Discussion on Electricity Spot Market Mode Adapting to Large-scale Renewable Energy Consumption

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Abstract. With the implementation of the "Thirteenth Five-Year Plan", the scale of my country's renewable energy installed capacity continues to expand, and the responsibility for consuming renewable energy power is becoming higher and higher. Promoting the reform of the electricity spot market provides a good opportunity to realize the consumption of large-scale renewable energy. This article aims at the northwest region where renewable energy accounts for a relatively high proportion in my country, and clarifies the factors that inhibit the consumption of renewable energy. Based on the investigation of the typical foreign power spot market model, a power spot market model suitable for large-scale renewable energy is proposed. According to the actual data of a province's power grid in the northwest region, the day-ahead spot market under different models was cleared separately. The results show that the centralized market model is more suitable for large-scale renewable energy grid-connected consumption, and is conducive to promoting energy conservation and emission reduction and reducing power generation costs.

1. Introduction
Northwest China is rich in wind and solar resources. It is estimated that by 2020, the renewable energy installed capacity of the Northwest Power Grid will account for 49% of the installed capacity. However, due to limited consumption space and insufficient peak shaving capacity, some provinces have a serious problem of abandonment of wind and solar. In 2019, the amount of solar abandonment in Northwest China accounted for 87% of the country's total. Renewable energy can reduce the performance risk caused by the uncertainty of output through the spot market [1][2]. With the advancement of the construction of China's electricity spot market, it is necessary to design a electricity spot market model that adapts to large-scale renewable energy based on the actual situation of the power grid in the northwest region and increase the consumption of renewable energy power.

Literature [3]-[5] put forward suggestions for the construction of domestic electricity spot market by combing through typical foreign electricity spot market models and analyzing the principle of spot market. Literature [6]-[7] designed the spot market development mode and transaction mechanism according to the actual situation of domestic power grids in different regions. At the same time, some scholars have deeply analyzed the typical international market mechanism to promote the consumption
of renewable energy [8]-[10], and proposed a flexible electricity market mechanism that adapts to the domestic consumption of renewable energy [11]-[14]. Literature [15]-[17] proposed a spot market clearing model considering renewable energy; literature [18] designed a spot market trading mechanism adapted to China's renewable energy quota system; literature [19] proposed to promote the absorption of high proportion of renewable energy by establishing the flexibility of the incentive system of power spot market, and designed the path of market construction. Existing studies have conducted certain studies on spot market construction and renewable energy participation in market transactions from multiple perspectives, but there is a lack of analysis and design of electricity spot market models that adapt to large-scale renewable energy. This article takes the northwest region with a high proportion of renewable energy installed capacity as an example. Based on the analysis of factors affecting the consumption of renewable energy, this paper compares and analyzes the centralized and decentralized power spot market models, from the medium and long-term contract delivery method and the spot market organization method, Market clearing and settlement mechanisms, etc., designed a spot market model that is suitable for large-scale renewable energy consumption; through example simulation, the clearance results of spot market under different modes are analyzed from the perspectives of day-ahead optimization space, renewable energy consumption and all-day power generation cost.

2. Analysis on Restricted Factors of Large-scale Renewable Energy Consumption

2.1. Market consumption space is limited
First, local electricity consumption is limited. The large-scale and concentrated development of renewable energy bases in Northwest China are mostly located in areas with backward economic development and weak grid structure, with low local consumption demand and surplus power supply; second, they are affected by the limitation of the capacity of external transmission channels. The consumption of large-scale renewable energy in Northwest China mainly depends on trans-provincial and trans-regional power supply. However, the construction of power grid lags behind the progress of power supply construction seriously, resulting in frequent over-limit transmission sections in the period of new energy boom in Northwest China, and severe wind and light abandonment in local areas and periods.

2.2. Insufficient flexibility to adjust resources
In the scenario of large-scale renewable energy grid operation, solar and wind power generation is intermittent and volatile, which brings great pressure to power forecast, operation deployment, grid-connection control, etc., and the demand for flexible resources is particularly vigorous. At present due to the power demand side management effect is not obvious, mainly rely on thermal power unit for active control in northwest China, as a result of the heating period heating, thermal power unit need to run "thermal power", the minimum operation load is higher, leading to a serious shortage of system load capacity, can’t adapt to large-scale wind power and photovoltaic power generation given requirements.

