Design of a New Energy Consumption Restriction Index System Based on Analytic Hierarchy Process

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Abstract - With the incredible and fast development of a low-carbon economy, the power supply of China's power system is rapidly shifting towards renewable energy sources, which also poses certain challenges to the use and consumption of new energy.The article analyzes some daily-seasonal-spatial deviation cases between new energy generation and consumer, summarizes various unfavorable factors that restrict the consumption. This article innovatively proposes a new energy consumption constraint indicator system design based on Analytic Hierarchy Process. By selecting 4 primary indicators such as the characteristics of new energy power sources, 12 secondary indicators are designed to form a new energy consumption constraint indicator system. Furthermore, the corresponding weights of each indicator are determined through calculation. This indicator system has certain value in promoting the improvement of new energy consumption level and has universal applicability.

Keywords - renewable energy; analytic hierarchy process; indicators; weights

1. Introduction

Under the backgrond of green and low-carbon development, China's power supply is accelerating its transformation from traditional thermal power plants to new energy generation. In the first half of 2023, China's renewable energy installed capacity increased by 109 million kilowatts, an increase of 98.3% compared to last year. The total installed capacity of renewable energy reached 1.322 billion kilowatts, an increase of 18.2% year-on-year, historically surpassing coal-fired power as the largest power source, accounting for approximately 48.8% of China's total installed power. As the penetration rate of new energy continues to increase, its consumption has become an important constraint factor affecting its development[1]-[3].

Taking into account the characteristics of new energy generation such as wind power and photovoltaic, there is a certain degree of mismatch between it and the electricity load in daily, seasonal, and spatial dimensions. In addition, the volatility, randomness, and uncontrollability of its power generation make the power grid subject to regulation capacity, which may lead to constraints on the consumption of new energy. How to scientifically analyze and develop a new energy consumption constraint indicator system is of great significance for early warning and pre control of new energy consumption. This article innovatively proposes a new energy

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consumption constraint indicator system design based on Analytic Hierarchy Process. By selecting 4 primary indicators such as power supply, grid structure, load, and peak shaving, 12 secondary indicators are designed to form a new energy consumption constraint indicator system. Furthermore, through Analytic Hierarchy Process, the corresponding weights of these secondary indicators are determined to guide the development, construction, and operation management of new energy planning in the region[4]-[6].

2. Analysis of the mismatch between new energy generation and electricity load

There are mainly mismatches between new energy generation and electricity consumption loads, such as intraday, seasonal, and spatial mismatches. (1) The mismatch between supply and demand during the day: Wind power output is mainly concentrated during windy periods, usually in the evening and at night,around 18-6 pm, while photovoltaic power output is mainly concentrated at noon, around 10-15 pm. However, the peak electricity load is concentrated at 8-11 and 18-22. (2) Seasonal supply and demand mismatch: Due to the high demand for cooling and heating in summer for residents and the tertiary industry, and the peak electricity season in the secondary industry due to rush work at the end of the year, electricity consumption has obvious seasonal characteristics. However, wind power has relatively weak output during the peak electricity consumption in summer, and photovoltaic power generation has insufficient output in winter. (3) Spatial supply and demand mismatch: Compared to China's electricity consumption concentrated in central, northern, and eastern China, wind and solar resources are mainly concentrated in the western and northwestern regions of China[5].

3. POSSIBLE Factors affecting the consumption of renewable energy generation

3.1 The Regulating Capacity of the Large Power Grid System

The regulation ability of the large power grid system is mainly related to the regulation performance of the unit itself and the system startup mode. The proportion of coal-fired power is high, there are many heating units, which are difficult to start and stop quickly, and the adjustment speed is slow. However, there are relatively few flexible units such as gas, hydropower, and pumped storage with deep peak shaving capabilities, so the overall regulation performance of China's power system is poor. Considering the uncertainty of new energy generation, its power generation fluctuations may seriously affect the peak shaving of the power grid, thereby restricting the consumption of new energy. In addition, the start-up arrangement of conventional power sources can also affect the regulation performance of the large power grid to a certain extent.[6]

3.2 Power grid transmission capacity

From a geographical perspective, wind power in China is mainly distributed in the Northeast, North China, and Northwest regions, while photovoltaic installation is mainly concentrated in the western region. Due to the limitations of the power grid and equipment transmission capacity, its external transmission may be affected, and due to the limited local electricity load, its new energy consumption space is limited. Therefore, improving the transmission capacity of the power grid, alleviating transmission congestion, and achieving wind power. The cross provincial and cross regional transmission of photovoltaic power generation has a positive effect.

