Cross Provincial and Cross Regional Spot Market Clearance Model Considering Total Output Control based on Big Data Analysis Technology

Baorui Cai[1], Ziyu Chen[1], Qinbiao Lin[1], Yihong Deng[2], Yanjie Liang[1] and Bo Zhao[3]

1Power Dispatching and Control Center, China Southern Power Grid Co.,LTD. Huangpu District, Guangzhou, China, 510700

2HYDROLANCANG ENERGY SALES CO.,LTD. Guandu District, Kunming, 650214

3Beijing QU Creative Technology Co.,Ltd. Wangjing District, Beijing,100102

Email: shpower20@126.com

***Abstract*:** The article analyzes existing cross-provincial and cross-regional electricity spot market clearing models. Then, aiming to minimize total generation cost and cross-provincial transmission cost, a clearing model for cross-provincial and cross-regional electricity spot markets is established. By integrating computer technology, big data analysis, and automation mechanical technology, a generation dispatching and transmission optimization strategy based on electricity market demand is proposed. The results show that: 1) With the total power control lower limit constraint, the clearing model can optimize the inter-provincial power transmission curve as much as possible to ensure positive inter-provincial imbalance. Combined with automation mechanical technology, real-time monitoring and dispatching of power transmission can be achieved, enhancing power transmission efficiency. Computers and big data can also be used for in-depth analysis and prediction of power transmission needs. 2) When the contracted electricity volume is the same, the curve shape has a limited impact on power return. Automation mechanical technology enables rapid collection and analysis of electricity market data, further optimizing the electricity spot market clearing model. Computers can process and store large amounts of data for more accurate analysis. 3) When the electricity price difference between Yunnan and Guangdong is negative, the lower the long-term contract electricity price, the higher the sender's return. Big data analysis can help identify price trends and optimize decision-making.

Keywords: spot market clearance model, big data analysis technology, Electricity Across

M. R. Mohyuddin and N. A. D. IDE (eds.), *Proceeding of the 2024 International Conference on Diversified Education and Social Development (DESD 2024)*, Advances in Social Science, Education and Humanities Research 899,
https://doi.org/10.2991/978-2-38476-346-7_22

1. INTRODUCTION

With the continuous progress of China's electric power system reform and the application of computer technology, big data analysis, and automation in the power sector, the development of power spot market is becoming an important future direction. In 2022, China Southern Power Grid Co., Ltd. and the Southern Supervision Bureau of the National Energy Administration jointly issued the Work Plan of Southern China Regional Power Market. It is pointed out that based on the existing spot pilot in Southern China (starting from Guangdong), the construction of regional spot market should be accelerated, the scope expanded, and a Southern regional power spot market covering the whole region gradually formed. However, due to unclear cost allocation of inter-provincial and inter-regional outbound power transmission, unbalanced funds emerge. Hence, it is urgent to combine the existing inter-provincial and inter-regional power spot market clearing mechanism and discuss the unbalanced fund distribution in sending and receiving regions and the inter-provincial income from outgoing electricity control.

Many scholars have studied the clearing model of spot market. Literature [4] takes the maximization of social welfare as the objective function and establishes a market-clearing mathematical model that considers the impact of inter-provincial transmission price on the optimal allocation of power generation resources in five provinces. Literature [5] proposes a robust optimization clearing model and pricing method of capacity market that consider flexible adjustment of demand, provides settlement rules for different types of resources, and verifies that the proposed capacity market mechanism can satisfy the nature of social efficiency, balance of payments, individual rationality, incentive compatibility, etc. Based on slope climbing demand curves with different elasticity, literature [6] constructs a market clearing model for slope climbing auxiliary services, and stimulates the construction of flexible slope climbing resources through the slope climbing auxiliary services market to improve the flexible slope climbing ability of power system. Literature [7] combined with the actual project in Yunnan, proposed the method of spot clearing ahead of the day in the high-proportion hydropower market, replaced the hydraulic constraint in the clearing model with the post-hydraulic check link, and constructed the conditional constraint set including the daily electricity constraint and the water abandonment constraint of cascade power station and the corresponding trigger conditions according to the causes of water abandonment and undergeneration problems. Based on the current situation of new power system construction, literature [8] analyzed the different flexible trading needs of multiple market players in combination with the Nordic electricity trading model and the New York multi-round clearing model. Based on the current typical clearing mechanism in China, literature [9] established a joint market sequential clearing mechanism model and a joint clearing model that included day-ahead security constraint combination and security constraint economic scheduling model. However, the above research results failed to realize the in-depth discussion of unbalanced funds and inter-provincial income in the process of cross-provincial and cross-regional delivery transactions, resulting in the failure to reflect the value contribution of the receiving provinces in the spot market environment.

