Mechanism and Method of Auxiliary Decision-Making for Dispatching Real-time Operation in Electric Spot Market

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Abstract: Starting from the market rules of the pilot provinces of the domestic spot market, this paper analyzes the mechanism of market intervention and suspension, the mechanism of the power supply period, and the mechanism of market clearing anomaly. At the same time, combined with the real-time operation of the Inner Mongolia power grid, the traditional dispatching mode and the power spot market operation dispatching mode are compared. Given the abnormal frequency, section overload, and insufficient spinning reserve in real-time operation, an auxiliary decision mechanism of manual intervention in the power spot market is proposed. The mechanism includes load bias setting, section limit bias setting, deviation monitoring, and other auxiliary functions, which provide a method of quick intervention under the electric spot market to ensure the safe and stable operation of the power grid.

1. Introduction

On August 28, 2017, the State Council and the National Energy Administration issued the "Notice on the Pilot Construction of the Power Spot Market", establishing eight spot pilot areas, including the Inner Mongolia power grid. Initially, they began the construction of the power spot market [1]. The construction of a power spot market plays a decisive role in giving full play to the guiding role of price signal, ensuring the real-time balance of power and the safe operation of the power grid through the market mechanism. In addition, it is significant for the country to promote the realization of the goal of "carbon peak and carbon neutrality" [2-5]. To the requirements of relevant documents, each pilot province carried out a day-ahead market and a real-time market to explore the road for constructing the electric spot market. With the continuous improvement and update of market trading rules, the trading mechanism of the spot market is gradually maturing. However, many problems must be considered and solved in real-time operation.

There may be various problems during the real-time operation of the power grid, such as the frequency being constantly high or low and the equipment power flow needing to be constantly full or exceeding the limit. So, the dispatcher needs to carry out necessary manual intervention to prevent the situation from deteriorating further. In the traditional dispatching mode, the dispatcher usually adjusts the output of the thermal power unit to control the power flow quickly. However, many interests are involved in the electric spot market, so balancing the relationship between manual intervention and market operation is necessary to ensure a fair market environment. Therefore, it is particularly important to study the mechanism and method of auxiliary decision-making in the real-time dispatching operation to ensure the coordination of necessary manual intervention in market operation and dispatching. This paper first analyzes and summarizes the electric spot market intervention and suspension mechanism in various provinces. Combined with the situation of the Inner Mongolia power grid, an auxiliary decision-making tool for the electric spot market is proposed for the first time in China, which improves the executable ability of quick dispatch intervention in power grid emergencies. In addition, this tool also guarantees the long-term, uninterrupted operation of the electric spot market as well as the safety and stability of the power grid.

2. Electric market intervention mechanism

2.1. Coordination mechanism of manual intervention and market operation

Due to the emergency caused by extreme weather, supply and demand relationship, and emergency events, each electric market has corresponding treatment measures. In the context of a high proportion of new energy access and low energy carbonization, the possibility of an emergency in the power market is relatively increased. The uncertainty and intermittency of new energy generation are the main factors affecting the power balance [6].

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2.2. Typical spot market manual intervention processing mechanism

Implementing the principle of power grid safety first, the operation of the power spot market should be suspended immediately if there is a threat to the safety of the power grid. Given a short electricity supply, Guangdong Province prioritizes the market demand-side response. If the intraday power balance still cannot meet the requirements, the orderly power consumption plan is started according to government regulations, and the load forecast data is adjusted [7-9]. Zhejiang Province makes thermal power units quit AGC to adjust output in view of the insufficient reserve [10]. The capacity compensation mechanism was established in Shanxi Province to decouple the capacity cost recovery of the unit from the power generation operation, ensuring sufficient system reserve capacity during peak hours [11-12]. Gansu Province adopts the method of emergency intervention of thermal power unit output or call of thermal power unit start-up to deal with power grid safety constraints and accidents. The intervention period is counted separately. All the on-grid electricity of the intervention thermal power unit does not participate in the spot market settlement. The electricity and electricity charges in the day-ahead and real-time spot market are set to zero, and all on-grid electricity is recorded as monthly medium and long-term electricity.

