging method of grid connection price in the practice of charging the connection fee from power generation enterprises and power loads.

The design and improvement of power grid connection price mechanism not only lies in that power grid enterprises can recover sunk and fixed costs, promote continuous investment and operation, but also can guide the correct selection points of power generation and electricity consumption, stimulate demand side response, and prevent the disordered expansion of power investment. At present, the power supply and load in

various parts of China are in the process of rapid growth and change, and the change of location and quantity also has very different requirements for power grid congestion and system expansion. Therefore, based on the current transmission and distribution price reform, it is of great significance to explore a scientific, reasonable and universal adaptive grid connection price pricing method, and guide resource allocation with price signals, which can reduce cross-subsidies, reduce various doubts and resistance, promote the balance between supply and demand and the development of power market, and ensure the implementation of energy strategy at the national level.

2. Power grid connection price

Power grid connection price, as an important part of power transmission and distribution price. It refers to the price of power grid operators providing connection system services for specific power users and load users, which is used to recover the expenses and costs incurred by power grid enterprises for users to connection the power transmission network. For the transmission network, the most important feature is the capacity constraint of the power grid. That is, the transmission network has its own capacity limit, and when this capacity is exceeded, it may cause the entire network to collapse. Therefore, the service cost to be recovered from the power grid connection price includes not only the construction, maintenance and operation cost of the dedicated connection system project, but also the increase in the

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operation cost of the shared network caused by the connection of users with specific capacity, as well as the long-term capacity expansion and reconstruction cost [1]. The power grid connection price is divided according to the service object into the power user connection price and the load user connection price. Among them, the power user connection price has not been implemented in China, because most of the power user connection system projects are invested and constructed by power supply enterprises. However, it has not been clear how to recover the operation and maintenance costs of connection assets and the capacity expansion costs caused by the power user's connection to the shared transmission network. As for the load user connection price, the related costs and benefits of power transmission services provided by power grid enterprises using special projects are compensated in the form of engineering projects, but the recovery of other costs is not clear in the first and second supervision cycle. On the one hand, this leads to the confusion of transmission cost sharing, the serious cross-subsidy problem, and the lack of in-depth cooperation among various users due to the unfair cost burden and benefit distribution. On the other hand, it leads to unreasonable recovery of power grid investment, which affects the continuous construction of power grid and the improvement of power transmission and distribution capacity. The most important reason is that without reasonable price signal guidance, the disorderly expansion of thermal power and the disorderly construction of renewable energy occur in the open market of supply and demand, resulting in excess thermal power and the inability of renewable energy to be transported and consumed online.

3. The pricing method of power grid connection

According to the different transmission and distribution network costs covered by power grid connection price, it can be divided into shallow connection cost recovery mode and deep connection cost recovery mode. Shallow connection cost recovery mode includes the construction, maintenance and operation costs of connection facilities from power users to the common network, while deep connection cost recovery mode, in addition to shallow connection cost recovery mode, also covers the cost of strengthening and expanding the shared network caused by users' connection. Correspondingly, there are two pricing models for power grid connection, one is shallow connection pricing model, the other is deep connection pricing model [2].

The advantages and disadvantages of the above two pricing models are opposite. For the shallow connection pricing model, the advantage is that it is simple and easy to implement. It only needs to determine the investment cost and operation and maintenance cost according to the connection project cost and electrical parameters. On the one hand, it can avoid the difficulty of defining the reinforcement cost of the superior power grid, and on the other hand, it can reduce the power connection barrier, which means that the shallow connection cost recovery

for renewable energy power generation is adopted. It can effectively promote the construction and expansion of renewable power. The disadvantage is that it cannot compensate all the costs. Under the current situation of limited capital sources and channels for power grid investment, it will affect the investment in power grid development, especially for the areas where the transmission network is already weak. Due to the lack of funds, the work of strengthening or increasing the capacity of the superior power grid will be repeatedly delayed.

