A Model for Regional Grid-Agent Power Purchase Business in China Electricity Grid

Yuou Hu[1], Liang Han[1], Jing Zhang[1], Jiawei Yu[2](✉), Hao Shi[2], Naijun Xu[1],
Fubo Cui[1], and Gang Luo[2]

[1] North China Branch of State Grid Co., Ltd, Beijing, China
[2] Beijing Tsintergy Technology Co., Ltd, Beijing, China
yujw@tsintergy.com

Abstract. With the rapid development of the social economic, China has launched a new round of electrical marketization reform to facilitate the cross-region transaction of electricity for the purpose of adapting to the requirements of power industry in the new era. In 2021, the government published a rule named《Notice on Further Deepening the Reform of Market-based On-Grid Pricing for Coal-fired Power Generation》, in which the industrial and commercial catalogue electricity price was cancelled, to push all the industrial and commercial users to participate in the market competition. In consequence, the grid-agent power purchase approach rose in response in recent two years, which has been one of the research hotspot in the power industry now. In this paper, a model for regional grid-agent power purchase business is proposed, aiming at solving the regional grid-agent power purchase clearing optimization problem in China, and the case of North China grid would be selected as the target to verify the feasibility and validity of the model proposed.

Keywords: Proxy power purchase · Power grid · Power market

1 Introduction

With the rapid development of the social economic, China has launched a new round of electricity marketization reform [1] to facilitate the cross-region transaction of electricity for the purpose of adapting to the requirements of power industry in the new era. In 2021, the NDRC (National Development and Reform Commission) published the Notice on Further Deepening the Reform of Market-based On-Grid Pricing for Coal-fired Power Generation, cancelling the industrial and commercial catalogue electricity price, to push all the industrial and commercial users to participate into the market competition [2]. However, considering the various influencing factors, the grid-agent power purchase approach rose in response in recent two years, which has been one of the research hotspot in the power industry now. Though, it is still immature and needs to be improved in some aspects. Unlike the traditional agent power purchase, the grid-agent power purchase preferentially consumes the renewable generation in the origin province and pays more attention to guarantee of power supply in the province [3, 4]. Moreover, the

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grid participates in the power spot market on behalf of all customers not willing to make deals in the market by themselves, reducing the price risk of each customer. To reduce the cost of transaction, the grid applies prediction-related technology [5] to collect the power demand of each agent-client, and predict the demand in the next period. Then, considering the power generation plan published by the PGPD (Power Grid Planning Department), the grid would predict the power price of the clients in the next period. Finally, the grid publish the price and make a deal with each agent-client [6], considering the settlement results from PGMD (Power Grid Marketing Department).

Recent years, lots of research have been conducted aiming at improve the profits of each side in the grid-agent power purchase. In order to solve imbalance between supply and demand caused by the high randomness and high volatility [7] of renewable generation, uncertainty analysis and price volatility quantitative analysis methods was adopted to create an annual power purchase optimal decision-making model [8]. This model considers the uncertainty and price volatility comprehensively. It could formulate the power purchase plan reasonably, considering the priority power generation, priority power consumption and the matching situation between them. However, its complexity is too high to solve, causing extreme need for the configuration of the calculating computer. Based on hierarchical sequential simulation approach, an optimization method of annual power purchase strategy was proposed [9], which establishes the objective constraint set and design the objective function of minimum comprehensive cost. Then, the means of hierarchical processing was applied to facilitate the speed of calculation, and the annual power purchase strategy can be obtained to optimize the cost of power purchase and promote the complementarity between energy. However, this model design is too idealized and ignores the safety of network operation and transmission loss, which means it could not consider the requirements of safety and stability of the power grid. To ensure the safely operating of the grid, a cross-province monthly power purchase decision-making model was constructed in [10], considering the constraints of cross-province power flow capacity, extreme-high voltage DC contact line and inter-province transmission channel capacity, to simplify the complexity of the model and reduce the difficulty of solving process. Though, only the inter-province coordinated optimization is considered in this model, which cannot satisfy the demand of optimization in a cross-region grid. To solve this problem, the approach of modelling the relevant rules mathematically to construct a clearing optimization model of grid-agent power purchase in regional grid could be conducted, increasing the profit of grid and ensuring the reliability of power supply in the core region in the grid [11].

In this paper, a model for regional grid-agent power purchase business is proposed, aiming at solving the regional grid-agent power purchase clearing optimization problem in China. The case of North China grid would be selected as the target to verify the feasibility and validity of the model proposed. Firstly, all the supply and demand data would be collected to clear the boundary conditions of the grid-agent power purchase case. Then, all the data would be input into the model and calculate the clearing quantity of each plant as well as the quantity distributed to each region. Finally, we would analyse the results of the model to figure out its rationality. The next section would introduce the model constructed for regional grid-agent power purchase in details.

