A Spot Transactions Model Considering New Energy Consumption in Complete Electricity Market

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Abstract. With the promotion of the market-oriented reform of China's electric power industry, carrying out day-ahead market transactions has become an important way to promote new energy wind power consumption. This paper designs a day-ahead market transaction and settlement model considering various energy trading modes and new energy consumption, and puts forward a method based on wind power absorption, combining medium-term and long-term contract power with day-ahead transaction. In order to deal with the uncertainty of wind power, a multi-scenario probability model is adopted, and scenario subtraction method is used in the basic model. For China's electricity market in the medium and long term, the transition from electricity trading market to spot market provides analytical tools and methodological guidance.

Keywords: Trading Model, Day-Ahead Market, Medium-Term and Long-Term Trading, Wind Farm Scenario

1. Introduction

In recent years, with the increasing installed capacity of wind power in China, how to safely and reliably absorb wind power has become a hot issue. The effective regulation and control of the market must be indispensable to the absorption of wind power. How to effectively establish a spot market that takes into account both medium and long-term contract transactions has become the key to deepening the reform of the electric power system. At present and in the future, China will continue to adopt medium-term and long-term electricity trading as the main form of transaction, while exploring the pre-day or real-time spot electricity trading mode. This kind of medium-term and long-term transactions through the signing of contracts, make the basic electricity demand of most users satisfied [1]. On the other hand, most generation plans can be made in advance by power producers to lock in profits in advance, which is conducive to avoiding market risks and effectively maintaining market stability. However, the power system needs to meet the balance between supply and demand. Therefore, the power trading center needs to decompose the medium and long-term contract power into days and hours, so that the demand is roughly equal to the supply. This will inevitably lead to the
deviation between the real-time operation of the system and the pre-scheduling plan. At this time, the introduction of spot market is an effective means to ensure the real-time power balance and realize the reliable and efficient operation of the power system.

This paper focuses on three aspects: Firstly, from the basic regulations, market composition, trading mode, quotation rules, settlement methods, the day-ahead market organization process and so on, the medium and long-term consideration is designed. Secondly, based on the current contract power decomposition method of China's power trading center, the medium-term and long-term contract power is decomposed and reflected as physical constraints in the liquidation model. Finally, in view of the uncertainties of wind power output, a multi-probability scenario of wind power output and a probability mode are established [2-5].

2. A Day-ahead Market Trading Model Considering Long-term and Medium-term Electricity Trading and Wind Power Participation

In view of the recent market model in China, which is dominated by medium and long-term electricity trading and supplemented by spot trading, this paper chooses market members including electricity suppliers, users and power trading centers. However, only generators participate in market bidding, without considering the specific market. Transaction elements are designed as follows [6].

In addition to declaring the price of electricity, the power producer also needs to declare the quotation of reserve capacity. The planned base electricity of a power plant shall be regarded as a medium-term and long-term bilateral contract signed between the power plant and the grid company. The day-ahead clearing model is settled by the current market electricity and the corresponding marginal price of the standby nodes. All medium-term and long-term contracts are regarded as physical contracts, and all medium-term and long-term contracts need to be submitted to the trading center in advance by the power producer. In order to restrain the abnormal fluctuation of electricity market price, the upper limit of Price Declaration is set for all kinds of generating units, including thermal power, hydropower and wind power. Generators can quote their total output up to three segments, each of which should include the corresponding electricity price and generation capacity interval. The total electricity reported should be all generation capacity, i.e. no retained capacity. Generators also need to declare the capacity price and actual invocation price for upgraded and downgraded standby. All medium-term and long-term contracts signed by power producers should be submitted to the trading center in advance. The trading center is responsible for the decomposition of contract power. Generators also need to submit parameters of each generating unit, including rated capacity, upper and lower output limits, climbing data, start-stop cost, minimum start-stop time, etc. Before the start of the market a day ago, the trading center should decompose the medium and long-term contract electricity submitted by the power producer into different periods of the next trading day according to the load forecasting situation. See Section 3.1 for the specific decomposition method. After the start of the market a few days ago, conventional generators submit power generation quotation, reserve capacity and its call quotation; wind power suppliers need to submit wind power output forecast information and quotation to the trading center, which is responsible for the formation of wind power generation scenarios [7,8]. The trading center collates the quotation data of each main body and clears the market before the day according to the clearing model established below. The clearing results before the announcement of the trading center include the winning bidding power of each main body and the marginal price and reserve price of each node at each time period. The trading center shall settle the settlement before the day in accordance with the results of the clearance before the day and the amount of bilateral contracts signed by each party [9,10].

