Stable Matching Model of Green Certificate Centralized Transaction Based on Virtual Power Plant

Ming Li[1] , Wenyu Zhang[2,*] Meng Yang[3], Hongyong Liu[4], Jie Ren[5], Jiageng Dai[6], Shuailiang Yao[7]

{565742354@qq.com[1], Zhang.wyu@hotmail.com[2], 790715461@qq.com[3], liu_hongyong123@126.com[4], 534971271@qq.com[5] , 595079685@qq.com[6], jwsu97@163.com[7]}

State Grid Hebei Zhangjiakou Scenery Storage and Transportation New Energy Co. LTD, Zhangjiakou, Hebei , China

Abstract. The green certificate trading system relies on market competitive dividends to achieve the goal of renewable energy development in the most cost-effective way, but the market design involves many complex issues such as the formulation of trading rules, the formation of price mechanisms and the implementation of control measures, so only a scientific and thorough market design can ensure the good operation of the green certificate trading market. Based on the market design idea of stable matching, this paper adopts Pro-rata matching algorithm to carry out "Research on stable matching model of green certificate centralized trading based on virtual power plant". The effectiveness of stable matching market design to solve the inefficiency problem of green certificate trading market is evaluated from two perspectives of stability and incentive.

Keywords. Green certificate trading; Quota system; Stable matching; VPP

1 Introduction

China renewable energy consumption, there are two ways to participate in the market trade and participate in the protection of consumption. China's green electricity trading has formed a "certification and electricity integration" mode, so after participating in green electricity trading, will automatically obtain the corresponding execution of the green card[1]. For the renewable energy part of the electricity purchased from the electricity sales company, the green certificate cannot be automatically obtained at present, and this part cannot directly obtain the green certificate of electricity, in the current discussion of green electricity/green certificate in the carbon emission reduction of purchased electricity, it is often very easy to be ignored. Among the electricity purchased directly by the user through the grid or the electricity selling company, the renewable energy electricity is mainly purchased by the renewable energy electricity consumption protection mechanism. Although the absorption guarantee mechanism can reduce the rate of wind and light abandonment and promote the development of renewable energy power generation enterprises, it cannot reflect the environmental attributes of renewable energy power[2]. Therefore, the on-grid electricity of renewable energy power that is guaranteed to be consumed can clarify the environmental attributes by applying for a green certificate, and it is expected to be realized in the carbon emission accounting of purchased power.

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In the process of green certificate trading, it is necessary to carry out green certificate centralized trading and bilateral trading at the same time. This system conforms to the general law of market development, and also helps China's green certificate trading market to play a role in promoting market liquidity and reducing volatility risks[4]. In this paper, the two-sided matching theory is used to construct the matching stability model of green certificate transaction, but the complexity of the green certificate transaction market makes it difficult to meet the use conditions of the traditional delayed acceptance algorithm.

2 Green card transaction matching based on virtual power plant

2.1 Green certificate trading market framework based on VPP

Market participants based on virtual power plant green certificate trading include distribution market operators, distribution system operators, green electricity producers, green electricity green certificate consumers.

Figure 1 is green certificate trading market framework based on VPP. The National Renewable Development Center issues green certificates to distributed and centralized new energy sources that meet the requirements, and virtual power plant operators purchase green certificates and connect green certificates to virtual power plants. The industrial users, commercial users and energy storage gathered in the virtual power plant can be green certified. Government departments conduct carbon accounting and dual-control configuration for industrial and commercial users, and recognize the deductibility of user green certificates.

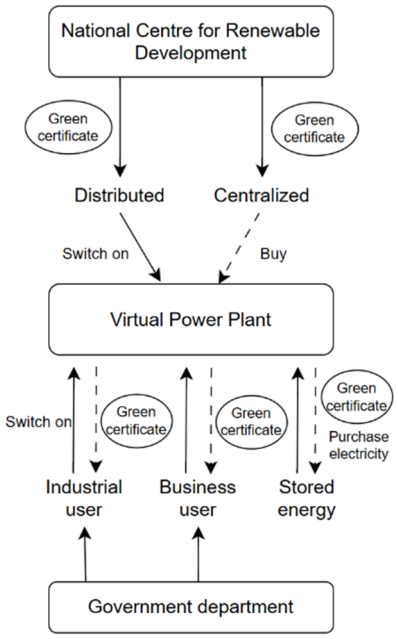

Figure 1 Market framework

2.2 Green certificate centralized transaction stable matching model

A stable matching result needs to have two basic characteristics of stability and incentive. In order to achieve stable matching of green certificate centralized trading, centralized matching trading based on matching algorithm needs to make the results of order execution and transaction allocation in green certificate centralized trading market stable and incentive[3]. The problem of price signal distortion exists in green certificate trading in China.

