Research on Evaluation of Bidding Effect of Hydropower Participating in Power Spot Market

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Abstract

With the reform of Chinese electricity spot market, hydropower stations need to be responsible for their own profits and participate in market bidding. Due to the repeatability of spot market bidding, hydropower stations need to accurately evaluate their bidding effect to guide the improvement of their bidding strategies. Combined with the current hydropower bidding process, market clearing mode and hydropower operation characteristics, this paper constructed the evaluation index system of hydropower bidding effect in the electricity spot market. Based on the index system, the trading results of 8 hydropower stations in a certain basin of Sichuan Province were selected as the research objects, and the Grey Relation Analysis combined with Analytic Hierarchy Process was used to evaluate and analyse the bidding results. The results show that: in the current environment of Sichuan electricity spot market, hydropower stations tend to adopt the bidding strategy of low price; hydropower stations need to widely collect and analyse market supply and demand information, clearly understand their own generation ability, formulate reasonable bidding strategy, and give priority to long term contract electricity trading to ensure their own benefits. The evaluation system pro-posed in this paper has strong practicability, which is convenient for hydropower stations to comprehensively analyse the bidding effect from multiple dimensions, and provides reference for adjusting their bidding strategies.

Keywords- *evaluation of bidding effect; hydropower; grey correlation analysis; electricity spot market*

1. Introduction

In China, before the reform of the power market, hydropower sold electricity to the power grid in the way of "one plant, one price". Due to the fixed price of electricity, the income of hydropower stations is only related to the power generation [1]. In order to give full play to the competitive role of the power market, restore the commodity attribute of power and effectively reduce the electricity price [2], in 2015, the CPC Central Committee and the State Council issued several opinions on further deepening the reform of power system, marking the beginning of China's power spot market reform [3]. In the electricity market of bidding for grid access, hydropower stations need to formulate corresponding electricity price declaration strategies to bid for grid access. Therefore, the quality of electricity price strategy is directly related to the interests of hydropower stations. As the reform of China's power spot market is still in the early stage, there are few data for reference, and there are a large number of bidding subjects in the market-oriented power market and many uncertain factors, there is an urgent need for corresponding theories to guide hydropower stations to formulate reasonable bidding strategies and ensure their own interests [4]. According to the order of transaction time, the optimization of bidding strategy can be divided into pre transaction bidding strategy optimization and post transaction bidding strategy improvement.

There have been a large number of research results for pre-trade bidding strategy optimization; literature [5,6] developed bidding strategies by predicting market clearing prices and combining them with their own bene-fit expectations, and literature [7,8] established optimization models for strategy solving, while bidding

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results often deviate from expectations due to market uncertain-ty, and the repetitive and infinite nature of market bid-ding makes such deviations a valuable experience for power stations. The analysis and evaluation of these deviations can provide a basis for future bidding strategy development [9]. Therefore there is also a need to evaluate and analyse the bidding effect after the end of the transaction.

Among the evaluation studies related to the electricity market: the literature [10] selected qualitative and quantitative indicators from five dimensions: market transactions, technical instruments, integrated energy services, management system, and social responsibility, to evaluate the effectiveness of energy saving and emission reduction of electricity retail enterprises. The literature [11] constructed a grid dispatch service quality evaluation index system from the perspective of multi-stakeholder differentiated demand satisfaction. The cur-rent evaluation study related to power sales is mainly focused on retailers, but the evaluation system is too general and has not yet taken into account the special characteristics of hydropower enterprises taking into account generation and bidding for access to the grid. For the benefit evaluation of a particular energy source, literature [12] combined hierarchical analysis with data envelopment analysis to establish an evaluation model for the business performance of photovoltaic enterprises. Although PV and hydropower are both clean energy sources, there are essential differences, and new energy sources such as PV are supported by policies and have not joined the market competition for the time being, the evaluation system is not applicable to hydropower efficiency. It can be seen that there is a lack of corresponding research on the post-trade evaluation of hydropower participation in the electricity market bidding.

This paper first analyses the current power spot market clearing rules and restrictions related to power plant operation, carries out the evaluation of the bidding effect of hydropower participation in the power spot market from two aspects: market and power plant operation, and establishes a bidding effect evaluation index system. It makes up for the lack of research related to the evaluation of the bidding effect of hydropower participation in the electricity spot market. Considering the uncertainty of market bidding, a gray correlation analysis method is proposed to solve the model jointly with the hierarchical analysis method. The feasibility and practicality of the proposed method are demonstrated by evaluating the bidding effect of eight hydropower plants in a Sichuan basin on a certain day in the calculation example.

2.Index system of bidding effect evaluation

There are two main factors to be considered for Hydropower to participate in power spot market bidding: (1) ensure the safe operation of hydropower; (2) Gain greater benefits from the market. Therefore, this paper chooses to evaluate the bidding effect from two aspects: the bidding results after the transaction and the operation status of hydropower.

2.1. Spot trading of hydropower

At present, China only opens the day-ahead market and the real-time market for unilateral bidding on the power generation side. In the day-ahead market, power producers submit their 96-point power-price curve for the next day the day before, while in the real-time market, they only need to submit the maximum power generation capacity of hydropower plants one hour in advance of the operating period, and the declared price follows the price declared in the day-ahead market. (see **Figure 1**).

