Study on the whole process evaluation of new energy grid connection based on AHP-entropy weight method

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Abstract. In order to promote the transformation of energy consumption structure to low carbon, in recent years, China has vigorously promoted the development of new energy and increased the proportion of new energy installed capacity in the power sector. However, due to the lack of benefits evaluation of the whole process of new energy grid connection at present, the existing project experience cannot provide reference and guidance for subsequent project construction to improve the benefits of new energy grid connection. Based on the existing operation data of the "New Energy Cloud" platform of State Grid Corporation of China, this study constructed the evaluation index system for the whole process of new energy grid-connection, and evaluated the benefits and quality of the project from the three stages before, during and after the grid-connection. The research results will be applied to the development of the evaluation module of the "new energy cloud" platform of State Grid Corporation of China, and can also provide a reference for the evaluation of the construction of new energy projects in the energy industry.

1. Introduction

Today, human beings are faced with many difficulties and challenges for survival and development, such as climate change, environmental pollution, and resource depletion [1], the continuous use of fossil fuels has led to a continuous increase in global carbon emissions, and countries have begun to actively seek effective ways to reduce carbon emissions [2, 3]. In December 2015, more than 200 Parties at the Paris Climate Change Conference agreed on the idea of working together for a global climate change [4, 5]; in 2020, China, currently the world's largest carbon emitter, pledged to reach a carbon peak by 2030 and strive to be carbon neutral by 2060 [6, 7]. For a long time in the past, coal has maintained a dominant position in China's energy structure, accounting for about 60% of energy production and consumption, making the country's energy transition and low-carbon economic development slow [8, 9]. From 2007 to 2018, China's carbon emissions continued to rise and exceeded 10 billion tons. The carbon emissions data of China, the United States, Japan, and the whole world are shown in Figure 1 [10, 11]. As the industry with the highest carbon intensity, the power sector is the largest source of carbon dioxide among all industrial sectors in China and plays a pivotal role in achieving the goal of carbon dioxide reduction [12]. To effectively reduce carbon dioxide emissions in the power industry, the power industry enterprises are gradually promoting the development of new energy, constantly increasing the new energy installed capacity, adjusting and optimizing the power supply structure [13].
On this basis, the ultimate goal of each enterprise is to steadily promote new energy grid connections and solve the problem of new energy consumption [14].

Fig. 1. China, the United States, Japan, India, and the world carbon emissions for 2007-2018.

At present, with the continuous increase of the scale of new energy generation, the complexity of grid connection has greatly increased [15], in the process of new energy grid connection, enterprises need to solve two major problems. The first is the research and development of key technologies connected to the grid [16]. At present, the new energy power generation technology has been relatively mature, but the new energy power generation mainly based on photovoltaic and wind power has the characteristics of randomness, volatility, and so on. The problems such as oscillation and off-grid caused by the grid connection will have a significant impact on the safe operation of the power system [17, 18]. The second is the whole process management of the grid-connection project and the evaluation of the grid-connection benefit [19]. The construction of new energy grid-connected projects should not only ensure the stability and security of the new energy power supply but also ensure certain economic benefits. Therefore, it is urgent to build a management and evaluation system covering the whole process of grid-connection, to provide a reference for subsequent project construction through the evaluation of completed projects and continuously improve the quality of new energy grid-connection projects. In terms of new energy grid-connected project management, the State Grid Corporation of China has carried out comprehensive digital control over new energy business through the construction of "new energy cloud" platform[20], among them, new energy project evaluation, as an important module of the platform, is also one of the key functions of the platform development. Therefore, the construction of the whole process evaluation index system of new energy grid-connection is not only the basis for the construction of the evaluation module of the "new energy cloud" platform of State Grid Corporation of China, but also the realistic demand of the power industry enterprises in the process of new energy grid-connection.