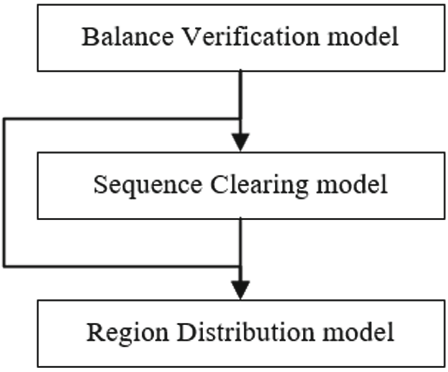

Fig. 1. Flow Diagram of the Model

2 Model of Regional Grid-Agent Power Purchase

2.1 Structure of Model

The model of regional grid-agent power purchase is divided into three parts—Balance Verification model, Sequence Clearing model and Region Distribution model. Firstly, the user should input demand and generation data from all regions into the Balance Verification model. The data of total regional demand, priority electricity, and other electricity (like replacing energy) would be collected to calculate the quantity of demand each region would buy from the central grid out, which are then used to figure out the quantity of electricity distribution to each sequence in grid.

Then, the results would be sent to the Sequence Clearing model to calculate the clearing energy for each plant. In this model, it would consider the declaring quantity, limit capacity, required capacity and the price comprehensively, but preferring the price only.

Finally, the quantity of clearing electricity distributed to different regions of each plant would be calculated, considering the results of Balance Verification model. The overall workflow of this model is shown in Fig. 1.

2.2 Balance Verification Model

In the Balance Verification model, the total demand and supply for each region would be calculated firstly. The total demand includes the grid-agent demand, residential and agricultural demand, and the loss of line transmission, which could be expressed as below:

$$q_{demand,r} = q_{GA,r} + q_{RA,r} + q_{LL,r} \tag{1}$$

where $q_{demand,r}$, $q_{GA,r}$, $q_{RA,r}$, $q_{LL,r}$ indicate the total demand, grid-agent demand, residential and agricultural demand and the loss of line transmission of the region r respectively. In this model, r includes r_1, r_2 and r_3, represents Beijing, Tianjin, and Hebei.

The supply of electricity consists of four parts, which are priority, extreme-high voltage, external transmission, and coal-fired power plants. The priority electricity includes the generation from wind power, photovoltaic, hydroelectric, biomass energy. Considering the extreme-high voltage (EHV) and external transmission (ET) are transmitted to the grid aggregately via certain transmission lines, the electricity from these two parts would be distributed to each region depending on the residential and agricultural demand, which is necessary for the social stability. Finally, using the total demand subtracts the priority electricity, EHV, ET and other supply like replacing energy to get the left demand, which would be filled by the coal plants completely. The expressions are shown below:

$$q_{priority,r} = q_{wind,r} + q_{PV,r} + q_{Hydro,r} + q_{Bio,r} + q_{gas,r} \tag{2}$$

$$q_{EHV,r} = q_{EHV,r} * (1 - \rho) * q_{RA,r} / \sum\nolimits_{r=1}^{R} q_{RA,r} \tag{3}$$

$$q_{ET,r} = q_{ET,r} * (1 - \rho) * q_{RA,r} / \sum\nolimits_{r=1}^{R} q_{RA,r} \tag{4}$$

$$q_{coal,r} = q_{demand,r} - q_{priority,r} - q_{EHV,r} - q_{ET,r} - q_{others,r} \tag{5}$$

where R indicates the total number of regions. The $q_{\mathrm{priority,r}}$, $q_{\mathrm{wind,r}}$, $q_{\mathrm{PV,r}}$, $q_{\mathrm{Hydro,r}}$, $q_{\mathrm{Bio,r}}$, $q_{\mathrm{gas,r}}$ represent the priority electricity, wind power, photovoltaic, hydroelectric, biomass energy and preferred gas electricity of region r. $q_{\mathrm{EHV,r}}$ and $q_{\mathrm{ET,r}}$ indicated the quantity of EHV and ET distributed to region r. ρ represents the line loss rate of the gird. The $q_{\mathrm{coal,r}}$ is the left quantity of electricity should be generated by the coal plants.

Then, the $q_{\mathrm{coal,r}}$ continues to be divided into two parts—low voltage part (voltage at 220 kilo Voltage) and high voltage part(500kV), based on the total capacity of plants of the low voltage sequence and that of the high voltage sequence. This could be expressed as below:

$$q_{LVcoal,r} = q_{coal,r} * \frac{Cap_{LV,r}}{Cap_{LV,r} + Cap_{HV,r}} \tag{6}$$

$$q_{HVcoal,r} = q_{coal,r} * \frac{Cap_{HV,r}}{Cap_{LV,r} + Cap_{HV,r}} \tag{7}$$

where $q_{\mathrm{LVcoal,r}}$ and $q_{\mathrm{HVcoal,r}}$ represent the coal electricity demand of the 220kV sequence and 500kV sequence in the region r. The $\mathrm{Cap}_{\mathrm{LV,r}}$ and $\mathrm{Cap}_{\mathrm{HV,r}}$ represent the total capacity of the 220kV sequence and 500kV sequence in the region r.

Because the central grid only has control over the plants at 500kV, so the electricity supplied by plants that central grid cannot control directly should be subtracted, which could be expressed as below:

$$q_{GridDemand,r} = q_{demand,r} - q_{priority,r} - q_{LVcoal,r} \tag{8}$$

where $q_{\mathrm{GridDemand,r}}$ indicates the total quantity should be purchased by region r from the central grid.