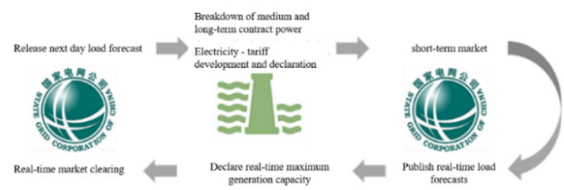

Figure 1 The time flow of spot trading

Generally speaking, hydropower manufacturers first decompose the medium and long-term contract power according to a certain curve type, and then formulate the power price plan in combination with the power sales target in each period. The bidding income of the power station is calculated according to the "contract for price difference", the actual power generation is settled according to the spot clearing price, and the difference between the actual power generation and the medium and long-term contract power is settled according to the difference between the spot clearing and the medium and long-term contract price. Hydropower's participation in the bidding operation of power spot market needs to meet the following constraints:

(1) Output balance

$$N_t = N_t^* = N_t^c + N_t^s \tag{1}$$

Where N_t 、 N_t^* 、 N_t^c and N_t^s are respectively the planned output, actual output, medium and long-term contract output and deviation output of hydropower in period t .

(2) Generation income

$$I_g = \sum_{t=1}^{T} \left(N_t^* \times P_t^m + N_t^c \times \left(P_t^c - P_t^m \right) \right) \times \Delta t \tag{2}$$

Where I_g is the power generation income of the power station; T is the total number of time periods; Δt

is the length of the period; P_t^m 、 P_t^c are market clearing price and medium and long-term contract price.

2.2. Hydropower operation

Safe production is the premise for hydropower stations to participate in market competition. Affected by the uncertainty of incoming water resources, multi-objective utilization needs such as hydropower flood control and navigation, in some cases, if the hydropower can not operate safely and efficiently according to the day ahead trading plan, it is necessary to evaluate the bidding results from the aspect of hydropower operation. For hydropower, its safe operation generally needs to meet the following constraints:

(1) Water balance constraint

$$V_{t+1} = V_t + \left(Q_t^{in} - Q_t^a - Q_t - Q_t^o\right) \times \Delta t \times 3600 \tag{1}$$

(2) Reservoir water level constraint

$$Z_t^{\min} < Z_t < Z_t^{\max} \tag{2}$$

(3) Storage capacity constraint

$$V_t^{\min} < V_t < V_t^{\max} \tag{3}$$

(4) Generation flow constraint

$$Q_t^{\min} < Q_t < Q_t^{\max} \tag{4}$$

(5) Output constraint

$$N_t^{\min} < N_t < N_t^{\max} \tag{5}$$

(6) Vibration zone constraint

$$\begin{cases} N_t^* < P_{1,t}^L \\ P_{j,t}^H < N_t^* < P_{j+1,t}^L \quad (j = 1, 2, \cdots, N-1) \\ P_{j,t}^H < N_t^* \end{cases} \tag{6}$$

(7) Nonnegative constraint

All the above variables are non negative (≥ 0).

where V_{t+1} and V_t are the storage capacity of the reservoir in t and $t+1$ period respectively; Q_t^{in} 、 Q_t^a 、 Q_t 、 Q_t^o refers to the flow of warehousing, waste water, power generation and other water in t period. Z_t 、 $Z_t^{\min}$ and $Z_t^{\max}$ are the reservoir water level, the lowest limit water level and the highest limit water level in t period. V_t 、 $V_t^{\min}$ and $V_t^{\max}$ are the reservoir capacity, minimum restricted capacity and maximum restricted capacity in t period respectively. Q_t 、 $Q_t^{\min}$ and $Q_t^{\max}$ are the generation flow, minimum generation limit flow and maximum generation limit flow in t period respectively. $N_t^{\min}$ and $N_t^{\max}$ are the minimum and maximum limited output in t period respectively. $P_{j,t}^L$ and $P_{j,t}^H$ are the upper and lower limit output of vibration zone j of hydropower station in t period respectively.

2.3. Evaluation index system

This paper analyses the bidding effect of hydropower participating in the power spot market from the perspective of market and hydropower operation. In terms of market, it mainly evaluates the electricity and electricity price obtained from the bidding of hydropower stations; In terms of hydropower operation, it mainly evaluates the safety production and operation efficiency of the power station. (see **Figure 2**)