Based on this, this paper proposes a cross-province and cross-region spot market clearing method considering the control of outgoing electricity. First of all, compared with the existing clearing mode in the inter-provincial and inter-regional power spot market, this paper proposes a clearing mode that considers the available transmission capacity of inter-provincial liaison lines and intra-provincial transmission lines, as well as the joint participation of various power supply types in the power spot market. Secondly, with the goal of minimizing the total power generation cost and inter-provincial transmission cost, the model of inter-provincial and inter-regional power spot market clearing is established. Finally, the paper selects Yunnan to Guangdong under the west-east power transmission project for empirical analysis, which effectively verifies the validity and scientificity of the proposed clearing model.

2. DESIGN THE IDEA OF CLEARING THE SPOT MARKET OF ELECTRICITY ACROSS PROVINCES AND REGIONS

The regional power spot market is at an initial stage, and the clearing mode adopted is more conducive to taking into account the safety of power grid operation and the fairness of market entities, and the mathematical model is adopted for quantitative support [10]. Since November 2021, the Southern regional power spot market has started trial operation for the first time, covering five provinces and regions, including Guangdong, Guangxi, Yunnan, Guizhou and Hainan, among which the delivery provinces are mainly Yunnan and Guizhou. The receiving province is Guangzhou, and its spot market clearing ideas need to consider three parts: safety-constrained unit, safety-constrained economic dispatch and node marginal price. The specific clearing ideas are as follows:

Compared with the existing inter-provincial and inter-regional spot market clearing mode, this paper realizes the optimal allocation of resources in a wider range by adding inter-provincial contact lines, the available transmission capacity of intra-provincial transmission lines, and considering the joint participation of various power types in the spot market of electricity. At the same time, due to the joint participation of all market units in the region and the inter-provincial return lines, it can be used as a boundary condition to clear the spot market of each province [11]. In addition, this paper further constrends the total electricity sent across provinces and regions to avoid the deviation of the result of inter-provincial market clearance from the actual working condition.

3. ESTABLISH THE MODEL OF ELECTRICITY SPOT MARKET CLEARING ACROSS PROVINCES AND REGIONS

A. *Objective function*

Aiming at the minimum total power generation cost and inter-provincial transmission cost, this paper establishes an inter-provincial and inter-regional power spot market clearing model. The specific mathematical expression is as follows:

$$F = \min \sum_{t=1}^{T} \sum_{r=1}^{R} \left[\sum_{i=1}^{N_{r,gen}} \left(\sum_{s=1}^{S} C_{is} P_{ist} + C_{it}^{U} \right) \right] + \sum_{t=1}^{T} \sum_{j=1}^{N_T} C_j^{trans} T_{jt}^{t} + \sum_{t=1}^{T} \sum_{j=1}^{N_{line}} M \left(\phi_l^{+} + \phi_l^{-} \right) \tag{1}$$

Where, T is the total trading period; R is the total number of power grids in the provinces within the region; $N_{r,gen}$ is the total number of units in the provincial power grid r; P_{ist} is the bid output in the s section of the unit i during the time period t; C_{is} is the declared price of the electricity energy of section s of unit i during the time period t; N_T is the total number of contact lines; T_{jt}^{t} is the transmission power of the inter-provincial liaison line in Article j during the time period t; C_j^{trans} is the transmission price of the inter-provincial link in Article j; M is the relaxation penalty factor. N_{line} indicates the total number of lines.

B. Constraint condition

The inter-provincial and inter-regional power spot market is subject to conventional unit operation constraints, provincial balance constraints, tie line constraints, and control constraints of total exported electricity, etc. The specific mathematical expressions are as follows:

(1) Operation constraints of conventional units

The corresponding constraints and specific mathematical expressions of renewable energy units and conventional thermal power units participating in the power spot market are presented in reference [12].

