Design of flexibility mechanism for electricity market to promote the consumption of new energy

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Abstract. With the development of new energy, it is an irresistible trend for the demand side to consume new energy on a large scale and in a high proportion. At present, China's installed capacity of new energy is growing rapidly, but the flexibility of the power system is insufficient, new energy consumption is difficult, and a large number of abandoned wind and light phenomena appear. In view of the high proportion of new energy consumption in the current environment, this paper designs the overall framework of the flexibility mechanism of the power market to promote new energy consumption, and puts forward the benefits of various market mechanisms in improving flexibility and promoting new energy consumption. Based on each market mechanism, the contribution index is put forward, the role of each market mechanism is analyzed quantitatively, and the considerable benefit of the market flexibility mechanism in promoting the consumption of new energy is proved by an example.

1. Introduction

In order to tackle global warming and achieve green and sustainable development, China has set the goal of "striving to peak carbon dioxide emissions by 2030 and striving to achieve carbon neutrality by 2060". In order to reduce carbon emissions on schedule and achieve carbon neutrality, China attaches great importance to the development of new energy. However, the rapid development of the new energy industry has brought severe challenges to the consumption of new energy, and the lack of system flexibility has led to a large number of phenomena of wind and light abandonment [1-2]. Therefore, it is necessary and significant to carry out flexible planning for future power systems with high proportion of renewable energy.

The concept of power system flexibility was formally proposed in 2005 [3]. In recent years, many scholars have produced a lot of research results on the flexibility mechanism of promoting the consumption of renewable energy. Literature [4] sorts out various definitions of flexibility and forms the definition of power system flexibility. Literature [5] points out that after ensuring sufficient capacity, the system must also be operable in operation, that is, it must have enough flexibility. Literature [6] analyzed the influence of grid constraints on flexibility by using two different flexibility evaluation indexes. In Literature [7], reliability index and Monte Carlo simulation method are used to estimate the reserve capacity configuration demand caused by large-scale wind power access. Literature [8], aiming at the European power market, discusses the allocation method of flexible climbing capacity. Literature [9-10] discusses the design of market mechanism that can...
motivate market participants to provide required climbing resources. Literature [11] defines the flexibility of the system resource at a certain moment as the schedulable capacity potential of the resource in a certain time in the future, and describes it with the concept of flexibility envelope. Literature [12] summarized the international experience of power market promoting system flexibility, and analyzed the key of power market mechanism design.

At present, the literature on the flexibility mechanism that promotes the consumption of new energy focuses on system flexibility, but few consider flexibility from the perspective of the electricity market. Therefore, it is very important to establish a power market mechanism that adapts to the characteristics of new energy sources. In response to this problem, this paper studies the market flexibility mechanism that promotes the consumption of new energy, designs a market flexibility mechanism framework that promotes the consumption of new energy, analyzes the significance of several market mechanisms to promote the consumption of new energy. For these market mechanisms, the contribution evaluation indicators are proposed, which provide a method for quantitative analysis of the contribution of various market flexibility mechanisms in promoting the consumption of new energy.

2. Framework design of electricity market flexibility mechanism promoting new energy consumption

![Framework Design of Electricity Market Flexibility Mechanism Promoting New Energy Consumption](image)

According to the development status of China's electric power market and the characteristics of resource and load distribution, this paper designs a flexible mechanism framework for promoting the consumption of new energy in the electric power market, as shown in Figure 1.

2.1. New energy mid-to-long-term trading in time segments

Trading in time segments is based on the TOU electricity price, dividing the amount of electricity traded by different periods. Trading in time segments is carried out by formulating the organization mode of Trading in time segments and the settlement rules of electricity and electricity charges for Trading in time segments. Time-phased trading mechanism established time related prices, is
essentially a formulation and corresponding electricity load curve of different interval, usually divided into peak stage, flat and valley, can affect the load curve, in the long-term by pushing stage peak valley of electricity load to low electricity load transfer, reduce the system peak valley, from the source to reduce flexibility requirements. For the power system, the reduction of peak difference brings the benefits of saving peak adjustment cost, and for the users, the electricity cost can be saved. The main implementation cost is the input cost of metering equipment.

New energy medium - and long-term time-divided transactions include the following transaction modes.