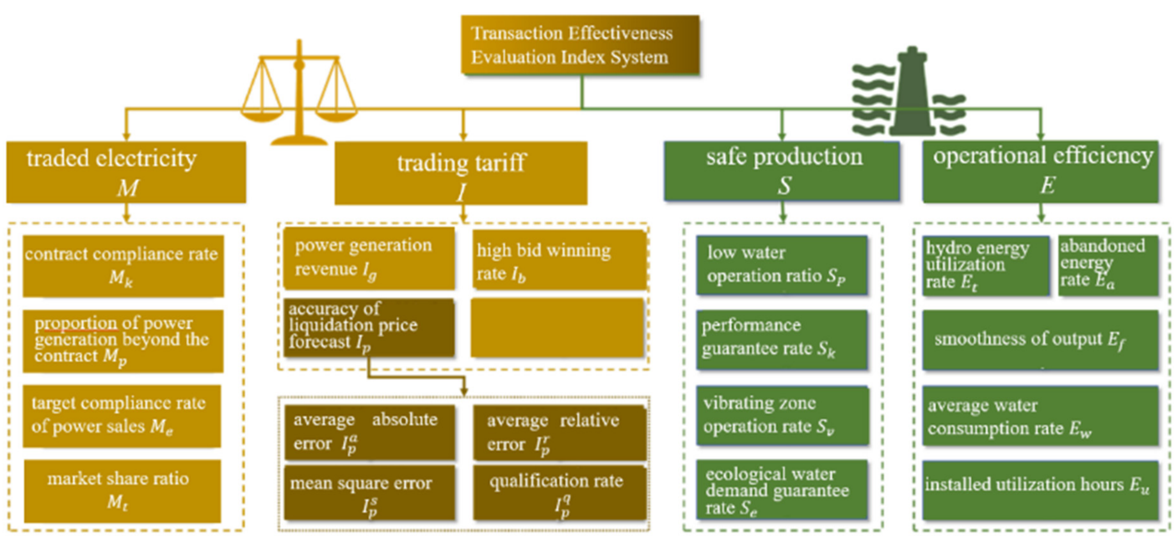

Figure 2 Evaluation index system of bidding effect

(a) Traded electricity

The power obtained from bidding is a visual representation of the results of hydropower participation in the power spot market bidding. Under the current power market bidding model, the ability to secure power from medium- and long-term contracts and to increase the winning power is the criterion for judging the good or bad power index of the transaction.

(1) Contract compliance rate M_k

The contract compliance rate is an indicator used to measure the completion of medium and long-term contracts and is calculated as follows.

$$M_k = \begin{cases} 1 & N_t \times \Delta t \geq C_c \\ \dfrac{\sum_{t=1}^{T} N_t \times \Delta t}{C_c} & N_t \times \Delta t < C_c \end{cases} \tag{7}$$

where C_c is the electricity quantity agreed in the contract.

(2) Proportion of power generation beyond the contract M_p

In addition to ensuring the medium and long-term contract power, strive for the on grid power as much as possible, so as to improve the income of the power station. The proportion of power generation beyond the contract refers to the proportion of on grid power generated by bidding that exceeds the contract power. The calculation formula is as follows:

$$M_p = \begin{cases} 0 & (N_t \times \Delta t \leq C_t) \\ \sum_{t=1}^{T} \dfrac{N_t \times \Delta t - C_t}{N_t \times \Delta t} & (N_t \times \Delta t > C_t) \end{cases} \tag{8}$$

where C_t is the quantity of electricity agreed in the contract during t period.

(3) Target compliance rate of power sales M_e

Before participating in the market bidding, hydropower enterprises will generally formulate an expected power sales target. The target compliance rate of power sales refers to the proportion of on grid power in the target power:

$$M_e = \frac{\sum_{t=1}^{T} N_t \times \Delta t}{C_e} \tag{9}$$

Where C_e is the expected electricity sales.

(4) Market share ratio M_t

There are many bidding subjects in the power market, which increases the difficulty of power stations to make a volume and price declaration plan from the game theory point of view, while a good plan can ensure that the power station will win more power bids in the competition, at the same time, the proportion of the winning power bid to the load demand of the time period can also reflect the degree of influence of the power station on the market. Market share ratio refers to the proportion of electricity traded in the day to the total market load demand.

$$M_t = \frac{\sum_{t=1}^{T} N_t \times \Delta t}{A} \tag{10}$$

Where A is the total market load demand.

(b) Trading tariffs

The transaction price is closely related to the revenue of power generation companies, and is also a direct reflection of the commodity properties of electricity. The ability to accurately predict the market trend and improve its own efficiency is the criterion for judging the good or bad indicators of the traded electricity price.

(1) Power generation revenue I_g

Power generation revenue refers to the revenue obtained by the power plant in the market competition. The price of medium and long-term contracts is often different from the spot market clearing price, and the power plant bids for power in each time period are also different from the medium and long-term contracts, so it is necessary to use the "contract for difference" method to calculate the benefit.

$$I_g = \sum_{t=1}^{T} \left(N_t^* \times P_t^m + N_t^c \times \left(P_t^c - P_t^m \right) \right) \times \Delta t \tag{11}$$

(2) High bid winning rate I_b

Under the current market bidding rules, for each time period, power stations need to divide the power of each time period into multiple segments for quotation, and the declared tariff is from low to high. The high winning rate is then the proportion of power stations winning bids for electricity above segment n .

$$I_b = \frac{T_n}{T} \tag{12}$$

where T_n is the number of periods where the winning bid is for n segments or more.

(3) Accuracy of liquidation price forecast I_p

The prediction of the market clearance price directly affects the development of the power plant quantity and price plan, as the boundary conditions of the offer, if the predicted clearance price is too high, will increase the risk of power plant abortion, while if the predicted clearance price is too low, it will harm the benefits of hydropower plants. The prediction accuracy of the clearing price can be measured from the average absolute error, average relative error, mean square error, pass rate of the predicted value and the actual value.

