Modeling Analysis and Study of Unbalanced Funds Impact on Power Spot Market with High Share of Clean Energy

Ruiqin Duan[1a*], Jinding He[1b], Yan Jiang[1c], Shuangquan Liu[1d], Qizhuan Shao[1e], Chuan Zhao[1f], Beiyu Gan[2g], Jianbin Lin[2h]

[1]Power Dispatch Center of Yunnan Power Grid Co. Ltd., Kunming 650011, China
[2]Beijing Tsintergy Technology Co. Ltd., Beijing 100080, China

Abstract-Under the background of "double carbon" and large-scale grid connection of clean energy, the uncertainty of clean energy output and the market reforms to deal with this uncertainty will affect the interests of market participants through settlement and unbalanced funds. Focusing on the background of the power spot market for clean energy, this paper first analyzes the unbalanced funds items specific to Chinese power spot market, then conducts a qualitative analysis of the impact of high proportions of clean energy on unbalanced funds. Finally, from the perspective of quantitative analysis, three prediction models for the impact of unbalanced funds are proposed to provide technical means for prediction and evaluation of the changes in the interests of power market participants under the background of China's energy transition in the future.

1. Introduction

With the construction of the electricity spot market on a large scale nationwide, each province and region are gradually carrying out the construction of the electricity spot market, and both the contract for differences (CFD) and the electricity spot market are settled on the floor. From the perspective of the central counterparty, if the total settlement funds of all counterparties are not zero, the difference is called "unbalanced funds", which means the unbalanced funds are the total market revenue minus the total market expenses. The reason why the electricity market generates cash flow is that the supplier provides a certain type of electricity derivative commodity and the demand side pays the cost. Then the market settlement needs to set up independent caption of account between the supplier and the demand side based on the counterparty relationships sorted out for all the electricity and electricity derivative commodity items to achieve the budget balance. Therefore, in a market with well-established settlement mechanism, the unbalance funds should be 0 regardless of the rounding of bills, measurement errors, etc. When the imbalance is not 0, it is inevitably due to the inequality between the costs incurred by the demand side and the costs received by the suppliers in the electricity and derivatives markets.

At present, China's provincial and regional electricity spot markets are in the preliminary construction stage, usually focusing more on the design of the electricity energy spot market and paying less attention to the settlement of electricity derivative commodities, such as: the need to encourage suppliers to meet the demand for capacity, peaking and other electricity derivative commodities through a unilateral market or cost compensation in order to guarantee the stable operation of the market and the grid; the congestion surplus caused by transmission congestion; and other costs like the China-specific dual-track deviation cost. These costs are subject to unclear settlement items and unclear division of authority and responsibility, resulting in the consolidation of multiple items that should be settled independently under one account of "unbalanced funds" for diversion. Therefore, the unbalanced funds in this paper refers to such broad unbalanced funds, and the study objects are the settlement items that are often combined in the unbalanced funds accounts in the electricity spot market of each province and region in China.

Existing studies in domestic electricity market mainly focus on classifying unbalanced funds and designing allocation mechanism, literature [1-3] classified unbalanced funds from different perspectives, literature [4] carried out the design of unbalanced funds allocation mechanism, literature [5] analyzed the impact brought by different unbalanced funds allocation mechanisms based on ABM model.

Under the policy goal of reaching carbon peak by 2030 and achieving carbon neutrality by 2060[6], clean energy will gradually become the main source of power supply. The uncertainty of clean energy and the market reforms to deal with this uncertainty will affect the interests of market participants through the settlement and unbalanced funds, and the impact of clean energy on unbalanced funds has not been analyzed yet.