From then, the distribution electricity for each sequence in the grid could be figured out with the results of $\mathrm{q_{GridDemand,r}}$. In the Chinese grid-agent power purchase business, there are always twice as many as sequences as the number of regions in the grid, including half sequences at low voltage and half at high voltage. Moreover, there sometimes would be a point-to-grid sequence, including all the plants that outside the grid, but supply electricity to the grid directly. The distribution electricity of point-to-grid sequence is a bit different from others, which depends on the total grid demand and the coal demand of high voltage sequence, while the distribution electricity of other sequences equals to the value of the coal demand of the related sequence. The expressions are shown below:

$$q_{P2G}^{seq} = \sum\nolimits_{r=1}^{R} (q_{GridDemand,r} - q_{EVH,r} - q_{ET,r}) - \sum\nolimits_{r=1}^{R} q_{HVcoal,r} \tag{9}$$

$$q_{HV,r}^{seq} = q_{HVcoal,r} \tag{10}$$

$$q_{LV,r}^{seq} = q_{LVcoal,r} \tag{11}$$

where $\mathrm{q_{P2G}^{seq}}$, $\mathrm{q_{HV,r}^{seq}}$, $\mathrm{q_{LV,r}^{seq}}$ represent the sequence distributed electricity of the point-to-grid sequence, the high voltage sequence in region r, and the low voltage sequence in region r.

2.3 Sequence Clearing Model

The Sequence Clearing model uses the results from the Balance Verification model to figure out the exact clearing electricity for each plant, considering the declaring quantity, limit capacity, required capacity and the price comprehensively. This model consists of 3 sub-models, which are Fundamental Clearing, Requirement Clearing, and Limit Clearing.

The Process of Fundamental Clearing.

In the Fundamental Clearing, the price index would be calculated firstly, which represents the level of the declare price of each plant in its sequence. It could be expressed as below:

$$PI_{i,n} = M + \frac{Price_n^{max} - Price_{i,n}}{Price_n^{max} - Price_n^{min}}, i \in S_n \tag{12}$$

where $\mathrm{S_n}$ indicates the set of sequence n, each which consists of several plants. $\mathrm{PI_{i,n}}$ indicates the price index of the plant i in the sequence n. The M represents the price index factor. The $\mathrm{Price_{i,n}}$, $\mathrm{Price_n^{min}}$ and $\mathrm{Price_n^{max}}$ indicate the declare price of plant i in the sequence n, the minimum and the maximum declare price of plants sequence n.

Then, the reference quantity and declare willingness should be figured out, which represent the will of each plant to participate in the market. The equations are expressed as below:

$$q_{i,n}^{ref} = q_{i,n}^{declare} * PI_{i,n}, i \in S_n \tag{13}$$

$$dw_{i,n} = \frac{q_{i,n}^{declare}}{\min\left\{q_{i,n}^{Limit} * \left(1 - \gamma_{i,n}\right) - q_{i,n}^{MT}, q_{i,n}^{KLimit}\right\}}, i \in S_n \tag{14}$$

where $q_{i,n}^{ref}$ and $q_{i,n}^{declare}$ indicate the reference quantity and declare quantity of the plant i in the sequence n. $dw_{i,n}$ represents the declare willingness of the plant i in the sequence n, showing the market participation level of each plant, affected by the ratio of its declare quantity and limit quantity. The $q_{i,n}^{Limit}$, $q_{i,n}^{MT}$, $q_{i,n}^{KLimit}$ represent the limit quantity, monthly trading quantity and K-limit quantity of the plant i in the sequence n respectively. The $q_{i,n}^{KLimit}$ is a requirement from the central grid to control the cap of the monthly tradable electricity of each plant, so there is a min calculation between the limit quantity subtracting the quantity traded already and the K-limit quantity to figure out the real limit cap for each plant. The $\gamma_{i,n}$ indicates the self-consumption rate of the plant i in the sequence n.

Followed by, the fundamental clear quantity, fundamental clear check quantity and final fundamental clear quantity should be calculated sequentially, which could be expressed as below:

$$q_{i,n}^{FundClear} = q_n^{seq} * q_{i,n}^{ref} / \sum\nolimits_{i=1}^{I} q_{i,n}^{ref}, i \in S_n, I = \{S_1, S_2, \ldots, S_N\} \tag{15}$$

$$\begin{cases} q_{i,n}^{FinalFundClear} = q_{i,n}^{FundClear}, q_{i,n}^{FundClear} \le q_{i,n}^{declare}, i \in S_n \\ q_{i,n}^{FinalFundClear} = q_{i,n}^{declare}, q_{i,n}^{FundClear} > q_{i,n}^{declare} and dw_{i,n} < 1, i \in S_n \\ q_{i,n}^{FinalFundClear} = q_{i,n}^{Fundclear}, q_{i,n}^{FundClear} > q_{i,n}^{declare} and dw_{i,n} = 1, i \in S_n \end{cases} \tag{16}$$

$$q_{i,n}^{FundClearCheck} = q_{i,n}^{FundClear} - q_{i,n}^{FinalFundClear}, i \in S_n \tag{17}$$

where I indicates the total number of plants in the grid, consisting of a set of n sequences in the grid. N indicates the total number of sequences in the grid. The $q_{i,n}^{FundClear}$, $q_{i,n}^{FinalFundClear}$, and $q_{i,n}^{FundClearCheck}$ indicate the fundamental clear quantity, final fundamental clear quantity and fundamental clear check quantity of the plant i in the sequence n. The q_n^{seq} represents the sequence distributed electricity of sequence n. The calculation of final fundamental clear quantity is divided into three situations, ensuring that each plant in the gird should be distributed different quantity depending on its declare willingness and declare quantity.