It is a common management method to construct an evaluation system and evaluate project benefits quantitatively. The construction of an evaluation system can be divided into three steps: index selection, system construction, and weight determination. In the process of the selection of evaluation indicators and the construction of an index system, methods such as literature research, field research, and expert interview are often combined to ensure the rationality of the selection of indicators. By summarizing and combing the existing literature, this study selects the evaluation indexes. Literature[21]discusses the influence of new energy grid connection on power system from three aspects: voltage quality, current quality and power supply quality; the comprehensive benefits of distributed photovoltaic power generation system are evaluated from four aspects: economy, technology, environment and
society[22]; the literature constructs the evaluation index system of grid-connected photovoltaic social benefit from energy environment, economic development and negative social effect, and constructs the comprehensive evaluation system of technology and economy of grid-connected ground photovoltaic project with three evaluation indexes of technology, economy and society[23]; seven indexes of power supply reliability, operation fault and voltage quality are used in literature to construct the evaluation index system of power grid operation state[24]; from three perspectives of economy, reliability and security, the literature constructs a comprehensive evaluation index system for distributed generation grid-connection[25]; the literature establishes a comprehensive evaluation system for positive and negative effects of new energy grid-connection on the distribution network. The positive effect evaluation indexes include power generation, power supply, energy conservation, and emission reduction, and the negative effect evaluation indexes include voltage quality, harmonic distortion, and power change, etc[26]. The summary of each evaluation index system is shown in Table 1.

Table 1. Summary of the evaluation index system.

| Scholars               | Literature                                                                 | The index name                                                                 |
|------------------------|-----------------------------------------------------------------------------|---------------------------------------------------------------------------------|
| Du Qiang etc           | Influence of new energy grid connection on power system                     | Voltage quality, current quality, power quality                                 |
| Li Xiaowei             | Comprehensive benefit analysis of distributed photovoltaic power grid-connected system | Technology, economy, environment, society                                       |
| Wu Minshuo             | Social benefit evaluation index system of the grid-connected photovoltaic system | Environment, economy, society                                                  |
|                        | The technical and economic comprehensive evaluation system for ground grid-connected photovoltaic projects | Technology, economy, society                                                  |
| Ge Shihan              | Evaluation index system of power network running state                      | Power supply reliability, operation failure, voltage quality, load rate, etc    |
| Li Yulong              | Synthetical evaluation index system of distributed generation connection     | Economy, reliability, and security                                              |
| Zhou Niancheng, Zhou Ying, et al | The comprehensive evaluation system of positive and negative effects of new energy grid connection on the distribution network | Power generation, power supply, energy-saving and emission reduction, voltage quality, harmonic distortion, power variation, etc |

In the process of weight determination, to ensure that the weight can better reflect the importance of the index, researchers will combine the subjective weighting method with the objective weighting method. The commonly used methods are the multi-attribute decision-making method, analytic hierarchy process, fuzzy comprehensive evaluation method, entropy weight method, and CRITIC method[27-31]. Lv Zhiying established a comprehensive evaluation model for power grid construction projects by using the fuzzy multi-attribute decision-making method, comprehensively, objectively, and reasonably evaluated and optimized multiple schemes and indicators of power grid investment and construction projects, and finally reached the conclusion that economy was the most effective evaluation standard and photovoltaic resources had the highest priority [32]; Danail et al. evaluated and ranked the renewable energy in Iran's five climate zones from the perspectives of technology, economy, energy security and society by AHP, and finally reached the conclusion that economy was the most effective evaluation standard and photovoltaic resources had the highest priority [33]; Celikta and Kocar used Delphi and SWOT methods to evaluate the future of renewable energy in Turkey from the dimensions of economy, environment, and living standards. The conclusion is that renewable energy is expected to meet about 50% of Turkey's energy needs by 2030[34]; to evaluate the water quality of the reservoir, Yang Jing uses the fuzzy comprehensive evaluation method and the analytic hierarchy process combined with entropy weight method to determine the index weight in the completed evaluation system and obtains the results close
to the artificial neural network model, which further verifies the effectiveness of the above methods[35].

The above evaluation methods and their research contents are summarized in Table 2.

Table 2. Summary of evaluation methods and research contents.

| Evaluation method                  | Scholars       | The research content                                                                 |
|------------------------------------|----------------|--------------------------------------------------------------------------------------|
| Multiple attribute decision making | Lv Zhiying      | The scheme and index of power grid construction investment project are evaluated comprehensively |
| AHP                                | Danail         | Evaluate and rank the renewable energy index in Iran                                  |
| Delphi, SWOT                       | Celiktas and   | To evaluate the future development of renewable energy in Turkey                     |
| Fuzzy comprehensive evaluation method |                | Establishment of reservoir water quality evaluation system                           |
| AHP- Entropy weight method         | Yang Jing      | Determine the weight of each evaluation index                                         |

To sum up, the evaluation of the whole process of new energy grid connection is not only the realistic demand of power industry enterprises but also a problem that needs to be further explored in the current theoretical research. Therefore, the main research contents of this paper are as follows:

How to comprehensively evaluate the three stages before, during, and after the new energy grid connection from the perspectives of foundation, quality, and benefit, to continuously improve the benefits of new energy projects.

