

Research on Bidding Model of Electricity Selling Company Considering Green Certificate Trading and Electricity Selling Blocking

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Abstract. This article considers the optimal bidding model of traditional thermal power generation companies' electricity sales companies, taking into account transmission congestion, under the influence of new policies such as the renewable portfolio standard (RPS) and the renewable exchange certificate (REC). Firstly, the transaction cost of green certificates is included in the cost of electricity sales, and an optimization model is established with the goal of maximizing the profit of the electricity sales company; Secondly, the node electricity price method is used to manage transmission congestion, and an optimization model is established with the goal of minimizing the cost of transmission congestion; Finally, multi agent technology and dynamic game theory are used to solve the optimal bidding strategy of the electricity selling company.

Keywords: Green Certificate Trading Renewable Energy Quota Transmission Blockage Bidding Model.

1. Introduction

With the gradual improvement of international and domestic standards for energy cleanliness and environmental friendliness, as well as the continuous progress and improvement of technology, China's energy development in the new era must adhere to the overall requirements of building a clean, low-carbon, safe and efficient energy system, and firmly follow the path of energy development with Chinese characteristics. Due to its renewable nature and good environmental friendliness, renewable energy has been regarded as the main means of solving energy shortages and achieving environmentally friendly development both domestically and internationally. By setting renewable energy quota targets, the proportion of renewable energy in the entire power system can be increased. This article first incorporates the cost of green card transactions into the cost of electricity sales, and establishes an optimization model with the goal of maximizing the profit of the electricity sales company; Secondly, the node electricity price method is used to manage transmission congestion, and an optimization model is established with the goal of minimizing the cost of transmission congestion; Finally, multi agent technology and dynamic game theory are used to solve the optimal bidding strategy of the electricity selling company.

2. Electricity trading mode under green certificate trading mechanism

The value of green certificate trading in the electricity trading model under the green certificate trading mechanism lies in affirming the driving role of the market's "invisible hands" in actively consuming renewable energy. Green certificate trading attempts to promote normal competition in the market by fully engaging market participants in the game, replacing government subsidies with market profits, and alleviating the pressure of high subsidies. Wind power enterprises can earn profits by selling green electricity from wind turbines, and can also earn excess profits by selling surplus green certificates.

Transactions in the renewable energy trading market can be divided into two categories:

The first category is that traditional energy generators need to complete their own renewable energy quota tasks generated by the necessary transactions. The traditional energy power generation enterprises' own renewable energy power capacity is insufficient, which is lower than the minimum quota requirements. It must subscribe to the green certificates of other renewable energy companies or other power companies with surplus green certificates.

The second category is that green certificates can be traded in a trading market for market participants, such as (renewable energy units, thermal power units, electricity consumers). The essence of market circulating goods lies

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in market credit endorsement. Green certificates on the trading market include the actual use value and credit value of wind power as a commodity. After the government uses its credibility to give credit value to the green certificate, the green certificate has the use value and credit value while circulating among the market participants. Therefore, analogous to the securities market, the two parties involved in the transaction of green certificates must develop a reasonable contract signing mechanism. According to the different needs of users, the duration of signing contracts can be divided into long-term and short-term. Large power customers and thermal power units can sign a large number of medium - and long-term contracts, while ordinary power consumers can sign short-term contracts.

Figure 1 shows the relationship between participants in the green certificate trading market. It is assumed that the enterprises selling green certificates in the electricity market are wind power enterprises.

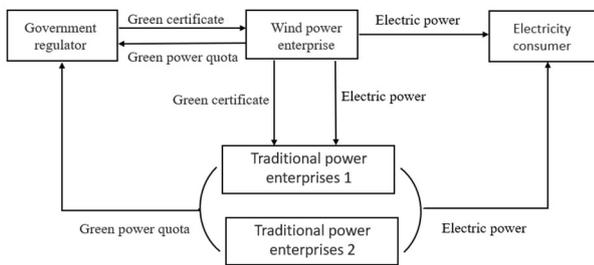


Figure 1. Wind power trading market reference chart.