For the deep connection pricing model based on the deep connection cost recovery mechanism, the advantage is that the cost can be fully and quickly recovered, including the investment cost of connection engineering and shared power grid construction, so that the investment capital of power grid development can be guaranteed. On the one hand, by distinguishing the different reinforcement and expansion costs caused by different users' connection in different locations, the

differential pricing can reduce cross-subsidy and promote fair competition at the power supply end. On the other hand, the location signal can be sent to guide the selection and construction of power supply. The disadvantage is that the evaluation is complicated, and the network topology, power supply and load parameters of the whole power grid need to be considered. Especially in the case of the lack of long-term power grid planning, it is difficult to accurately verify the differentiated reinforcement and expansion costs caused by different connection to the superior power grid. In addition, the deep cost recovery mechanism means that power users need to pay relatively high connection fees, which will increase the barrier of power connection and is not conducive to the consumption of clean energy.

Through the analysis of grid connection charging practices in different countries, although Australia, Germany and other countries implement connection pricing with deep cost recovery mechanism, considering that renewable energy often has high connection costs due to the main selection sites built in remote areas. In order to promote the construction and consumption of renewable energy, they give special treatment to the connection of renewable energy generation, especially the connection of distributed power generation. They adopt a shallow cost recovery mode different from other power users, and even do not need to pay the connection fee[3].

4. Pricing basis for power grid connection

Grid connection pricing is based on connection assets that serve specific users. Therefore, to properly price grid connection services, it is necessary to classify transmission and distribution assets according to the topology of the transmission and distribution grid, and to divide the boundaries between connection assets and shared network assets. Connection services need to deliver power upstream of transmission and distribution from the power source to the shared network and from the shared network to the power consumer. The devices and

equipment involved in these two delivery services are connection assets. Therefore, connection assets include not only the power transmission and transformation facilities between the high-voltage side of the power outlet boost substation and the common network connection point, but also the power distribution and transformation facilities from the common network connection point to the power side, specifically including transmission and distribution lines, load switches, circuit breakers and other equipment as well as the corresponding protection facilities[4]. As for whether the substation facilities at the common network connection points belong to the connection assets, there are different definitions in different countries. For example, in the United Kingdom, it is included in the connection assets, and the shallow connection pricing model is adopted to recover the above connection assets. For example, Australia adopts the deep cost recovery mechanism, and the connection assets include not only the assets that increase the capacity of the substation due to user connection, but also the assets that reinforce the upstream common network due to user connection[5].

In addition, there are other approaches in use to define connection assets and shared assets. For example, when planning the transmission and distribution network, it is assumed that one or more nodes do not exist, and the construction input cost can be saved, that is, the connection asset portion. This is based on the fact that the necessary equipment in the transmission network belongs to the common network assets, and the unneeded part of the assets belongs to the connection assets dedicated to some node customers. However, when the connection assets are beneficial to improve the utilization efficiency of the transmission network, their costs can be classified as shared network assets. Therefore, on the one hand, the definition of connection assets is based on its service characteristics, whether it serves specific users or all users; On the other hand, from the perspective of its impact on transmission network, connection assets can improve or reduce the benefits of other users[6].

At present, there are two ways to define connection assets and shared network assets in various countries: First, for both new and old users, the connection assets for shallow recovery can be determined by verifying the related facility construction costs invested from users to power grid connection points; second, for the connection assets for deep recovery, for new users, the related facility construction costs invested in the reinforcement of the common network caused by user connection can be verified; For the old users, the node deletion method can be adopted to determine the connection assets in the common network, but the premise is to have a perfect and clear network planning[7]. As shown in the following table:

Table 1 Connection Asset definition

Country	Connection asset definition	Handling of shared connection assets
Britain	Identify connection assets for shallow recovery by assessing the cost of building related facilities from users to grid connection points	1. New connection users use the connection assets of old users to pay the lease fee to them
Ireland	Approved connection assets for deep recovery for new users Do not define connection assets for existing users	1. Apportion shared connection assets per MW. 2. A certain percentage of the shared connection fee is charged to new users based on the value of the assets, while the connection fee already charged is refunded to original users
Norway	Approved connection assets for shallow recovery	New users use existing connection assets, and old users are compensated

Note: According to the literature[3,5,6,7]

After defining the connection asset, another problem is how to handle the connection asset when two or more users share it. It includes not only the allocation of connection fees for users with shared connection assets, but also the collection of connection fees for new users using the connection assets of old users and the return of old users, as well as the handling of the withdrawal of one user from the shared connection assets. For new users to connection the transmission grid through the connection assets of old users, whether a certain proportion of funds should be returned to the old users. Most of the above-mentioned countries have regulations on this, which are summarized in the table above[8].

