A Medium and Long Term Contract Trading Model for New Energy Units Based on Incomplete Information Game Theory

Chuang Dong[1,a], Jie Gao[2,b], Fanqi Li[3,c*] , Wenbin Zhang[4,d],Jianwei Gu[5,e], Ping Zhang[6,f]

{1136887048@qq.com [a], gaojie20231129@163.com[b], ncepu_lfq@163.com[c*], 1228120513@qq.com[d], w12062023@163.com[e], 367047510@qq.com[f]}

PowerChina Northwest Engineering Corporation Limited, Xian, Shanxi, China[1, 4 ,6]
China Renewable Energy Engineering Institute, Beijing, China[2 ,5]
North China Electric Power University, Beijing, China[3]

Abstract. Under the goal of carbon neutrality and carbon peaking, a high percentage of wind power and photovoltaics access to the power system. As China's power trading mechanism improves, new energy is encouraged to be consumed through participation in power trading. Under the centralized power market, the medium and long-term trading power accounts for more than 90% of all traded power. This paper is based on the characteristics of the contract trading in medium-term and long-term, and volatility of new energy output, to construct incomplete information game trading model of the new energy units and power users. At the same time, according to the power medium and long-term trading to form the requirements of the trading curve, selected a trading day in the monthly trading as the object, the trading day 24 hours of trading electricity and price of the game simulation analysis. The results show that the game method effectively improves the overall income of new energy units participating in contract trading, and the price formed by the game can better respond to the supply and demand relationship in the market.

Keywords: incomplete information game; medium and long-term contract transactions; new energy units

1 Introduction

Under the carbon neutrality and carbon peaking objectives, new energy sources are being developed in a large-scale and high-quality manner on a sustained basis. A high percentage of wind power and photovoltaics access to the power system and needs to be consumed through market-based trading. Under the centralized power market, the traded power in medium-term and long-term market accounts for 90% of the total power, and new energy units need to explore strategies and methods to participate in mediu-term and long-term trading in order to gain revenue.

Many scholars have conducted relevant research. The current research on new energy participation in trading includes, new energy participation in spot trading, new energy and adjustable resources joint participation in the spot market and so on. Literature [1] establishes a two-layer multi-agent decision optimization model including renewable energy day-ahead market and residual renewable energy consumption. Literature [2] adopts CVaR to describe the

ICEMME 2023, November 17-19, Beijing, People's Republic of China

DOI 10.4108/eai.17-11-2023.2342756

uncertainty of wind power output and proposes a two-stage optimization model for coordinated participation of wind and thermal power in the day-ahead-real-time market.Literature [3] optimizes the joint wind-photovoltaic-storage participation in the power market strategy and shows that the benefits of joint wind-photovoltaic-storage participation in the power market are higher than the benefits of independent operation of wind and PV units. Literature [4] adopts a stochastic programming approach to deal with the uncertainty of wind farm output power, day-ahead and real-time market prices, and proposes a trading strategy for offshore wind power entities to participate in the spot market with optimal returns.

The research on medium and long-term power trading includes, among others, market transaction settlement model, the way interface with the spot market with the power spot market, and the assessment mechanism of the deviation. Literature [5] analyzes the three-phase path for the transition from medium- and long-term trading to spot trading in China, based on the development experience of foreign power markets and considering the characteristics of power generation and consumption in China.Literature [6] puts forward a new clearing mechanism for the deviation problems existing in medium and long-term power trading in the current spot environment and verifies the feasibility of the mechanism through examples. Literature [7] examines the linkage between medium and long-term trading and the spot market from the current situation of electricity market operation. Literature [8] proposes a mixed integer programming model based on portfolio theory to describe the trading strategies of large user electricity in the spot market and medium to long term market, and validates it through the Iberian electricity market case. Literature [9] proposes a blockchain-based methodology for medium and long-term electricity trading.Literature [10] analyzed the special characteristics and unique value connotations of electric energy commodities, and constructed a market trading mechanism based on the theory of energy segments.

The current research lacks research on the participation of new energy units in the medium and long-term contract market, this paper is based on the requirements of medium and long-term trading curve decomposition, to the medium and long-term contract signed on a certain day of the curve agreement as an example, to build an incomplete information game model, and use the iterative method of solving, the results of the example show that after the game of the new energy units to improve the overall income. The research in this paper has a guiding effect on the participation of new energy units in medium and long-term contract trading. The abbreviations used in this article are listed in Table 1.