3. A bidding model of electricity selling companies considering the impact of renewable energy quota and green certificate trading

For the convenience of description, only one trading period is considered in this paper, that is, the unit start-stop constraint is not considered. Suppose that M sales companies in the electricity market are set up by M thermal power producers, each of which has only one thermal power unit (but this method is also applicable to the general situation).

3.1 The cost function and quotation function of the selling company

Since the renewable energy quota power generation of traditional thermal power generators is all generated by green certificate trading, the i ($i = \{1, 2, \dots, M\}$) the green certificate transaction cost of electricity sales company is:

$$C_{ri}(P_i) = \rho \cdot kP_i \quad (1)$$

where ρ is the trading price of wind power green certificate, referring to the online trading situation of the green certificate subscription platform in July 2017, ρ is 15\$/MWh; k is the proportion of renewable energy generation quota stipulated by the National Development

and Reform Commission, meeting $k \geq 15\%$; P_i is the total amount of electricity sold per unit trading period. The cost function of electricity sold by electricity selling company i is:

$$C_{ii}(P_{ii}) = 0.5a_iP_{ii}^2 + b_iP_{ii} + c_i \quad (2)$$

Where, P_{ii} is the electricity sold per unit trading period, then $P_{ii} = (1-k)P_i$ is the power generation of thermal power units; a_i , b_i , c_i are the cost coefficient of electricity sold by the selling company.

After considering the transaction cost of green certificate, the cost function of electricity selling company i becomes:

$$\begin{aligned} C_i(P_i) &= C_{ii}(P_{ii}) + C_{ri}(P_{ri}) \\ &= 0.5a_i[(1-k)P_i]^2 + b_i(1-k)P_i + c_i + \rho kP_i \quad (3) \\ &= 0.5a_i(1-k)^2P_i^2 + [b_i(1-k) + \rho k]P_i + c_i \end{aligned}$$

the corresponding marginal cost curve is:

$$\begin{aligned} C_i'(P_i) &= a_i(1-k)^2P_i + b_i(1-k) + \rho k \\ &= \alpha_i + \beta_iP_i \quad (4) \end{aligned}$$

Where, α_i and β_i are the marginal cost parameters of the electricity selling company i .

The electricity selling company determines its own quotation based on load prediction, cost estimation, risk appetite, probability description of competitors' quotation behavior and other factors. Assuming that the market rules require the quotation function of the electricity selling company to be a linear function, in order to more directly reflect the characteristic that the actual quotation curve of the electricity selling company changes around the real marginal cost curve, the quotation function of the electricity selling company i is set as follows:

$$\xi_i(\lambda_i, P_i) = \lambda_i(\alpha_i + \beta_iP_i) \quad (5)$$

Where λ_i is the quotation parameter of the electricity selling company i .

3.2 Unconstrained bidding model of electricity selling company

After receiving the quotation of the selling company, the power market trading center first carries out unconstrained scheduling. In the case that the transmission capacity constraint is ignored, the real-time electricity price of all nodes in the system is the same, set to ξ_x . At this time, the electricity selling cost function of the electricity selling company is:

$$W_1 = \sum_{i=1}^M \xi_x P_i \quad (6)$$

Without considering the capacity constraints of the transmission system, the optimal pricing strategy problem of selling company i can be described as the problem of solving the maximum profit model of selling company i . On the premise of satisfying equations (7) and (8), the maximum value of equation (9) is obtained:

$$\sum_{i=1}^M P_i = D \quad (7)$$

$$P_{i\min} \leq (1-k)P_i \leq P_{i\max} \quad (8)$$

$$\max f_1 = \max(\xi_x P_i - C_i(P_i)) \quad (9)$$

$$= \max\{\xi_x P_i - [0.5a_i(1-k)^2 P_i^2 + [b_i(1-k) + \rho k]P_i + c_i]\}$$

Where D is the predicted system load, equation (7) is the active power balance constraint of the system, and equation (8) is the power sales constraint of the power selling company. By solving the above model, we can determine the node real-time electricity price ξ_x and the electricity sold by each electricity selling company under unconstrained conditions.