Focusing on the background of the power spot market for clean energy, this paper first analyzes the unbalanced

[a*]duanruiqincsg@hotmail.com, [b]hejinding@yn.csg.cn, [c]jiangyan@yn.csg.cn, [d]liushuangquan@gmail.com, [e]shaoqizhuan@yn.csg.cn, [f]zhaochuan@yn.csg.cn, [g]bybeatricegan@126.com, [h]linjb@tsintergy.com

© The Authors, published by EDP Sciences. This is an open access article distributed under the terms of the Creative Commons Attribution License 4.0 (https://creativecommons.org/licenses/by/4.0/).

funds items specific to China's power spot market, then conducts a qualitative analysis of the impact caused by high share of clean energy on unbalanced funds, and finally, from the perspective of quantitative analysis, proposes three predictive models of unbalanced funds impact: a prediction model based on simulation clearing, a prediction model based on copula function and fluctuation contagion chain, and a prediction model based on ES and quantile regression. It also puts forward suggestions on the application scenarios of the forecast model for the impact of unbalanced funds, and provides technical means for predicting and evaluating the changes in the interests of power market participants in the context of China's energy transition in the future.

2. Unbalanced Funds Specific to China's Power Spot Market

2.1. Dual-track deviation

Chinese electricity industry is transitioning from planning-based mechanism to market-based mechanism. In the power spot market clearing model, there is no division between units and loads as to whether they are market participants, and the clearing model is the optimization of the output of units and loads on the whole network, so when there is no line congestion and the units and loads on the whole network are settled according to the locational marginal prices (LMP), the market expenditure and revenue are balanced.

$$\sum_i P_{\text{u-m},i} \cdot Q_{\text{u-m},i} + \sum_j P_{\text{u-p},j} \cdot Q_{\text{u-p},j} = \sum_\beta P_{\text{l-m},\beta} \cdot Q_{\text{l-m},\beta} + \sum_\varepsilon P_{\text{l-p},\varepsilon} \cdot Q_{\text{u-p},\varepsilon} \quad (1)$$

Where, $Q_{\text{u-m},i}$, $Q_{\text{u-p},j}$, $Q_{\text{l-m},\beta}$ and $Q_{\text{u-p},\varepsilon}$ respectively denote the spot power market clearing power of market unit i, planned unit j, market load β, and planned load ε , and $P_{\text{u-m},i}$, $P_{\text{u-p},j}$, $P_{\text{l-m},\beta}$, $P_{\text{l-p},\varepsilon}$ denote the clearing prices of market unit i, planned unit j, market load β, and planned load ε , respectively.

However, the current market settlement requires separating the settlement of units and loads that are still in the planning-based system and those that have become market participants. The revenue and expenditure of units and loads in the market are likely to be unbalanced, i.e. $\sum_i P_{\text{u-m},i} \cdot Q_{\text{u-m},i} \neq \sum_\beta P_{\text{l-m},\beta} \cdot Q_{\text{l-m},\beta}$, and the unequal part of these two is the dual-track deviation.

Depending on the dual-track mode adopted by each province, Guangdong province adopts the decoupling mode[7] , in which the unit output is re-classified as "whether or not it is market output" at the settlement stage, so that the market unit output is equal to the market load, and the deviation of the dual-track system is only caused by the price mismatch between market power generation and market consumption, i.e. $P_{\text{u-m},i} \neq P_{\text{u-p},j}$; Shanxi, Shandong and other provinces adopt the non-decoupling mode in which power will not be adjust at the settlement stage[7][8], and the deviation of the dual-track system is brought by the mismatch of both quantities and prices between the market power generation and market consumption.

2.2. CfD basis amount

(1) Basis cost between the medium- and long-term market and the day-ahead market

At present, all provinces and regions have adopted the "day-ahead energy market + real-time energy market" electricity spot market design structure, that is, the market structure adopted by PJM, CAISO and other electricity markets. With this market structure, the real-time power market is the real "spot market", and the day-ahead power market is financial in nature and can be regarded as an ultra-short-term contract for difference in the real-time power market, so PJM market has introduced non-actual electricity generating and producing institutions such as financial institutions as participants in virtual transactions in the day-ahead electricity energy market in order to activate day-ahead energy market transactions and discover market prices. In addition, the futures on financial exchanges and the current medium- and long-term CfDs in China are CfDs for longer time periods. Thus, under such a market structure, the market settlement would be calculated as follows.

