Optimal Decision-making of Multi-market Trading of Power Sales Companies Based on Renewable Portfolio Standard on Electricity-Consumption Side

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Abstract. In the electricity market where the renewable energy quota system is implemented on the electricity selling side, the electricity selling company can complete the quota of consumption and realize profit through electricity trading, consumption trading, green certificate trading and other forms. Based on the all day renewable energy generation curve trading mode, this paper puts forward the corresponding trading rules, which can effectively promote the active consumption of renewable energy in the power selling side. This paper comprehensively compares the trading income of electricity selling companies in electricity market, green certificate market and transferable load market. Aiming at the maximum profit, it studies the operating strategy of electricity selling companies, which can provide reference for multi market trading decision-making of electricity selling companies.

1. Introduction
In recent years, with the expansion of renewable energy development scale, wind power, photovoltaic, hydropower and other renewable energy sources have been developed rapidly in China. At the same time, the intermittence and fluctuation of renewable energy have brought uncontrollable influence to power dispatching, and the peak valley difference of power load in China is large, the flexibility of system power supply is insufficient, and the market incentive policy for renewable energy consumption is lack, which leads to the serious phenomenon of wind, light and water abandonment in China. For a long time, China has been implementing the subsidy mechanism of fixed feed in price for renewable energy power generation. The government has a serious financial subsidy crisis, and the gap of subsidy funds is too large.

At present, China has begun to implement the renewable energy quota system, which marks that China's market-oriented consumption of renewable energy has entered a new stage. In order to encourage the investment and consumption of renewable energy, on May 10, 2019, the national development and Reform Commission and the National Energy Administration jointly issued the notice on establishing and improving the guarantee mechanism for the consumption of renewable energy power, clarifying the specific implementation mechanism of the renewable energy quota system. According to the quota system of our country, the power consumption responsibility weight of
renewable energy is set according to the provincial administrative region. The power selling companies, including the power grid, the power users participating in the wholesale market and the enterprises with their own power plants are assessed as the market subjects bearing the responsibility of consumption, and the power grid enterprises are responsible for the implementation of the responsibility weight. The market entities that bear the responsibility of consumption can complete the consumption volume mainly by the actual consumption of renewable energy power, and can complete the consumption volume by purchasing the excess consumption of renewable energy power from the market entities that exceed the annual consumption volume and voluntarily subscribing for the supplement (replacement) of renewable energy green power certificate. The regulations clearly put forward that we should do a good job in the connection between the implementation of the weight of responsibility elimination and power trading.

Different from the previous implementation of the renewable energy quota system on the power generation side, the guarantee mechanism issued by the Chinese government adopted the implementation of the renewable energy quota system on the power sales side, which made it clear that market entities such as grid companies, power sales companies and power users need to bear the weight of consumption responsibility. At the same time, the guarantee mechanism stipulates that the electricity selling company can sell the excess consumption of renewable energy in the form of green energy certificate, which enriches the means of electricity selling company participating in the electricity market transaction and has positive significance for encouraging the electricity selling company to actively consume renewable energy.

When designing the market mechanism based on the renewable energy quota system on the electricity selling side, how to encourage the electricity selling companies to absorb renewable energy in their own way is the key point to be considered. The previous research of domestic scholars [1-4] mainly focused on the renewable energy quota system on the power generation side. With the continuous promotion of the new round of electricity reform, the research on the renewable energy quota system at the electricity sales side is gradually in-depth. Literature [5-7] discusses the system design, market mechanism, trading system and trading mode of renewable energy quota system on the electricity selling side. Literature [8-11] analyzes the impact of renewable energy quota system on the long-term development of renewable energy power generation industry based on system dynamics. Literature [12] analyzes the renewable energy quota system and the behavior of power generation enterprises through the establishment of evolutionary game model. The evolution process between strategies and the influence of key parameters in the evolution process are analyzed. In reference [13], the optimal decision-making of high load consumption of blocked wind power in the period of down peak load regulation is studied by establishing the dynamic game model of supply chain. In reference [14], a multi-agent five-stage game model is constructed to analyze the optimal procurement and pricing mechanism of smart grid under multi-source and multi category consumers. In reference [15], considering the trading behavior of electricity selling companies in forward contracts, spot contracts, options and other markets, the paper uses conditional risk value to measure the size of losses, and establishes the expected purchase cost loss risk model, which provides a reference for electricity selling companies to purchase electricity in multi market environment. The above research laid a foundation for this study.