3.3 The bidding model of electricity selling company with constraint

After the unconstrained scheduling between the power trading and dispatching center, the system parameters and the expected load level of each node are announced, and the power selling company i conducts power flow check on the results. The DC power flow check model is as follows:

$$\theta = B_0^{-1}P, \quad P_{ij} = \frac{\theta_i - \theta_j}{x_{ij}} \quad (10)$$

Where, θ is the node voltage phase Angle vector; B_0 is the admittance matrix; P is the node net injection power vector; P_{ij} is active power flow of line; x_{ij} is line reactance; θ_i, θ_j are the voltage phase angles of the nodes at both ends of the line.

The characteristic of the tributary power flow method is to replace the AC power flow (active power and reactive power) of the power system with the equivalent DC current. The derivation of the above formula is shown below. Figure 2 shows the branch model.

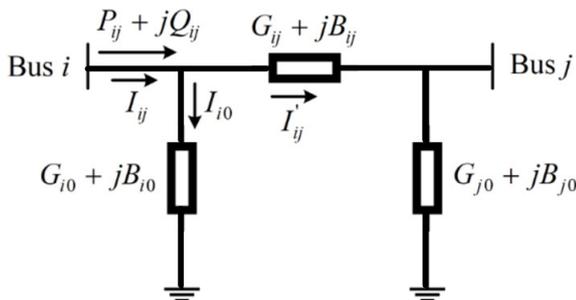


Figure 2. Branch model.

From the figure above:

$$P_{ij} + jQ_{ij} = \dot{U}_i \dot{I}'_{ij} = \dot{U}_i (\dot{I}'_{i0} + \dot{I}'_{ij}) \quad (11)$$

$$\begin{cases} \dot{I}'_{i0} = \dot{U}_i (G_{i0} + jB_{i0}) \\ \dot{I}'_{ij} = (\dot{U}_i - \dot{U}_j)(G_{ij} + jB_{ij}) \end{cases} \quad (12)$$

Also known

$$\begin{cases} \dot{U}_i \dot{U}_i^* = U_i^2 \\ \dot{U}_i \dot{U}_j^* = U_i U_j \angle \theta_{ij} = U_i U_j (\cos \theta_{ij} + j \sin \theta_{ij}) \end{cases} \quad (13)$$

By combining formula (11), formula (12) and formula (13), we get:

$$\begin{cases} P_{ij} = U_i^2(G_{i0} + G_{ij}) - U_i U_j (B_{ij} \sin \theta_{ij} + G_{ij} \cos \theta_{ij}) \\ Q_{ij} = -U_i^2(B_{i0} + B_{ij}) + U_i U_j (B_{ij} \sin \theta_{ij} - G_{ij} \cos \theta_{ij}) \end{cases} \quad (14)$$

According to the need of DC power flow calculation, P_{ij} is simplified in three ways:

- (1) Branch reactance is much larger than branch resistance, ignore branch resistance; At the same time, the conductance to the ground can also be ignored. So we have $G_{ii} = 0, G_{ij} = 0$;
- (2) When calculated according to per unit value, the expected rated voltage of node voltage has little difference, so there is $|U_i| = |U_j| = 1$;
- (3) The voltage phase Angle difference $(\theta_i - \theta_j)$ at both ends of the line is small, so there is $\sin \theta_{ij} = \theta_i - \theta_j, \cos \theta_{ij} = 1$.