2. Research methods

2.1. Analytic Hierarchy Process

In the 1970s, Professor T. L. Saaty, an American operations researcher, put forward a multi-criteria decision-making method that can conduct quantitative analysis on qualitative problems, namely the analytic hierarchy process (AHP). It calculates the weight value of each index in each level and sorts it by mathematical method. Compared with other decision-making methods, AHP is relatively simple and highly practical, and has been paid attention to and widely used in the fields of multi-objective decision-making analysis, development planning, management evaluation, and so on [36-38].

The steps of using AHP for analysis and evaluation are as follows [39]:

(1) Construct the judgment matrix according to the nine-scale method

Nine scale method is a proportional scale method, which compares the importance of indicators and measures the importance by scoring 1-9 points. The core values and their meanings are shown in Table 3 below. Score according to the expert opinions, and get the judgment matrix in pairs.

(2) Calculate the eigenvectors and check the consistency

The consistency of the judgment matrix is tested by mathematical methods. Only when the consistency test is passed, can the conflict between the indexes of the same important level be avoided, to ensure the model is reasonable and effective. The specific steps of the inspection method are as follows [40, 41]:

1. The maximum eigenvalue of the judgment matrix was calculated $\lambda_{max}$;

2. Calculate consistency index $CI = (\lambda_{max} - n)/(n-1)$, consistency ratio $CR = CI/RI$, $RI$ is a random consistency index and is a fixed value. After calculation, if the test index $CR \leq 0.10$, it will pass the test; if $CR > 0.10$, the matrix needs to be checked and adjusted to ensure that the model is available.

Table 3. “1-9” proportional scale method.

| Scale values | The meaning                                           |
|--------------|-------------------------------------------------------|
| 1            | They are equally important compared to each other     |
| 3            | Comparing the two indicators, the former is slightly more important than the latter |
Compared with the two indicators, the former is significantly more important than the latter.

Compared with the two indicators, the former is strongly important than the latter.

Comparing the two indicators, the former is extremely important than the latter.

The median value of the above adjacent judgments.

### 2.2 Entropy weight method

In 1850, the German physicist Clausius proposed a new physical quantity -- entropy; in 1948, Shannon, an American scientist, used entropy to represent the uncertainty of signals in information sources. The larger the amount of information, the smaller the uncertainty and the smaller the entropy; on the contrary, the smaller the amount of information, the greater the uncertainty and the greater the entropy. Therefore, according to this characteristic, the entropy value can be calculated to judge the degree of dispersion of an index. The entropy weight method is an objective weighting method to determine the weight according to the above principles. It determines the weight according to the relationship between the original data and does not depend on the subjective judgment of people. Therefore, its evaluation results have a strong mathematical theory and logical basis [28, 42, 43]. The steps of using the entropy weight method for analysis and evaluation are as follows:

1. **Data standardization**

Firstly, each index is de-dimensionalized. Assume that \(m\) indicators are given: \(X_1, X_2, ..., X_m\), where \(X_j = \{x_{1j}, x_{2j}, ..., x_{nj}\}\). Suppose the normalized values of each index data are: \(Y_1, Y_2, ..., Y_m\), then,

\[
Y_j = \frac{X_j - \min(X_j)}{\max(X_j) - \min(X_j)}
\]

2. **Calculate the ratio of each index in each scheme**

\[
p_{ij} = \frac{Y_j}{\sum_{i=1}^{n} Y_j}, i = 1, ..., n, j = 1, ..., m
\]

3. **Find the information entropy of each index**

\[
E_j = -\ln(n)\sum_{i=1}^{n} p_{ij} \ln p_{ij}, \text{ where } E_j \geq 0, \text{ if } p_{ij} = 0, \text{ then } E_j = 0.
\]

4. **Determine the weight of each index**

\[
W_j = \frac{1 - E_j}{k - \sum_{j=1}^{m} E_j}, (j = 1, 2, ..., m)
\]