The Process of Requirement Clearing.

In this part, the required quantity planned by the central grid and the gap between the required quantity of each plant should be considered comprehensively to figure out the adjustment amount to its declare quantity to compensate the gap. Firstly, the total required quantity and grid required quantity are figured out using the sequence required rate index, which are expressed below:

$$q_{i,n}^{TRequire} = q_{i,n}^{Require} * \left(1 - \gamma_{i,n}\right), i \in S_n \tag{18}$$

$$q_{i,n}^{GRequire} = q_{i,n}^{Require} * \left(1 - \gamma_{i,n}\right) * \pi_n, i \in S_n \tag{19}$$

where $\mathrm{q}_{\mathrm{i,n}}^{\mathrm{TRequire}}$ and $\mathrm{q}_{\mathrm{i,n}}^{\mathrm{GRequire}}$ represent the total required quantity and grid required quantity of the plant i in the sequence n. $\mathrm{q}_{\mathrm{i,n}}^{\mathrm{Require}}$ indicates the required quantity of the plant i in the sequence n.The π_{n} indicates the required rate index of sequence n.

Then, the require gap is calculated depending on the declare willingness and required quantity of the plant, which is expressed as below:

$$\begin{cases} q_{i,n}^{RequireGap} = q_{i,n}^{GRequire} - q_{i,n}^{FinalFundClear}, dw_{i,n} = 1, i \in S_n \\ q_{i,n}^{RequireGap} = 0, dw_{i,n} < 1 and q_{i,n}^{FinalFundClear} \geq q_{i,n}^{TRequire}, i \in S_n \\ q_{i,n}^{RequireGap} = q_{i,n}^{GRequire} - q_{i,n}^{FinalFundClear}, dw_{i,n} < 1 and q_{i,n}^{FinalFundClear} < q_{i,n}^{TRequire}, \\ \qquad i \in S_n \end{cases} \tag{20}$$

where $\mathrm{q}_{\mathrm{i,n}}^{\mathrm{RequireGap}}$ represents the require gap of the plant i in the sequence n.

After figuring the gap quantity, the quantity of compensation for the gap would be calculated, which is expressed below:

$$\begin{cases} q_{i,n}^{RComp} = q_{i,n}^{RequireGap}, \sum_{i=1}^{I} q_{i,n}^{FundClearCheck} \geq \sum_{i=1}^{I} q_{i,n}^{RequireGap}, i \in S_n \\ q_{i,n}^{RComp} = \sum_{i=1}^{I} q_{i,n}^{FundClearCheck} * q_{i,n}^{RequireGap} / \sum_{i=1}^{I} q_{i,n}^{RequireGap}, others, i \in S_n \end{cases} \tag{21}$$

where $\mathrm{q}_{\mathrm{i,n}}^{\mathrm{RComp}}$ indicates the compensation for the require gap of the plant i in the sequence n.

Followed by, the quantity over require quantity should be tailored, which could be expressed as below:

$$q_{i,n}^{OverTRequire} = max\{q_{i,n}^{FundClearCheck} - q_{i,n}^{TRequire}, 0\}, i \in S_n \tag{22}$$

$$q_{i,n}^{OverGRequire} = max\{q_{i,n}^{FundClearCheck} - q_{i,n}^{GRequire}, 0\}, i \in S_n \tag{23}$$

$$\begin{cases} q_{i,n}^{OverRequireScale} = q_{i,n}^{OverGRequire}, dw_{i,n} = 1, i \in S_n \\ q_{i,n}^{OverRequireScale} = q_{i,n}^{OverTRequire}, dw_{i,n} < 1 and q_{i,n}^{OverTRequire} > 0, i \in S_n \\ q_{i,n}^{OverRequireScale} = q_{i,n}^{OverGRequire}, dw_{i,n} < 1 and q_{i,n}^{OverTRequire} = 0, i \in S_n \end{cases} \tag{24}$$

where $\mathrm{q}_{\mathrm{i,n}}^{\mathrm{OverTRequire}}$ and $\mathrm{q}_{\mathrm{i,n}}^{\mathrm{OverGRequire}}$ indicate the quantity over total require quantity and grid require quantity, respectively. $\mathrm{q}_{\mathrm{i,n}}^{\mathrm{OverRequireScale}}$ represents the scale of quantity over require quantity, the equation of which considers the declare willingness level of each plant. The purpose of these three is to calculate out the total quantity should be tailored later.