The P_{ij} in the simplified formula (14) is:

$$P_{ij} = -B_{ij} \sin \theta_{ij} \quad (15)$$

The formula (15) is expressed in polar coordinates, thus:

$$P_i = \sum_{j=1}^N (B_{ij}(\theta_i - \theta_j)) = \sum_{j=1, j \neq i}^N B_{ij} \theta_i - \sum_{j=1, j \neq i}^N B_{ij} \theta_j \quad (16)$$

The above formula can be written in matrix form:

$$P = B\theta \quad (17)$$

Since $G_{ij} = 0$, then $jB_{ij} = 1 / jx_{ij} = -j / x_{ij}$. Formula

(15) can be rewritten as:

$$P_{ij} = -B_{ij} \sin \theta_{ij} = \frac{\theta_{ij}}{x_{ij}} = \frac{\theta_i - \theta_j}{x_{ij}} \quad (18)$$

The DC power flow checking model can be obtained.

If transmission congestion occurs, this pricing strategy needs to be adjusted. At this time, the real-time electricity price ξ_x of nodes in the system may be different, and the electricity selling cost function of the electricity selling company is:

$$\begin{aligned} W_2 &= \sum_{i=1}^M \xi_i (P_i^0 + \Delta P_i) \\ &= \sum_{i=1}^M \lambda_i [\alpha_i + \beta_i (P_i^0 + \Delta P_i)] \cdot (P_i^0 + \Delta P_i) \end{aligned} \quad (19)$$

In the formula, P_i^0 and ΔP_i are respectively the original electricity sold and the adjusted amount sold by the electricity selling company i .

After transmission congestion occurs, the maximum profit function of power selling company i is:

$$\begin{aligned} \max f_2 &= \max(\xi_i (P_i^0 + \Delta P_i) - C_i (P_i^0 + \Delta P_i)) \\ &= \max\{\lambda_i [\alpha_i + \beta_i (P_i^0 + \Delta P_i)] \cdot (P_i^0 + \Delta P_i) \\ &\quad - 0.5a_i(1-k)^2 (P_i^0 + \Delta P_i)^2 \\ &\quad + [b_i(1-k) + \rho k](P_i^0 + \Delta P_i) + c_i\} \end{aligned} \quad (20)$$

3.4 Transmission congestion management model

The transmission line is the channel that sends the electric energy from the generator to the user, because the transmission line always has its transmission capacity

limit, when the power flow of a transmission line reaches or exceeds its transmission capacity limit, the transmission congestion phenomenon occurs. The available transmission capacity (ATC) of a line reflects the difference between the line's capacity limit and its current power flow in the current operating state. Obviously, the phenomenon that the line is blocked is the case of ATC 0.

If unconstrained scheduling causes transmission congestion, then the power trading and dispatching center needs to carry out congestion management and require the power selling company to modify its bidding strategy to eliminate the congestion. In this paper, the transmission congestion management model is established with the aim of minimizing the congestion management cost, that is, the difference of the cost of electricity sales is minimized before and after the company modifies the bidding strategy. The problem can be described as follows:

$$\begin{aligned} \min f_3 &= \min(W_2 - W_1) \\ &= \min\left[\sum_{i=1}^M \xi_i (P_i^0 + \Delta P_i) - \sum_{i=1}^M \xi_x P_i\right] \end{aligned} \quad (21)$$

$$= \min\left[\sum_{i=1}^M \lambda_i [\alpha_i + \beta_i (P_i^0 + \Delta P_i)] \cdot (P_i^0 + \Delta P_i) - \sum_{i=1}^M \xi_x P_i\right]$$

$$\sum_{i=1}^M (P_i^0 + \Delta P_i) = D, \quad \mathbb{E}\left[\sum_{i=1}^M \Delta P_i\right] = 0 \quad (22)$$

$$P_{i\min} \leq (1 - k)P_i^0 + \Delta P_i \leq P_{i\max} \quad (23)$$

$$\theta = B_0^{-1}P, \quad P_{ij} = \frac{\theta_i - \theta_j}{x_{ij}} \quad (24)$$

$$P'_{ij} \leq P_{ij\max} \quad (25)$$

Where, P'_{ij} and $P_{ij\max}$ are the active power flow of branch $i - j$ after congestion management and the transmission capacity limit of the line.