2.3. The market mechanism is not sound
In the process of power generation and electricity consumption transition from the plan to the market, most of the priority power generation of renewable energy in Northwest China participates in the market transaction in the way of "quantity without price", and the transaction price is formed through market competition. However, the current market trading of renewable energy requires the same bidding with non-renewable energy, which cannot reflect the environmental value of renewable energy and its competitiveness is not significant enough. At the same time, the annual and monthly trading cycle of the market is difficult to adapt to the characteristics of volatility and randomness of new energy power generation, unable to form a time-sharing price signal, so as to reflect the new energy fluctuations and the supply and demand of electricity surplus and shortage; In addition, in the
absence of provincial spot market, the surplus electricity space cannot be accurately defined on the basis of clear provincial load demand, and it is difficult to absorb the surplus renewable energy electricity through inter-provincial spot market of surplus renewable energy power.

3. Comparison of Electricity Spot Market Models

From a worldwide point of view, the development mode of electricity spot market can be generally summarized into two categories: decentralized market and centralized market. Among them, the distributed market refers to the bilateral physical contract signed by the issuing parties in the medium and long-term trading stage (years ago, months ago, weeks ago), and the amount of electricity agreed in the contract needs physical delivery. In the pre-day stage, market members arrange the generation and consumption curve of the next day by themselves according to the signed bilateral contracts; Real-time balancing stage, the market members to declare send electricity curve is raised and lowered for quotation, dispatching institutions keep hair electricity curve of the physical implementation, at the time of the load deviation or network congestion members raised and lowered a quotation based on the market, in order to minimize the adjustment cost optimization scheduling for targets, and power balance and power grid in order to ensure safety. Most European countries, such as the UK and Northern Europe, adopt a decentralized trading model. In the Nordic electricity market, renewable energy is allowed to directly participate in spot trading, and renewable energy is allowed to adjust the price within the operating day, and intra-day market and balanced market are coordinated to solve the system imbalance caused by the fluctuation of renewable energy output.

Medium and long-term transactions in the centralized market can also be determined by market members through consultation, but they belong to the scope of financial price difference contracts to avoid risks and lock prices. The electricity agreed in the contract does not require physical execution, nor does it impose restrictions on the system's safe and economic scheduling, but only has the significance of settlement. In the day-ahead and real-time spot market, both parties shall declare the total electricity to participate in the centralized bidding, and on the premise of satisfying all kinds of safety constraints, the centralized optimization of clearing will form an executable power generation and consumption plan curve. If the market members really require the physical execution of the bilateral contract, it can be marked in the pre-day market declaration. At this time, it defaults to the lowest quotation in the market, and priority clearance can be realized under the premise of meeting the security constraints of the power grid. Centralized markets are widely used in regional power markets in the United States, Australia, New Zealand and Singapore. In the PJM power market, renewable energy power generation enterprises can directly participate in day-ahead and real-time market transactions, declare the electricity generation and power generation price at the same time, and settle the electricity generation with the unified clearing price of the market or the nodal price of the node in which they are located. Renewable energy units can adjust the price according to the latest forecast result of the generation capacity ceiling, but cannot report the price in operation.

4. Research on Electricity Spot Market Mode Adapting to Large-scale Renewable Energy Participation

4.1. Market model selection

In the decentralized mode, market entities need to determine the day-ahead power generation and consumption curve according to medium and long-term contracts, which solidifies most of the regulatory capacity and substantially reduces the adjustment space for system operation, making it difficult to balance the volatility and intermittency of renewable energy output. In addition, the spot price formed by the decentralized transaction can only reflect the price of the deviated part, so it is difficult to effectively guide the issuer and use the resources of both sides to match optimally. The centralized spot market can effectively guarantee the real-time balance of electric power and the safe and stable operation of the power grid through the centralized optimization of the whole electric power.
In a centralized market based on the principle of marginal cost bidding, renewable energy can be cleared in priority compared with conventional units.