The tailor quantity would be distributed into each plant in the same sequence, which could be expressed as below:

$$\begin{cases} q_{i,n}^{Cut} = 0, \sum_{i=1}^{I} q_{i,n}^{FundClearCheck} \geq \sum_{i=1}^{I} q_{i,n}^{RequireGap}, i \in S_n \\ q_{i,n}^{Cut} = \left(\sum_{i=1}^{I} q_{i,n}^{RequireGap} - \sum_{i=1}^{I} q_{i,n}^{FundClearCheck}\right) * \frac{q_{i,n}^{OverRequireScale}}{\sum_{i=1}^{I} q_{i,n}^{OverRequireScale}} \\ \quad , \sum_{i=1}^{I} q_{i,n}^{FundClearCheck} < \sum_{i=1}^{I} q_{i,n}^{RequireGap}, i \in S_n \end{cases} \tag{25}$$

where $\mathrm{q}_{\mathrm{i,n}}^{\mathrm{Cut}}$ indicates the tailor quantity of the plant i in the sequence n.

Finally, the require clearing quantity could be figured out with the fundamental clear check quantity, require gap and the tailor quantity, which could be expressed below:

$$q_{i,n}^{RequireClear} = q_{i,n}^{FundClearCheck} + q_{i,n}^{RequireGap} - q_{i,n}^{Cut}, \quad i \in S_n \tag{26}$$

where $\mathrm{q}_{\mathrm{i,n}}^{\mathrm{RequireClear}}$ indicates the final require clearing quantity of the plant i in the sequence n.

The Process of Limit Clearing.

Due to that each plant in the gird has its limit capacity and K-limit capacity, therefore, all the quantity over the limit should be distributed to the plants with left capacity unscheduled in the grid. Firstly, the left capacity of each plant should be calculated, which could be expressed as below:

$$q_{i,n}^{LeftLimit} = \min\left\{q_{i,n}^{Limit} * \left(1 - \lambda_{i,n}\right) - q_{i,n}^{MT}, q_{i,n}^{KLimit}\right\} - q_{i,n}^{RequireClear}, \quad i \in S_n \tag{27}$$

where $\mathrm{q}_{\mathrm{i,n}}^{\mathrm{LeftLimit}}$ indicates the left capacity of the plant i in the sequence n. $\mathrm{q}_{\mathrm{i,n}}^{\mathrm{Limit}}$ represents the limit quantity of the plant i in the sequence n.

Then, the quantity over limit of each plant would be calculated as below:

$$q_{i,n}^{OverLimit} = min\{q_{i,n}^{TRequire} - q_{i,n}^{RequireClear}, 0\}, i \in S_n \tag{28}$$

where $\mathrm{q}_{\mathrm{i,n}}^{\mathrm{OverLimit}}$ indicates the quantity over limit of the plant i in the sequence n. As for the plant without any over quantity, the $\mathrm{q}_{\mathrm{i,n}}^{\mathrm{OverLimit}}$ equals zero, which means its require clearing quantity is beyond its total require.

In order to calculate the total over limit quantity for each sequence, the declare check quantity of each sequence would be figured out firstly, which could be expressed as below:

$$q_{n}^{DeclareCheck} = max\{\sum\nolimits_{i=1}^{I} q_{i,n}^{FundClearCheck} - \sum\nolimits_{i=1}^{I} q_{i,n}^{RequireGap}, 0\}, i \in S_n \tag{29}$$

$$q_{n}^{TotalOverLimit} = q_{n}^{DeclareCheck} + \sum\nolimits_{i=1}^{I} q_{i,n}^{OverLimit}, \quad i \in S_n \tag{30}$$

where $\mathrm{q}_{\mathrm{n}}^{\mathrm{DeclareCheck}}$ indicates the declare check quantity of sequence n. $\mathrm{q}_{\mathrm{n}}^{\mathrm{TotalOverLimit}}$ indicates the total over limit quantity of the plant i in the sequence n.

Finally, the total over limit quantity in the grid would be apportioned among all other plants with left capacity, which could be expressed below:

$$q_{i,n}^{LimitClear} = (-1) * (\sum\nolimits_{n=1}^{N} q_{n}^{TotalOverLimit}) * q_{i,n}^{LeftLimit} / \sum\nolimits_{i=1}^{I} q_{i,n}^{LeftLimit}, i \in S_n \tag{31}$$

where $\mathrm{q}_{\mathrm{i,n}}^{\mathrm{LimitClear}}$ indicates the quantity distributed to the plant i in the sequence n, depending on its left capacity proportion among all left capacity of the grid.

The final clear quantity of each plant equals to the sum of its require clear quantity, over limit quantity and limit clear quantity, which could be expressed as below:

$$q_{i,n}^{FinalClear} = q_{i,n}^{RequireClear} + q_{i,n}^{OverLimit} + q_{i,n}^{LimitClear}, \quad i \in S_n \tag{32}$$

2.4 Region Distribution Model

In this subsection, the final clear quantity of each plant would be distributed to each region in the grid, depending on the centrally-controlled demand, which equals to the difference between the grid demand and the sum of extreme-high voltage and external transmission electricity of each region. There, all the final clear quantity should be distributed equitably depending on the actual demand of each region, ensuring there would not be power shortage in any region. It could be expressed as below:

$$\alpha_r = q_{GridDemand,r} - q_{EVH,r} - q_{ET,r} \tag{33}$$

$$q_{i,n,r}^{FinalClear} = q_{i,n}^{FinalClear} * \frac{\alpha_r}{\sum_{r=1}^{R} \alpha_r} \tag{34}$$

where α_r indicates the ratio of regional distribution. The $\mathrm{q}_{\mathrm{i,n,r}}^{\mathrm{FinalClear}}$ represents the quantity distributed to region r of the final clear quantity of the plant i in the sequence n.