Equation (22) is the power balance constraint. Formula (23) is the constraint of electricity sales. Equation (24) is the power flow constraint. Equation (25) is the capacity constraint of transmission network.

The algorithm flow for the problem presented in this section is shown as follows:

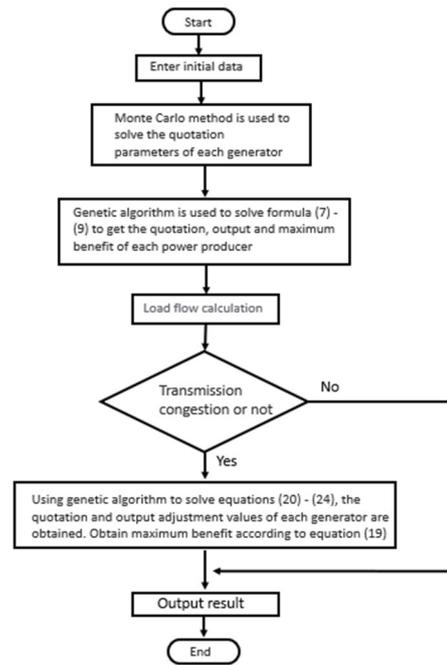


Figure 3. Algorithm flow chart.

4. Analysis of examples

The standard IEEE 14-node system is taken as an example to illustrate the method proposed in this paper. Figure 4 shows the wiring diagram of the IEEE 14-node system, and the system parameters are shown in reference.

Assume that the total demand load announced by the market $D = 369MW$. Nodes 1, 2, 3, 6 and 8 are power selling companies established by five traditional thermal power producers. Assuming that each power producer has only one generator set, the proportion of renewable energy quota k is 15%, and the parameters of power selling companies are shown in Table 1. Taking company 2 as the research object, it is assumed that the quotation parameters of other competitors follow the normal distribution form, and the quotation parameters of competitors are independent of each other, and the values of expected value and variance are $\mu_i = 1.2, \sigma_i = 0.15, (i = 1, 3, 4, 5)$.

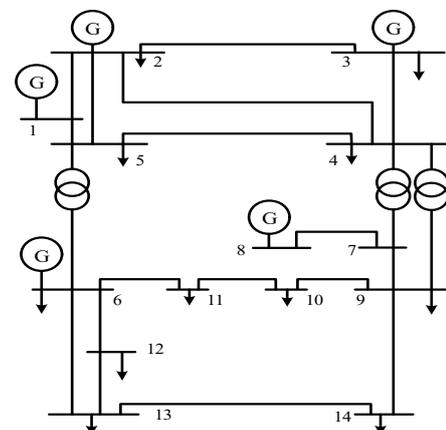


Figure 4. IEEE 14 node system wiring diagram.

Table 1. Electricity selling company parameters

Electricity sales company i	a_i \$/ (MW ² h)	b_i \$/ (MWh)	c_i \$/ h	Minimum electricity sales /MW	Ceiling of electricity sales /MW	Node number
1	0.0750	4.00	0	15	100	1
2	0.1375	3.00	0	15	90	2
3	0.0525	5.25	0	20	100	3
4	0.0875	3.00	0	20	100	6
5	0.0750	5.00	0	20	120	8

Table 2. The amount of electricity sold by each electricity selling company without constraint

Electricity sales company i	1	2	3	4	5
power sale quantity P_i / MW	88.011	53.021	76.188	72.845	78.935

When MC method is used to randomly sample the quotation parameters of competitors, the given number of random simulations is $T=3000$. In each simulation, the bidding parameters of the competitor are fixed. The population size of GA is 50, the maximum allowable genetic algebra is 50, and the crossover and mutation probabilities are 0.9 and 0.005, respectively. Here, it is required to solve the optimal quotation parameter λ_2 of the selling power company 2, which is a one-place search problem of a single optimization parameter, because the actual quotation curve of the selling power company is higher than the marginal cost curve, and the search interval given λ_2 is [1,2.98].

