Benefit Equilibrium Optimization of Pumped Hydro Storage Participating in Hydro-Thermal Bundling for Cross-Regional Consumption and Absorption

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Abstract: At present, the problem of benefit distribution of multi-energy joint delivery alliance which is affected by the "dual carbon" target needs to be solved urgently. On the basis of the traditional Shapley value method, considering the contribution fairness, four indexes of resource input, risk allocation, carbon policy influence, and contribution degree are introduced, and the improved Shapley model based on the cloud gravity method is constructed. The example analysis shows that compared with the traditional Shapley value allocation strategy, the improved Shapley model based on the cloud gravity method better matches the benefits of the subject and the comprehensive contribution.

Keywords: water and fire baling; water and electricity delivery; Shapley value method; cloud center of gravity method; benefit distribution

1. Introduction

Since the implementation of the west-east power transmission strategy, it has not only effectively alleviated the growing power demand pressure of the receiving provinces, but also brought significant economic benefits to the enterprises participating in the strategy[1-2]. Among them, the transmission mode integrating thermal power dispatching not only ensures the stable supply of power, but also promotes the formation of a joint transmission alliance composed of power grid, hydropower and thermal power. Therefore, the alliance has obtained rich cooperation benefits. In this context, how to fairly and reasonably distribute the interests within the alliance has become a key issue to be solved urgently[3-4].

The academic circle has deep research on the distribution of alliance benefits. As a classic and mainstream benefit distribution method, Shapley value method has been widely adopted by many scholars, and has expanded and innovated[5-6] on this basis. However, with the proposal of the "two-carbon" target, the possible impact on the benefit distribution pattern of the delivery alliance has not been fully explored, and there are still gaps in relevant research.

So this paper introduces the influence factor of outgoing benefit distribution, and fully considers the new requirements of "two-carbon" target for the benefit distribution of outgoing alliance, and improves the Shapley value method based on the cloud gravity method. The effectiveness of the improved model is verified, and it provides a new solution for the benefit distribution problem of the joint delivery alliance in the context of "two-carbon".

2. Model construction

2.1 Impact factor calculation of benefit distribution

In order to calculate the impact of the "two-carbon" target on the benefit distribution of the outgoing alliance, in the process of benefit distribution, we should not only consider the direct economic benefits, but also consider the incidental environmental benefits [7]. Therefore, the factors that may affect the distribution of benefits are summarized, and their calculation methods are given. The specific calculation formula is shown in Table 1:

Table 1. Table of influencing factors and indicators

Level 1 INDICATORS	SECONDARY INDICATORS	CORRELATION FORMULA	EXPLAIN
Resource Input	Investment amount Installation cost Human costs	$A_{ij}=\frac{C_{ij}}{\sum_{i=1}^{n}C_{ij}}$ $\alpha_i=\sum_{i=1}^{n}(A_{ij}\times P_j)$	C_{ij} (i represents the different participants; j represents the different resources invested) represents the cost A_{ij} value i j of the first resource; α_i represents the proportion i of participants invested j in the first resource; P_j represents the importance of the first resource in all resource categories.
Spreading Of Risk	Market risk Technical risk Construction risk Natural risk	$R_i=\sum_{j=1}^{m}f_{ij}\times w_j$ $\beta_i=\frac{R_i}{\sum_{i=1}^{n}R_i}$	R_i : the risk value of the participant; m : the total risk type; f_{ij} : the cost of the first risk for participation; w_j : the weight value of different risk factors; : β_i the risk bearing proportion of the participant.
Contribution Degree	Benefit optimization	$L_i=S_i'-S_i$ $\gamma_i=\frac{L_i}{\sum_{i=1}^{n}L_i}$	L_i : the benefit changes of the participants; S_i S_i' : the benefits obtained by each subject after selling electricity separately and participating in the outsourcing alliance; γ_i : the contribution ratio of the participants.
Policy impact	Carbon emission	$E_S=I_x\times f_x\times(1+\alpha_x)$ $E_H=\gamma\times Q_h\times\pi$ $E_D=E_{SF_6}+E_\alpha$	E_S : the carbon emission of hydropower enterprises; I_x : the materials required during the construction; f_x : the carbon emission intensity of the construction materials; α_x : the unit consumption coefficient of materials; E_H : the carbon emission of the thermal power enterprise, Q_h : the fuel of the thermal power enterprise; π : the conversion coefficient of fuel per unit electricity consumption; E_D : the carbon emission; E_{SF_6} : the greenhouse gas emissions (tons of carbon dioxide equivalent); E_α : the accounting emissions of the transmission and distribution of the power grid enterprises.