3. A Day-ahead Clearing Model for Wind Power Market with Medium and Long Term Contract Volume Constraints

3.1 Medium and Long Term Contract Decomposition Method

Under the current electricity market transaction mode in China, medium-term and long-term bilateral
contracts occupy a very important position, and most of them belong to electricity contracts at this stage, that is, only the total electricity in the contract period is given. There is no restriction on the real-time power curve in the contract. Therefore, a reasonable decomposition of the electricity in medium-term and long-term contracts is not only beneficial to the safe and economic operation of the system, but also to the main bodies of the market. The fairness of transaction settlement is also very important. The method of decomposition of medium and long-term electricity contract is as follows:

(1) Earlier in the year, trading centers forecast daily load forecasting curves for the next year $S^i(t), \text{Total annual electricity consumption } P^s$

(2) Based on the annual load forecasting results, the total planned generation capacity of non-bidding units, such as nuclear power units, commissioning units, which have not yet participated in the market, is obtained. $P^s_{m}(t), \text{On the basis of the daily total load forecasting curve minus the output curve of the units not participating in the market, the output curve of the units left to participate in the market bidding is obtained:}$

$$S_{MT}(t) = S^i(t) - S_{NMT}(t) \quad (1)$$

$S_{MT}(t)$: Daily output curve reserved for units participating in market bidding, $S_{NMT}(t)$: Daily output curve reserved for units participating in market bidding.

(3) According to the total medium-term and long-term contract electricity quantity signed by the generating units, the proportion of the same electricity quantity of each generator combination to the total electricity generation of the units participating in the market bidding can be obtained:

$$b_i = \frac{P^{C}_{i}}{(P^t - P^s_{m})} \quad (2)$$

$b_i$: proportion of Contract Volume of Generator Units to Total Generation Volume Participated in Market Bidding, $P^{t}$: Total Power Generation Participating in Market Bidding, $P^{C}_{i}$: Total number of contracts signed by Generator Unit $i$.

(4) According to the daily bidding load curve and the proportion of contract electricity, the medium-term and long-term contract decomposition amount in each period of trading day can be known. Specifically, the medium-term and long-term contract decomposition amount in each period $T$ appears in the clearing model with the minimum unit output constraint:

$$P^{C}_{it} = b_i \int_{t_{it-1}}^{t_{it}} S_{NMT}(t) dt \quad (3)$$

$P^{C}_{it}$: The Contract Decomposition for Generator Unit $i$ in $t$ Period.

3.2. Uncertainty Modeling of Wind Power Output

The objective function of the clearing model is to minimize the total dispatching cost. The objective function consists of two parts: the day-ahead dispatching cost and the expected reserve cost to deal with the uncertainty of wind power output.

(1) Date-ahead scheduling cost

Day-ahead dispatching cost refers to the total cost of day-ahead dispatching stage recorded as $C_1$, as follows:

$$C_1 = \sum_{a} \sum_{i} \sum_{t} C^{a}_{s_{it}} s^{a}_{it} + \sum_{a} \sum_{i} C^{g}_{s_{it}} P^{g}_{a_{i}} + \sum_{i} \sum_{t} C^{R_{it}} R^{g}_{it}$$

$$+ \sum_{i} \sum_{t} C^{down}_{s_{it}} R^{down}_{s_{it}} + \sum_{i} \sum_{t} s^{u_{it}} (1 - u_{it-1}) \quad (4)$$
\( C_{oi}^g \) : it denotes the quotation of conventional unit \( i \) in time \( t \) period \( o \), \( C_{wt}^g \) represents the quotation of wind turbines \( w \) at time \( t \), \( C_{rit}^{up}, C_{rit}^{down} \) represents the quotation of the reserve capacity of conventional units for up-regulation and down regulation respectively, \( p_{oi}^g, P_{wt}^g \) represents the clearing power of conventional units and wind turbines respectively, \( R_{it}^{up}, R_{it}^{down} \) indicate up/down reserve clearing capacity, \( S \) quotation for start-up and shutdown of unit \( i, u_i \) : the binary variable is 0-1, which represents the start-up state of unit \( i \) at time \( t \).

2) Expected Standby Cost

Expected reserve cost refers to the total cost corresponding to the actual reserve power generation to mitigate the uncertainty of wind power. It is expressed in \( C_2 \). The probability of each wind farm scenario is multiplied by the actual reserve call cost under the corresponding scenario, and the benefits/penalties derived from the actual oversupply/underdevelopment of wind turbines are subtracted. As follows:

\[
C_2 = \sum_{s} \Pi_s \left[ \sum_{t} \sum_{i} \left( C_{it}^{up} r_{it}^{up} - C_{it}^{down} r_{it}^{down} \right) - \sum_{w} \sum_{t} C_{wt}^{g} \left( p_{was}^g - p_{wts}^g P_{wts} \right) \right]
\]

(5)

\( C_{it}^{up}, C_{it}^{down} \) : indicate the invocation price of up and down standby for conventional units respectively, \( r_{it}^{up}, r_{it}^{down} \) : represents the actual call volume for up/down standby under scenario \( s \), \( p_{was}^g, p_{wts}^g \) the forecasting power generation and abandoned air volume of wind turbines in scenario \( s \) are represented respectively.