In the case of the day-ahead market suspension, Shanxi Province, Guangdong Province, Shandong Province, and Zhejiang Province prepare the day-ahead power generation plan based on the principle of power grid safety. Day-ahead market clearing is not carried out on the day. The actual execution results and real-time market prices are used for settlement. In the case of the suspension of the real-time market, the settlement period corresponding to the market suspension period shall be based on the actual execution result and the real-time market price of the same period of the previous trading day. As for the suspension of the auxiliary service market, Guangdong Province and Shandong Province shall call the auxiliary service according to the principle of system needs and take the actual execution result and the market price of the auxiliary service in the same period of the previous trading day as the basis for the settlement. Among them, Shandong Province intervenes in the power market using price control when the price is abnormal and declares the corresponding trading period as the price control period [13]. When the electric spot market is suspended in Sichuan Province and Fujian Province, the power dispatching agency will prepare the day-ahead power generation plan and the real-time rolling power generation plan based on the principle of power grid safety and not carry out market transactions and clearing. Besides, the actual execution results will be settled by market trading rules or the method specified by the competent government department.

2.3. Conclusion

After analyzing the relevant rules and measures formulated by the provincial spot market of domestic typical pilot units for insufficient power supply period, insufficient spinning reserve period, price abnormal period, power grid security constraint or sudden failure, market suspension, and other issues, the following conclusions are drawn:

First, in the case of affecting the safe operation of the power grid, each typical pilot provincial spot market takes timely disposal measures according to the principle of safety to prevent the expansion of risks. What's more, to avoid the total suspension of the market as far as possible, the power market of each province takes measures to deal with classification. In other words, certain market intervention measures are taken to prevent the extension of the market suspension.

Second, suspending the spot market will lead to no operating results, resulting in a certain amount of suspension costs. Therefore, all regions have stipulated the settlement basis and settlement method when the market is suspended, and some regions put forward the principle of common cost sharing. In some provinces, the power trading institution adopts the method of price control together with the power dispatching institution and declare the corresponding trading period as the price control period.

Third, when it is in short supply in some periods of the load forecast, the market demand response resources are preferentially invoked to meet the power balance.

3. Research on manual intervention mechanism of Inner Mongolia power grid spot market

3.1. Inner Mongolia power spot market manual intervention mechanism

During the real-time operation of the spot power market, there are many problems, such as abnormal frequency, insufficient spinning reserve, and tie lie over-load, etc. To avoid market risks, the dispatcher should try not to manually adjust the unit generation plan and use a standardized process to deal with such problems.

3.2. Frequency anomaly

The main frequency of the grid will fluctuate near the power frequency under the action of the frequency modulation unit and the power balance constraint is given in equation 1.

$$\sum_{i=1}^{I} p_{i,t} - \sum_{j=1}^{J} P_{j,t} - s_t^+ + s_t^- = 0 \qquad (1)$$

In this equation, $p_{i,t}$ represents the total units output, $P_{j,t}$ represents the total load demand, s_t^+ and s_t^- represents the slack variable. The total units output is equal to total load demand, then the grid frequency remains stable. However, if there is a large continuous deviation of load forecast or a serious blockage of thermal power units, it may lead to insufficient capacity of frequency modulation units, contributing to the continuous abnormal frequency of the system. Under this circumstance, the dispatch agencies in many provinces will immediately call the thermal power unit by the market rules to restore the frequency. Inner Mongolia's power grid innovatively corrects ultra-short-term load forecasts to indirectly change the spot system clearing results to solve the problem of insufficient spinning reserves.

3.3. Section overload

Section power flow is a constraint in the process of market clearing calculation given in equation 2.

$$F_{m,t}^{min} - s_{m,t}^{-} \leq \sum_{i=1}^{I} SF_{m,i,t} p_{i,t} - \sum_{j=1}^{J} SF_{m,j,t} P_{j,t} \leq F_{m,t}^{max} + s_{m,t}^{+} \tag{2}$$

In this equation, $F_{m,t}^{min}$ and $F_{m,t}^{max}$ represents the lower and upper limits of the section, $SF_{m,i,t}$ and $SF_{m,j,t}$ represents the flow transfer factor of the section, $p_{i,t}$ represents the total units output, $P_{j,t}$ represents the total load demand, $s_{m,t}^{+}$and $s_{m,t}^{-}$ represents the slack variable. The section power flow needs to be kept within the constraint range from $F_{m,t}^{min}$ to $F_{m,t}^{max}$ for the grid to be safe and stable. In real-time operation, there may be a large deviation between the predicted value of the bus load and the actual value, which may lead to the continuous overload of the section power flow. This may cause serious grid accidents and should be controlled in time. In traditional dispatching mode, the dispatcher can adjust the output of relevant thermal power units according to sensitivity. However, to avoid market risks during real-time operation [14-15], Inner Mongolia Power Grid changed the section limit value to make the spot system recalculate to solve the problem of section overload for the first time in China.