Table 1. Abbreviations

Abbreviation	Original Word
M-L-T	Medium and long-term
NE	New energy

2 Game model of M-L-T contract transaction

M-L-T contract trading by the buyer and seller negotiated contracts, the seller is a NE unit, the buyer is a large user or seller of electricity, this paper analyzes the example of direct power trading, that is, consider the buyer for the case of large users. The development of the power market gradually requires market players to sign M-L-T contracts with power curves or agreed curve formation, so the model in this paper is established in accordance with the 24-hour formation of the hourly trading volume and price. Analyze the benefits of the contract transaction parties.

The benefit of the new energy unit is as shown,

$$I_g = \sum_t^T Q_{s,t}\left(P_{g,t} - C_t\right) \tag{1}$$

Where, $Q_{s,t}$ is the electricity purchased directly from customers in t, $P_{g,t}$ is the price of electricity sold by the unit in t, C_g is the unit cost of electricity generation. Adopt a dynamic costing approach,

$$COE = \frac{I * R + C_{O\&M}}{Q_{AE}} \tag{2}$$

Where, I is initial investment funds for the project; R is equivalent financial recovery factor; $C_{O\&M}$ is annual operation and maintenance costs; Q_{AE} is annual output. Since M-L-T contracts are concluded on a time-of-day basis, power producers need to estimate the cost of generating electricity on a time-of-day basis and deflate the annual dynamic cost to the time-of-day cost. It can be abbreviated as,

$$\begin{cases} C_t = \lambda Q_{s,t}^{-1} \\ \lambda = \dfrac{I * R + C_{O\&M}}{365 * 24} \end{cases} \tag{3}$$

Due to the fact that the NE unit output affected by environmental factors cannot be provided according to the demand, the traded power needs to meet the constraints considering the risk of NE unit deviation assessment.

$$Q_{s,t} \le Q_t^{new} \tag{4}$$

Where, Q_t^{new} is the predicted value of NE unit output. The buyer benefit is as follows,

$$I_s = \sum_t^T R_{p,t} - Q_{s,t} P_{g,t} \tag{5}$$

$R_{p,t}$ is economic benefits to buyers from the use of electricity production.

For the buyer, the purchased electricity is firstly used for production and obtains economic benefits. Furthermore, due to the green attributes of NE power, the buyer can obtain renewable energy consumption benefits, such as exporting green products to Europe and the United States, and completing renewable energy consumption weighting incentives. A primary function is used to represent the relationship between the buyer's overall revenue and the amount of green electricity purchased.

$$R_{p,t} = \alpha Q_{s,t} + \beta \tag{6}$$

For buyers, purchasing power does not exceed actual demand,

$$Q_{s,t} \le Q_{\max,t} \tag{7}$$

In summary, the set of game decision makers can be obtained as $\left\{M_{\mathrm{g}}, M_{s}\right\}$, the set of decision maker's payoff functions is $\left\{I_{\mathrm{g,t}}, I_{s,t}\right\}$, The set of strategies is $\left\{P_{\mathrm{g,t}}, Q_{s,t}\right\}$. Construct the Nash equilibrium equation.

$$\begin{cases} P_{g,t}^{*} = \arg\max I_{g,t}(P_{g,t}, Q_{s,t}^{*}) \\ Q_{s,t}^{*} = \arg\max I_{s,t}(P_{g,t}^{*}, Q_{s,t}) \end{cases} \tag{8}$$

3 Game model solving and Nash equilibrium existence analysis

In bilateral trading, both buyers and sellers know a little about each other's trading strategies through historical transactions, but they are not clear about each other's actual returns, which belongs to the game of incomplete information. In the game, they need to make predictions about each other's trading strategies in the first place.

The electricity user, as a buyer, is required to forecast the seller's power sales price. Predicting prices based on costs. Based on knowledge of the seller, a functional relationship is assumed to exist between the power trading price and electricity generation cost, and this functional relationship is fitted by historical data.

$$P_{g,t} = a_0 + a_1 C_t \tag{9}$$

Generating units, as sellers, are required to forecast the seller's demand for electricity. Since the power generation group as a seller cannot obtain accurate information on electricity consumption by customers, it cannot independently construct a forecast model of electricity demand by customers and needs to rely on historical transaction data to forecast electricity demand on the trading day.

Derive optimization models for each of the buyer and seller.

$$\max\ I_{\mathrm{s}} = \sum_{t}^{T} (\alpha - P_{g,t}) Q_{s,t} + \beta$$

$$\text{s.t.}\quad Q_{s,t} \le Q_{\max,t}$$

The buyer determines the amount of power to be purchased based on its own demand, so the buyer's revenue is a function of the transaction price of electricity. For NE generators, the transaction price is related to the cost of generation. Based on the equation relating the transaction price to the generation cost, the seller's revenue function on the traded electricity is obtained.

$$\begin{aligned} \max\ I_{\mathrm{g}} &= \sum_{t}^{T} Q_{s,t} \left(P_{g,t} - C_{t}\right) \\ &= \sum_{t}^{T} Q_{s,t} \left(a_0 + a_1 Q_{s,t}^{-1} - \lambda Q_{s,t}^{-1}\right) \\ &= \sum_{t}^{T} a_0 Q_{s,t} + a_1 - \lambda \end{aligned}$$

$$\text{s.t.}\begin{cases} 0 \le P_{g,t} \\ Q_{s,t} \le Q_{t}^{new} \end{cases}$$

Analyze the existence of Nash equilibrium solutions of the above model.