In financial markets, the two types of algorithms used by central clearing houses are the Pro-rata algorithm and the Price/Time algorithm. Among them, the proportional allocation algorithm allocates an incoming offer in proportion to its scale in a limited number of orders, usually maximizing the trading volume satisfied by the order allocation, which is helpful to narrow the price difference between bids and bids. The price/time algorithm allocates orders on the exchange based on the principle of the best offer or the first entry principle, that is, The motivation of using this algorithm is to narrow the price spread. However, its "first-in first-out principle" makes the order entering the transaction after the transaction can only obtain less of the assigned transaction object, and also inhibits more market participants from entering the transaction to a certain extent.

Similar to the carbon emission trading market[7]. The green certificate trading market prepares the market attributes of financial derivatives, learns from the methods of carbon emission trading market and financial market to improve market efficiency, introduces the virtual power plant mechanism and matching algorithm into the green certificate centralized trading market, and builds a stable matching model of green certificate centralized trading based on the virtual power plant mechanism and Pro-rata algorithm. The process is in Figure 2.

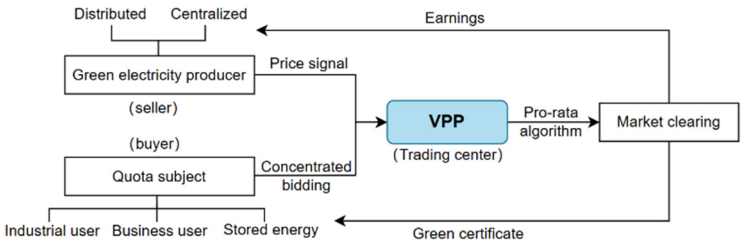

Figure 2 The stable matching process of green certificate centralized trading market

It is assumed that there are three types of market participants in the green certificate centralized trading market: VPP, quota subject and green electricity producer. Where the number of quota subjects is m and any quota subject is denoted as b_i, where $(i \in 1,2,\ldots, m)$ the utility of quota subject b_i is $u(b_i)$ and $u(b_i)$ is monotonically increasing concave function of green card consumption. In a trading cycle, the demand of quota subjects for green certificates is divided into basic demand d_1 (refers to the purchase decision made by quota subjects to meet the requirements of quota obligations) and speculative demand d_2 (refers to the purchase decision made by quota subjects to meet the speculative demand). The uncertainty coefficient of the total demand of the river and the production cost are different.

It is assumed that the basic demand d_1 of the quota subject b_i is fixed in the short term, and the speculative demand d_2 is uncertain due to the influence of the price of the green certificate trading market and supply and demand. Let $d_1 = \overline{d_1}$, $d_2 = \beta\overline{d_2}$, $\overline{d_1}$ and $\overline{d_2}$ represent the maximum value of basic demand and speculative demand respectively, and β is the uncertainty coefficient $\beta \in [0,1]$, α represents the probability of speculative demand being satisfied, (1-α) represents the probability of speculative demand being satisfied, and $l(d_2)$ represents the loss function caused by speculative demand.

In green certificate centralized transaction, the pricing formula of green certificate is as follows (1):

$$c(\cdot) = p_{n,\ fix}\overline{d_n} + p_{n.var}d_n \tag{1}$$

The utility function of quota subject b_i can be derived from formula (1) as follows (2):

$$\begin{aligned} U(b_i) = ud_1, d_2 - p_1\overline{d_1} - p_{2.\ var}\beta\overline{d_2} \\ -p_2\overline{d_2} - (1-\alpha)l(\theta\overline{d_2}) \end{aligned} \tag{2}$$