To sum up, the analytic hierarchy process is a subjective weighting method. It assigns values to specific evaluation indicators according to the experience and judgment of relevant experts, which reflects the subjective judgment of the evaluator, but makes the results subjective and arbitrary, and the weight value obtained is unstable. The entropy weight method is a kind of objective weighting method, which has a strong logical basis and avoids the influence of subjective factors, but it may cause the weight value to be inconsistent with reality. As a result, a single-use a kind of method to evaluate index system, easy to make the evaluation results subjective or objective, this study mainly USES the subjective and objective combination empowerment method, to determine the index weight, according
to the characteristics of the new energy grid evaluation, selection method of AHP and entropy weight method to determine the weight, get the final weight value of specific indicators [44, 45].

3. Construction of new energy grid connection evaluation index system

3.1. Constructing evaluation index system

The key point of constructing the whole process evaluation index system of new energy grid connection is to select and calculate the basic index and calculate the weight of each index [46]. Existing research focused on the evaluation of single phase of the grid, in the literature review and data collection of new energy grid project, based on this study from the grid, grid quality, interconnection benefits three perspectives, after the new energy grid in the former three stages, building as shown in table 4 new energy grid evaluation index system of the whole process. Based on the research on the grid-connection foundation in the early stage, whether the demand forecast is accurate, whether the relevant technology is feasible and whether the relevant steps and processes are clear are directly related to whether the subsequent operation of new energy grid-connection can be carried out smoothly. In the middle stage, active power, reactive power, and load compensation are all important indicators to reflect the operation results of the grid-connected system. The accident rate also measures the operation quality of the new energy grid-connected system from the perspective of safety. In the later stage, the benefits of grid connection are mainly studied. The benefits of economy, environment, and society can reflect the contributions brought by the operation of the grid connection system of new energy.

Table 4. The whole process evaluation index system of the new energy grid connection.

| Evaluation index system of new energy grid connection | The first indicators (B) | The second indicator (C) |
|------------------------------------------------------|--------------------------|-------------------------|
| Grid-based (B1)                                      | Accuracy of demand forecasting(C1) | Technical feasibility(C2) |
|                                                     | Clarity of process responsibility definition(C3) | Active power(C4) |
| Grid quality (B2)                                    | Degree of load compensation(C6) | Accident rate(C7) |
|                                                     | Economic benefits(C8) | Environmental benefits(C9) |
| Grid benefits (B3)                                   | Social benefits(C10) |

In the above evaluation index system, the specific meaning of each index is as follows:

Grid-based(B1)

The work content of the basic stage of grid connection is a solid foundation for the follow-up work. The new energy grid-based phase involves work is various, mainly need to consider the grid electricity demand forecasting, all kinds of grid technology is feasible and grid in the process of the preparation process are appropriate departments clear duties, etc., so the demand forecast accuracy, technical feasibility and process responsibility definition three Angle based evaluation index system of the new energy grid.

Accuracy of demand forecasting(C1)

Grid-connected electricity demand prediction is a necessary condition for new energy grid connection and the basis for the preparation of an industrial production plan. Accurate and reliable demand prediction can effectively improve the operation efficiency and safety of new energy grid connections. The accuracy rate of demand forecast is used to reflect the close degree between forecast quantity and actual data. For new energy grid-connection, the methods of grid-connection electricity demand prediction in different stages are not consistent, so the accuracy of corresponding demand prediction is not completely the same. At present, it is common to forecast short-term grid-connected
electricity demand, so the accuracy of short-term demand prediction is higher than that of other stages [47-49]. The formulas listed below are mainly used to study the accuracy of short-term demand prediction in the grid-connected stage of new energy.

Assuming that the prediction accuracy of grid-connected electric quantity at this stage in the previous stage is $X_1$, the prediction accuracy of grid-connected electric quantity at this stage is $X_2$, and the availability of market data is $X_3$, then the demand prediction accuracy $C_1$ can be expressed as:

$$C_1 = X_1 \times 65\% + X_2 \times 25\% + X_3 \times 10\%$$

Among them:

$$X_1 = (1 - |A - C| \div C) \times 100\%$$

$$X_2 = (1 - |B - C| \div C) \times 100\%$$

$$X_3 = (1 - D \div E) \times 100\%$$

In the formula, $A$ is the predicted value of the grid-connected electric quantity at this stage in the previous stage, $B$ is the modified value of the grid-connected electric quantity at this stage, $C$ is the actual value obtained from relevant application systems, $D$ is the number of report delays and data errors, and $E$ is the total number of report reports.