$$R_i = \sum_c Q_{c,i} \cdot (P_{c,i} - P_{\text{base},c,i}) + Q_{\text{da},i} \cdot (P_{\text{da},i} - P_{\text{rt},i}) + Q_{\text{rt},i} \cdot P_{\text{rt},i} \quad (2)$$

where R_i represents the revenue of unit i, $Q_{c,i}$, $P_{c,i}$ and $P_{\text{base},c,i}$ denotes the contract volume, contract price and settlement point price of the cth CfD or futures of market participant i, $Q_{\text{da},i}$ and $P_{\text{da},i}$ denotes the clearing volume and price of market participant i in the day-ahead spot market for electricity, , $Q_{\text{rt},i}$ and $P_{\text{rt},i}$ denotes the clearing volume and price of market participant i in the real-time spot market for electricity, respectively.

Under the current settlement mechanism of power market in China's provinces and regions, the revenue $R_{\text{set},i}$ of the unit i can be presented at in the following form.

$$R_{\text{set},i} = \sum_c Q_{c,i} \cdot P_{c,i} + (Q_{\text{da},i} - Q_{c,i}) \cdot P_{\text{da},i} + (Q_{\text{rt},i} - Q_{\text{da},i}) \cdot P_{\text{rt},i} \quad (3)$$

Let $A_{\text{con}} = R_i - R_{\text{set},i}$, then it can be found that equation (3) ignores the basis difference between the CfD settlement point price and the day-ahead market LMP compared to equation (2), resulting in a deviation charge $A_{\text{CfD2da},i}$.

$$A_{\text{CfD2da},i} = \sum_c Q_{c,i} \cdot (P_{\text{da},i} - P_{\text{base},c,i}) \quad (4)$$

Similarly, the expenses C_j , $C_{\text{set},j}$ for load j, and the deviation charges $A_{\text{CfD2da},j}$ can be formulated as in equation (2) (3) (4). Since the CfD and the electricity energy spot are both settled on the floor, the sum A_{CfD2da} of the deviation expense is calculated on both sides of the generation and consumption.

$$A_{\mathrm{CfD2da}}=\sum_{c}Q_c\cdot(P_{\mathrm{da},i}\text{-}P_{\mathrm{da},j}) \quad (5)$$

where Q_c represents the contract volume of the cth CfD, and unit i and load j are the counterparties to this CfD, respectively.

(2) Basis cost between the day-ahead market and the real-time market

Based on $\sum_i R_i-\sum_j C_j$,the deviation cost between generation and consumption costs can be calculated as follows.

$$\sum_i R_i-\sum_j C_j=\sum_i Q_{\mathrm{da},i}\cdot P_{\mathrm{rt},i}-\sum_j Q_{\mathrm{da},j}\cdot P_{\mathrm{rt},j}-A_{\mathrm{da,block}}-A_{\mathrm{rt,block}}-A_{\mathrm{CfD2da}} \quad (6)$$

where $A_{\mathrm{da,block}}$, $A_{\mathrm{rt,block}}$ are the congestion surpluses in the day-ahead and real-time markets, respectively. It can be found that there is a deviation cost A_{da2rt} between the revenue on the generation side and the expenditure on the consumption side.

$$A_{\mathrm{da2rt}}=\sum_i Q_{\mathrm{da},i}\cdot P_{\mathrm{rt},i}-\sum_j Q_{\mathrm{da},j}\cdot P_{\mathrm{rt},j} \quad (7)$$

Comparing equations (5) and (7), it can be found that the form of the two deviation cost calculation formulas is the same, for the medium- and long-term CfDs and the day-ahead market for two different time scales of CfDs, whose incomplete hedging causes a price basis difference and thus accumulating the market deviation cost.