There are two types of green certificates in the VPP: green certificates issued in the current period and green certificates not traded in the past. Since the green certificate has a validity period after issuance, the pricing of the two green certificates is also different. This paper simplifies the model, the green certificate of Jiading that has not been traded in the past is regarded as speculative transaction. In a trading cycle, the fixed and variable costs paid by the virtual power plant are p_i and p_t , and the price of green certificate transfer by the virtual power plant operator is p_n , then the profit function of the VPP operator can be expressed as:

$$\begin{aligned} P_e = p_1\overline{d_1} + p_{2.\ var}\beta\overline{d_2} + p_2\overline{d_2} - p_{\bar{a}}\overline{a} - p_{\bar{b}}b \\ -p_a a - p_n\left(\overline{b} + a - \overline{d_1} - \beta_2\overline{d_2}\right) \end{aligned} \tag{3}$$

It is assumed that there are two types of green electricity producers: one is distributed photovoltaic a and the other is centralized photovoltaic b During each trading cycle, both types of green power producers can access the virtual power plant, assuming that their fixed production costs are $C_{fix}(\overline{a})$ and $C_{fix}(\overline{b})$ respectively. The additional benefits were $p_a a$ and $p_b b$ The variable costs for both are $C_{var}(a)$ and $C_{var}(b)$ Then the profit function of the two types of green electricity producers is:

$$P_a = p_{\bar{a}}\overline{a} + p_a a - C_{fix}(\overline{a}) - C_{var}(a) \tag{4}$$

$$P_b = p_{\bar{b}}\overline{b} + p_b b - C_{fix}(\overline{b}) - C_{var}(b) \tag{5}$$

$\mathbb{E}U$ is the expected utility of the quota subject, $\mathbb{E}U$ is a function of profit probability α and price level $c(\cdot)$ and uncertainty parameter θ based on formula (2); $\mathbb{E}P_e$ s the expected return

of the virtual power plant operator, $\mathbb{E}P_e$ s a function of profit probability α and price level $c(\cdot)$ and uncertainty parameter θ based on formula (3); $\mathbb{E}P_a$ and $\mathbb{E}P_b$ re the expected returns of distributed photovoltaics and centralized photovoltaics, respectively, based on the functions of formula (4) and (5) regarding the profit probability α and price level $c(\cdot)$ and the uncertainty parameter θ.

2.3 Central clearing matching algorithm

In this paper, Pro-rata matching algorithm is introduced in the green certificate centralized trading, that is, the trading principle of Pro-rata matching is executed, the allocation principle only considers the price or limit price of the order, and does not consider the usual price/time priority. When a new order is placed in the virtual power plant, the Pro-rata matching algorithm will automatically match the order according to the percentage of the number of green certificates required by the quota subject to the number of green certificates accessed in the virtual power plant.

In a trading cycle, green power producers obtain W unit green certificates issued by the National Renewable Development Center through the production of renewable energy power, and green power manufacturers will connect all green certificates to virtual power plants during the cycle; Pricing strategy $Q\left(c(\cdot),W\right)$ formed by the virtual power plant operator according to Formula (1), and submitted to the central clearing house; Then enter the quota subject centralized bidding stage.

In each trading cycle, there are m quota subjects, the number of orders submitted by any quota subject b_i to the central clearing house is x_i the total demand of quota subjects is $N=\sum_1^m x_i$, the proportion allocated by Pro-rata matching algorithm is r_i, the actual quantity obtained is recorded as x_i', the formula is as follows :

$$x_i' = \frac{x_i}{W} \times N \tag{6}$$

For the scenarios where the imbalance between supply and demand leads to an incomplete match, they are as follows:

(1) Supply exceeds demand, W>N, indicating that in the trading cycle, the number of green certificates in the virtual power plant exceeds the demand of the quota subject. According to the Pro-rata matching algorithm, the remaining green certificates will not be able to continue trading in the trading cycle, and will accumulate to continue trading in the next cycle;

(2) In short supply, W<N, indicating that the number of green certificates in the virtual power plant cannot meet the demand of the quota subject during the trading cycle. For example, in the green card concentration, there are 3 quota subjects in the Chiayi market, quota subject 1 needs 50 green cards, quota subject 2 needs 200 green cards, and ligand subject 3 needs 500 green cards, while only 600 green cards can be traded in the virtual power plant. According to the Pro-rata matching algorithm, quota subject 1 gets 40 and quota subject 2 gets 160. Quota body 3 gets 400.