(2) Provincial balance constraints mainly consider system load balance constraints and provincial and regional positive and negative reserve capacity constraints, the specific mathematical expression is as follows:

1) System load balance constraint: Within the t period, the sum of the total output of the power system generator set and the net injected power of the liaison line is equal to the predicted value of the power system load, and the specific mathematical expression is as follows:

$$\sum_{i=1}^{N_{r,gen}} P_{irt} + \sum_{j=1}^{N_{rt}} T_{jrt}^{t} = D_{rt} \tag{2}$$

Where, P_{irt} is the bid-winning output of unit i within r of the province in time period t; T_{jrt}^{t} is the power injected into the liaison line j in the provincial r during the time period t. When $T_{jrt}^{t} > 0$, it means incoming; when $T_{jrt}^{t} < 0$, it means outgoing; D_{rt} is the predicted value of the net load in r of the province during the time period t.

2) Constraints on positive and negative reserve capacity by province and region: Within the t period, the positive/negative reserve capacity provided by each unit in the power system must meet the positive/negative reserve capacity of the system, the specific mathematical expression is as follows:

$$\sum_{i=1}^{N_{r,gen}} \alpha_{it} P_{irt}^{\max} \geq D_{rt} - \sum_{j=i}^{N_{rt}} T_{jrt}^{t} + R_{rt}^{U} \tag{3}$$

$$\sum_{i=1}^{N_{r,gen}} \alpha_{it} P_{irt}^{\min} \le D_{rt} - \sum_{j=i}^{N_{rt}} T_{jrt}^{t} - R_{rt}^{D} \tag{4}$$

Where, α_{it} is the start-stop state of unit i during the time period t. When $\alpha_{it}=1$, it indicates the startup state of the unit; when $\alpha_{it}=0$, it indicates the shutdown state of the unit; $P_{irt}^{\max}$、$P_{irt}^{\min}$ is the maximum/minimum technical output of unit i during the period t; R_{rt}^{U}、R_{rt}^{D} is the positive/negative reserve capacity requirement corresponding to r in the province or region.

(3) The constraint of the contact line mainly considers the current balance constraint of the AC-DC link line, the transmission power constraint of the AC-DC link line, the transmission power climb constraint of the DC link line, and the power adjustment frequency constraint of the DC link line. The specific mathematical expression is as follows:

1) The power supply balance constraint of the AC-DC link line [13] : under the DC link line, the receiving end is equivalent, the receiving province is equivalent to the generator set, and the sending province is equivalent to the demand-side resources, and the output power of the equivalent generator set is equal to the output power of the equivalent demand-side resources minus the DC line loss. The output power of the AC tie line is related to the associated unit output, tie line power, load power, etc. The specific mathematical expression is as follows:

$$T_{jrt}^{R} + (1-\eta_{jr}) T_{jrt}^{S} = 0 \tag{5}$$

$$T_{lrt}^{A} = \sum_{i=1}^{N_{r,gen}} G_{li} P_{it} + \sum_{i=1}^{N_{rt}} G_{lj} P_{jrt} - \sum_{k=1}^{K} G_{lk} D_{kt} \tag{6}$$

Where, T_{jrt}^{R} is the injected power of the receiving end of the DC link line j; T_{jrt}^{S} injects power into the feed end of the DC connection line j; η_{jr} is the network loss rate of DC contact line j; T_{lrt}^{A} is the transmission power of AC link line l; G_{li} is the power transfer factor of the node where unit i is located to the AC liaison line l. G_{lj} is the transfer factor of contact line j to AC contact line l; K is the total number of nodes in the system; G_{lk} is the transfer factor of node k to AC contact line l. D_{kt} is the bus net load value of node k in the t period.

2) AC-DC link line transmission power constraints: AC-DC link line transmission power maximum and minimum technical output range, specific mathematical expression, namely:

$$T_{jrt}^{\min} \le T_{jrt}^{s} \le T_{jrt}^{\max} \tag{7}$$

Where, $T_{jrt}^{\min}$、$T_{jrt}^{\max}$ is the maximum and minimum transmission power limits of the AC-DC link line in the t period.

3) The gradient constraint of the transmission power of the DC link line: When the DC link power is adjusted upward/downward, the gradient speed requirements should be met. The specific mathematical expression is as follows:

$$-x_{jrt}^{-}\Delta T_{jrt}^{D} \le Ts_{jrt}^{D} - Ts_{jrt-1}^{D} \le +x_{jrt}^{+}\Delta T_{jrt}^{U} \tag{8}$$

Where, ΔT_{jrt}^{D}、 ΔT_{jrt}^{U} is the maximum and minimum climbing rate of the DC contact line; x_{jrt}^{+}、 x_{jrt}^{-} is the 0-1 variable of whether the DC contact line j is adjusted up and down during the period t.