3. Qualitative Analysis of the Impact of Clean Energy on the Unbalanced Funds in the Electricity Spot Market

3.1. Impact of high proportion of clean energy on existing unbalanced capital account

According to the unbalanced cash items of electricity in various provinces and regions, the possible impacts of high proportion of clean energy on them are summarized as follows:

(1) Double-track mechanism deviation

Affected by the double-track market mechanism, it is difficult to form a matching balance relationship between priority generation and power purchase on the curve, while after large-scale clean energy integration, its power generation uncertainty leads to an increase in the deviation of power generation and purchase curve, thus expanding the unbalanced funds.

(2) Energy compensation cost for frequency regulation

In the frequency regulation ancillary service market, the clean energy stations that bidding during each trading session, participating in real-time frequency regulation, lead to the deviation between the actual power generation and the planned clearing of the real-time spot market, which results in unbalanced funds.

(3) Capacity compensation cost

The clean energy stations participate in the capacity market, resulting in a decrease in the utilization hours of the units. It is necessary to compensate the clean energy units to recover the fixed costs. The compensation is the market imbalance fund.

3.2. New unbalanced funds that may be brought about by high proportion of clean energy

When the generation of power grid is mainly turned into clean energy, the uncertainty of its output brings about the demand for new power derivatives. Facing with these demands, in order to motivate service providers, the preliminary stage may be in the form of compensation. Through the unbalanced fund account, the service recipient shall bear the cost

(1) Flexibility service

Under the environment of high proportion clean energy electricity market, in order to enhance the flexibility of power system flexible regulation, flexible resources are needed to provide flexibility value, such as system climbing service and system sliding service [9-12].

(2) Adequacy service

In order to ensure the reliability of system power supply, it is necessary to have resources to provide adequacy value, such as the service cost of reserve capacity generated by the electric energy capacity market service, and the peak shaving service cost generated by the flexible resource capacity market [13].

(3) Grid stability service

The uncertainty of clean energy output and the inherent physical characteristics of clean energy power generation units will impact the stability of the power system after the clean energy is integrated to the grid. Therefore, it is also necessary to add the service cost of the moment of inertia [14], the service cost of the stability control machine cutting, and the service cost of the fast load cutting.

4. Prediction method of unbalanced funds impacts on clean energy power spot market

4.1. Unbalanced funds impact prediction model

In the above analysis, it can be known that after the high percentage of clean energy enters the power spot market, it may not only cause new unbalanced funds terms, but also cause fluctuations in the original unbalanced funds terms. Therefore, it is necessary to forecast the possible impact of unbalanced funds in the high share of clean energy power spot environment, as shown in figure 1.

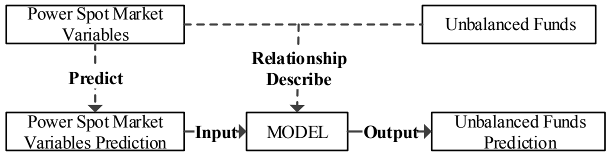

Figure.1 Model framework for forecasting the impact of unbalanced funds

(1) Predict variables based on historical data of power spot market variables

(2) Based on historical data, describe the relationship between power spot market variables and unbalanced funds by modeling, and the resulting model will be used to predict unbalanced funds.

(3) Obtain the prediction of unbalanced funds impacts by setting the variable prediction of the power spot market as the input of the model.

The core of the prediction of the unbalanced funds impact is mainly composed of two parts:1) Prediction of power spot market variables; 2) Modeling of the impact of power spot market variables on the unbalanced funds.

For the prediction of power spot market variables, there already are many mature methods for different variables, such as literature [15] describes different types of load forecasting methods, and the literature [16] reveals wind turbine output forecasting methods for different technical routes. This paper mainly focuses on the second point, i.e., the modeling of the impact of power spot market variables on unbalanced funds.

4.2. Unbalanced funds impact model based on simulated clearing

In the ideal case where the basic data are sufficient and the technical methodology is mature, a prediction model based on power spot simulation clearing can be used. All variables of the high percentage of clean energy power spot market are forecasted and put into the simulation system for clearing, so that the clearing results of the electricity energy and electricity derivative commodity market can be obtained [17]. Based on the market results, the amount of each unbalanced funds term is further calculated for each time period, and finally, the unbalanced funds are forecasted for a certain period in the future. This method is essentially a process of simulating the clearing and settlement of the power spot market for a certain period in the future.