3 Case Study

In this section, a clearing case for a monthly grid-agent power purchase in North China regional grid would be studied. Some data of the plant has been modified artificially, considering the need of confidentiality. The specification of North China regional grid is that there are totally 3 regions, and the central region is not installed with any plants. So, it could be found in the 4.1 subsection below that there 3 regions, but 5 sequences only (normally, there should be 7 sequences because one region should have one low voltage and one high voltage sequence). Moreover, there is one region without any plant, has the hugest demand for electricity. Though, this case is a bit extreme, this case is one of the most typical cases to imply the core aim of the regional grid-agent power purchase—ensuring the power supply for each region in the grid.

3.1 Input Data

The input data is divided into 4 parts—data of plants, data of EVH and ET, data of regional demand, and the clearing index. Input data source: a power grid company in North China, all the input data are shown in the Tables 1, 2, 3 and 4.

3.2 Model Performance

Using the regional grid-agent power purchase model proposed in this paper to calculate this case, the output data is shown in the Fig. 2 below.

It could be seen from the Fig. 2 that the final clear quantity distributed to R1, R2, and R3, of different plants are different and the region 1is apportioned with most quantity, which is comply with the assumption before. Because there are no installed plants in R1, but the demand is huge.

In the Fig. 3, we choose A6–A9, totally 4 plants with the same declare price to find out if the model could output the results considering the declare quantity comprehensively. It could be seen that although A7–A9 have the same declare price, the final clear quantity distributed to R2 of each plant is a bit different, influenced by the declare quantity and the declare willingness.

Table 1. Detailed data of each plants in the grid

Plant index	Capacity /MW	γ	$q^{Require}$ /MWh	q^{Limit} /MWh	q^{KLimit} /MWh	$q^{Declare}$ /MWh	q^{MT} /MWh	*Price* yuan/MWh	*Sequence*
A1	200	0.0561	612,000	1,057,100	72,252	64,219	743,110	413.86	PG
A2	360	0.0664	1,091,200	1,588,010	130,054	0	1,315,439	392.26	PG
A3	252	0.0953	772,440	1,331,946	91,037	80,917	863,056	413.19	PG
A4	100	0.0801	404,000	549,863	36,126	36,126	446,414	413.22	PG
A5	252	0.0610	766,560	1,179,139	91,037	0	1,018,884	392.26	PG
A6	258	0.0749	789,480	1,363,659	93,205	50,000	903,230	392.26	PG
A7	240	0.0895	787,200	1,268,520	86,702	75,110	977,882	392.26	PG
A8	132	0.0727	403,920	697,686	47,686	47,600	440,604	392.26	PG
A9	120	0.0822	348,000	528,240	43,351	10,000	416,931	392.26	PG
A10	120	0.0561	367,200	634,260	43,351	39,251	449,576	419.76	PG
A11	70	0.0744	214,200	369,985	25,288	25,288	269,168	414.68	PG
B1	98.55	0.1025	366,606	520,886	35,837	35,837	388,525	438.6	TJLV
B2	70	0.0880	214,200	369,985	25,455	0	192,374	438.6	TJLV
B3	35	0.0796	130,200	184,993	12,728	0	136,901	438.6	TJLV
B4	120	0.0719	367,200	634,260	43,637	0	375,470	438.6	TJLV
B5	66	0.0701	201,960	348,843	24,001	24,001	275,529	438.6	TJLV
B6	70	0.0621	260,400	369,985	25,455	25,455	295,830	438.6	TJLV
B7	32.85	0.1055	122,202	173,629	11,946	4,373	138,626	438.6	TJLV

(*continued*)

Table 1. (*continued*)

Plant index	Capacity /MW	γ	$q^{Require}$ /MWh	q^{Limit} /MWh	q^{KLimit} /MWh	$q^{Declare}$ /MWh	q^{MT} /MWh	*Price* yuan/MWh	*Sequence*
C1	133	0.0646	416,860	640,352	48,186	31,828	432,501	435.74	JBLV
C2	70	0.0714	221,900	369,985	25,361	19,480	199,301	441.99	JBLV
C3	70	0.0665	221,900	369,985	25,361	25,361	184,809	446.4	JBLV
C4	60	0.0591	190,200	317,130	21,738	7,107	133,357	446.4	JBLV
C5	70	0.0599	218,620	364,405	25,361	16,752	234,559	435.74	JBLV
C6	66	0.0883	209,220	348,843	23,912	20,795	231,434	435.74	JBLV
C7	66	0.1023	209,220	348,843	23,912	11,742	194,031	446.4	JBLV
C8	33	0.0824	130,020	181,593	11,956	11,950	106,585	434.35	JBLV
C9	21	0.0941	50,400	110,996	7,608	7,608	41,315	446.4	JBLV
C10	42	0.0928	133,140	221,991	15,217	15,217	103,923	446.4	JBLV
C11	70	0.0651	221,900	340,148	25,361	17,489	227,162	436.84	JBLV
C12	70	0.0641	221,900	369,985	25,361	17,489	224,941	436.84	JBLV
C13	60	0.0880	190,200	317,130	21,738	14,984	188,070	446.4	JBLV
C14	60	0.0815	190,200	286,440	21,738	10,500	168,754	446.4	JBLV
C15	70	0.0799	221,900	328,213	25,361	10,300	210,066	446.4	JBLV
C16	64	0.0754	200,680	338,272	23,187	0	189,026	437.72	JBLV
C17	63	0.0668	198,060	332,987	22,825	22,825	188,872	437.72	JBLV
C18	22	0.0904	52,800	116,281	7,971	7,971	50,663	446.4	JBLV
C19	66	0.0692	209,220	348,843	23,912	16,490	217,941	436.84	JBLV