4) Constraints on the number of power adjustment times of the DC link line, the specific mathematical expression is as follows:

$$\sum_{t=1}^{T}\left(x_{jrt}^{-} + x_{jrt}^{+}\right) \le N_{jr}^{\max} \tag{9}$$

Where, $N_{jr}^{\max}$ is the maximum number of adjustments of the all-day DC contact line j.

5) AC link line transmission power constraints, the specific mathematical expression is as follows:

$$T_{lrt}^{\min} \le T_{lrt}^{A} \le T_{lrt}^{\max} \tag{10}$$

Where, $T_{lrt}^{\min}$、 $T_{lrt}^{\max}$ is the maximum and minimum transmission power limit of the AC contact line l within the time period t.

(4) Control constraints on the total quantity of outgoing electricity, specific mathematical expressions, namely:

$$\sum_{i=1}^{N_{r,gen}} P_{irt} \le \sum_{t=1}^{T}\sum_{i=1}^{N_{rt}} P_{irt}^{t} \tag{11}$$

Where, P_{irt}^{t} is the maximum output power of multi-type unit i in province r during the time period t.

4. EXAMPLE ANALYSIS

A. Basic parameter

In order to verify the validity of the cross-province and cross-region electricity spot market clearing model established in this paper, this paper selects a typical daily trading situation of a western province to Guangdong to carry out a numerical analysis.

B. Basic data

According to the situation of power transmission and sale between the west and east power transmission entities, 3982 nodes, 762 units, 5830 lines and 96 time periods are considered in the cross-province and cross-region power spot transaction from Yunnan to Guangdong. At this time, the total power sent across provinces and regions is set at 105 million kW.h, and four scenarios are set for analysis, as detailed in Table 1.

Table 1 Four scenarios

Scenario	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Phenome-non	Daily mean curve	Plane-peak curve	Flat-valley curve	Peak flat val-ley curve

Note: In scenario 1, the power is the same at all times of the day; According to the peak-valley TOU price policy, in scenario 2, 10-12 o 'clock and 14-19 o 'clock are set as peak hours, and the rest are set as flat segments; In scenario 3, 0-8 o 'clock is set as the low period, and the rest is set as the flat period; In scenario 4, peak hours are set from 10-12 o 'clock and 14-19 o 'clock, trough hours are set from 0-8 o 'clock, and the rest are set as flat periods. For specific contract decomposition curves, see Figure 1.

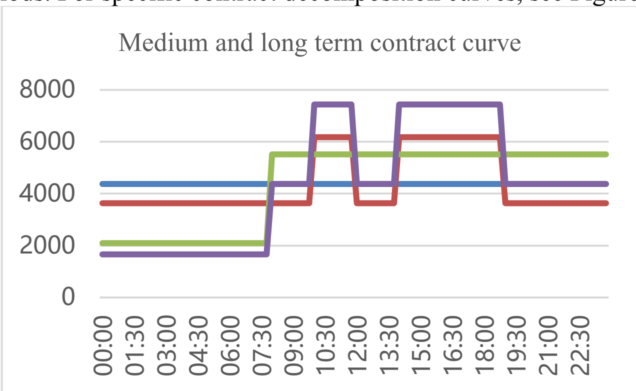

Figure 1 Contract decomposition curve of medium and long term scenario 1-4

C. Result analysis and discussion

1. Unbalanced fund outcome analysis

In the electricity deviation settlement of the spot market, due to the different nodes of the market entities, the settlement price of the sending province and the receiving province is different, and the settlement price of the power supply side and the user side is different, resulting in the imbalance of funds in the regional inter-provincial spot market under different scenarios, as shown in Table 2.

Table 2 Inter-provincial unbalanced funds in Medium and long term Scenario 1-4 (Unit: Yuan)

Scenario 1	Scenario 2	Scenario 3	Scenario 4
942087	551207	472512	71270

It can be clearly seen from Table 2 that although the electricity price difference between Guangdong and Yunnan is negative, due to the relaxation of the prior clearance curve relative to the contract decomposition curve, the negative electricity price difference and the negative curve difference are multiplication to positive, resulting in positive inter-provincial unbalanced funds and surplus inter-provincial unbalanced funds among the receiving provinces. It shows that the clearing model will optimize the inter-provincial power transmission curve as much as possible and ensure that the unbalanced funds between the provinces are positive by using the lower limit constraint of total power control.