A game describes the decision-making process of two or more participants pursuing their respective goals. Under the premise that participants are pursuing benefit maximization, any subject can not obtain greater benefits by changing strategy alone, that is to say, the Nash equilibrium is reached. This paper utilizes the characteristics of Nash equilibrium to provide an optimal solution for NE units to participate in M-L-T power trading. In the game proposed in this paper, the set of decision makers is the NE generator and the electricity purchaser $\left\{G, S\right\}$. The strategy combinations are trading price and trading power $\left\{P_{g,t}, Q_{s,t}\right\}$. The set of payment functions is $\left\{I_g, I_s\right\}$. When the strategies of a game are non-empty bounded 'lower convex' closed subsets on the Euclidean space, and the payoff function is continuous and proposed to be 'upper convex' to the strategies, then there exists a Nash equilibrium in the sense of the pure strategies of the game [11]. In this paper, the buyer's revenue function is a primary function of the transaction price, and the primary term is not 0, and the second derivative is not less than 0. This revenue function is an 'upper-convex' function. The payoff function of the seller of electricity is a function of the transaction electricity, and the primary term is not 0, and the second derivative is not less than 0. The payoff function is an "upper-convex" function. Therefore, the game model constructed in this paper has a Nash equilibrium state.

4 Simulation example

Simulation is carried out for M-L-T contract trading. Based on the simulation data, the regression relationship between the buyer's electricity consumption and revenue appreciation is constructed and passed the T-test and F-test, and the calculation results are as follows,

$$R_{p,t} = 7.21 * Q_{s,t} - 6.45 \tag{10}$$

Different styles of generator trading offers have different relationships with generation costs, and simulation data were used to perform a preliminary fit of the correlation between a generator's trading tariffs and generation costs, and the results of the fit are as follows,

$$P_{g,t} = 1.25 C_t \tag{11}$$

Based on the above parameter settings, the yalmip solver of matlab is invoked to solve the model iteratively and the transaction results are shown in Fig.1, Fig.2, and Fig.3.

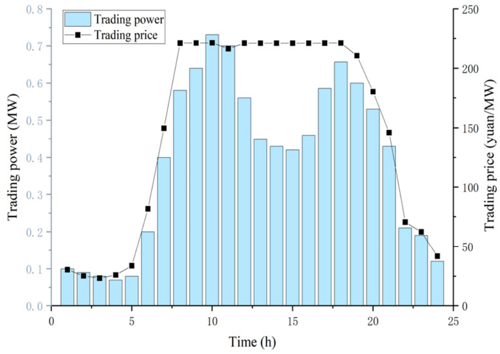

Fig. 1. Electricity and price of trading in the equilibrium state of the game.

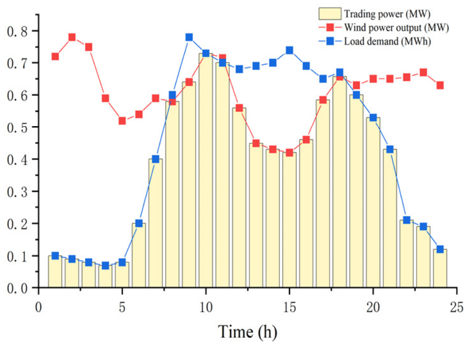

Fig. 2. Relationship between the traded electricity and wind power output and load demand in each time slot.

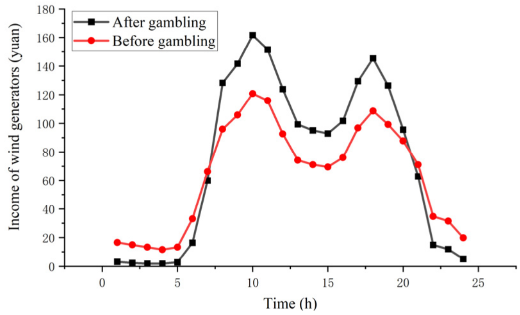

Fig. 3. Revenue of the power seller in each time slot before and after the game.