In view of the above situation, in order to realize the optimal allocation of power resources to a greater extent and to ensure the full absorption of large-scale renewable energy, the spot market with large-scale renewable energy should choose the centralized market model. Based on a provincial northwest area as an example, based on the centralized model to build a electric energy market and real-time electric power market, long-term deal with the spot market in the form of contracts for differences to realize full and optimization, power centralized price bidding for physical implementation of medium and long-term trading power, can be marked in day-ahead market declare to achieve preferred liquidation.

4.2. Medium and long-term contract delivery method

On May 10, 2019, the Energy Bureau of the National Development and Reform Commission issued the Notice on Establishing and Improving the Guarantee Mechanism of Renewable Energy Consumption, which clarified the implementation mechanism of the renewable energy quota system, and the user side of the market subject should assume the responsibility of consumption. The purpose of the quota system is mainly to discover the monetary value of the positive externalities of renewable energy (mainly environmental value) [18][20], so that the price of renewable energy can truly reflect the monetary evaluation of the positive externalities of renewable energy by the demander. Therefore, for medium - and long-term trading contracts bound with the environmental value of renewable energy, the amount of electricity traded can be included into the consumption amount of the demand side, such as the amount of electricity purchased with fixed price signed by power grid companies and renewable energy generators, and the amount of electricity traded under inter-provincial framework agreements.

Because it is difficult to realize simple settlement of price difference between medium and long-term transactions bound with environmental value and spot market transactions containing only electric energy value, this kind of transactions only sign physical contracts and carry out physical delivery in the spot market. For medium - and long-term contracts that are not included in the consumption of the user side, financial contracts can be signed and physical delivery is not mandatory.

There are mainly three ways for medium - and long-term contract electricity decomposition. First, the supply and demand parties agree by themselves (bilateral negotiation and transaction of electricity); The second is by the market subject independent declaration (listed trading electricity); The third is decomposed by the dispatching agency (centralized bidding trading electricity). Due to the randomness and volatility of new energy power generation, both sides of the transaction can adjust the medium and long-term transaction decomposition curve after reaching a consensus the day before.

4.3. Electricity spot market organization method

Spot market to adopt the "unified declaration, centralized optimization of clearing" organization. Considering that the market decision-making ability of the user side in the early stage of the market is insufficient, it is necessary to gradually train the marketization awareness of the user side. The user side of the day-ahead market only needs to declare the load forecast curve, but does not need to declare the price willingness. According to the centralized requirement, both producers and consumers declare the total electricity, that is, the generation side declares the price information between the minimum technical output and the maximum technical output, and the user side declares the total electricity demand curve of the next day. For the intraday dissolved electric quantity of the long-term renewable energy power contract requiring physical execution, the power producer shall mark it in the market declaration before the scheduled date, and default quotation shall be the lowest in the market to ensure priority clearance. Considering the uncertain characteristics of new energy power generation, new energy stations need to declare the ultra-short-term power generation prediction curve in the real-time market, and can modify the quotation according to the ultra-short-term power generation prediction.
4.4. Market clearing and settlement mechanism

Before the inter-provincial spot market declaration, it is necessary to pre-clear the intra-provincial spot market and participate in the inter-regional inter-provincial surplus renewable energy power spot market transaction on the basis of clarifying the residual power generation capacity of the new energy in the province. Finally, according to the results of inter-provincial spot market clearance, the relevant boundary conditions are adjusted to carry out the formal clearance of intra-provincial spot market. The provincial spot market aims at minimizing the power generation cost of the whole network. According to the latest operating state and forecast information of the power grid, the centralized clearance of units and power grid operation constraints is carried out, and the clearance models include the combination of security constrained units (SCUC) and security constrained economic dispatching (SCED) models. The SCUC model is mainly used for the combination of generator sets on the next day of day-ahead market clearance, while the SCED model is used for the 15-minute generation and electricity consumption plan and nodal price of market participants in day-ahead market and real-time market clears [21]. When the decomposition curve of medium- and long-term physical contracts cannot be fully cleared due to the security constraints of the power system or the physical constraints of the unit, the decomposition curve of medium- and long-term physical contracts of the power generator and the user can be reduced simultaneously according to the principle of equal reduction.

The clearing quantity in the spot market shall be settled by deviation settlement method. Among them, the medium- and long-term transaction settlement curve is settled according to the price agreed in the contract; the deviation between the day-ahead market clearing curve and the medium-and long-term transaction settlement curve is settled according to the day-ahead nodal price; the deviation between the actual power generation curve or electricity consumption curve and the day-ahead market clearing curve is settled according to the real-time market nodal price.