Average absolute error.

$$I_P^a = \frac{\sum_{t=1}^{T} \left| P_t^* - P_t^m \right|}{T} \quad (13)$$

Average relative error.

$$I_p^r = \frac{\sum_{t=1}^{T} \frac{\left| P_t^* - P_t^m \right|}{P_t^m}}{T} \quad (14)$$

Mean square error.

$$I_p^s = \frac{\sum_{t=1}^{T} \left| P_t^* - P_t^m \right|^2}{T} \quad (15)$$

Qualification rate.

$$I_p^q = \frac{T_q}{T} \quad (16)$$

Where I_P^a is the average absolute error; P_t^* is the predicted liquidation price for time period t, I_p^r is the average relative error, I_p^s is the mean square error , I_p^q is the passing rate; T_q is the number of time periods for which the predicted clearing price meets the prediction accuracy.

(4) Revenue target attainment rate I_q

Same as the electricity sales target attainment rate, the revenue target attainment rate refers to the ratio of power plant generation revenue to desired revenue.

$$I_q = \frac{I_g}{I_e} \quad (17)$$

Where I_q is the revenue target attainment rate; I_e is the expected revenue.

(c) Safe production

As the basic engineering of national economy, safety is the premise of hydropower production. Improper operation mode will not only threaten Hydropower Safety, but also cause great losses in environment, life and property. Whether it can meet the requirements of safe and efficient operation and environment is the standard to judge whether hydropower production is safe and reasonable.

(1) Low water operation ratio S_p

The low water operation ratio refers to the ratio of low water operation time to the whole time of hydropower.

$$S_p = \frac{T_l}{T} \quad (18)$$

where T_l is the number of periods of low water operation for hydropower.

(2) Performance guarantee rate S_k

The performance guarantee rate refers to the ratio of the time periods in which the hydropower generation capacity meets the winning bid to the full time period.

$$S_k = \frac{T_a}{T} \quad (19)$$

Where T_a is the number of periods during which the power can be generated to meet the winning bid.

(3) Vibrating zone operation rate S_v

Vibrating zone is a prominent problem for hydropower safety production. When hydropower is operated in the vibrating zone, it will increase the wear and tear of hydropower equipment and even lead to production accidents. Vibrating zone operation rate refers to the ratio of operating hours of hydropower in the vibrating zone to the whole time.

$$S_v = \frac{T_v}{T} \quad (20)$$

Where T_v is the number of hours that the hydropower operates in the vibration zone.

(4) Ecological water demand guarantee rate S_e

In addition to the task of power generation, hydropower often also undertakes the task of ecological environmental protection, and has ecological flow requirements for hydropower operation. The ecological water demand guarantee rate refers to the ratio of the time when the flow rate of hydropower discharge meets the ecological requirements to the whole time.

$$S_e = \frac{T_e}{T} \quad (21)$$

Where T_e is the number of periods when the discharge flow meets the ecological flow requirements.

(d) Operational efficiency

Making full use of hydro energy resources and maximizing the revenue from hydropower generation remains the primary objective of energy development. The ability to efficiently use hydro energy resources and obtain more efficient benefits is the criterion for judging whether hydropower operation is efficient.

(1) Hydro energy utilization rate E_t

Hydropower utilization rate is an important index to measure the operation efficiency of hydropower station, which represents the ratio of actual power generation to theoretical power generation in a certain period of time:

$$E_t = \frac{N_t^*}{k_w \times Q_t^{in} \times H} \tag{22}$$

Where k_w is the hydropower plant generation coefficient; H is the hydropower plant design head .

(2) Abandoned energy rate E_a

Energy abandonment will lead to the loss of hydropower resources. Energy abandonment loss refers to the ratio of hydropower abandonment to the bid winning power:

$$E_a = \frac{C_a}{\sum_{t=1}^{T} N_t \times \Delta t} \tag{23}$$

Where C_a is the amount of abandoned hydropower.

(3) Smoothness of output E_f

When the output fluctuates greatly, the hydropower needs to constantly adjust the operation strategy, which makes the dispatching operation more difficult. The output stability is calculated according to the following formula:

$$E_f = \frac{\bar{N}}{N_{\max}} \tag{24}$$

Where $\bar{N}$ and $N_{\max}$ are the average output and maximum output of the whole period respectively.

(4) Average water consumption rate E_w

Water consumption rate is an important index to characterize the efficiency of hydropower station converting water energy into electric energy. Ensuring that hydropower operates at a low water consumption rate can increase hydropower operation efficiency and improve hydropower generation capacity and performance capacity. Average water consumption rate refers to the average water consumption rate in the whole period:

$$E_w = \frac{\sum_{t=1}^{T} k_t^w}{T} \tag{25}$$

Where k_t^w is the water and electricity consumption rate for t period.

(5) Installed utilization hours E_u

Installed utilization hours refer to the ratio of power generation in hydropower installed capacity during the period, which is an important index reflecting hydropower utilization rate:

$$E_u = \frac{\sum_{t=1}^{T} N_t \times \Delta t}{N_C} \tag{26}$$

Where N_C is the installed hydropower capacity.