Technical feasibility ($C_2$)

The new energy grid-connected technology mainly refers to the grid-connected technology of photovoltaic, wind power, and other new energy power generation. It is very important to study the relevant technical feasibility and evaluate it for the safe and stable operation of the grid-connected system. To solve the above problems, the development of maximum power point tracking technology (MPPT) has become the focus of current research. Therefore, it is of great significance to evaluate the feasibility of a photovoltaic power station [50]. The large-scale wind power grid connection will limit the flexibility of the power grid operation. Meanwhile, the anti-peak regulation, intermittency, and randomness of wind power will increase the difficulty of peak regulation and the burden of frequency regulation of the power grid [51]. Wind power grid technology involves a wide range of issues, and it is necessary to evaluate the feasibility of relevant technologies in the basic stage of grid connection.

Clarity of process responsibility definition ($C_3$)

In the basic stage of grid-connection, the new energy grid-connection system can improve the control degree of the system through fine management, and improve the work efficiency and the reasonable allocation degree of resources through optimizing the process. Clarity of the definition of process responsibility refers to the degree to which the process responsibility in the basic process of new energy grid connection is clear to the post. In the basic process of new energy grid connection, all processes should have clear positions to undertake and the staff of the corresponding posts can clear their work content and responsibilities.

Grid quality ($B_2$)

In the context of sustainable development, solar energy, wind energy, and other new energy are gradually added to the power system, and the connection of new power systems is gradually becoming an important trend in the development of the current power industry. New energy grid connection has realized the diversification of power grid, but to some extent, it has a different influence on its quality, so it is necessary to evaluate the quality of grid connection. The grid-connection quality evaluation index system includes four indexes: active power, reactive power, load compensation degree, and accident rate.

Active power ($C_4$)

The power that directly consumes electric energy and converts it into other forms of energy and uses the energy to do work is called active power. The grid-connected power should be taken into account when making various plans for power stations. The temporal resolution of short-term grid-connected active power in photovoltaic power stations is 1 hour, and the temporal resolution of ultra-short-term active power is 15 minutes [52, 53]. The main factors affecting the grid-connected active power of photovoltaic power stations are sunlight intensity, atmospheric pressure, temperature, and humidity, etc. To adjust the grid-connected power of wind power and keep the transmitted power in a stable state, the
power prediction technology of wind power grid connection generally includes super short term, short term, and medium-term power prediction [54, 55].

Reactive power (C5)
The inductive load in the grid has the characteristic that this delay of the inductive load can maintain the direction of the current for some time even if the applied voltage changes direction. Once there is such a phase difference between the current and voltage, negative power will be generated and fed back to the grid. When the current and voltage are in the same phase again, and the same amount of electric energy is needed to build a magnetic field in the inductive load, the reverse electric energy of the magnetic field is the reactive power [56]. The problem of voltage instability occurs when wind power is connected to the grid. The main reason is that the wind farm does not need reactive power during operation, and the large capacity of the wind farm makes the reactive power cannot be effectively controlled [55].

Degree of load compensation (C6)
Load compensation refers to the addition of a compensation device on the load side to adjust the unbalanced load to reduce the current imbalance to balance the whole system [57], load compensation degree is a value that measures the load compensation ability of the system. $E_1$ and $E_2$ represent power generation and average load electricity consumption, then load compensation degree $C_6$ is [26]:

$$C_6 = \frac{E_1}{E_2} \times 100\% \quad \text{if } E_1 < E_2 \quad (5)$$

$$C_6 = 1, \quad \text{if } E_1 > E_2 \quad (6)$$

Accident rate (C7)
The safe and reliable operation of the power grid is the basis of the sustainable, healthy, and stable development of the national economy [58]. The grid-connection quality can be effectively evaluated with the index of the accident rate. Its calculation formula is as follows:

$$C_7 = \frac{\text{Count the total number of accidents within the period}}{\text{Number of people exposed to accidents during the same period}} \times 100\% \quad (7)$$

Interconnection benefits (B3)
The comprehensive evaluation of the benefits of grid connection needs to consider the influence of many factors, so starting from three angles of economic benefit, environmental benefit, and social benefit, and each Angle is analyzed by different evaluation indexes, to establish the evaluation index system of the benefits of grid connection of new energy.