To sum up, the total objective function is shown:

\[
\text{Min } \beta = \min( C_1 + C_2 )
\]

(6)

In the objective function, \( p_{oi}^g, p_{wt}^g, R_{it}^{up}, R_{it}^{down}, r_{it}^{up}, r_{it}^{down}, p_{was}^g \) for decision variables, the rest are known parameters.

4. Transaction Settlement Method

Transaction settlement refers to the settlement of the results of the clearing before the day after the clearing of the market.

1) Conventional Power Generators

The revenue of conventional generators at the time of settlement consists of three parts: the revenue from long-term bilateral contracts, the revenue from sales of electricity in the day-ahead market and the income from providing reserve for wind power:

\[
R_i = \left[ (p_{it}^g - Q_i^c) \lambda_{it} + \sum_s \gamma_{nts} (r_{its}^{up} - r_{its}^{down}) + p_{nts}^c Q_{nt} \right]
\]

(7)

\( Q_i^c \) : represents the medium and long term contract volume of conventional unit \( I \) in time \( t \) period, \( p_{it}^g \) : contract price, \( \lambda_{it} \) : Indicates the marginal price of the current market node \( n \) at time \( t \), \( \gamma_{nts} \) : represents the marginal price of standby nodes for market node \( n \) in time \( t \) period scenario \( s \).

2) Wind Turbines

Wind turbines income at settlement is composed of four parts: medium and long term contract income, electricity sales income, corresponding revenue/penalty due to overrun/underpayment of uncertainty, and the cost of providing reserve for conventional units. For a certain wind turbines, the gross daily income \( Rw \) is as follows:
\[ R_w = \sum_{t} \left[ \sum_{w} r_{tw} (p_{tw}^m - p_{tw}^d - p_{tw}^{up} - r_{tw}^{up} + r_{tw}^{down}) + p_{tw}^c Q_{tw}^c + (p_{tw}^c - Q_{tw}^c)\lambda_{tw} \right] \]

\( Q_{tw}^c \) represents the medium and long term contract volume of wind turbine \( w \) in \( t \) period, \( p_{tw}^c \) represents the medium and long term contract price of wind turbine \( w \) in \( t \) period.

5. Conclusions

The research results provide a day-ahead market clearing analysis model considering both medium-term and long-term trading and wind power participation. It also provides a simulation model for the analysis of medium-term and long-term contract execution, wind power participation in the market, and ancillary services transactions. It provides analysis tools and methodological guidance for the transition of China's power market from medium-term and long-term electricity trading market to spot market.

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References

[1] Ruiz C, Conejo A J, Smeers Y: Equilibria in an oligopolistic electricity pool with stepwise offer curves. IEEE Transactions on Power Systems, 27(2), 752-761(2012)
[2] Liu X, Wang B, Li Y: A transmission-constrained stochastic unit commitment model with real-time pricing for high wind power integration. In: Proceedings of Power and Energy Engineering Conference, Asia-Pacific, 1-6(2013).
[3] Gao Zhihua, Ren Zhen, Huang Wenying. Peak regulation right and the corresponding transaction mechanism in electricity market. Proceedings of the CSEE, 25(5),88-92(2005)
[4] Zhang Shaohua, Wang Xian, Kang Xiaoning, et al: Integration of genco’s risk preference in cournot equilibrium analysis of electricity markets. Power System Technology, 35(9),176-180(2011).
[5] Zhao Wenhui, Yan Haonian, He Wei: Equilibrium model of electricity market based on non-cooperative game of wind farms, thermal power plants and power grid company. Power System Technology, 42(1), 103-109(2018).
[6] Gholizad, A., Ahmadi, L., Hassannayebi, E., Memarpour, M., & Shakibayifar, M: A system dynamics model for the analysis of the deregulation in electricity market. International Journal of System Dynamics Applications, 6(2), 1-30(2017).
[7] Zhou, H. Z. H.: Forecast of residential energy consumption market based on grey Markov chain. IEEE International Conference on Systems. IEEE, (2009).
[8] Kelly, C., Ruzzelli, A., & Mangina, E.: Using Electricity Market Analytics to Reduce Cost and Environmental Impact. Green Technologies Conference. IEEE, (2013).
[9] Hao-Yong, C., Sen-Lin, Z., & Yao, Z.: Energy-saving power generation dispatching in regional electricity market. Power System Technology. (2008).
[10] Ge, R., Chen, L., Wang, Y., & Liu, D.: Optimization and design of construction route for electricity market in china. Dianli Xitong Zidonghua/Automation of Electric Power Systems, 41(24), 10-15(2017).