(*continued*)

Table 1. (*continued*)

Plant index	Capacity /MW	γ	$q^{Require}$ /MWh	q^{Limit} /MWh	q^{KLimit} /MWh	$q^{Declare}$ /MWh	q^{MT} /MWh	*Price* yuan/MWh	*Sequence*
C20	107	0.0808	314,280	565,549	38,766	32,348	395,016	434.83	JBLV
C21	65	0.0648	203,520	343,558	23,549	16,240	208,352	436.84	JBLV
D1	106	0.0645	413,416	598,455	0	0	471,520	438.6	TJHV
D2	400	0.0577	1,224,000	1,926,650	0	0	1,387,673	438.6	TJHV
D3	120	0.0699	367,200	634,260	0	0	483,890	438.6	TJHV
E1	200	0.0395	612,000	1,057,100	72,902	52,020	771,078	443.98	JBHV
E2	256	0.0849	783,360	1,314,896	93,314	66,577	819,750	446.4	JBHV
E3	123	0.0647	367,200	537,587	44,835	35,113	367,328	446.4	JBHV
E4	70	0.0669	214,200	369,985	25,516	18,200	197,792	441.99	JBHV
E5	120	0.0579	367,200	634,260	43,741	28,090	379,718	446.4	JBHV

Table 2. Data of regional demand

Region index	q_{GA} /10^8 kWh	q_{RA}/10^8 kWh	q_{LL} /10^8 kWh	q_{wind} /10^8 kWh	q_{PV} /10^8 kWh	q_{Hydro} /10^8 kWh	q_{Bio} /10^8 kWh	q_{gas} /10^8 kWh	q_{others} /10^8 kWh
R1	50.27000	35.93000	2.87000	0.14350	0.75550	0.06840	1.80170	37.08000	0.64121
R2	28.71569	17.69534	2.07138	1.21658	1.56839	0.12068	1.47688	12.72536	4.62976
R3	46.08869	25.28803	10.69230	18.33765	11.77569	0.41256	2.10069	0	0

Table 3. Data of EVH and ET transmitted to grid

Extreme-high voltage quantity /10^8 kWh	External Transmission /10^8 kWh
28.23218	43.26497

Table 4. Data of clearing index

ρ	M	Required rate for each sequence π				
		PG	TJLV	JBLV	TJHV	JBHV
0.0272	1	0.37	0.19	0.12	0.19	0.12

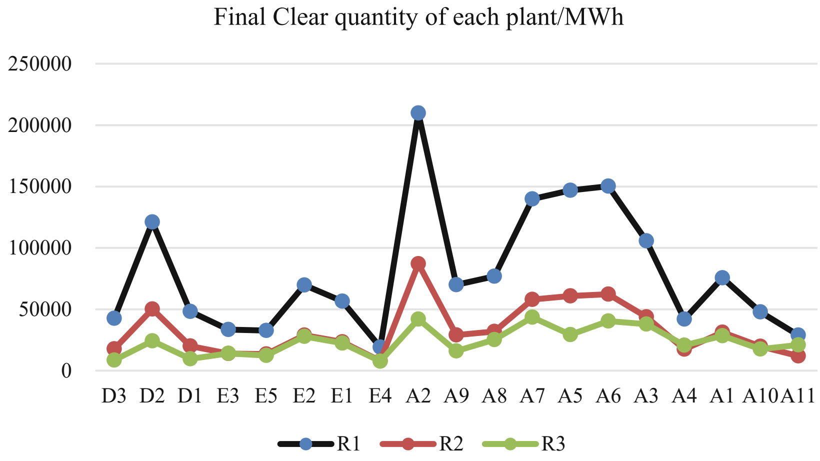

Fig. 2. Final clear quantity of each plant

4 Conclusion

In conclusion, the model proposed in this paper comprehensively considers the influence of declare quantity and declare willingness of each plant, not only the declare price, on the final clear quantity. Therefore, this model is adaptive for the regional grid-agent power purchase business in China, ensuring the power supply and the individual interest for each plant in the regional electricity market.