Economic benefits (C8)
The economic benefit evaluation of grid connection is the most important aspect of comprehensive benefit evaluation. It is necessary to evaluate the process and effect of grid-connection financial activities by combining financial theories and comprehensive evaluation methods and finally draw a comprehensive conclusion. Multiple factors affecting the economic benefits of grid connection are considered comprehensively, including profitability and operation capacity, and specific evaluation indexes are selected on this basis [59]. Profitability refers to the ability to obtain profits, which is usually expressed as the total amount of income in a certain period. The profitability of the new energy grid-connected system can be analyzed by using several indicators such as net interest rate, cost-profit rate, and return rate on total assets. Operating capacity usually refers to operating capacity, namely the ability to use limited resources to obtain profits. It can be evaluated mainly through current asset turnover, fixed asset turnover, and total asset turnover, to reflect the capital operation turnover and resource management and utilization efficiency of the new energy grid-connected system.

Environmental benefits (C9)
Environmental benefits refer to the impact on the local environment during the construction and subsequent use of the project. The grid-connected system of new energy power generation has significant environmental benefits. Photovoltaic power generation after nearly ten years of development,
in China, has formed a relatively large scale; wind power is clean and renewable, further increasing the diversity of the country's energy production. The new energy grid system based on the traditional thermal power grid, effectively reduce the electricity grid peak pressure, enhance the flexibility of the power grid, more importantly, the new energy power generation can save coal consumption and reduce the burning of fossil energy from carbon dioxide and other greenhouse gas emissions, provide an effective path to achieve double carbon in China.

According to the coal consumption and carbon dioxide emission reduction to evaluate the environmental benefits, the average energy consumption level of domestic power plants, new energy instead of thermal power for each additional kilowatt-hour, the corresponding saving of 0.36kg standard coal, can reduce pollution emission of 0.997kg of carbon dioxide [22].

Social benefits(10)

Social benefit is a qualitative index, it refers to the good impact on the society and the contribution for the society, also known as an external indirect economic benefit. At present, the social benefits of the new energy grid connection are evaluated from the aspects of promoting economic structural adjustment, coordinating regional economy, improving local investment environment, contributing to regional GDP and fiscal revenue, and supporting the sustainable development capacity of the region and surrounding areas [59].

3.2. Determination of index weight

In this study, AHP and entropy weight method were combined to determine the final index weight. The weight calculation process is shown in Figure 2 below:

![Diagram](image)

Fig. 2. The whole process evaluation framework of the new energy grid connection.

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**Step 1:** Determine Research Objectives

**Step 2:** Constructing evaluation index system

**Step 3:** Determine index weights

**Step 4:** Results

The whole process of new energy grid connection is evaluated

Constructing the whole process evaluation index system of new energy grid connection

AHP

Entropy weight method

Construct judgment matrix

Data standardization

Calculate the eigenvectors and check the consistency

The information entropy of each index was calculated

Index weight A

Index weight B

Final Index Weights
Table 5. List of experts, professional titles, and units to which they belong.

| Serial number | Title           | Subordinate units              | Years of working |
|----------------|-----------------|-------------------------------|-----------------|
| 1              | professor       | North China Electric Power University | 31 years       |
| 2              | professor       | North China Electric Power University | 26 years       |
| 3              | professor       | North China Electric Power University | 25 years       |
| 4              | Associate professor | North China Electric Power University | 20 years       |
| 5              | Associate professor | North China Electric Power University | 18 years       |
| 6              | Senior engineer | The state grid                 | 20 years       |
| 7              | Senior engineer | The state grid                 | 18 years       |
| 8              | Senior engineer | The state grid                 | 17 years       |
| 9              | lecturer        | North China Electric Power University | 8 years        |
| 10             | lecturer        | Tsinghua university            | 7 years        |

Step1: AHP index weight determination
Firstly, this study selected 10 experts from universities and State Grid Corporation of China (the basic information of the experts is shown in Table 5) and constructed a judgment matrix.
Secondly, each judgment matrix is calculated and the consistency test is carried out. A consistency test was carried out on all the judgment matrices obtained. Judging from the calculation results, the judgment matrices passed the consistency test and met the requirements of AHP. Finally, the specific weight of each index is obtained, and the results are shown in Table 6.