This paper proposes a day ahead electricity market trading rule based on electricity generation and consumption curve trading, and establishes a profit model of electricity selling company, taking into account the transfer load cost of electricity selling company, and studies the optimal decision-making method of multi new energy power plants participating in the market trading scenario. The trading rules proposed in this paper can promote the whole power market to consume clean energy at a lower cost. At the same time, the decision-making method proposed in this paper can provide a reference for the decision-making of power selling companies under specific circumstances.
2. Market based on curve Trading

2.1. General thinking
At present, the quota system issued in China only considers that users must complete a certain amount of renewable energy quota, does not distinguish the contribution of users to the consumption of renewable energy, and does not differentiate the cost they should pay for the consumption of renewable energy according to the contribution of users. In the actual power system, the power generation curve of wind power station, photovoltaic power station and other new energy generating units has certain regularity and characteristics. The similarity between the power generation curve and the power consumption curve of the power selling company affects the cost of clean energy consumption of the power selling company to a certain extent. Some of the electricity selling companies have high similarity between their own electricity load curve and clean energy generation curve, and some of them have strong demand side response ability, which can change the electricity load curve to a certain extent. The common feature of these power selling companies is that the cost of clean energy consumption is lower than other power selling companies and users. If they are encouraged to consume more clean energy, the cost of clean energy consumption in the whole power system can be reduced. Therefore, to build a curve based renewable energy power market and encourage users to absorb renewable energy in their own way is a feasible way to achieve lower cost consumption of renewable energy in the market way.

2.2. Trading rules
Every day before the opening of the day ahead electricity market of conventional energy, the day ahead market of renewable energy shall be carried out, which shall be organized by the electric power trading agency, and the physical transaction of binding electric energy value and environmental value shall be carried out. The renewable energy day ahead market is trading based on the renewable energy all day generation curve.

Renewable energy power generation enterprises declare the supply price of renewable energy and its generation curve. The user side can choose the power generation curve and purchase quantity of the power generation enterprise, and can purchase from multiple renewable energy sources cumulatively. The final bid winning curve of the user is the superposition of the delisted curve, and the final bid winning curve of the renewable energy power generation enterprise is the superposition of all the curves listed and delisted by the user.

In the market design, the renewable energy day ahead market does not take the electricity quantity and electricity price of each period as the trading target, because the consumption of renewable energy is not a single period problem, but a coupling problem of each period of the whole day. If the time-sharing electricity trading method is adopted, users with poor similarity of power generation and consumption curve can still compete with users with high similarity in peak hours, it is difficult to distinguish the impact of user electricity consumption behavior on renewable energy consumption, and it is difficult to really encourage users with good electricity consumption behavior. The users with low similarity can only purchase a small part of the electricity in the day ahead market of renewable energy, and the load demand in the peak period of the remaining load needs to be purchased at a high price in the day ahead market of time-sharing bidding, punishing its negative effect on the consumption of renewable energy sources; while the users with high familiarity with the curve can purchase a small part of the electricity in the day ahead market of renewable energy. More high-value clean energy (including electric energy value and environmental value) will be purchased in the market, and its positive role in renewable energy consumption will be rewarded, so as to achieve the design goal of market mechanism to encourage users to actively cut peak and fill valley, and promote renewable energy consumption.
3. An analysis of the economic benefits of the electricity selling company

3.1. Profit source of electricity selling company
In the electricity market, the electricity selling company purchases renewable energy and conventional energy to generate electricity, and sells the electricity to the agent's electricity customers, so as to earn a profit from the price difference. When the purchased renewable energy power generation fails to meet the requirements of consumption quota, it is necessary to purchase the certificate from the green energy certificate market, or purchase the excess consumption from other power selling companies that consume the renewable energy power generation. If the purchased renewable energy power generation exceeds the demand of consumption quota, the excess consumption can be obtained by selling it on the market Additional revenue.