The advantage of this model is that it can obtain the exact amount of unbalanced funds for each future time period. However, the drawbacks of this method are: 1) High forecasting accuracy is required for all boundary conditions of the simulation system, and the market clearing model itself is a nonlinear optimization model, which may magnify the further error of the method boundary conditions forecasting, and the convergence of the obtained unbalanced funds forecasting results cannot be guaranteed. 2) The application scenarios of unbalanced funds impact analysis are usually long-period analysis with annual and monthly cycles, and after time scale lengthening, the deviation of the simulation clearing model may also be cumulatively enlarged.

4.3. Unbalanced funds impact model based on copula function and fluctuation contagion chain

The impact model of power spot variables on unbalanced funds is a nonlinear model, which can be subdivided into two models according to the different types of unbalanced funds:

4.3.1 The amount of unbalanced funds is a function of the volume and price of power spot clearing

Unbalanced funds such as dual-track deviation costs, congestion surplus, and medium- and long-term congestion costs all fall into this category and can be abstracted and expressed as the following equation.

$$A = f(P_i, Q_i) \tag{8}$$

where A denotes the unbalanced funds costs, and P_i, Q_i denote the ith clearing price and clearing volume of the electric energy spot, respectively.

The dual-track deviation can be expressed as follows.

$$A_{t,\mathrm{bi}} = (p_{t,s} - p_{t,l}) \cdot (q_{t,s} - q_{t,l}),\ s \in S, l \in L \tag{9}$$

where $A_{t,\mathrm{bi}}$ represents the dual-track deviation cost at time t, $p_{t,s}$ and $q_{t,s}$ respectively denote the LMP and clearing power of unit s at time t, $p_{t,l}$ and $q_{t,l}$ denote the LMP and load level of load l at time t, and S and L denote the set of market units and market loads, respectively.

The congestion surplus can be calculated as follows with the market portion of generation and consumption balanced.

$$A_{t,\mathrm{block}} = \sum_{s \in S} p_{t,s} \cdot q_{t,s} - \sum_{l \in L} p_{t,l} \cdot q_{t,l} \tag{10}$$

where $A_{t,\mathrm{block}}$ represents the cost of unbalanced funds at time t.

If the power generation and consumption of the market portion are unbalanced, the calculation is as follows.

$$A_{t,\mathrm{block}} = \sum_{s \in S} p_{t,s} \cdot q_{t,s} - \sum_{l \in L} p_{t,l} \cdot q_{t,l} - A_{t,\mathrm{bi}} \tag{11}$$

The medium- and long-term congestion costs can be expressed as:

$$A_{t,s,c} = q_{t,s,c}(p_{t,s} - p_{t,s,c}), c \in C \tag{12}$$

where $A_{t,s,c}$ represents the medium- and long-term congestion costs incurred by unit s in contract c at time t, $p_{t,s}$ and $p_{t,s,c}$ respectively denotes the spot market price of unit s at time t and the agreed price of contract c. When $q_{t,s,c}$ and $p_{t,s,c}$ are the volume and price of the medium- and long-term CfD contracts, respectively, and $p_{t,s}$ is the day-ahead spot price of electricity, then $A_{t,s,c}$ represents the unbalanced funds from the basis difference between the medium- and long-term CfD contracts and the day-ahead spot market of electricity; when $q_{t,s,c}$ and $p_{t,s,c}$ are the clearing volume and price of the day-ahead spot market, respectively, and $p_{t,s}$ is the price of real-time market, $A_{t,s,c}$ represents the unbalanced funds from the basis difference between the day-ahead spot market and the real-time spot market.