3.Evaluation Models and Methods

3.1. Grey correlation analysis method of joint analytic hierarchy process

The grey correlation analysis method can be used to analyse some known systems. It has low requirements for the number of data samples. It is mostly used to describe the actual laws of the system, and has been widely used in research [13] .The evaluation of each evaluation object can be made by calculating the correlation degree of each object to be evaluated. The correlation degree of the sequence to be evaluated is calculated by the following formula.

$$r_{0i} = \frac{1}{m}\sum_{k=1}^{m} \zeta_i(k) \tag{27}$$

$$\zeta_i(k) = \frac{\min_i \min_k \left|x_0(k) - x_i(k)\right| + \rho \max_i \max_k \left|x_0(k) - x_i(k)\right|}{\left|x_0(k) - x_i(k)\right| + \rho \max_i \max_k \left|x_0(k) - x_i(k)\right|} \tag{28}$$

Where r_{0i} is the correlation degree between sequence i and reference sequence; m is the number of sequence indicators; $\zeta_i(k)$ is the correlation coefficient between sequence i and index k corresponding to the reference sequence; $x_i(k)$ is the value of the k -th index in sequence i ; ρ is the resolution coefficient.

When there are more indicators in the index system, the importance of each indicator to the evaluation is often different, and the idea of weighting can be introduced to optimize the calculation of the correlation degree [14] . Analytic hierarchy process (AHP) is an effective method to solve the weight set [15]. In order to ensure the rationality of index weight selection, analytic hierarchy process is introduced to calculate the weight of each index and optimize the calculation of correlation degree. The optimized correlation degree is calculated as follows.

$$r_{0i}^{'} = \frac{1}{m}\sum_{k=1}^{m}\omega_k \times \zeta_i(k) \tag{29}$$

Where $r_{0i}^{'}$ is the optimized correlation; ω_k is the weight of the index k calculated according to the hierarchical analysis.

3.2. Evaluation Steps

The steps for evaluating the effect of hydropower participation in the electricity spot market bidding are shown in Figure 3, and the specific steps are as follows.

Step 1: Collect relevant data to complete the index calculation, determine the reference data columns and form the initial matrix.

The power stations participating in the evaluation are formed into a set of series A; the set of evaluation indicators is B . Any element C in the set of power station series can be expressed as a vector D composed of evaluation indicators. The optimal value of each indicator constitutes the reference data column as follows

$$y^* = \left(y_1^*, y_2^*, \cdots, y_m^*\right) \tag{30}$$

Where y_m^* is the optimal value of the k -th indicator (the maximum value is taken for the positive indicator and the minimum value for the negative indicator) . The optimal set of indicators and the set of evaluation indicators form the initial matrix E as follows

$$E = \begin{Bmatrix} y^* \\ a_1 \\ a_2 \\ \vdots \\ a_n \end{Bmatrix} = \begin{pmatrix} y_1^* & y_2^* & \dots & y_m^* \\ y_{11} & y_{12} & \cdots & y_{1m} \\ y_{21} & y_{22} & \cdots & y_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ y_{n1} & y_{n2} & \cdots & y_{nm} \end{pmatrix} \tag{31}$$

Step 2: Dimensionless processing of index values.

The raw data need to be dimensionless because the metrics are of different magnitudes and cannot be compared.

$$C_{ik} = \frac{y_{ik} - y_k^{\min}}{y_k^{\max} - y_k^{\min}} \tag{32}$$

Where C_{ik} is the dimensionless index y_{ik} ; $y_k^{\min}$ and $y_k^{\max}$ are the minimum and maximum values of the index.

The composition of the dimensionless matrix is as follows

$$E^* = \begin{pmatrix} C_1^* & C_2^* & \cdots & C_m^* \\ C_{11} & C_{12} & \cdots & C_{1m} \\ C_{21} & C_{22} & \cdots & C_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ C_{n1} & C_{n2} & \cdots & C_{nm} \end{pmatrix} \tag{33}$$

Step 3: Calculate the gray correlation coefficient.

After dimensionless, the correlation coefficient $\zeta_i(k)$ between the i -th hydropower station a_i the k -th indicator C_{ik} and the corresponding indicator C_k^* of the reference series is expressed as

$$\zeta_i(k) = \frac{\min_i \min_k \left|C_k^* - C_{ik}\right| + \rho \max_i \max_k \left|C_k^* - C_{ik}\right|}{\left|C_k^* - C_{ik}\right| + \rho \max_j \max_i \left|C_k^* - C_{ik}\right|} \tag{34}$$

Where ρ is the resolution coefficient, $\rho \in [0,1]$.

Step 4: Calculate the weights of each index using hierarchical analysis.

According to the 1-9 scale theory [16], the judgment matrix is constructed by two-comparison of indicators b_k and b_j in the l -th level.

$$B_l = \left(b_{kj}\right)_{d\times d} \tag{35}$$

Where B_l is the judgment matrix of the l -th level; b_{kj} indicates the importance of indicator k relative to indicator $j\ (j = 1, 2, \cdots m)$; d is the number of indicators in the l -th level.

To avoid the influence of subjective factors, the maximum characteristic roots of the judgment matrix and the normalized eigenvectors are calculated, and the consistency test of the judgment matrix is performed.

Introduce consistency metrics CI .

$$CI = \frac{\lambda_{\max} - d}{d - 1} \tag{36}$$

Where CI is the consistency index; $\lambda_{\max}$ is the maximum eigenvalue of the judgment matrix. If the value of CI is smaller, it indicates that the consistency of the judgment matrix is better.