5. Analysis of market clearing results under different modes

Taking A Province in Northwest China as an example, the spot market of this province is cleared according to the decentralized market and the centralized market model. According to the clearance results, A comparative analysis is made from three aspects, namely, day-ahead optimization space, consumption of renewable energy and all-day power generation cost. The new energy installed capacity in A province accounts for more than 50%, and it is a typical region of power delivery. Recently, it was predicted that the maximum power generation space (including system load and tie line output power) of A Province on the next day would be 14724 MW, the maximum online power of planned generating units would be 9411 MW, and the maximum output power of new energy (wind power and solar power) would be 7969 MW. Specific clearance results are as follows.

5.1. Day-ahead optimization space

The decentralized market and the centralized market have different unit priorities, which has led to a big difference in the spot bidding space recently, as shown in Figure 1.

![Figure 1. Bidding space in the spot market](image)
market, it needs to be carried out first, resulting in a smaller optimization space. The larger the optimization space, on the one hand, can improve the optimization effect, reduce the cost of power generation, and achieve the maximum social welfare; On the other hand, it also makes the dispatching space of the power grid larger and easier to deal with the power fluctuation of the power grid, especially suitable for large-scale renewable energy grid with more power fluctuation.

5.2. Renewable energy consumption

Figures 2 and 3 show the winning bids of different types of units in the spot market. It can be seen that the bidding output of coal-fired units in the centralized market is lower than the bidding output in the decentralized market, and renewable energy sources (hydropower, wind power and solar energy) occupy more power generation space. In terms of electricity, the total amount of renewable energy in the centralized market is 18,600.95 MWh higher than the decentralized one. Among them, hydropower is 5407.15 MWh higher, wind power is 10370 MWh higher, and solar power is 2823.14 MWh higher.

Figures 4 and 5 show the proportion of all-day output corresponding to the three types of units. It can be seen that the proportion of coal power output in the decentralized market has reached 12%, which is 7% higher than that in the centralized market. Accordingly, the output of new energy (wind power and solar power) in the decentralized market has decreased by 5%, and the output of hydropower has decreased by 2%. Therefore, the centralized market is more advantageous than the decentralized market and the consumption of large-scale renewable energy, which is more in line with the national energy-saving and emission-reduction requirements.

5.3. Full-day power generation cost

The total power generation cost of the whole network includes all the power generation costs of new energy units, hydropower units and coal-fired units. The total power generation cost of the whole
network under the two market modes is shown in Fig. 6. It can be seen that the total power generation cost of the whole network in the decentralized market is higher than that in the centralized market, which is 1.91 million yuan higher in just one day, accounting for 4% of the total power generation cost in the centralized market. Obviously, the decentralized market is more likely to waste resources due to unreasonable resource allocation. The centralized market has a higher degree of optimal resource allocation and lower power generation cost, which is conducive to reducing the electricity purchase cost of market users and actively absorbing more renewable energy.

6. Results & Discussion
Taking Northwest China as an example, this paper analyzes the main factors that restrict the consumption of renewable energy based on the actual situation of the power grid and the current situation of the electricity market. By investigating the development mode of typical foreign spot electricity market, it proposes to take the centralized mode as the basis for the development of the spot market in Northwest China with high proportion of renewable energy. The delivery mode of medium and long-term contract, the organization mode of spot market, and the clearing and settlement mechanism are designed to adapt to large-scale renewable energy consumption. Finally, northwest province power grid based on the actual data, respectively has the spot market for centralized and decentralized market clearing, by comparing the market space for the optimization of the two modes, new energy given situation, the three aspects of electricity purchasing cost, prove that the centralized market model is more suitable for large-scale renewable energy grid given, promote energy conservation and emissions reduction, and reduce the cost of power generation.

The discussion in this article is still limited to the current policy and market environment. With the subsequent increase in the market awareness of electricity users, the development of the renewable energy green certificate market and the excess consumption market, and the improvement of the auxiliary service and capacity market system, the need will continue Carry out more in-depth research on spot trading rules and market connection methods.

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