Table 6. The weight of each evaluation index is obtained by the analytic hierarchy process.

| Composite indicator $A$ | Level indicator $B_i$ | The weight $W_i$ | Specific indicators $C_j$ | The weight $W_j$ | The comprehensive weights $\tilde{W}_{ij}$ |
|------------------------|-----------------------|-----------------|--------------------------|-----------------|-------------------------------------------|
| Evaluation index system of new energy grid connection A | Grid-based B1 | 0.6274 | Accuracy of demand forecasting C1 | 0.5813 | 0.3647 |
| | | | Technical feasibility C2 | 0.3091 | 0.1939 |
| | | | Clarity of process responsibility definition C3 | 0.1096 | 0.0688 |
| | Grid quality B2 | 0.2859 | Active power C4 | 0.5030 | 0.1438 |
| | | | Reactive power C5 | 0.3001 | 0.0858 |
| | | | Degree of load compensation C6 | 0.0731 | 0.0209 |
| | | | Accident rate C7 | 0.1237 | 0.0354 |
| | Grid benefits B3 | 0.0867 | Economic benefits C8 | 0.5571 | 0.0483 |
| | | | Environmental benefits C9 | 0.3202 | 0.0278 |
| | | | Social benefits C10 | 0.1226 | 0.0106 |
Step 2: Entropy weight method to determine the weight of indicators

When applying the entropy weight method to assign the weight of the evaluation index, this paper takes Qing-Yu Project, Zhang-Bei Project, and Zhang-Xiong Project, three large-scale new energy grid connection bases, as the research object. These three new energy grid connection bases have huge scale, high technical requirements, and great difficulty, and all the projects have been put into use recently. The values of each index are of good reference significance for the evaluation of subsequent project construction. The general engineering characteristics of the three projects are shown in Table 7 below.

| Engineering characteristics | Qing-Yu engineering | Zhang-Bei engineering | Zhang-Xiong engineering |
|-----------------------------|----------------------|------------------------|-------------------------|
| Region                      | Northwest-Central China | North China            | North China             |
| Commissioning time          | 2020.12              | 2020.6                 | 2020.8                  |
| Power feeding system        | Ultra-high voltage direct current | Flexible dc | Ultra-high voltage alternating current |
| Total investment (100 million RMB) | 226                  | 125                    | 59.8                    |
| Transmission distance (km)  | 1587                 | 666                    | 315                     |
| Terminal power structure    | Mainly to photovoltaic, direct-drive wind power full power conversion | Through Zhangbei, Kangbao two isolated island stations access to the power grid | Multi-stage transformer boost collection, no synchronous machine support |

The index data of the above three projects are calculated and standardized to obtain the information entropy of each index and determine the weight of the index. The results are shown in Table 8 below.

| Composite indicator $A$ | Level indicators $B_i$ | Specific indicators $C_j$ | Entropy weight $U_{ij}$ |
|-------------------------|------------------------|---------------------------|-------------------------|
| Evaluation index system of new energy grid connection $A$ | Grid-based $B_1$ | Accuracy of demand forecasting $C_1$ | 0.0609 |
|                         |                        | Technical feasibility $C_2$ | 0.0255                 |
|                         |                        | Clarity of process responsibility definition $C_3$ | 0.0105 |
|                         | Grid quality $B_2$    | Active power $C_4$        | 0.0104                 |
|                         |                        | Reactive power $C_5$      | 0.0007                 |
|                         |                        | Degree of load compensation $C_6$ | 0.0478 |
|                         | Grid benefits $B_3$   | Accident rate $C_7$       | 0.7766                 |
|                         |                        | Economic benefits $C_8$   | 0.0299                 |
|                         |                        | Environmental benefits $C_9$ | 0.0263 |
|                         |                        | Social benefits $C_{10}$  | 0.0114                 |

Step 3: Final weight determination

In this study, two methods were used separately to evaluate the weight of the evaluation index, and the mean value of the two calculation results was taken to get the final evaluation index weight of the whole process of new energy grid connection, as shown in Table 9 below.
Table 9. New energy grid-connected whole process evaluation index weight.