3 Green certificate transaction stable matching evaluation

The benchmark case is mainly used to analyze the impact of Pro-rata matching algorithm implemented by the central clearing house on the green certificate centralized trading market[5]. When the initial values of other variables remain unchanged, the validity of the Pro-rata matching algorithm can be tested by comparing the implementation of the Pro-rata matching algorithm with the current implementation of the trading mode in China's green certificate trading market.

(1) China currently implements the voluntary green certificate trading without market maker system, and market participants repeatedly game based on their own utility maximization, and finally form a stable equilibrium of free-riding behavior. Set the number of market makers in the simulation parameter as retailer=0, the number of green power manufacturers as generator=20, the number of quota entities as buyer=20, and the Pro-rata matching algorithm as "Off".

As shown in Figure 3, the blackline indicates the listing (or transaction) price of the green certificate in each trading cycle, and the red line indicates that the price performance of the green certificate fluctuates greatly during 1000 trading cycles, and the fluctuation has no change rule, and the average unit price of the green certificate is 0.707.

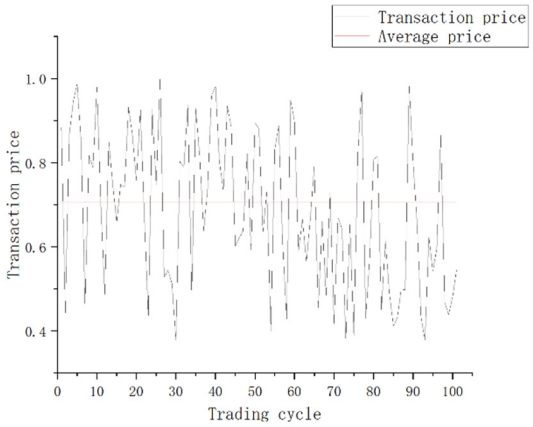

Figure 3 The trend of green certificate trading price without without Pro-rata matching rules

When simulating the current green certificate trading in China, the simulation model in this paper basically highlights the two prominent characteristics of the low efficiency of China's green certificate trading market and the "price without market" of green certificates, and also conforms to the Werker-Brenner Approach [6] proposed by Fagiolo and Moneta (2007). The method verifies the validity of agent-based model.

(2) Implement Pro-rata matching algorithm in the green certificate centralized trading market. The simulation parameters are set as follows: the number of market makers is represented by retailer=5, the number of green power manufacturers is represented by generator=20, the number of quota entities is represented by buyer=20, and the Pro-rata matching algorithm is "On".

As shown in Figure 4, the red discount and red line represent the same meaning as in Figure 3 Through the implementation of the Pro-rata matching rule, the market trading price of green certificates is higher at the beginning of the trading, but in addition, the price of green certificates is less volatile, fluctuating around the average price. The average price of a green certificate is 0.493 yuan. Usually, the transaction price of the green certificate should not be higher than twice the base price, otherwise the quota subject would rather pay a fine than buy the green certificate. The base price of green certificate is roughly within the range of [0.31 yuan/kwh,0.4 yuan/kwh]. Therefore, the average price of the green certificate is 0.493 yuan, which reflects the validity of the simulation model to a certain extent.

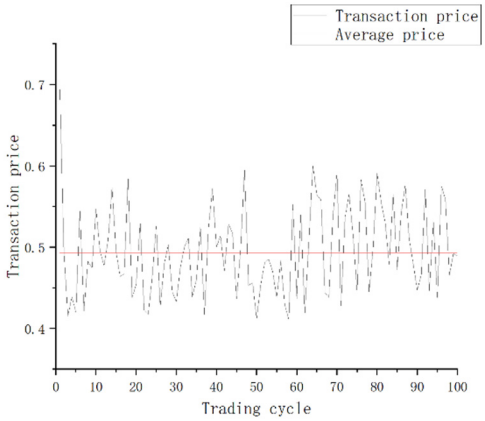

Figure 4 The trend of green certificate trading price with Pro-rata matching

4 Conclusions

The influence of the quantity change of green power manufacturers and quota subjects on the market efficiency of green certificate centralized trading market is asymmetrical. Among them, green power manufacturers have a significant effect on the transaction rate of green certificate by affecting the supply of green certificate, while quota subjects have a significant effect on the transaction price of green certificate by affecting the demand for green certificate. That is, green electricity manufacturers have a greater impact on market liquidity, and quota subjects have a greater impact on market price volatility.

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