According to the calculation process shown in Figure 4.3, the optimal quotation parameters of power selling company 2 are $\lambda_2^* = 1.086$, on-grid power $P_2^* = 53.021MW$, the optimal quotation $\xi_2^* = 10.933\$ / MW$, and the maximum profit is 185.539\$ without considering the transmission capacity constraints. The electricity sold by the corresponding electricity selling companies is shown in Table 2. Based on the above results, the power flow is calculated in the network. It is found that branch 4 and Branch 12 are congested. Table 3 lists the specific data.

Table 3. The branch transmission is blocked

Branch number	Bus end number	Branch power flow (per-unit value)	Upper limit of branch power flow(per-unit value)
4	1-5	0.594	0.4
12	6-12	0.378	0.2375

After transmission congestion occurs, power selling companies adjust their own bidding strategy and electricity sales, then solve the transmission congestion model, and get the output adjustment value of each power selling company after management. For electricity selling company 2, the adjusted value of electricity sold $\Delta P_2^* = 21.609MW$, then the offer $\xi^* = 13.264\$ / MW$, the maximum profit is 355.046\$.

It can be seen that the bidding strategy formulated by the power selling company 2 after the transmission congestion management greatly improves the profit compared with the unconstrained situation. The corresponding adjustment of the electricity sales of each electricity selling company is shown in Table 4, positive value means that the electricity sales increase, negative value means that the electricity sales are reduced.

Table 4. The adjusted value of electricity sold by each electricity selling company

Electricity sales company i	1	2	3	4	5
Electricity sales adjustment value P_i / MW	-45.531	21.609	-15.068	-1.965	40.965

In the case of transmission congestion management, we analyze the change of bidding strategy of electricity selling companies when the impact of renewable energy quota and green certificate trading is not considered. At this time, excluding the transaction cost of green certificate ($k = 0$), the cost of electricity sold by the electricity selling company will change, and the quotation will also change, which will cause the change of

electricity sold. For power selling company 2, the optimal offer parameter is $\lambda_2^{*'} = 1.194$, power selling $P_2^* = 78.70 MW$, the optimal offer is $\xi_2^{*'} = 16.502 \$ / MW$, and the maximum profit is 636.791\$. The electricity sold by the corresponding electricity selling companies is shown in Table 5.

Table 5. Sales volume of electricity companies before and after considering green certificate costs under transmission congestion management

Electricity sales company i	1	2	3	4	5
Electricity sold including the cost of green card P_i / MW	42.48	74.63	61.12	70.88	119.99
Electricity sold without considering the cost of green certificates P_i / MW	39.11	78.70	63.94	67.35	119.99

Through comparison, it can be clearly and directly found that when executing the optimal quotation strategy of power selling company 2, the output of each power selling company does not change significantly without considering the impact of renewable energy quota and green certificate transaction, which mainly affects the quotation and profit of power selling company 2, both of which have significantly increased.

5. Conclusions

Under the influence of the new policy of renewable energy quota and green certificate trading, the optimal bidding model of power selling companies established by traditional thermal power producers is established, taking into account transmission congestion. Through research and analysis, it can be seen that when the electricity selling company includes the green certificate transaction cost into the electricity selling cost, it can meet the policy demand and make the model more accurate. When formulating the optimal bidding strategy, quantifying the newly issued green certificate trading policy, including the cost of selling electricity, using probability function to describe the bidding behavior of competitors, and considering the possible network congestion before quoting, not only can improve the success rate of a transaction, but more importantly, can obtain higher profits, which proves the practicability and reliability of this method.

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