| Composite indicator \( A \) | Level indicators \( B_i \) | Specific indicators \( C_i \) | Entropy weight \( U_i \) |
|-----------------------------|-------------------------|---------------------|--------------------|
| Evaluation index system of new energy grid connection | Grid-based \( B_1 \) | Accuracy of demand forecasting \( C_1 \) | 0.2128 |
|                            |                        | Technical feasibility \( C_2 \) | 0.1097 |
|                            |                        | Clarity of process responsibility definition \( C_3 \) | 0.0396 |
|                            | Grid quality \( B_2 \) | Active power \( C_4 \) | 0.0771 |
|                            |                        | Reactive power \( C_5 \) | 0.0433 |
|                            |                        | Degree of load compensation \( C_6 \) | 0.0344 |
|                            |                        | Accident rate \( C_7 \) | 0.4060 |
|                            | Grid benefits \( B_3 \) | Economic benefits \( C_8 \) | 0.0391 |
|                            |                        | Environmental benefits \( C_9 \) | 0.0271 |
|                            |                        | Social benefits \( C_{10} \) | 0.0110 |

4. Results analysis

It can be seen from the index weight table that the most important hierarchical index for the evaluation of new energy grid connection is the grid foundation, followed by the grid quality, and finally the grid benefit. The grid-connection foundation is the cornerstone of the whole process of new energy grid-connection, which is related to whether the new energy grid-connection system can operate with high quality and create sustainable grid-connection benefits. The grid-connection quality of new energy is the key in the whole grid-connection process. The maximum reasonable use of grid-connection foundation to ensure the grid-connection quality can improve the economic, environmental, and social benefits of grid-connection.

From the specific measures, in the three indicators of grid-based, maximum weight to demand forecasting accuracy, is 0.2128, this is because the demand forecast is accurate new energy grid system has a close relationship with subsequent series of work will go smoothly, accurate and reliable electric power demand forecasting is to raise the level of new energy grid system is an important premise; technical feasibility, process responsibility to define the definition of two indicators weight were 0.1097, 0.0396, new energy grid technology is an important guarantee of the normal operation of the system as a whole, can strengthen the power grid scheduling ability, exert power grid comprehensive balance ability, process responsibility defines clearly can improve system efficiency, and create more profits. In grid-connected quality, the weights of active power and reactive power are 0.0771 and 0.0433, respectively. These two indexes can clearly and intuitively reflect the operation state and working efficiency of the new energy grid-connected system. The weight of the accident incidence index is 0.4060, which is in line with the principle of safety first in system operation. The load compensation degree ranked last, with a weight value of 0.0344. Compared with the first two levels of indicators, the weight of grid connection benefit is low. The weight of economic benefit, environmental benefit, and social benefit are 0.0391, 0.0271, and 0.0110 respectively, which reflects the importance of the three indicators.

5. Conclusion

Previous literature research single new energy grid is analyzed from the Angle of technical evaluation, no construction overall evaluation system, single and not enough in-depth research contents, research Angle innovation point of this research is to consider the various factors to build the new energy grid evaluation index system of the whole process, in the process of new energy grid system comprehensively evaluating and analyzing each link solves the existing demand evaluation problems in the industry and provides a reference for the subsequent construction of new energy grid connection projects. In this
paper, based on the study of the whole process of the new energy grid, from before grid, grid, interconnection of the three Angle to build new energy grid evaluation index system, specific analysis of the indexes in the role and influence in the new energy grid system, and by using analytic hierarchy process (AHP) and entropy weight method to determine the weight value of each index, analyzes the final results are discussed. From the perspective of management, the construction of new energy grid-connected evaluation index system improves the operational efficiency of the grid-connected system, points out the management key points for managers, and makes the whole management process more smooth. In the practical sense, this study provides a reference for the detailed evaluation in the subsequent stage and is conducive to guiding the specific practice.

The shortcoming is that although this paper involves multiple evaluation indicators and calculates their weights, it fails to consider all the indicators due to limitations and has not studied the relationship and influence among the evaluation indicators. In the process of index selection, to maximize the consideration of the common characteristics of new energy grid-connected systems, some individual characteristics are ignored, and there are still shortcomings in the evaluation of a specific new energy grid-connected system. In addition, because the research is only for new energy grid process evaluation, all of them, and in the process of literature study, there may be some limitations, at the same time, not according to the specific types of new energy, the solar, wind, and other concrete elaboration research deeply on the new type energy grid process, in the latter study, with the improvement of the various types of energy grid data, the whole process of grid-connection can be evaluated in detail according to energy types.

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