2.2 Delivery benefit distribution model based on improved Shapley

Step 1: Measure the index cloud

For the qualitative indicators in the indicators, they can be expressed as "no, weak, small, general, large, huge", and quantitatively normalized according to the upper E_x E_n and lower limits of the data. The calculation formula of the expected value and entropy of each cloud model is as follows:

$$E_x = \frac{(E_{x_1} + E_{x_2} + \cdots + E_{x_n})}{n} \quad (1)$$

$$E_n = \frac{\left(\max(E_{x_1}, E_{x_2}, \cdots E_{x_n}\right) - \min(E_{x_1}, E_{x_2}, \cdots E_{x_n}))}{6} \quad (2)$$

Where this $E_{x1}, E_{x2}, \cdots, E_{xn}$ is the exact n value of the expert.

Step 2: Build the system state

The above four indicators can be expressed by a four-dimensional comprehensive cloud. When the system state reflected by the T four indicators' changes $T = (T_1, T_2, T_3, T_4)$, the shape and center of gravity of the four-dimensional integrated cloud will also change accordingly. The calculation formula is as follows:

$$T_i = a_i \times b_i \quad (3)$$

Where, the a_i expected i value of b_i the first i index is indicated, and the weight of the first index is normalized. Suppose the ideal value of each indicator $G^0 = (G_1^0, G_2^0, G_3^0, G_4^0)$ of the model is 1, and the ideal cloud center of gravity.

Step 3: measure the index weight

The weight of each index was determined n by the entropy weight method R. Set the original matrix from each expert rating matrix:

$$R = \begin{pmatrix} r_{11} & \cdots & r_{14} \\ \vdots & \ddots & \vdots \\ r_{n1} & \cdots & r_{n4} \end{pmatrix} \quad (4)$$

Where, the r_{ij} expert i scores j the first indicator.

The raw data is then normalized, namely:

$$Y_{ij} = \begin{cases} \dfrac{r_{ij} - \min(r_i)}{\max(r_{ij}) - \min(r_{ij})}, r_{ij} > 0 \\ \dfrac{\max(r_i) - r_{ij}}{\max(r_{ij}) - \min(r_{ij})}, r_{ij} < 0 \end{cases} \quad (5)$$

Where, for Y_{ij} the r_{ij} results obtained after the normalization treatment.

The evaluation of each expert was normalized, namely:

$$p_{ij} = Y_{ij} \Big/ \sum_{i=1}^{m} Y_{ij} \quad (6)$$

Where, are p_{ij} the Y_{ij} results obtained after the normalization treatment.

Calculate the i entropy e_i value of the index, namely:

$$e_i = \frac{-1}{\ln m} \sum_{i=1}^{m} p_{ij} \ln p_{ij} \quad (7)$$

Finally, the entropy i right ω_i of the index is calculated, namely:

$$\omega_i = (1 - e_i) / 4 - \sum_{i=1}^{4} e_i \quad (8)$$

Step 4: Calculate the deviation index

To determine the four-dimensional $\alpha(-1<\alpha<0)$ cloud α weighted deviation degree, the larger the value, the greater the deviation from the ideal state. The ideal state is explained in this paper as the state where all parties of the Delivery Alliance T^0 invest as much resources as possible, with the greatest risk, the largest contribution and the largest carbon emission reduction contribution. The center of cloud in this state is expressed as:

$$T^0 = a' \times b = (T_1^0, T_2^0, T_3^0, T_4^0) \quad (9)$$

Where, it a' is the expected value of each indicator in the ideal state. The vector $T^G = (T_1^G, T_2^G, T_3^G, T_4^G)$ was subsequently normalized to obtain the vector:

$$s.t.\begin{cases} T_i^G = \dfrac{T_i - T_i^0}{T_i^0}, T_i < T_i^0 \\ T_i^G = \dfrac{T_i - T_i^0}{T_i}, T_i \ge T_i^0 \end{cases}, i = 1,2,3,4 \quad (10)$$

$$\alpha = \sum_{i=1}^{4} \omega_i \times T_i^G \quad (11)$$

Step 5: calculate and correct the distribution coefficient

The weighted deviation α degree of each subject is normalized α^* to obtain the weight of each $\Delta\varphi_z(v)$ subject, and $\varphi_z(v)$ then the correction value $\varphi_z(v)^*$ of the subject interests is calculated, and the initial interests of each subject are added to obtain the actual interests of each subject, as shown in the formula.