3.3 System load characteristics

Generally speaking, the load characteristics of power consumption have a certain degree of randomness. At the same time, the larger the peak valley difference in the power grid, the greater the peak shaving pressure on the system itself, making it more difficult for large-scale consumption and use of new energy for power generation. There are differences in grid load rates and peak valley differences among different date attributes. For example, the workload on weekdays is high throughout the day and fluctuates greatly, with peaks occurring during the day and positively correlated with photovoltaic output, which is beneficial to the consumption of new energy power generation; During the Spring Festival holiday, the load is relatively small and the changes are stable. During the day, there is a large amount of photovoltaic energy, which puts a lot of pressure on consumers. Therefore, reducing the peak valley difference of the daily load curve through electricity price response and introducing interruptible loads can improve the consumption level of new energy generation.

3.4 Penetration rate of new energy generation

For a certain power system, theoretically speaking, the larger the installed capacity and penetration rate of new energy, the greater the demand for peak shaving capacity, and the more difficult it will be to absorb new energy. Therefore, in power system planning, the installation specifications of new energy should be reasonably planned to prevent excessive construction and resource waste.

3.5 System reserve capacity

Generally speaking, in order to ensure the safe and stable operation of the large power grid, a certain reserve capacity will be reserved in advance during its operation. If the reserve regulation capacity reserved by the system is insufficient, then when the output of new energy generation is at a high output period, it will increase the possibility of power abandonment, resulting in a decrease in the consumption level of new energy generation.

4. Constructing Constrained Factor Indicators for New Energy Consumption Based on Analytic Hierarchy Process

Analytic Hierarchy Process (AHP) is a hierarchical weighted decision analysis method proposed by Senior Sister in the 1970s, first proposed by Professor Satie of the University of Pittsburgh in the United States. The Analytic Hierarchy Process decomposes decision-making related elements into levels such as goals, standards, and plans, and conducts qualitative and quantitative analysis on this basis[7].

The AHP method decomposes decision problems into different hierarchical structures in the order of overall objectives, sub objectives at all levels, evaluation criteria, and alternative plans. Set up a judgment matrix using mathematical methods and solve the judgment matrix to obtain its eigenvectors. Then solve this feature vector to obtain the priority weight of each element at each level over a certain element at the previous level. Finally, the weighted sum method is used to gradually merge the final weights of each sub objective into the overall objective, obtaining the best solution with the highest weight[8]-[10].

Based on the above principles, it is generally inferred that AHP modeling is divided into the following four steps, which are gradually carried out:

Step 1. Establish a model based on the hierarchical relationship between objectives

According to the decision-making objectives, criteria, and interrelationships of various objects set in the Analytic Hierarchy Process, the objects analyzed in the Analytic Hierarchy Process are divided into three levels: highest, middle, and lowest. A hierarchical structure diagram is drawn based on these levels. Generally speaking, the highest level setting is used to solve decision-making purpose problems. The lowest level setting is to solve the problem of alternative solutions in the decision-making process. The middle layer is used to consider the role of decision-making factors and decision-making standards. In the Analytic Hierarchy Process, the adjacent two layers, the adjacent upper layer is called the target layer, and the adjacent lower layer is called the factor layer. Overall, the number of layers required for a hierarchical structure is related to the complexity of the problem and the level of detail that needs to be analyzed. Usually, the number of layers can be unlimited, but the number of elements considered in each level usually does not exceed 9.

Step 2. Build a judgment matrix based on important relationships as a whole

According to importance, when setting the weight coefficients of the standard layer, the weight coefficients of each standard may not necessarily be the same, depending on the decision-maker's decision objectives and their weights, which are represented by a certain range. In the Analytic Hierarchy Process, the judgment matrix is defined as $A=(a_{ij})_{nxn}$, Among them, using the reciprocal of numbers 1 to 9 is called scaling. Scales from 1 to 9 indicate increasing importance, with 1, 3, 5, 7, and 9 respectively representing equally important, slightly important, more important, very important, and extremely important. 2. 4, 6, and 8 represent the intermediate values of two importance levels.

Step 3. Ranking and consistency check of hierarchical lists

1) Set consistency index (CI) and calculate it

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

Among them, $\lambda_{\max}$ is the maximum eigenvalue of the judgment matrix.