2.1.1. *Direct trading of new energy power.* Direct trading of new energy power includes intra-provincial direct trading of new energy power and inter-provincial outbound trading. The sellers of such transactions are new energy power generation enterprises and thermal power enterprises; The buyer is the electricity user, the electricity selling company. When the new energy is blocked in the local consumption space, because the long-distance transmission of new energy is easy to cause the loss of electricity and line loss, and its output volatility is large, which is not conducive to the reliability of the power system, the new energy and thermal power can be bundled and conveyed to the grid enterprises at the receiving end through inter-provincial delivery transactions. In addition, new energy power direct trading also includes coal to electricity market trading. Coal to electric heating users, bundled by the power grid enterprise authorized by the power sales company agent for market transactions. Users can choose the most economical pricing method according to the actual heating and electricity consumption, including peak and valley electricity price for heating, electricity consumption pricing method and segment electricity price pricing method. For the new energy enterprises that have reached a deal with the heating users of "coal to electricity", the power dispatching agency will give priority to dispatching power generation when the grid is abandoned in the case of wind and light.

2.1.2. *New energy and thermal power generation rights trading.* New energy enterprises can trade power generation rights with local conventional thermal power plants and self-provided power plants. By transferring the planned electricity to new energy enterprises, they can get a bigger profit space than their own power generation and promote the local consumption of new energy. Similarly, conventional thermal power plants and self-supplied power plants outside the province can conduct cross-regional and cross-provincial power generation rights transactions with new energy enterprises, reduce the amount of wind and light abandoned within the province, and open up a new way for new energy to be absorbed in a large range by adopting the market-oriented mechanism.

2.1.3. *New energy and thermal power bunding trading.* Due to the reverse distribution of new energy resources and load in China, long-distance transmission of wind power is the key to solve the problem of wind power consumption. In order to help the wind power transmission with fluctuation, the combined wind and fire transmission is put forward. Through the cooperation of stable and controllable thermal power and wind power with fluctuation, the wind power can be exported to other cities.

2.2. *Peak-shaving ancillary service trading*
In the current environment of the rapid growth of new energy installed capacity, it is necessary to perfect the market mechanism of power auxiliary service and encourage all kinds of resources to provide system regulation ability. Due to factors such as insufficient peak compensation and lack of demand-side response mechanism, various resources are not active enough to participate in system regulation frequently and the system is not flexible enough, which affects the priority scheduling of new energy. Therefore, we need to further increase the new energy short-term trading recently, real-time, with the aid of market-oriented means mining system flexibility, and perfecting the market trades on FM, spare and encouraging regulation ability demand side resources, and other emerging subject
participate in ancillary services market, explore the transmission mechanism of power auxiliary service charge to the user side.

2.3. Flexible load trading
In the context of the rapid development of renewable energy, demand response has changed the traditional power dispatching control mode of "electricity moving with the load". Through the active response of users' loads, it can effectively alleviate the impact of renewable energy output on the power grid, ensure the stability of renewable energy grid-connected operation, and promote the consumption of renewable energy.

Implement demand response so far countries after the project's economic and social benefits, demand response projects of large-scale implementation can not only help power users to save electricity cost, lower energy consumption and environmental protection, power grid companies and power generation business investment and operation and so on various pressure, can also greatly optimizing the investment decision-making level of the power industry and energy consumption structure, to achieve the development of clean and green development of the society as a whole has an irreplaceable role in promoting.In addition, distributed energy, electric vehicles, user loads or emerging market players are allowed to participate in the power market with virtual power plants as the carrier, and virtual power plants are encouraged to actively participate in demand-side response and ancillary service market transactions.

3. Evaluation index of the contribution of market mechanism to new energy consumption
After designing the flexible mechanism of power market to promote the consumption of new energy, how to choose the appropriate flexible trading mechanism for different provinces and regions has become a major difficulty. This paper puts forward the evaluation index of the contribution of the following market mechanisms to the new energy consumption, which provides a theoretical basis for the actual selection and application of the market mechanism.

3.1. New energy mid-to-long-term trading in time segments
In the trough period of load, the new energy power generation reaches its peak. At this time, by reducing the electricity price during the trough period, the grid load is encouraged to transfer to this period to promote the consumption of new energy. The evaluation index of contribution of segmented trading to new energy consumption in the trough period is as follows:

\[ P_{p,con} = \int_{t_1}^{t_2} P_d \times k_{t,val} \times k_{p,val} \times \varepsilon_d \]

Among them, \( P_{p,con} \) is the contribution of trough electricity price to promoting new energy consumption; \( P_d \) is the load covered by the TU electricity price mechanism; from \( t_1 \) to \( t_2 \) is the trough period of load; \( k_{t,val} \) is the proportion of the duration in trough period; \( k_{p,val} \) is the percentage of the reduction of electricity price in trough period; \( \varepsilon_d \) is the elastic coefficient of load.

3.2. Peak-shaving ancillary service trading
When the phenomenon of wind and light abandonment occurs, the flexible power supply of the system can open up space for new energy consumption by reducing its own output.