3.4. Emergency plan of suspension of electric spot market

When there is a special situation that endangers the stable operation of the power grid and affects the order of the power market, the dispatcher shall intervene or suspend the power spot market in time. In addition, dispatchers should deal with accidents and arrange power system operations according to relevant regulations, and timely report to the competent government departments and energy regulatory agencies [16].

When intervening or suspending the power spot market, Inner Mongolia Power Grid takes the following measures:

First, when the day-ahead market is suspended, the corresponding intra-day and real-time markets are suspended simultaneously, restoring to the no-spot trading mode.

Second, when the real-time market is suspended, the power dispatching agency adjusts the output of thermal power units based on the real-time operation and ultra-short-term load forecast information to ensure a balanced power supply. During the suspension of the spot market, it will be restored to no spot trading mode, and the result of day-ahead market clearing will not be settled.

Third, the dispatching agency shall record the reasons for the suspension of the spot market and the measures taken, promptly filing with the competent government departments and energy regulators and announcing to the relevant market members. When the abnormal situation is resolved, and the grid resumes safe operation, the electric spot market will be resumed accordingly.

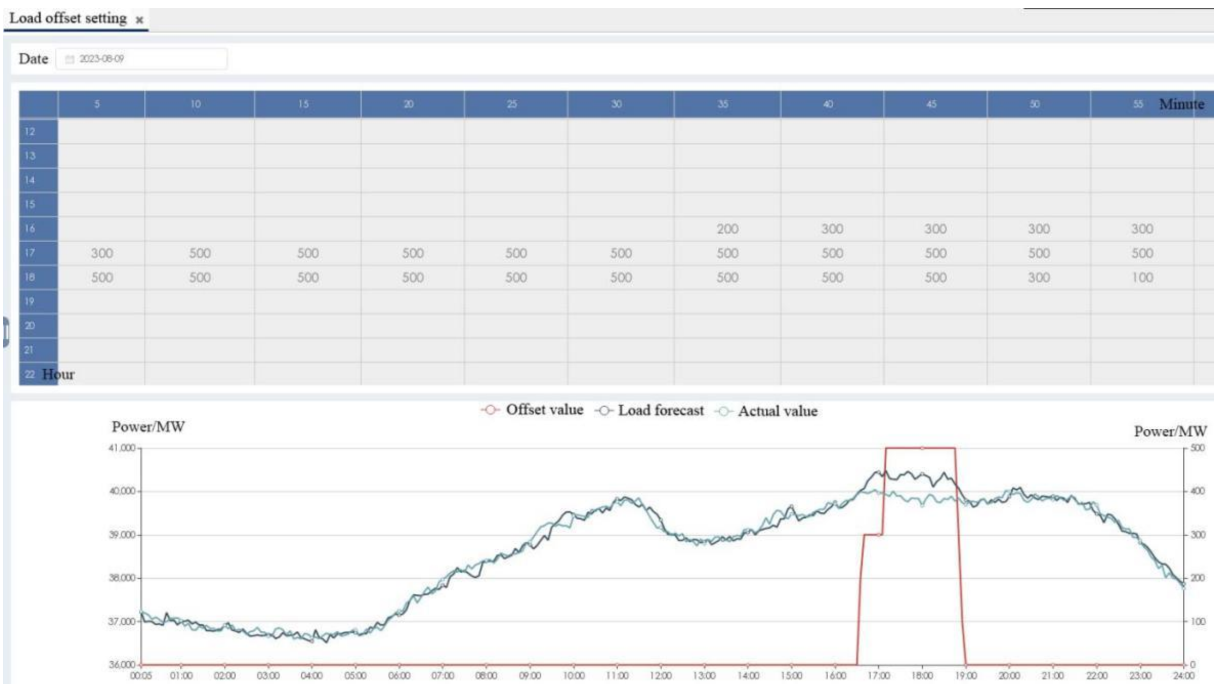

Figure 1. System load forecasting bias setting

4. Power dispatching real-time operation decision aid software

4.1. Load forecasting bias setting

When there is a large continuous deviation of load forecast or a serious blockage of thermal power units, the system frequency may be persistently high or low. To solve this problem effectively, the dispatcher can superimpose a bias quantity based on the forecast load through the software. The Inner Mongolia Power spot system periodically accesses the ultra-short-term system load forecast file, and the data range is the next 4 hours. Meanwhile, the spot system will directly modify the system load forecast data according to the load offset set by the dispatcher, which is used as the reference data for the later clearing calculation. Thus, the accuracy of spot system clearing results will be improved.

The front-end interface is shown in Figure 1, showing three curves, including the predicted load value, the actual load value, and the deviation value. The dispatcher can set the load bias through different periods on this page. However, the historical period is gray and cannot be modified. For example, a maximum load bias of 500 MW was set from 17:30 to 19:00 in Figure 1 so that the ultra-short-term prediction curve would be higher than the actual curve during the modified period. The spot market will calculate according to the adjusted load forecast curve and call the thermal power unit to compensate for the blocked output or unexpected actual load.

