Investigation on evaluation of new electric system in state grid of province

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Abstract. The construction of the new electricity system is a key measure to conform to the trend of energy transition and ensure energy security and efficient supply. However, the current comprehensive evaluation index system for power systems has significant limitations—it cannot fully and accurately reflect the new multi-dimensional characteristics of the power system after a substantial increase in the proportion of new energy. By sorting out typical domestic and international cases, present study proposes a method for constructing a development index system of the new electricity system in State Grid Jibei: based on the five characteristics of clean and low-carbon, safe and sufficient, economical and efficient, supply-demand coordination, and flexible and intelligent.PCA is used to extract core elements from key influencing factors, thus constructing a dedicated index system for the Jibei region. In the implementation of evaluation, the cloud model is applied to conduct a comprehensive analysis of the indicator data of the Jibei new electricity system, so as to fully assess the system's operation status, development effectiveness, and contribution to the "dual-carbon goals".

Keywords: Evaluation; new electricity system, entropy weight and ANP.

1. Introduction

The international smart grid is in accelerated development, with Europe, the U.S., Japan, and South Korea promoting new-type grids via quantified subsidies. Mainstream evaluation frameworks include IBM's Smart Grid Maturity Model, U.S. DOE Evaluation System, EPRI Construction Evaluation System, and EU Benefit Evaluation System [1-2]. IBM's Model uses two dimensions to set three goals (reliability, renewable energy integration, user interaction) and five development levels, covering 8 fields with ~200 indicators to serve as a global standard [3]. EPRI's System focuses on project lifecycle management and cost-benefit analysis for efficient technology promotion [2]. The EU released strategic documents (e.g., Strategic Deployment Plan for Smart Grids) with 6 mandatory priorities (e.g., grid optimization, renewable integration) [3]. ENTSO-E & E.DSO's joint system, covering 6 core dimensions, uses quantitative-qualitative methods and dynamic weights, supporting the EU "Green Deal".

In early 2024, SGCC first proposed "new-type grid" to advance new electric systems, but domestic research focuses on smart grid planning/R&D, lacking new-type grid effectiveness evaluation and unified standards. Reference [4] established low-carbon indicators for generation-transmission-distribution-consumption. Safety evaluation: Reference [5] created a three-level system with uncertainty analysis. Intelligence evaluation: Reference [6] developed a three-tier system for Fujian's robust grid.

Comparison shows foreign systems are practice-integrated, while China lacks unified standards and carbon/regional integration, demanding a China-adapted system.

2. Investigation method

The effectiveness evaluation method for new-type power system construction based on combined evaluation theory adopts the concept of subjective-objective combined evaluation to comprehensively assess the weights of influencing factors. This section first introduces the subjective weight determination method—Analytic Network Process (ANP), then elaborates on the combined application of ANP and objective evaluation methods—the entropy weight-ANP combined weight determination model.

2.1. Subjective Weight Determination Method

As a more comprehensive decision-making theory, ANP accounts for internal cycles in hierarchical structures and dependencies/feedback between levels, using a "supermatrix" to synthesize weights of interacting factors. It divides system elements into two parts: (1) The control layer, including the goal and decision criteria (mutually independent and governed only by the goal); (2) The network layer, consisting of elements governed by the control layer with mutual dependence. The key steps of applying ANP to weight determination for new-type power system attributes are as follows:

1. Analyze the problem and construct the network structure: Identify elements influencing the evaluation goal, judge their dependence/feedback relationships, and divide the system into the control layer and network layer.

2. Determine the single ranking weights of hierarchical elements: Based on specific criteria, conduct pairwise comparisons of elements within and between groups to obtain normalized ranking weights.

3. Construct the supermatrix: For the control layer element *Ps* and network layer element groups *C*1, *C*2, *CN*, use AHP's rating scale (1=equally important, 3=slightly important, ..., 9=extremely important; 2,4,6,8=intermediate values) to compare element influence, construct judgment matrices, and derive ranking vectors via eigenvalue method. Conduct consistency (consistency ratio *CR*=*CI*/*RI*): *CR*<0.1indicates satisfactory consistency (for *n*≤2, *RI*=0; for *n*>2, refer to *RI*values: 3=0.58, 4=0.90, ..., 9=1.45). Finally, construct the supermatrix *W*by integrating submatrices *Wij*.