Contributions of peak adjustment ancillary service transactions to the promotion of new energy consumption are:
Among them, \( P_{a,con} \) is the contribution value of peak regulation auxiliary services to promote new energy consumption, \( P_{n,d}(t) \) is the net load curve of the system, \( P_{down}(t) \) is the downregulation power curve of the system, \( P_d(t) \) is the load curve of the system, \( P_{wp}(t) \) is the wind power curve of the system, and \( P_{pv}(t) \) is the photovoltaic power curve of the system.

3.3. Flexible load trading

The contribution of flexible load trading to new energy consumption is as follows:

\[
P_{f,con} = \sum_{i} Q_{f,i}
\]  

Among them, \( P_{f,con} \) is the contribution value of flexible load transaction to promoting new energy consumption, and \( Q_{f,i} \) is the load of the flexible load transaction \( i \).

4. Example analysis

Taking 96-point load and new energy data of a typical winter day in 2019 as an example, the province carried out time-divided trading and peak-shifting auxiliary service trading, and calculated the evaluation index of the contribution of the two market mechanisms to new energy consumption respectively.

4.1. New energy mid-to-long-term trading in time segments

Based on the province existing time-sharing electricity prices, in the peak period of electricity price (the price is not only related to the voltage grade, also affected by electricity time) by 10%, while in GuShiDuan electricity prices to fall by 10%, in this case, assuming that the load of the elastic coefficient is 0.2, in the peak period, 20% of daily average load can participate in the peak clipping, in GuShiDuan can participate in the valley, the load peak clipping and valley filling of power distribution in each period, before and after the adjustment of load curve is shown in figure 2.

![Figure 2. Load curve comparison before and after adjustment](image-url)
The peak-valley difference and power income of load before and after adjustment were calculated respectively, and the results are shown in Table 1 below.

Table 1. The effect of trading in time segments on peak-trough differentials and power gains

|                  | Peak load(MW) | Valley load(MW) | Peak valley difference(MW) | Power gains (million yuan) |
|------------------|---------------|-----------------|-----------------------------|---------------------------|
| Before adjustment| 29018.21      | 23318.05        | 5700.16                     | 297.27                    |
| After adjustment | 28860.37      | 23745.89        | 5384.48                     | 301.15                    |

By increasing the electricity price at peak time to 110%, and reducing the electricity price at trough time to 90%, the peak-valley difference of load was reduced from 5700.16MW to 5384.48MW, reducing 315.68MW. Since the electricity price of transmission and distribution and the electricity price of capacity do not change with time, the reduced load during the peak period is completely transferred to the valley period, and the revenue calculated thereby increases from 297.27 million yuan to 301.15 million yuan, an increase of 3.8747 million yuan. According to equation (1), the contribution value of time-divided trading to promoting new energy consumption is 101.02MWh.

4.2. Peak-shaving ancillary service trading

Based on the load curve of a typical winter day in a province in 2019, it is assumed that the average annual load growth of a typical day in 2022 will be 4.8%, the average annual growth of wind power output will be 20%, and the average annual growth of photovoltaic output will be 26%. According to the above assumptions, load curve and net load curve in 2022 are calculated, as shown in green and blue curves in Figure 3 respectively. Take the upper regulation output of the system as the sum of 5% of the load and the maximum load, and the lower regulation output of the system as the sum of 50% of the system boot capacity and 3% of the maximum load. Thus, the upper regulation curve and the lower regulation curve of the system are calculated as shown in purple and orange in Figure 3.

The peak-shaving capacity of the power system is related to the flexible power supply connected to the system. The upper regulating output and the lower regulating output of the system form the peak-shaving range. When the net load curve exceeds the peak-shaving range of the system, the amount of wind and light abandoning will appear, as shown in the yellow part in Figure 3.
According to equation (2), the contribution value of the peak-shaving auxiliary service transaction promoting the absorption of new energy is calculated to be 10543.56MWh, which is the yellow part in Figure 3. This part of electric quantity needs to be regulated by the flexible power supply of the system. Through the peak-shaving auxiliary service transaction, the absorption capacity of new energy can be improved to meet the demand of the system for peak regulation.

5. Conclusion
It can be seen from the above analysis that the market flexibility mechanism can effectively promote the consumption of new energy. Time-divided trading guides users to change their electricity habits through price incentive measures. This regulation means can promote the consumption of new energy, reduce the peak valley difference of load, and reduce the peak regulation demand of the system. In addition, it is necessary to fully develop and utilize the auxiliary service market of peak shaving to promote the absorption of new energy.

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