The consistency ratio CR was introduced to test the consistency of the judgment matrix.

$$CR = \frac{CI}{RI} \tag{37}$$

Where CR is the consistency ratio; RI is the stochastic consistency index, if $d = 4$,then $RI = 0.9$;if $d = 5$,then $RI = 1.12$.

If $CR < 0.1$,the judgment matrix is considered to have good consistency, and if it is not satisfied, it is necessary to adjust the judgment matrix and re-test the matrix consistency [17].

If it passes the test, the normalized feature vector ω is the weight vector of the indicator of this layer to the indicator of the previous layer.

Step 5: According to the weights of each indicator, the optimized correlation degree of each power station is calculated, and the bidding effect of each power station is evaluated and analysed.

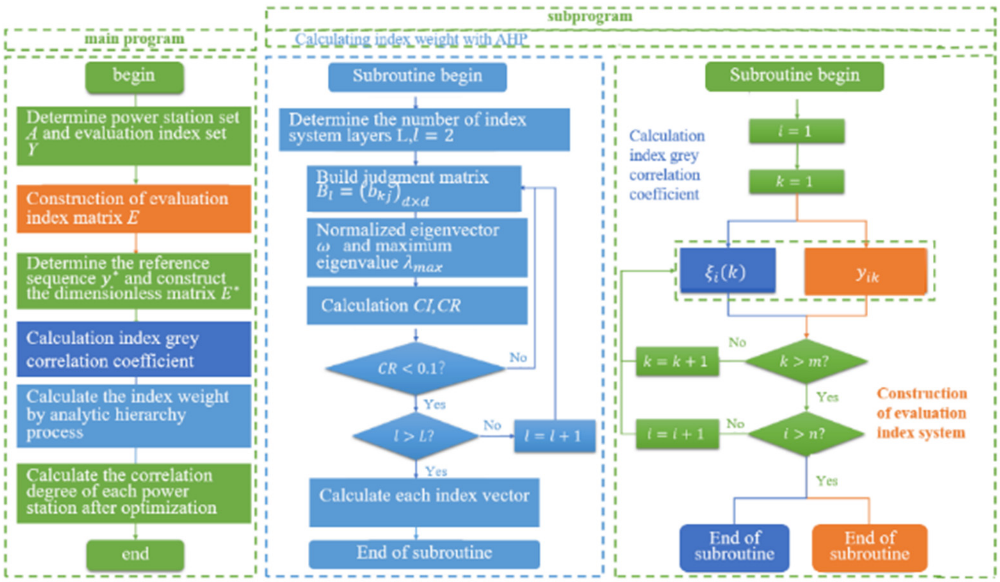

Figure 3 Flow chart of evaluation

4.Example

4.1. Basic Information

Although the bidding process is basically the same for each pilot of China's electricity spot market reform, the specific bidding rules are different. Considering the abundant hydro energy resources and the large number of hydropower stations in Sichuan, the Sichuan electricity spot market is used as an example to apply the method proposed in this paper.

Power stations A-H are 8 hydropower stations in a basin in Sichuan Province. According to the current bidding rules of Sichuan spot market, hydropower stations need to declare electricity price in 10 segments in each period of the day ahead market. The sum of the first two sections of electricity is the decomposed electricity of the power station in the medium and long-term contract, the remaining eight sections are the same, and the total electricity of section 10 is the corresponding electricity of the maximum power generation capacity of the power station. In the current Sichuan trading rules, the quotation shall meet the following constraints:

$$E_i > 10 \tag{38}$$

$$75 \le P_i \le 253 \tag{39}$$

$$P_{i+1} - P_i \ge 10 \quad (i > 2) \tag{40}$$

Where E_i is the power output of the power station in section i, ; P_i is the declared tariff of the power station in section i, $i \in [1,10]$.

The offer strategies for the eight power stations were divided into three.

Strategy 1: Low price filing

$$\begin{cases} P_i = 75 & i \le 2 \\ P_i - P_{i-1} = 10 & 2 < i \le 10 \end{cases} \tag{41}$$

Strategy 2: Conservative filing strategy

$$\begin{cases} P_i = 75 & i = 1 \\ P_i - P_{i-1} = 10 & 2 < i \le 10 \end{cases} \tag{42}$$

Strategy 3: Declaration based on forecasted liquidation price

$$\begin{cases} P_i = 75 & P_t^* < 85, i \le 2 \\ P_i = 75 & P_t^* > 85, i = 1 \\ P_i - P_{i-1} = 10 & else \end{cases} \tag{43}$$

The basic information and quotation strategy of each station are shown in Table 1.

Table 1 Hydropower station information

power station	Installed capacity /MW	normal storage level /m	dead storage level /m	Discharge for maximum power / (m³ /s)	Ecological flow / (m³ /s)	bidding strategy
A	1700	1842	1802	1474	160	3
B	2600	1130	1120	1834	165.4	2
C	3600	850	790	2772	188	3
D	660	660	655	2619	327	1
E	720	624	618	2697	327	1
F	345	554	550	2825	412	2
G	770	528	520	1876	345	3
H	700	474	469	2536	345	1

4.2. Bidding Effect Analysis

According to the collected information, complete the index calculation of each power station, and select the reference data column according to the index attribute:

$$y^* = \begin{Bmatrix} 1.00, 0.60, 1.00, 0.09, 12.38, 0.51, 16.36, 0.08, \\ 358.23, 0.66, 1.00, 0.00, 1.00, 0.00, 1.00, 1.32, \\ 0.00, 0.82, 2.58, 19.60 \end{Bmatrix}$$

After adding the reference data column, the index data is dimensionless. The performance of bidding results of each power station under the index system is shown in Figure 4.