In order to analyze the sensitivity of contract electricity to inter-provincial unbalanced funds, three scenarios were further set up based on scenario 4, as shown in Table 3.

Table 3 Scenario setting of unbalanced fund sensitivity analysis

Scenario	Scenario 5	Scenario 6	Scenario 7
Phenomenon	Hang the peak and smooth the valley	Scenario 4*1.2	Scenario 4*0.9

Note: In scenario 5, 10-12 o 'clock and 14-19 o 'clock are set as the trough period curve, 0-8 o 'clock is set as the peak period, and the rest are set as the flat period; In scenario 6, the power of each period in scenario 4 is changed to 1.2 times; In scenario 7, the power of each period in scenario 4 is changed to 0.9 times, and the specific contract decomposition curve is shown in Figure 2.

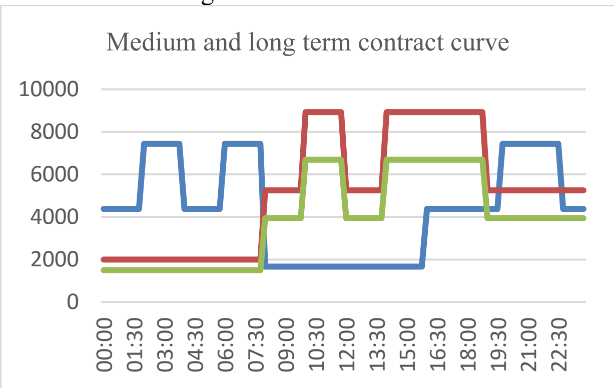

Figure 2 the contract decomposition curve for medium and long term scenarios 5-7

After calculation, the regional and provincial unbalanced funds under the above three scenarios are shown in Table 3.

Table 3 Inter-provincial unbalanced funds in Medium and long term Scenarios 5-7 (Unit: Yuan)

Scenario 4	Scenario 5	Scenario 6	Scenario 7
71270	1664977	2105371	-945781

As can be seen from Table 3, with the increase of long-term contract electricity and the relaxation of liquidated electricity in the past few days, the imbalance between provinces increases. When the medium and long-term contract electricity decreases, the relaxation of the liquidated electricity decreases, and the imbalance between provinces decreases.

2. *An analysis of inter-provincial income results is presented*

Assuming that the medium and long-term contract electricity price between Yunnan and Guangdong Province is 453 yuan /MWh, and the medium and long-term contract price of Yunnan transmission section power plant is 377.5 yuan /MWh, the inter-provincial income is calculated according to the above seven scenarios in the way of "medium and long-term total electricity settlement + day-before electricity deviation settlement", and the results are shown in Table 4.

Table 4 presents inter-provincial income (Unit: Yuan)

Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7
40332935	40083655	39765859	39605658	40500407	37637934	40589521

As can be seen from Table 4, the maximum income difference between scenario 1-4 is 727,277 yuan, indicating that when the contract electricity is the same, the curve shape has little influence on the output income. The results of scenario 6-7 show that when the electricity price difference between Guangdong and Yunnan is negative, the lower the medium and long-term contract electricity, the higher the return on the sending side.

Further observation shows the deviation return of regional power spot market, and the results are shown in Table 5.

Table 5 presents the return of spot deviation between provinces (Unit: Yuan)

Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7
695432	446152	128356	67249	961998	-9808157	5004953

As can be seen from Table 5, spot deviation return of regional power is positively correlated with spot deviation quantity. When the day-ahead deviation quantity of scenario 6 is negative, spot deviation return is negative. When the day-ahead deviation electricity of scenario 7 is positive, the spot deviation return is positive.

For further observation, the spot deviation of regional power is shown in Table 6.

Table 6 delivered inter-provincial spot deviation electricity (Unit: MWh)

	Total positive spot deviation electricity	Negative spot deviation energy sum	Spot deviation electricity sum
Scenario 1	24371	-24371	0
Scenario 2	16321	-16321	0
Scenario 3	13310	-13310	0
Scenario 4	12308	-12046	263
Scenario 5	41291	-41029	263
Scenario 6	7109	-27794	-20685
Scenario 7	16462	-5726	10736

As can be seen from Table 6, under scenario 1, 2 and 3, the sum of regional power spot deviation is 0. Under scenario 4, 5 and 7, the total amount of regional power spot deviation is positive. Under scenario 6, the total amount of regional power spot deviation is negative.