4.2. Section limit offset setting

In real-time operation, some sections may be continuously full load due to the large deviation of local bus load prediction. The dispatcher can set a bias quantity based on the normal limit of the section, and the market clearing calculation will control the suction power flow according to the superimposed section limit to solve the situation that the actual section power flow continues to be full.

The front page is shown in Figure 2, through which the dispatcher can set the limitation of each section according to different periods, supporting batch and box selection modifications. For example, the limit of the selected section was modified from 540 MW to 700 MW in Figure 2. Besides, the grey display of historical periods cannot be changed.

Figure 2. Section limit offset setting

4.3. Deviation monitoring

The reason for the deviation is that the planned power flow needs to be consistent with the actual power flow. Therefore, the active power deviation monitoring function is mainly used to assist the dispatcher in finding and adjusting the deviation between the plan and the actual value in time. The active power deviation monitoring function is mainly divided into four aspects: tie line monitoring, generation monitoring, bus load monitoring, and sectional power flow monitoring.

Tie line monitoring

Name of tie line Find

Name of tie line	Planned value	Actual value	Deviation value	Average value
North China tie line	-3150.00	-3061.78	88.22	-3412.00
Hangu tie line	-965.94	-889.32	76.62	-1015.09
Fengwan tie line	-2184.06	-2172.46	11.60	-2396.91

Figure 3. Tie line monitoring

The tie line monitoring function is mainly responsible for monitoring the power flow information of the Inner Mongolia power grid to the North China Power Grid, including the main pass, the South passage, and the north passage. The deviation amount and percentage are obtained by detecting the actual power flow and comparing it with the planned value, as shown in Figure 3. This feature supports object retrieval, sorting, and filtering by criteria. We click on a specific object to display the historical information, and it supports the curve export function.

Generation monitoring

Name of power plant Find

Name of power plant	Planned value	Actual value	Deviation value	Average value
Fenghuangling 2#G	241.49	296.65	55.16	0.00
Wusitai 2#G	221.00	274.00	53.00	0.00
Kangbashi 1#G	268.25	320.45	52.20	0.00
Huitengliang wind power	3.05	51.94	48.89	11.61
Songjiaqu 4#G	509.66	557.47	47.81	0.00
Fenghuangling 1#G	274.35	314.07	39.72	0.00

Figure 4. Generation Monitoring

Power generation monitoring periodically detects the planned output and actual output of thermal power units and new energy stations, as shown in Figure 4. The deviation value and percentage of deviation are obtained by detecting the actual output and comparing it with the planned output. This function supports object retrieval and arrangement. The historical planned output and actual output can be displayed by clicking on the specific power plant, and the curve export function is supported.