5. Price design of connection services

With the new round of power market reform, the construction of China's power market is gradually advancing, and the complete power market and price mechanism are still in the process of establishment. In the power industry generation, transmission, distribution, use (electricity sales) of the four links, front-end power generation and tail-end electricity sales two links are introducing competition, allowing social capital to enter the electricity sales business, giving users the freedom to choose, through the market mechanism to determine the price, forming a more buy more sell competition pattern; The intermediate transmission and distribution links are typical natural monopoly links, although qualified market

players are allowed to carry out new distribution business, it cannot violate the objective law of exclusive monopoly operation in the power supply operation area. Therefore, based on its monopoly nature, it is necessary to implement government supervision and price verification to ensure that the power grid is fair and open to the trading subjects of the electricity sale link. As mentioned above, the power system structure of "controlling the middle and liberalizing the two ends" is gradually taking shape, which also brings about the adjustment and change of market subjects, and changes the role and identity of the supply and demand side of connection service in the power market. Therefore, based on the analysis of the characteristics and demands of the supply and demand side of connection service, a more fair and comprehensive connection price standard that balances the interests of all parties is required to promote the enterprises in different regions in the four links of power generation, transmission, distribution and electricity consumption (electricity sales) to break barriers, deepen cooperation and continuously improve the level of power service.

5.1 Analysis of connection service suppliers

On the one hand, power grid enterprises are responsible for the investment, construction, maintenance and operation of power grid to ensure the smooth transmission and distribution of electric energy from the production enterprise to the power supplier; On the other hand, they are also responsible for the transaction of the ownership of power in the process of the above transfer. This means that power grid enterprises have to transmit power, distribute power, and sell power. This profit model based on the price difference between purchase and sale of power affects their fairness as power dispatching enterprises and hinders market competition. The current distribution and distribution separation model separates the transaction business and transmission and distribution business undertaken by the original power grid enterprises, so that they are transformed from profit-making units into public utilities, independent of the power market transaction, focusing on transmission and distribution services, and only charging the transmission and distribution price approved by the government, which is "the combination of permitted cost and reasonable income". In addition, the current power grid construction lags behind the power supply construction, which is the fundamental reason for the nest power phenomenon. Compared with the rapid growth of power generation capacity, the corresponding supporting power transmission and transformation project construction is relatively weak, the development can not keep up with the development speed of power supply, and the proportion of power grid construction investment shows a downward trend. Therefore, the design of more accurate and reasonable connection price standard can enable power grid enterprises to safely withdraw from the market competition, focus on the construction and development of transmission and distribution network, and attract various investment entities to join the construction of new distribution network, so as to promote the overall transmission and transformation capacity of power grid to

be consistent with the power generation capacity and power demand.

5.2 Analysis of connection service demander

Among power supply end of connection service demanders, at present there are no clear regulations on the charge of thermal power generation connection to power grid. In addition, due to the lack of power point and quantity planning from a national perspective, the disorderly expansion of thermal power has led to serious overcapacity in the current thermal power industry, which has been included in the primary category of national supply-side reform. In terms of wind and solar power generation, due to the fact that China's landscape resource endowment is mainly in the northwest, the land is sparsely populated, the electricity load is low, and the power grid construction is relatively backward, it needs a large amount of investment in the construction of connection facilities, and needs to be delivered to the southeast through the power grid. At present, the power transmission and distribution price document of the third regulatory cycle points out that the construction of new energy supporting network connection projects should be carried out through major national policy investment, and the allowable cost and reasonable income of the investment after the state recognition shall be included in the power transmission and distribution price. On the one hand, it supports the consumption and utilization of new energy, and on the other hand, it makes clear the recovery of connection assets.

The connection service demanders that convert between the power and load end include various user-side distributed power sources such as solar, wind, biomass power generation and gas-fired "heat, power and cooling" co-generation invested and constructed by enterprises, institutions, communities and households according to their respective conditions, as well as grid-connected microgrids. In addition to self-use, these connection service demander are also allowed to connection the distribution network and terminal power system of various voltage levels, or directly connect to the large power grid through the microgrid, and the surplus power generation is sold online to connect to the power grid as the power source. In case of insufficient power generation or system failure, it is connected to the power grid by the load side.