3.2. Transferable load
In view of the high economic and environmental value of renewable energy power generation, which can bring higher benefits to the power selling companies, some of the power selling companies may use the method of transferring load to purchase more renewable energy power generation, so as to obtain greater benefits. Generally speaking, the transfer load calls need to pay the related fees. One of the decision-making points for a power selling company to get the most profit is to choose how many transferable loads to call.

3.3. Green energy Certificate Market
The consumption volume purchased by the electricity selling company in the consumption volume market and the certificate purchased in the green energy certificate market can be used to complete its renewable energy consumption quota task. From this perspective, the consumption volume market is equivalent to a green energy certificate market. The difference is that the traditional green energy certificate market is provided by new energy power generation enterprises, while the consumption market is provided by power users such as power sales companies.

4. Optimal decision model of power selling company and Practical example

4.1. Profit model
Considering the expenditure of conventional energy, renewable energy, revenue in green energy certificate market, expense of transferring load and revenue from selling electricity, the expression of total revenue is as follows:

\[
P = Q_a P_s - Q_r P_r - (Q_a - Q_r) P_c + (Q_r - Q_q) P_g - C_t
\]

Among them, \(P\) is the total revenue of the electricity selling company, \(Q_a\) is the total electricity sold by the electricity selling company, \(P_s\) is the average sales price, \(Q_r\) is the purchased renewable energy power generation, \(P_r\) is the average price of the purchased renewable energy power generation, \(Q_a - Q_r\) is the purchased conventional energy power generation, \(P_c\) is the average price of the purchased conventional energy power generation, \(Q_r - Q_q\) is the renewable energy quota to be completed by the electricity selling company, \(P_g\) is the green energy. Certificate price, \(C_t\) is the fee paid by the seller to call the transferable load.
When $Q_r > Q_q$, the renewable energy generation purchased by the seller is greater than the consumption coordination, $(Q_r - Q_q)P_g > 0$, it means that the seller gains profits by selling the excess consumption. When $Q_r < Q_q$, the renewable energy power generation purchased by the seller is greater than the consumption cooperation, $(Q_r - Q_q)P_g < 0$, it means that the seller needs to pay for the green energy certificate.

The constraints are as follows:

$$Q_a \geq Q_r \geq 0$$

(2)

That is to say, the renewable energy power generation purchased by the electricity selling company shall not exceed its electricity sales and shall not be less than zero.

4.2. Example conditions and data

The specific agreement in this example is as follows. The renewable energy power generation enterprises declare the estimated power generation capacity of each hour of tomorrow every day, and the predicted power generation capacity of 24 hours constitutes the predicted power generation curve of tomorrow. The electricity selling company applies for renewable energy power generation according to its own electricity load curve (also divided into 24-hour consumption points). The electricity selling company can purchase the power generation of a certain renewable energy power plant in full or only part of the power generation. When purchasing only part of the generation, the share of the purchased generation in each of the 24 time periods of the day must be the same. When the electricity selling company calls the transferable load, it can only reduce the power load during the 10 hour peak period from 8:00 a.m. to 18:00 p.m. and the 10 hour low period from 22:00 p.m. to 8:00 a.m. the next day. The proportion of load reduction and increase in each period is the same.

The expected power generation curve and power consumption curve of wind power plant 1, wind power plant 2 and power selling company are shown in Fig. 1.