$$\Delta\varphi_z(v) = (\alpha^* - \frac{1}{n}) v_{\{S\}} \quad (12)$$

$$\varphi_z(v)^* = \varphi_z(v) + \Delta\varphi_z(v) \quad (13)$$

Where, for $v_{\{S\}}$ the benefits obtained when each subject sells electricity separately.

3. Example analysis

3.1 Initial benefit distribution

When the power generation enterprise is delivered separately, the revenue of hydropower enterprise is 5.932 billion, the thermal $v_{\{1,3\}}$ power enterprise $v_{\{2,3\}}$ is 1.387 billion $v_{\{1,2,3\}}$, and the power grid is 2.845 billion; the alliance revenue is 4.182 billion, 1.023 billion and 11.053 billion. Therefore, the traditional Shapley value method to calculate the income distribution is 3.343 billion yuan, 2.29 billion yuan and 3.684 billion yuan. After normalization treatment, the income distribution coefficient of hydropower enterprises, thermal power enterprises and power grid enterprises is (0.54,0.19,0.27).

3.2 Amend the distribution of subject interests

The weight of each index is calculated according to the given steps, and the weight of the first-level index is shown in Table 2.

Table 2. Grade I index weight

MAIN BODY	RESOURCE INPUT	SPREADING OF RISK	POLICY IMPACT
Hydropower Enterprises	0.33	0.44	0.23
Thermal Power Enterprises	0.36	0.28	0.36
Power Grid Enterprises	0.47	0.29	0.24

The cloud focus of hydropower enterprises, thermal power $T_1=(1.17,0.4788,0.4288)$ enterprises $T_2=(0.624,0.855,0.480)$ and $T_3=(0.702,0.855,0.8576)$ power $(\alpha_1,\alpha_2,\alpha_3)$ grid enterprises is,,. The degree of offset of the three main subjects is (0.34,0.3,0.47).

After normalization $\alpha*=(0.306,0.423,0.271)$. It is calculated that the revised benefits of each subject are 6.8044 billion yuan, 3.4374 billion yuan and 3.858 billion yuan respectively. After the revision, the benefit distribution coefficient of each subject is (0.483,0.244,0.273). Comparing and analyze the results of the traditional Shapley value method and the revised Shapley value method, as shown in Table 3.

Table 3. Comparison of each subject's income under different methods

MAIN BODY	INCOME ALONE	CONVENTIONAL METHOD	IMPROVES THE METHOD
Hydropower Enterprises	65.82	76.23	68.04
Thermal Power Enterprises	23.75	26.53	34.47
Power Grid Enterprises	21.71	28.58	29.76

Compared with before the revision, the interests of hydropower enterprises decreased by 5.22%, the interests of thermal power enterprises increased by 2.3%, and the interests of power grid enterprises increased by 1.78%. As the main conveying party of the delivery project, the income of hydropower enterprises accounts for 48.3% of the total income, which is the party with the highest benefit distribution in the delivery alliance. For thermal power enterprises, due to the mode of "water and fire bundling", the power generation hours have increased significantly, so the income of thermal power enterprises also increases. At the same time, the grid will increase because of the increase in total power supply.

4. Conclusion

(1) The improved Shapley value method makes the interests of all parties more closely matched with their comprehensive contribution, contributes to the fair distribution of interests between hydropower, thermal power and transmission, and also promotes the deeper cooperation between the three parties in the external transmission alliance.
(2) A more equitable distribution coefficient can also form a driving force of stable external power supply, which can not only promote the consumption of clean resources, reduce the rate of abandoned water, but also increase the benefits of thermal power enterprises.

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