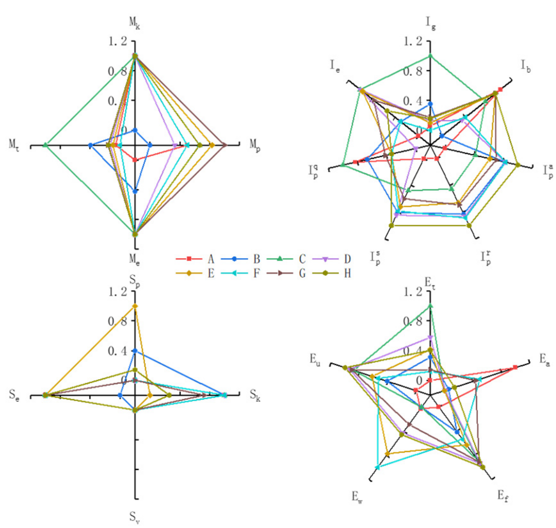

Fig. 4 The specific performance of each hydropower station under twenty criteria

On the whole, there is an aggregation of lines on indicators such as contract compliance rate, power sales target attainment rate, market share share, power generation revenue, vibration zone operation rate, ecological water storage guarantee rate, etc. It can be seen that most of the power stations in this transaction result in more satisfactory revenue and better meet the safety production and environmental needs.

In terms of market transactions, under the current market environment, all power stations, except for Power Station B, ensured a better completion of medium- and long-term contracted power in the bidding and secured a certain amount of spot power in the market according to their own capacity size. Except for Power Station A and Power Station B, all the power stations have completed their own power sales targets, while Power Station A has the lowest satisfaction level among all power stations in the bidding due to its over-set targets combined with its own strategy formulation mistakes. In terms of market share, it is generally believed that power stations with larger installed capacity perform better in the market competition, but from the results, the market share ratio of this transaction is not consistent with the size of each power station's installed capacity. In terms of power generation revenue, except for power station A, which has a large difference between the revenue earned and the market share, the revenue of the remaining power stations has a good consistency with the winning power bid, while power station A has the best high bid winning rate among all power stations and power station B has the lowest high bid winning rate. Overall, the power generation revenue of each power station is inversely correlated with the forecast error of its clearing price and positively correlated with the forecast passing rate, and except for power stations A and B, the remaining power stations all have good satisfaction with the revenue.

In terms of power station operation, in order to meet the operating demand of the transaction, Power Station E and Power Station B had a large ratio of low water operation, while Power Stations E, G and H did not reach 100% of their performance guarantee rate due to the wrong prediction of their own power generation capacity, which led to their inability to complete the winning power bid in certain periods, thus resulting in the loss of benefits. To ensure the operational safety of power stations, all power stations did not operate in the vibration zone, while all power stations, except for Power Station B, ensured the downstream ecological water demand. In terms of power station operation efficiency, Power Station C has the highest water energy utilization index among all power stations due to the use of inventory generation and high generation efficiency, while Power Station A is limited by the trading results, resulting in its lower water energy utilization and higher energy abandonment rate. In terms of output smoothness, the overall output of Power Station C and Power Station D is relatively smooth, while the average water consumption rate of Power Station B and Power Station C is smaller and the operating efficiency is higher.

It can be seen from the above analysis that although the performance of each power station is relatively clear in each index, each station has its own advantages and disadvantages in different indexes. Therefore, it is necessary to use the evaluation method to evaluate the bidding effect of the power station as a whole. Although there is a large gap in some indicators in the bidding results of the eight stations, due to the different relative importance of each index, the analytic hierarchy process is used to weight each index in the evaluation, and the weight distribution of each index is obtained, as shown in Figure 5. From the three strategies adopted in the quotation of 8 power stations, different strategies have different sensitivity to the accuracy of clearing price prediction. Therefore, the weight of the four indicators corresponding to the accuracy of clearing price prediction is low, and safety production is the most important in the transaction.

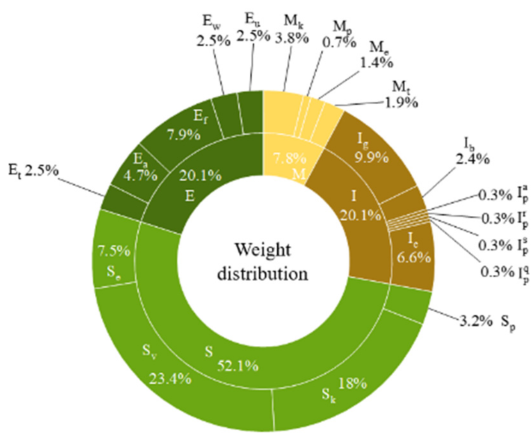

Figure 5 Distribution of weight results

The optimized correlation is calculated using grey correlation analysis combined with hierarchical analysis

$$r' = \begin{Bmatrix} 0.0373, 0.0348, 0.0483, 0.0431, \\ 0.0346, 0.0376, 0.0384, 0.0365 \end{Bmatrix}$$

The results of this evaluation are: C>D>G>F>A>H>B>E.