5. CONCLUSION

In the context of the widespread application of computer technology, big data analysis, automation, and mechanical innovation, this article builds on existing inter-provincial and cross-regional electricity spot market clearing models. Considering factors such as the available transmission capacity of inter-provincial contact lines and inland transmission lines, the participation of various types of electricity in spot market transactions, and the constraint of cross-provincial total generation capacity, it proposes an inter-provincial and cross-regional electricity spot market clearing method. Combined with automation mechanical technology, the following conclusions are drawn:

(1) By leveraging automation technology, the available transmission capacity of inter-provincial contact lines and inland transmission lines can be monitored and predicted, providing real-time and accurate data support for electricity spot market transactions.

(2) An artificial intelligence-based electricity market clearing model can be developed, integrating factors such as total generation cost and inter-provincial transmission cost to optimize the transaction process of the electricity spot market.

(3) Through the use of automated mechanical equipment and intelligent algorithms, optimized dispatching of cross-provincial electricity resources can be achieved, enhancing the operation efficiency and stability of the power system.

REFERENCE

1. GAO Hongchao, Chen Qixin, Jin Tai et al. Spot market clearing model and flexibility premium evaluation method considering flexible regulation characteristics of virtual power plant [J]. Power Grid Technology, 2019,47(01):194-207.
2. Yuan Quan, Zhang Qiang, Xuan Peizheng et al. Research on Simulation Analysis of bilateral Transaction in Power Spot Market in Southern China (starting from Guangdong) [J]. Guangdong Electric Power,2022,35(06):10-17.
3. Xing Xubin, Chen Miao, Li Feiyu et al. A two-stage flexible power delivery strategy for offshore wave energy generation system based on collaborative optimization of power exchange ships [J]. Guangdong Electric Power,2022,35(12):1-10.
4. CAI Baorui, Liang Yanjie. Design of spot electricity market clearing model in Southern China considering cross-provincial priority plans and transmission rates [J/OL]. China Southern Power Grid Technology :1-10[2023-08-23].
5. Qu Ying, Xiao Yunpeng, Zhang Chen et al. Capacity market clearing model and pricing method considering flexible demand adjustment [J/OL]. Automation of Electric Power Systems :1-21[2023-08-23].
6. ZHAO Yue, CAI Qiuna, Wang Long et al. Market clearing model for climbing auxiliary services considering different demand elasticity [J/OL]. Automation of Electric Power Systems :1-15[2023-08-23].
7. Zhang Yang, Shen Jianjian, Zhao Qihao et al. Pre-day spot clearing method of high proportion hydropower market [J/OL]. Zhujiang People :1-17[2023-08-23].
8. ZHANG Zhixiang, Chen Yufang, Dong Zhixin et al. Research on multi-transaction combination Model and Step-by-step clearing Model of Power Market [J]. Electrotechnical Engineering,2023(09):1-4.
9. LIU Xinyuan, ZHAO Shuqiang, Bo Liming et al. Comparative study on sequential market clearing and joint market clearing under different load conditions [J/OL]. Journal of North China Electric Power University (Natural Science Edition):1-9[2023-08-23].
10. Jing Zhaoxia, Xu Yuting. Exploration on cross-province trading mechanism of national unified large market [J]. China Electric Power Enterprise Management,2022(25):29-32.
11. Ji Peng, Zeng Dan, Sun Tian et al. Research on the deepening construction of national unified electricity Market system: Taking the design of inter-provincial and intra-provincial market coupling evolution path as the entry point [J]. Price Theory and Practice,2022(05):105-109.
12. Cheng Jifeng, Yan Zheng, Li Mingjie et al. Optimization method of surplus new energy power cross-province trading plan based on conditional VAR and output forecasting [J]. High Voltage Technology, 2002,48(02):467-479.
13. Yang Jianhua, Li Pengfei, Fan Chenkai et al. Design of medium and long term trans-provincial electricity market trading mechanism under the liberalization of electricity generation plan [J]. Journal of Hydropower and Energy Science,2021,39(05):207-210+10