4. Construct the weighted supermatrix: Normalize *W* to obtain the weight.

5. Calculate the limit supermatrix and indicator weights: Compute the limit supermatrix *W*∞=*k*→∞lim*Wk*. If convergent and unique, the *j*-th column of *Wk*represents the limit relativeranking of network layer elements for element.

6. To ensure the credibility of hierarchical single ranking, it is necessary to conduct a consistency test on the judgment matrix. The consistency ratio is calculated as: CR = CI/RI, where CI refers to the consistency index value and RI denotes the average random consistency index value. The larger the dimension of the judgment matrix, the worse the consistency of the judgments. Therefore, a correction value (i.e., the average random consistency index RI, as shown in the table below) is introduced to relax the consistency requirements for high-dimensional judgment matrices.

Table 1. Average random consistency index (RI).

Hierarchy	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
RI value	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45

2.2. Entropy Weight-ANP Combined Weight Determination Model

Entropy weight reflects the relative difference of indicators (not their actual importance), making full use of data information. However, it cannot reflect indicators' practical significance. Thus, combining ANP (subjective weight) and entropy weight method (objective weight) ensures scientific evaluation results. The steps are as follows:

1. Establish the hierarchical model: Divide into target layer (comprehensive evaluation of new-type power system), criterion layer (6 attributes: robustness, reliability, efficiency, economy, environmental friendliness, interactivity), and indicator layer (bottom indicators).

2. Determine bottom indicator weights:

Subjective weight: Calculated via ANP.

Objective weight: For the decision matrix *X*=(*xij*)*n*×*m*(*n*= schemes, *m*= indicators), first standardize *X* to *Y*=(*yij*)*n*×*m*. Then calculate entropy:$e\left(y_j\right) = -\frac{1}{\ln n}\sum_{i=1}^{n}\frac{1+y_{ij}}{y_j}\ln\left(\frac{1+y_{ij}}{y_j}\right)$

3. Determine comprehensive weight: The comprehensive weight ωi integrates subjective ($\omega i'$) and objective ($\omega i''$) weights: $\omega i=\alpha\omega i'+(1-\alpha)\ \omega i''$, where $0\leq\alpha\leq1$;

$\alpha=0.75$ is adopted based on the indicator system's actual situation.

3. Model apllication

3.1. Calculation results

To grasp the effectiveness of new-type power system construction in Jibei, this study takes five cities (Z city, C city, T city, Q city, and Lcity) as research objects. Data are collected from the statistical results of third-level indicators for the new-type power system in the five cities of Jibei (2024). Dimensional influence is eliminated through standardization (e.g., "carbon emission per kWh" is standardized to the interval [0, 1]).

Table 2. Average random consistency index (RI).

City	Distance to Positive Ideal Solution (D^+)	Distance to Negative Ideal Solution (D^-)	Relative Closeness (C_i)	Ranking
C city	0.1881	0.1413	0.7245	1
Z city	0.0988	0.2306	0.7098	2
Average	0.1775	0.1519	0.6804	3
Q city	0.1317	0.1977	0.6598	4
T city	0.2316	0.0978	0.6583	5
L city	0.2375	0.0920	0.6494	6

Based on a five-category first-level indicator system (including "low-carbon randomly coupled power sources"), the entropy weight method is used to calculate weights, and the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) is applied to evaluate the comprehensive level. Results show that C city (0.7245) and Z city (0.7098) rank top two, while L city (0.6494) ranks last. The gap between cities is small (maximum difference: 0.0751). Recommendations such as "optimizing green power structure and upgrading smart power grids" are proposed to address local shortcomings, providing references for regional power system development.