4.3.2 The amount of unbalanced funds is a function of the demand for a certain type of electricity commodity

This type of unbalanced funds is the cost of meeting the needs of a certain type of market, that is, the cost of electricity derivative commodities. This type of market demand is often met through cost compensation, which usually includes: capacity, ramping and other service costs; variable costs, start-up and shutdown costs, and other compensation costs. The amount of such unbalanced funds can be expressed as follows.

$$A_{t,d} = q_{t,d} \cdot p_{t,d} \tag{13}$$

where $A_{t,d}$ represents the unbalanced funds generated by d demand at time t, $q_{t,d}$ and $p_{t,d}$ denote the supply and unit price of d demand at time t, respectively.

For (A) type unbalance funds, the effect of the power spot variable on the unbalanced funds can be described as figure 2.

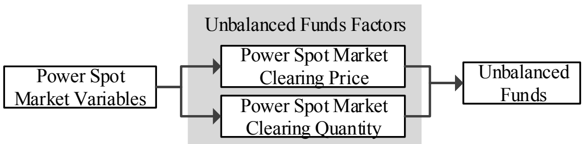

Figure.2 Influence of spot power variable on (A) type unbalanced funds

For (B) type unbalance funds, the effect of the power spot variable on the unbalanced funds can be described as figure 3.

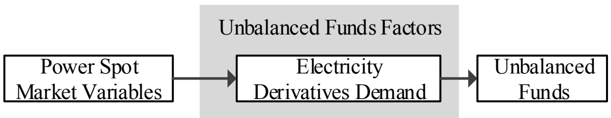

Figure.3 Influence of spot power variable on (B) type unbalanced funds

For (A) type unbalance funds, the effect of the power spot variable on the unbalanced funds can be described as follows.

It can be found that the mapping relationship from power spot market clearing price to unbalanced funds and the mapping relationship from electricity derivative commodity to unbalanced funds can be described by analytical equations, but the mapping relationship from power spot market variables to power spot clearing price and electricity derivatives demand (hereafter collectively referred to as unbalanced funds impact factor) is obviously a nonlinear system that cannot be described by analytical equations, so the Copula function is used to describe the relationship between these two relationship.

Copula function was proposed by Sklar in 1959[18] for separating randomness and coupling between multiple variables, randomness is measured by the respective marginal distributions of the variables and coupling is measured by the Copula function.

Suppose $X_1, X_2, \cdots, X_N$ is the N market factors in the power market with their respective edge distributions $F_1(x_1), F_2(x_2), \cdots, F_N(x_N)$, then there exists a Copula function such that:

$$H(x_1, x_2, \cdots, x_N) = C(F_1(x_1), F_2(x_2), \cdots, F_N(x_N)) \tag{14}$$

The Copula model is obtained by estimating the parameters of the Copula function between the actual market data of a single power spot variable and a single unbalanced funds impact factor; when the unbalanced funds impact is actually predicting, the output of the unbalanced funds impact factor is obtained by using the power spot variable as the input of this model.

If focus on multiple power spot market variables, the correlation between the multiple variables and the unbalanced funds impact factor can be described by a vine-copula [19].

4.4. Unbalanced funds impact model based on ES and quantile regression

The application scenario of unbalanced funds prediction is usually market operation risk assessment, which can assess risk based on the small granularity results of "hourly electricity price and unbalanced funds volume", but if the small granularity results cannot be obtained with guaranteed accuracy, we can also refer to the experience of financial risk field and focus only on the overall level and tail effect of unbalanced funds and thus construct the impact model of unbalanced funds.

ES index is commonly used in the field of risk quantification to measure tail risk, and in the context of unbalanced funds impact analysis, it means the maximum amount of expected value of unbalanced funds that could occur in a given future period under a certain probability level.

$$A_{\mathrm{ES},i,\alpha} = E(A_i \mid A_i \ge A_{\mathrm{VaR},i,\alpha}) \tag{15}$$

where $A_{\mathrm{ES},i,\alpha}$ represents the expected value of the most possible amount of unbalanced funds i under the probability of α , $E(\cdot)$ represents the expected value, A_i represents the amount of unbalanced funds i, and $A_{\mathrm{VaR},i,\alpha}$ represents the maximum possible amount of unbalanced funds i under the probability of α , satisfying the following equation.

$$P(A_i \le A_{\mathrm{VaR},i,\alpha}) = \alpha \tag{16}$$

where $P(\cdot)$ represents the probability.