4.3. Analysis of evaluation results and adjustment of bidding strategy

For power station C, due to its huge installed capacity, power station C has good performance ability, which has laid a solid foundation for obtaining more market share and ensuring higher income. Although power station C has a good performance in this bidding, it is also found that there are deficiencies in the bidding strategy of power station C in this bidding. Power station C adopts strategy 3. In this strategy, the accuracy of clearing price prediction is very important. However, the low accuracy of clearing price prediction of power station C leads to its low bid winning rate of high price, fails to win more power generation in the market, and its output stability and installed utilization hours fail to reach the optimal value. It can be seen that strategy 3 is an effective bidding strategy for power station C, However, the accuracy of settlement price prediction needs to be improved.

For power station B, although it also has a large installed capacity, due to the improper selection of its bidding strategy, the medium and long-term contract power cannot be completed. Compared with power station f adopting the same bidding strategy, power station B fails to obtain the ideal on grid power in the competition, resulting in a large loss of revenue. For power station B, it is necessary to adjust the bidding strategy in time and analyse the market supply and demand situation more accurately.

For power station a, although it also has a large installed capacity, its bidding effect is not as good as that of power stations D, G and F with small installed capacity. Like power station C, power station a also adopts strategy 3, and its clearing price prediction error is small in all power stations, but its prediction qualification rate is lower than that of power station C, resulting in power station a's failure to obtain sufficient on grid power, serious shortage of installed utilization hours and high energy rejection rate.

Although power station E and power station h adopt strategy 1 as power station D, due to the poor performance ability of power station E and power station h, the operation efficiency of power station is low, and the low price bidding strategy makes the standard electricity more, resulting in the failure of the two power stations to complete the bid winning electricity. It can be seen that power stations E and H need to master their power generation capacity and performance capacity more accurately, and can not blindly pursue high and medium standard electricity.

Based on the analysis of the evaluation results, the strategy optimization recommendations for each power station are shown in Table 2.

Table 2 Suggestions on bidding strategy adjustment

Power Station	Recommendation
A	The bidding effect is poor, the prediction error of the clearance price is small, but the qualification rate is poor and the abandonment energy is large, it is recommended to adopt strategy 1 or strategy 2 to enhance the winning power
B	Failure to guarantee medium and long-term contract power, the bidding strategy needs to be adjusted, and it is recommended to adopt

	strategy 1, giving priority to guarantee medium and long-term power transactions
C	With better bidding results, you can continue to bid using strategy 3, but you need to improve the accuracy of the liquidation price prediction
D	Bidding effect is good, continue to use strategy 1 bidding, pay attention to improve their own operating efficiency can get better returns
E	Poor bidding results, but more winning bids, can continue to use strategy 1 bidding, but need to combine their own performance capacity when declaring power, conservative declaration of power
F	The bidding effect is good, strategy 2 can continue to be used, but the power station needs to actively declare power with a view to a higher winning bid
G	The bidding effect is good, and it is recommended to improve the qualification rate of the bid price forecast or adopt a low price conservative bidding strategy to better utilize the hydropower generation to enhance efficiency
H	The bidding effect is good, you can continue to use strategy 1 bidding, but you need to combine your own performance ability when declaring power, and conservatively declare power

5.conclusion

Combined with the current situation of China's power spot market, this paper constructs the evaluation index system of hydropower participating in the bidding effect of power spot market from the two aspects of market and hydropower operation, evaluates the bidding effect of hydropower by combining the grey correlation analysis method of analytic hierarchy process, and evaluates and analyses the bidding effect of 8 hydropower stations in a certain day in a river basin in Sichuan, It proves that the evaluation index system proposed in this paper has strong practicability. The conclusions are as follows:

(1) The index system proposed in this paper has simple calculation and strong operability. It can evaluate and analyse the bidding effect of hydropower participating in the power spot market from the perspectives of market and hydropower operation, and guide the improvement of hydropower bidding strategy, which has strong practical value.

(2) For hydropower stations, the installed capacity can not guarantee the better trading effect. The correct way of market competition is to formulate a reasonable bidding strategy, timely evaluate the bidding results and constantly improve the bidding strategy. Under the current market situation, each power station is more inclined to adopt the strategy of low-cost access to the Internet to participate in the market bidding. Although this strategy can better ensure that the power station can obtain more electricity from the market, it is necessary to make a reasonable evaluation of its performance ability while reporting the volume and price, so as to prevent the failure to complete the bid winning electricity.

(3) Although the strategy of clearing price declaration based on prediction can improve the income of the power station, it has high requirements for the accuracy of clearing price prediction. Once there is a deviation in the prediction, it is likely to cause great loss to the benefit of the power station. Therefore, the power generation side should actively grasp the market supply and demand situation and conservatively declare the volume and price on the basis of reasonable prediction of the market clearing price.

(4) This paper mainly puts forward the evaluation index system of hydropower participating in the bidding effect of power spot market, makes up for the lack of current relevant research, and applies the evaluation system in an example. In the future research, it will more specifically study how to adjust the power price scheme of power station through the evaluation system.

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