![Figure 1. Power generation curve of wind power plant and power consumption curve of power selling company](image)

The agreed price for the purchase of renewable energy is 780 ¥/MW·h, the fixed price for the purchase of conventional energy is 660 ¥/MW·h, the fixed price for the sales of electricity companies
is 690 ¥/MW·h, and the fixed price for the purchase or sale of green energy certificates is 150 ¥/MW·h. The formula for the seller to pay for transferring the load is as follows.

\[ C_i = P_i Q_a \eta_i \]  \hspace{1cm} (3)

\[ P_i = 8,0.04 \geq \eta_i \geq 0 \]  \hspace{1cm} (4)

\[ P_i = 200\eta_i, 0.20 \geq \eta_i > 0.4 \]  \hspace{1cm} (5)

Where, the total cost \( C_i \) is equal to the call unit price \( P_i \) multiplied by the sales volume \( Q_a \) multiplied by the call proportion \( \eta_i \). \( P_i \) unit is yuan / MW · h, \( Q_a \) unit is MW. The unit of \( \eta_i \) is 1, which indicates the proportion of the transferred load called to the sales volume \( Q_a \). When the call proportion \( \eta_i \) is less than or equal to 0.04, \( P_i \) is fixed at 8 yuan / MW · h; when \( \eta_i \) is greater than 0.04, \( P_i \) increases linearly with the increase of \( \eta_i \), indicating that the more transferable load the seller calls, the more expensive the call unit price. And \( \eta_i \) cannot exceed 0.2 at most.

4.3. Comparison between single purchase and combination purchase

First of all, consider the case of no transfer load. At this time, the power selling company can choose to purchase the power generation of a certain wind farm alone or a combination of two wind farms. Use MATLAB software to solve the model, and get the highest proportion of the power generation of each wind power plant purchased by the power selling company and the profit of the power selling company in each case, as shown in Table 1.

| Category                  | Purchase only wind power plant 1 | Purchase only wind power plant 2 | Combined purchase of two wind power plants |
|---------------------------|----------------------------------|----------------------------------|-------------------------------------------|
| Proportion of power generated by purchasing wind power plant 1 | 0.7143                           | 0                                | 0.3650                                    |
| Proportion of power generated by purchasing wind power plant 2 | 0                                | 0.8553                           | 0.7400                                    |
| Total wind power purchased | 673.6 MW                         | 908.3 MW                         | 1130.1 MW                                 |
| Profit from sale of electricity | 83 thousand                    | 90 thousand                      | 96 thousand                               |

From the data in Table 1, it can be seen that the renewable energy generation capacity and profits purchased by the power selling company are higher than those purchased by any wind power plant alone in the case of combined power purchase, so the power selling company should give priority to the strategy of combined power purchase to obtain the maximum benefits.

4.4. Benefit comparison of transferring load

When the power selling company adopts the combined power purchasing strategy, it can obtain more profits by calling the transferable load. At this time, the proportion of the transfer load is an important factor affecting the profit. Use MATLAB software to solve the profit model, and calculate the
maximum renewable energy generation purchased by the seller and the maximum profit of the seller when the transfer proportion is between 0 and 0.2, as shown in Fig. 2.

![Figure 2. Maximum renewable energy generation purchased and profit on sale under different proportion](image)

It can be seen from Figure 2 that with the increase of the transfer proportion, the maximum renewable energy generation and the profit on electricity sales increase first and then decrease, but the maximum values of the two are different. This shows that the more renewable energy is purchased, the higher the profit of the power selling company is. Only when the transfer proportion is reasonably selected according to the market situation can the maximum profit be obtained.

5. Conclusion
In order to adapt to the renewable energy quota system proposed by the Chinese government, and promote the active consumption of renewable energy by users, this paper proposes a renewable energy day ahead trading market rule based on curve trading, in which users can only purchase power in proportion to the generation curve in each period. This kind of transaction rules can effectively promote the users with high similarity between the power load curve and the discovery curve to buy more renewable energy and reduce the cost of consumption of the whole society. Under the transaction rules, this paper constructs the profit model of the power selling company, compares the benefits of single power purchasing and combined power purchasing, and studies how the power selling company transfers the transferable load to achieve the maximum profit. The research results of this paper can promote the renewable energy quota system to play a better role, and provide a reference for the operation decision of the power selling company.

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