Bus load monitoring

Name of bus load Find

Name of bus load	Planned value	Actual value	Deviation value	Average value
Tailiang line	-0.73	37.77	38.50	-0.73
Jingao 1#T	0.00	37.28	37.28	0.00
Gaoqian line	8.21	40.55	32.34	8.51
Jingao 2#T	0.00	31.70	31.70	0.00
Xingang line 1	21.83	53.10	31.27	19.87
Ejina 1#T	1.00	32.13	31.13	1.00

Figure 5. Bus load monitoring

Bus load monitoring mainly displays the deviation between planned and actual values. The bus load prediction is transformed into the pure bus load prediction after the modeling modification of the small unit. Similarly, the monitoring function measures the actual load of the bus according to the small unit coupling model. Thus, the deviation value can be obtained by comparing the planned and actual values, as shown in Figure 5. This feature supports object retrieval, sorting, and filtering by criteria. We click on a specific object to display the historical predicted value, actual value, deviation value, and support curve export function.

Section power flow monitoring

Name of section Find

Name of section	Planned value	Actual value	Deviation value	Average value
Huayun three units	0.00	921.78	921.78	0.00
Load of Huangqihai & Tianpishan	0.00	911.25	911.25	0.00
Buwu line & Dehe line	-743.54	0.00	743.54	-1907.82
Load of Meiligeng	0.00	623.95	623.95	0.00
Dengxiang line	-169.21	397.12	566.33	415.93

Figure 6. Section power flow monitoring

Compared with the planned power flow, the section power flow monitoring function detects the current section power flow, obtaining the deviation value. Through this function, dispatchers can find the section with a large deviation and then analyze the possible reasons for the large deviation in this section to optimize the spot market operation results. The front-end page, as shown in Figure 6, displays the planned, actual, and deviation values of the power flow of each section and supports retrieval, sorting, and filtering according to requirements. We click on a specific object to display historical trend information and support the curve export function.

4.4 Evaluation of decision aid software

The auxiliary decision software was proposed by Inner Mongolia Power Grid for the first time in China, providing a method of manual intervention for the dispatcher. Besides, it provides a solution for the coexistence of the stable operation of the power grid and the uninterruptible operation of the power spot market. In the traditional dispatching mode, the dispatcher directly adjusts the power generation plan of the unit when various problems occur in real-time operation, such as continuous abnormal frequency, insufficient system backup, and exceeding the limit of section power flow. The advantage of direct intervention is that it can be timely and quickly intervened. However, the downside is that the dispatcher decides the intervention subjectively and may not be the best measure. Under the power spot market, there are many interests involved. So, the dispatcher should try to make decisions with the cooperation of the system, reducing the influence of subjective factors and ensuring the fairness of the market. The intervention through the auxiliary decision software only needs to set the offset amount without adjusting the specific unit plan, avoiding the market risk to the greatest extent and optimizing the spot market results.

5. Conclusion

Based on the real-time operation of the power spot market of the Inner Mongolia power grid, this paper draws the following conclusions:

First, the construction of the power spot market is currently in its infancy, and the pilot provinces are actively exploring and improving the rules of the spot market. When there is a state of emergency or abnormal spot system, the most serious may lead to suspending the spot market. Therefore, emergency measures should be configured in the spot market rules of each province, including power generation plan changes, auxiliary service market adjustments, and electricity settlement mechanisms. When the power spot market cannot persist in operation, it should be suspended in time to ensure the safety of the power grid.

Second, the deviation between the planned value and the actual value in the real-time operation of the power spot market may lead to various abnormal situations. For example, a large deviation of ultra-short-term load prediction or serious power generation obstruction of thermal plants will lead to continuous abnormal frequency. Similarly, a large deviation in the bus load prediction may lead to continuous exceeding of the section power flow. At this time, the dispatchers need to adjust in time to ensure the balance of power supply and demand.

Third, manual intervention will cause a deviation between the plan and actual value in the case of power spot market operation. For example, when the grid spinning reserve capacity is insufficient, some thermal power units may be called to generate beyond the planned value. At this time, on account of the many interests involved in the real-time operation of the spot market, corresponding rules and methods should be considered when manual intervention. In other words, manual intervention should ensure market fairness and avoid market risks as far as possible.

Fourth, to optimize the operation of the power spot market, the Inner Mongolia power grid has established the power flow monitoring system of the spot market for the first time in China. This system allows the unit with blocked output to be found in time and adjusted accordingly to ensure the balance of power supply and demand. Monitoring tie-line power flow helps analyze the power flow transfer to the North China power grid and judge the external power transmission capacity of the Inner Mongolia power grid. Moreover, monitoring the section power flow and bus load helps analyze the reason for the section power flow over-limit and optimize the small unit mounting model.