When measuring not a single term of unbalanced funds, but comprehensively considering the impact of different unbalanced funds, the indicator SES (systemic expected shortfall) can be used [20], calculated as follows.

$$A_{\mathrm{SES},\alpha} = \sum_i k_i E(A_i \mid A_i \ge A_{\mathrm{VaR},i,\alpha}) \tag{17}$$

where k_i denotes the contribution weight caused by the unbalanced funds i to the total impact A of the unbalanced funds, satisfying $A=\sum_i k_i A_i$.

At this point, $A_{\mathrm{ES},i,\alpha}$ is the MES (marginal expected shortfall) of the imbalanced funds i.

To evaluate the SES, the idea of quantile regression [21] can be used to construct a regression model with the power spot variable as the explanatory variable. With different α as the explanatory variable, the regression model is constructed as follows.

$$A_{\mathrm{VaR},i,\alpha} = g(\mathbf{X}) \tag{18}$$

where $g(\cdot)$ represents the regression model and $\mathbf{X}$ denotes the power spot market variable, which is a vector with the number of variables as the dimension.

The technical tools used for regression can be either econometric linear regression models or intelligent algorithms such as SVR [22], LSTM [23].

5. Conclusion

This paper studies the background and types of unbalanced funds in China's power spot market, conducts a qualitative analysis of the possible impact of the clean energy spot market environment on unbalanced funds, and designs three kinds of prediction models for the impact of unbalanced funds in the clean energy power spot market, including the unbalanced fund impact model based on simulated clearing, the unbalanced fund impact model based on copula function and fluctuation contagion chain, and the unbalanced funds impact model based on ES and quantile regression.

For the impact model of unbalanced funds proposed in this paper, its application scenarios include:

(1) Settlement risk warning

The impact of unbalanced funds on different time scales is assessed to support the work of early warning of settlement risk. The cost of unbalanced funds will eventually be transmitted to customers through the unbalance funds allocation mechanism or spontaneous market adjustment. Therefore, the early warning of unbalanced funds risk is an early warning of customers' electricity cost. Short-term prediction mainly assesses the tail risk of unbalance funds and issues early warnings under weekly and monthly time scales; long-term prediction mainly assesses the fluctuation trend of unbalance funds and evaluates the improvement of customers' electricity costs under multi-month and yearly time scales.

(2) Improving the allocation methods of unbalanced funds

In addition to the need for impact assessment of the total amount of unbalanced funds, it is also necessary to focus on the amount of unbalanced funds caused by different types of market participants under the existing allocation methods. Since the allocation methods can be expressed analytically, the impact analysis results can be obtained based on the forecast results of total unbalanced funds. For market participants who may bear large amounts of unbalanced funds, the fairness and incentive signals of the existing allocation methods need to be considered.

On the other hand, for the unbalanced fund costs incurred to meet the demand for a certain type of electricity derivative commodity, in the context of an energy mix with a high percentage of clean energy, the total costs associated with such demand, such as the cost of capacity compensation, need to be fully evaluated to make a decision on whether to make that power derivative commodity a separate market and encourage resource participation through competitive bidding to fully optimize the resources.

Acknowledgments

This work was supported by Yunnan Power Grid Technology Project (Research on Unbalanced Funds in Spot Market of High Proportion Clean Energy Power, YNKJXM20210124).