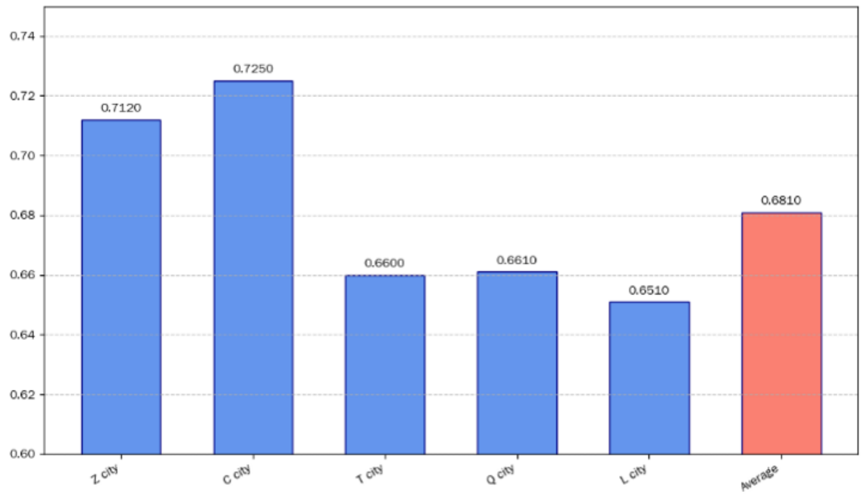

Fig 1. Comprehensive Scores of New-Type Power System Construction.

3.2. Analysis

Five cities in northern face different challenges due to variations in resources, infrastructure, and policy environments.

Low-Carbon and Randomly Coupled Power Sources: Optimize the green power structure. Prioritize supporting resource-rich areas like Q city and Z city in developing large-scale wind and photovoltaic (PV) projects, and increase the proportion of green power through wind-PV complementarity and energy storage synergy. For areas with limited resources such as L city and C city, fill the power gap via regional power synergy, and promote flexible coupling of green power with traditional power sources (e.g., wind-solar-storage integration, flexible dispatching of coal-fired power units).

Strong, Flexible, and Smart Power Grid: Accelerate the construction of smart grids and microgrids in L city and C city, and upgrade the existing power grids in Q city, T city, and Z city. Advance grid automation and dynamic dispatching to improve the ability to cope with wind-PV fluctuations and load changes.

Diversified and Collaborative Interactive Loads: Establish demand response mechanisms in Q city and T city to guide users in shifting electricity consumption away from peak hours. Use big data and AI to predict load changes, and intelligently dispatch diversified loads (industrial, residential, etc.) to balance power supply and demand.

Large-Scale and Diversified Shared Energy Storage: Deploy large-scale diversified energy storage facilities (e.g., pumped storage, lithium-ion battery storage) in northern Hebei, with a focus on wind-solar-storage integration projects in Q city and Z city to ease peak-valley differences. Build shared energy storage platforms through policy support and market-oriented mechanisms to enhance dispatching flexibility.

Comprehensive and Secure Data Empowerment: Strengthen the construction of intelligent data collection and monitoring systems (e.g., smart meters, sensors). Establish cross-entity (power enterprises, government, research institutions) data sharing platforms, and use big data to support intelligent decision-making in grid dispatching, load forecasting, etc.

4. Summary

This paper conducts an in-depth study on the evaluation method for the construction level of the new-type power system, and carries out case analysis based on the actual conditions of five cities. It comprehensively evaluates the construction and development level through a evaluation framework combining the entropy weight method and the ANP. Present analysis combined with actual data reveals that some regions have problems, which require technological innovation and infrastructure construction to improve the flexibility and adaptability of the system; meanwhile, some cities face the issue of unbalanced energy structure in terms of renewable energy integration, which calls for increasing investment in green energy and optimizing the power supply structure. This study puts forward countermeasures and suggestions, including accelerating the construction and upgrading of smart grids and promoting the development of diversified renewable energy projects. These countermeasures and suggestions aim to further optimize the Jibei power system, enhance its operational efficiency and sustainable development capacity, and provide a reference for subsequent decision-making in power system construction.

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