To sum up, the diversification of connection service demanders makes the pricing of connection services not generalized, but flexible and standardized to meet the connection needs of market players of different types and investment sources.

5.3 Power grid connection pricing model

According to the regulation of power transmission and distribution price document of the third regulatory cycle, the client's connection fee has been uniformly included in the power transmission and distribution price and collected separately. Therefore, China should design and charge power grid connection fee mainly for power generation enterprises at present. Based on the analysis of connection pricing and charging methods in various

countries, considering the advantages of transparent and intuitive shallow connection recovery mode, and in order to avoid high connection barriers caused by adopting deep connection mode in the process of pilot connection price for power generation enterprises, referring to the UK shallow connection cost recovery policy, combined with the actual situation of China's transmission and distribution price reform and the characteristics of pilot areas, In accordance with the principle of "who uses, who shares", this paper establishes a shallow connection model that is suitable for China's national conditions and does not consider the special connection fee. It also considers that with the deepening of the implementation of connection price in China and the change of connection situation, it may need to be adjusted to the deep connection mode when conditions are ripe.

According to the latest round of power system reform, the transmission and distribution price is determined based on the principle of allowable cost plus reasonable revenue. As part of the transmission and distribution price, the grid connection price should also be determined according to this principle. In addition, although China's power grid has a relatively perfect structure after a period of rapid development, with the continuous growth of the economy, the growth of power demand requires to maintain a certain degree of power grid investment. Therefore, the supervision mode based on return on investment, through the verification of effective assets, to control with a reasonable return on investment, can promote the sound development of power grid[8].

In addition, based on the current rapid growth of new installed capacity of wind power and solar power generation, and this type of new installed capacity is often special in the construction of connection projects due to the region, so a case-by-case discussion method is adopted to verify the investment of connection projects and price the connection fee[9]. To sum up, the shallow connection fee pricing model based on return on investment is as follows:

$$CC = GCA \times D + NCA \times R + NCA \times O \& M \times (1+R)$$

Where: CC is the connection fee payable in the current approved period of the power supply; GCA is the total amount of approved connection assets; D is the depreciation rate of assets, and NCA is the net value of connection assets after depreciation in the current verification period; R is the return on investment approved by the government; O&M is the operation and maintenance cost coefficient

The rationality of R setting is very important, which often needs to be based on the capital structure, capital cost, debt cost, tax and other factors of power grid enterprises, so as to promote power grid investment on the one hand, and on the other hand, it will not cause heavy burden to power supply enterprises[10].

6. Conclusions and Suggestions

Firstly, the advantages and disadvantages of deep and shallow connection cost recovery mechanisms are compared and analyzed. Secondly, based on the analysis of the practice of connection charging in different

countries, the basic method of connection asset verification is clarified. Finally, a shallow connection cost recovery model is designed by analyzing the characteristics of China's connection service suppliers and demanders.

In order to further promote the construction of renewable energy power generation, based on the designed shallow connection recovery model, the connection price policy recommendations are as follows:

Firstly, different classified tariff systems based on energy characteristics should be clarified. When using shallow connection method, renewable generation units must pay the cost of the closest or most reasonable grid connection point, including installing metering devices to record the transmitted and received electricity.

Secondly, distributed power generation mainly uses renewable energy, and relatively high technical and economic benefits, so distributed power users can pay no fixed fee, system usage fee, and can have priority to connect and use the power grid. At the same time, compared with conventional power plants, distributed power plants have priority access rights, and their power generation can be preferentially traded in power trading.

Third, considering that renewable power generation is basically far away from the load center, it is considered as shallow connection recovery, and the connection fee is higher than that of thermal power, it is necessary to seek the state to establish a certain subsidy policy for the connection fee. Renewable energy can also apply for national subsidies when it is connected to the power grid to ensure the further development of renewable energy.

In short, based on the design mechanism of connection price, it is necessary to adjust the proportion of connection fee collection according to generation capacity, load capacity, connection distance and power supply characteristics. In addition, it is necessary to adjust the cost recovery mode according to the different stages of economic development, and clarify the responsibilities of the government, power grid enterprises, power users, industrial and commercial users and residential users in the process of connection price pilot and promotion, so as to promote the gradual implementation of the overall reform, so as to continuously optimize the power supply layout, guide the selection and construction of clean energy, and promote the consumption and utilization of clean energy.

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