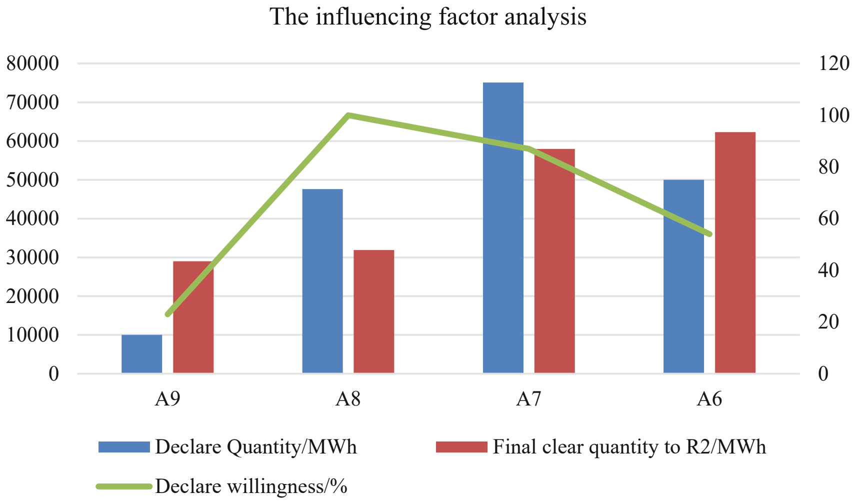

Fig. 3. Analysis of the influencing factor of final clear quantity

References

1. Lu Q, Li J N, Zhang N, et al. (2023) Evaluation of unbalanced cost of dual-track system under Agent Purchasing Power System. J. Elec. Power Autom. Equip., :1–12. https://doi.org/10.16081/j.epae.202303033.
2. Ji B, Qian J, Chang L, et al. (2023) Analysis and discussion on the problem of Power grid enterprise agent Power users participating in the market electricity purchasing business. J. Integ. Intell. Energy, 45(03): 57–65. https://kns.cnki.net/kcms2/article/abstract?v=3uoqIhG8C44YLTlOAiTRKibYlV5Vjs7ioT0B.
3. Zhou B R, Li X L, et al. (2023) Function design of simulation operation system of Southern regional Power Market. J. China South. Power Grid Tech., 14(05): 65–73. https://doi.org/10.13648/j.cnki.issn1674-0629.2020.05.010.
4. Mei S F, Tan Q L, Dai M. (2022) Energy storage capacity configuration considering seasonal fluctuation of wind-wind output. J. Elect. Power Engin. Techn., 41(4): 51–57. https://kns.cnki.net/kcms2/article/abstract?v=3uoqIhG8C44YLTlOAiTRKibYlV5Vjs7iJTKGjg9uTdeTsOI_ra5_XVWgdHRBcChxI4ucLezxOeCMFKGlg5RbJ4s06KnlpxUE&uniplatform=NZKPT.
5. Zhao S Q, Hu L N, Tian J F, et al. (2019) Contract Capacity decomposition Model of multi-energy power System Based on Medium and long term wind power PV prediction. J. Elect. Power Autom. Equip., 39(11): 13–19. https://doi.org/10.16081/j.epae.201911018.
6. Yang N, Zhu L Z, Wang B, et al. (2022) Research on power network agent purchasing business method and its Influence on power network operation. J. Scien. and Techn. Indus., 22(06): 104–108. https://kns.cnki.net/kcms2/article/abstract?v=3uoqIhG8C44YLTlOAiTRKibYlV5Vjs7iJTKGjg9uTdeTsOI_ra5_Xfo0RqGuleAB5ukJJDKUI6YADJLK_-gb2KmUNHLNs2Jl&uniplatform=NZKPT.
7. Jiang H, Yang Z F, Lin W, et al. (2022) Virtual Power Plant Scheduling Boundary Probability Distribution Method with Distributed New Energy Uncertainty. J. Proce. of the CSEE, 42(15): 5565–5576. https://doi.org/10.13334/j.0258-8013.pcsee.211194.

8. Liu D N, Xu X F, Li G Z, et al. (2023) Power Purchasing optimization Decision of power grid enterprises considering supply and demand uncertainty and price fluctuation. J. Power Grid Techn., :1–16. https://doi.org/10.13335/j.1000-3673.pst.2023.0273.
9. Lin Z G, Yan W, Luo X B, et al. (2023) Optimization Method of annual power Purchase Strategy for provincial power grid Companies based on hierarchical sequential production simulation. J. Power Grid Techn., :1–14. https://doi.org/10.13335/j.1000-3673.pst.2022.0403.
10. Li F S, Li X Q, Luo C C, et al. (2021) Monthly power purchase decision across provinces and regions considering multiple constraints and plan-market coordination. J. Elec. Power Scie. and Techn., 36(01): 206–215. https://doi.org/10.19781/j.issn.1673-9140.2021.01.024.
11. Wang J Y, Zhang H J, Cheng K, et al. (2019) Modeling of Combat Simulation entity State transition Rule based on finite state Machine. J. Infor. Syst. Engi., (09):121–123. https://kns.cnki.net/kcms2/article/abstract?v=3uoqIhG8C44YLTlOAiTRKibYlV5Vjs7iLik5jEcCI09uHa3oBxtWoFXIlhBXWFPDJa1CHbnYOJDTSH_sE_Py3xOKALwoEQQh&uniplatform=NZKPT.