References

1. Gu Feng, He Aimin. See clearly the "unbalanced funds" [J]. China Power Enterprise Management, 2020 (25): 22-26.
2. Ye Ze, Chen Nianbin, Xie Qing. Formation Mechanism and Management Countermeasures of Unbalanced Funds in Power Market [J]. China Power Enterprise Management, 2021 (19): 36-41.
3. Summary of Unbalanced Funds in Power Market: Causes, Countermeasures and Prospects [J/OL]. Power System Technology:1-15[2023-02-24].https://doi.org/10.13335/j.1000-3673.pst.2022.2033.
4. Ding Weibin, Tan Zhongfu. Study on the settlement mechanism of the power market considering the treatment of unbalanced funds [J]. Power Construction, 2022,43 (07): 13-23.
5. Wu Zhaoyuan, Zhou Ming, Kou Yinggang, et al. Research on unbalanced fund allocation mechanism based on ABM model [J]. Power Grid Technology, 2021,45 (09): 3408-3416.
6. Xinhua News Agency. Xi Jinping delivers important speech at 75th UN General Assembly general debate [EB/OL] . (2020-09-22) [2021-11-14] . http://www.gov.cn/xinwen/2020-09/22/content_5546168.htm.
7. Southern Energy Regulatory Bureau, Notice on Matters Related to the Supervision of the 2022 Settlement and Trial Operation Market of the Southern (starting from Guangdong) Power Spot Market [Z] 2022.01.17.
8. Notice of the People's Government of Shanxi Province on Printing and Distributing the Administrative Measures for the Operation of Shanxi Electric Power Market (Jin Zheng Ban Fa [2022] No. 87) [Z] 2022.10.26.

9. Shandong Development and Reform Commission of the Shandong Regulatory Office of the National Energy Administration of Shandong Energy Administration, Notice on Doing a Good Job in the Settlement and Trial Operation of Shandong Electric Power Spot Market in 2022 (LJNSH [2022] No. 8) [Z] 2022.09.28.
10. CAISO．Flexible ramping product：revised draft final proposal [R]．California：CAISO，2015.
11. MISO．Ramp capability for load following in MISO markets white paper[R]．Indiana：MISO，2016．
12. NYISO． Market assessment design concepts-flexible ramping product [R]．New York：NYISO，2018．
13. Liu YQ, Zhang HP, Li Qun et al. Design and practice of power peaking auxiliary service market in Northeast Power Grid[J]. Power System Automation,2017,41(10):148-154.
14. JIANG Han，YUE Chengyan，YAN Xingyu，et al．Influence of system inertia on flexibility resource analysis for an interconnection system with a high proportion of intermittent renewable energy[J]．Power System Protection and Control，2021，49(18)：44-51(in Chinese)．
15. Kang, Chongqing, Xia, Qing, Zhang, Bo-Ming. A review of power system load forecasting research and development direction[J]. Power System Automation,2004(17):1-11.
16. Gu Xingkai,Fan Gaofeng,Wang Xiaorong et al. A review of wind power forecasting techniques[J]. Power Grid Technology,2007(S2):335-338.
17. Zhou Baorong, Li Xiaolin, Zhao Wenmeng, et al. Functional design of the southern regional power market simulation operation system[J]. Southern Power Grid Technology,2020,14(05):65-73.DOI:10.13648/j.cnki.issn1674-0629.2020.05.010.
18. Sklar A. Fonctions de repartition an dimensions et leurs marges[J]. Publ. Inst. Statist. Univ. Paris, 1959(8): 229-231.
19. Bedford Tim, Cooke Roger. Vines: A new graphical model for dependent random variables[J]. The Annals of Statistics, 2002, 30(4): 1031-1068.
20. Acharya V,Pedersen L H,Philippon T,et al.Measuring systemic risk[J].Review of Financial Studies,2017,30(1):2-47.
21. Bassett G W, Koenker R. A Quantile Regression Memoir[M]//Handbook of Quantile Regression. Chapman and Hall/CRC, 2017: 3-5.
22. Cortes C, Vapnik V. Support vector machine[J]. Machine learning, 1995, 20(3): 273-297.
23. Hochreiter S, Schmidhuber J. Long Short－term Memory[J]. Neural Computation, 1997(8) : 1735－1780.