Fifth, to improve the maneuverability and compliance of manual intervention, Inner Mongolia Power Grid has innovatively developed an auxiliary decision-making tool. The dispatcher adjusts the grid indirectly by setting the load bias and section limit bias via this tool. After that, the spot system calculates the power output of each unit according to the modified data and distributes it. This tool solves the fairness problem in manual intervention from a system perspective.

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References

1. YANG Chunxiang, ZHANG Xuanrong, YAO Xun, et al. (2022) Construction Analysis Based on Domestic and Foreign Power Spot Market. Journal of Electrical Engineering, 17(4): 290-299.
2. LI Pingjun, FU Zhaoqing, LIU Kangping, et al. (2020) Analysis of Comprehensive Decision-Making of Power Generation Companies Based on Prospect Theory in Electricity Spot Market. Inner Mongolia Electric Power, 38(4): 13-19.
3. M. Khavaninzadeh, M. Rashidinejad and A. Abdollahi. (2015) Benefit of customers competition on power market. In: 2015 20th Conference on Electrical Power Distribution Networks Conference (EPDC). Zahedan, Iran, pp. 60-65.
4. LI Youliang, WANG Zhengfeng, LIANG Xiao, et al. (2022) Analysis of the Impact of Electricity Spot Market on Power Grid Dispatching. Journal of Anhui Electrical Engineering Professional Technique College, 27(2): 19-25.
5. C. Brunner and D. Möst. (2015) The impact of different flexibility options on future electricity spot prices in Germany. In: 2015 12th International Conference on the European Energy Market (EEM). Lisbon, Portugal, pp. 1-6.
6. F. Veselov, I. Erokhina and E. Nikulina. (2020) Modeling of Price Consequences in the Competitive Electricity Market in Russia with the Intensive Development of Non-Carbon Power Plants. In: 2020 13th International Conference "Management of large-scale system development" (MLSD). Moscow, Russia, pp. 1-4.
7. KUANG Minliang. (2023) Reflections on Formulating Medium and Long Term Trading Strategies of Thermal Power Generation Enterprises under Guangdong Electricity Spot Market. Guangdong Electric Power, 36(5): 11-17.
8. MA Hui, CHEN Yuguo, CHEN Ye, et al. (2018) Mechanism design of Southern China (starting from Guangdong Province) electric spot market [J]. Southern Power System Technology, 12(12): 42-48.
9. LIAO Binjie, LI Ruiqi. (2017) Research and design of grid energy dispatch model based on demand response. Electric Power, 50(7): 64-68, 152.
10. ZHOU Ziqing, DENG Hui, FANG Le, et al. (2022) New energy market trading mechanism and benefit analysis of Zhejiang electricity spot market. Zhejiang Electric Power, 41(8): 42-48.
11. WANG Xiaoang, ZOU Peng, REN Yuan, et al. (2022) Problems and Solutions of Medium & Long-term Trading Connected with Electricity Spot Market in Shanxi Province. Power System Technology, 46(1): 21-27.
12. DING Qiang, REN Yuan, HU Xiaojing, et al. (2021) Design and Practice of Joint Optimization Mechanism for Spot Market and Deep Peak Shaving Regulation Market of Shanxi in China. Power System Technology, 45(6): 2220-2227.
13. WANG Yong, YOU Daning, FANG Guanghua, et al. (2020) Mechanism Design and Trial Operation Analysis of Shandong Power Spot Market [J]. Electric Power, 53(9): 38-46.
14. WU Yunliang, LI Bao, LUO Huihong, et al. (2020) Conditional section constraints modeling in spot market clearing. Power System Technology, 44(8): 2819-2829.
15. Ricardo Cartaxo, Ângelo Casaleiro, Ricardo Pastor, et al. (2022) Market Coupling in Europe - Principles and Characteristics. In: 2022 4th International Conference on Power and Energy Technology (ICPET). Beijing, China. pp. 882-887.
16. XIAO Yunpeng, GUAN Yuheng, ZHANG Lan, et al. (2021) Analysis and Construction Path of Risk Hedging Mechanism in Centralized LMP-based Electricity Spot Market. Power System Technology, 45(10): 3982-3991.