From Fig.1 and Fig.2, it can be seen that the buyer's load demand spikes are not synchronized with the maximum output of the wind power unit in time, which leads to the existence of a large wind abandonment at night time, and the wind power is unable to satisfy the buyer's full load demand at noon. Due to the mismatch between supply and demand, the trading price is lower at night time and higher at noon time, and the profit space of the wind power unit is limited. From Fig.3, it can be seen that the game formation price better reflects the supply and demand relationship of electricity in each time period, reflecting the value of electricity in different time periods, and at the same time, the overall revenue of power producers after the game is also improved.

5 Conclusions

This paper establishes an incomplete information game model for NE participation in M-L-T contract trading and solves it by iterative method. The proposed model is simulated and analyzed. Simulation example results indicate that the game can effectively improve the revenue of NE units in the M-L-T contract transactions, and the transaction price formed by the game can better reflect the supply and demand relationship in electricity market. However, due to the volatility of the NE unit's own output, the output of the NE units cannot fully match the customer load demand, resulting in wind and light abandonment, and leading to the profit space of the NE unit is limited. To solve this problem, NE units can be configured with energy storage to smooth out the output curve and convert low-value electricity into high-value electricity for a larger profit margin.

Acknowledgments. The authors wish to acknowledge assistance or encouragement from the Yellow River Water Science Research Joint Fund Project of the National Natural Science Foundation of China (U2243232),the core technology research project of "unveiling and leading" of the Power China Northwest Engineering Corporation Ltd. (DJ-HXGG-2022-01), the Technology projects of the Power China Northwest Engineering Corporation Ltd. called (DJ-ZDXM-2022-10), the Technology projects of the Power China Northwest Engineering Corporation Ltd. (DJ-ZDXM-2021-26), the Technology projects of the China Renewable Energy Engineering Institute (ZX-KJGH-20220003) and the Technology projects of the China Renewable Energy Engineering Institute (ZS-KJGH-20220009).

References

[1] X. Lin, J. Chen, S. Chen, W. Chen, H. Chen and Y. Li:Multi-agent Optimization Model of Power Spot Market under Renewable Portfolio Standard, 2022 IEEE 6th Conference on Energy Internet and Energy System Integration (EI2), pp. 1899-1904(2022).

[2] Aydogdu Aycan, Tor,Osman Bulent, Guven, Ali Nezih: CVaR-based stochastic wind-thermal generation coordination for Turkish electricity market. Journal of Modern Power System and Clean Energy,2019,7(5):pp.1307-1318.

[3] Gomesji Joao Graca, Juan J, Cheng T C, Telhada Joao, et al:Hybrid solar PV-wind-battery system bidding optimisation: A case study for the Iberian and Italian liberalised electricity markets, Energy,2023,263:pp.126043.

[4] Kordkheili Ramin Ahmadi, Pourakbari-Kasmaei Mahdi, Lehtonen Matti, Pouresmaeil Edris: Optimal Bidding Strategy for Offshore Wind Farms Equipped with Energy Storage in the Electricity Markets, 10th IEEE PES Innovative Smart Grid Technologies Europe,pp. 859-863(2020).

[5] L. Y. Wang, S.Y. Lin, X. M. Lin, n and L. Y. Wang: Research on Coordination between MediumLong-Term Electricity Trade and Spot Market Trade, 2022 4th International Conference on Smart Power & Internet Energy Systems (SPIES), pp. 2165-2170(2022).

[6] S. Zhao, Y. Zhang, J. Kuai, K. Zhang and N. Xia,Analysis and Research on Deviation Settlement Mechanism of Medium and Long Term Electricity Transaction under Spot Environment. 2022 2nd International Conference on Electrical Engineering and Control Science (IC2ECS), pp. 838-841(2022).

[7] Y. Lu, X. . Gu, S. Yin, et al Research on self balancing transaction scheduling strategy of new energy power within County considering section load rate. Comprehensive smart energy, 2022,44 (07): pp.66-72.

[8] Emanuel Canelas, Tania Pinto-Varela, Bartosz Sawik. Electricity Portfolio Optimization for Large Consumers: Iberian Electricity Market Case Study. Energies,202013(9):pp.1-21.

[9] C. Du, X. F. Wang, X. L. Wang: A Block-Based Medium-Long Term Energy Transaction Method. IEEE Transactions on Power System, 2016,31(5):pp.4155-4158.

[10] Y. Li, Q. Le, H. Wang, Z. Xie, G. Li and J. Liang, Design of Standardized Model Framework for Medium and Long term Power Transaction by Time Periods, 2023 3rd International Conference on Energy Engineering and Power Systems (EEPS), pp. 834-838(2023).

[11] W. Jiang, J. Wu, W. Feng, et al: Bilateral Game Model of Power Supply and Demand sides with Incomplete Information in Day-ahead Electricity Market.Automation of Electric Power Systems.2019,43(02):pp.18-24+75.