2) Find consistency indicator RI

Table 1 Consistency Index RI Standard Values of the judgment matrix

order	10	9	8	7	6	5	4	3	2	1
RI	1.49	1.46	1.41	1.36	1.24	1.12	0.89	0.52	0	0

The consistency indicator RI is shown in Table 1.

3) Calculate consistency ratio (CR)

$$CR = \frac{CI}{RI} \tag{2}$$

If $CR \le 0.1$, it is generally believed that the consistency of the judgment matrix is acceptable; Otherwise, it is necessary to weight and adjust the judgment matrix to ensure consistency.

Step 4. Overall hierarchical sorting and checking

For each level, calculate the relative importance of all elements to the overall goal based on their weights, and rank them accordingly. Overall, calculate from the highest level down to the lowest level. Once all are completed, the calculation is complete.

Based on the above ideas, this article constructs a new energy consumption constraint factor indicator system from four dimensions: new energy characteristics, power grid characteristics, load characteristics, and peak shaving capacity. Four primary indicators and 12 secondary indicators are established, as shown in Figure 1.

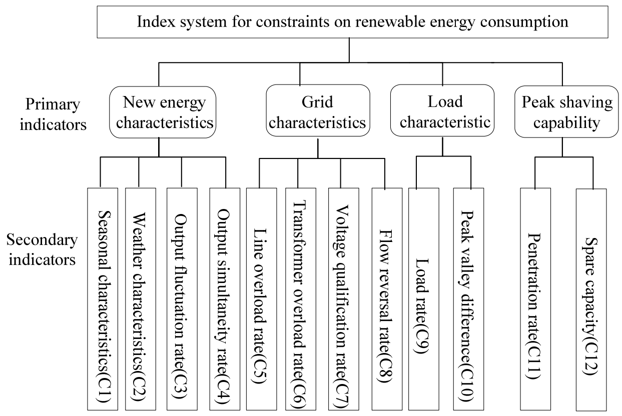

Figure1 Indicator System for Constraints on New Energy Consumption

5. Calculation of Index Factor Weights and Analysis of System Rationality

In the AHP method, there are four main methods for calculating the weight of indicators: geometric average, arithmetic average, eigenvector method, and least squares method. For these four calculation methods, different weight vectors can be calculated separately. Generally speaking, the values obtained by these four calculation methods will be relatively close, but in some cases, the differences caused by these calculations may also lead to different results in solving practical problems.

(1) Geometric average method (root method)

$$W_i = \frac{\left(\prod_{j=1}^{n} a_{ij}\right)^{\frac{1}{n}}}{\sum_{i=1}^{n}\left(\prod_{j=1}^{n} a_{ij}\right)^{\frac{1}{n}}}, \quad i = 1, 2, ..., n \tag{3}$$

(2) Arithmetic mean method

$$W_i = \frac{1}{n}\sum_{j=1}^{n}\frac{a_{ij}}{\sum_{k=1}^{n} a_{kj}}, \quad i = 1, 2, ..., n \tag{4}$$

(3) Eigenvector method

Multiply the weight vector W to the right by the weight ratio matrix A:

$$AW = \lambda_{\max} W \tag{5}$$

(4) Least square method

$$\begin{aligned} &\min Z = \sum_{i=1}^{n}\sum_{j=1}^{n}(a_{ij}w_j - w_i)^2 \\ &s.t. \sum_{i=1}^{n} w_i = 1 \\ &w_i > 0, i = 1, 2, ..., n \end{aligned} \tag{6}$$

Table 2 Judgment matrix for the importance of secondary indicators

a_{ij}	I_1	I_2	I_3	I_4	I_5	I_6	I_7	I_8	I_9	I_{10}	I_{11}	I_{12}
I_1	1	1	1/3	1/3	1/4	1/5	1	1/2	1/6	1/7	1/3	1/5
I_2	1	1	1/3	1/3	1/4	1/5	1	1/2	1/5	1/7	1/3	1/5
I_3	3	3	1	1	1/3	1/3	1/5	1	1/6	1/5	1	1/2
I_4	3	3	1	1	1/3	1/3	1/5	1	1/6	1/5	1	1/2
I_5	4	4	3	3	1	1	1/3	3	1/5	1/3	3	1
I_6	5	5	3	3	1	1	1/3	3	1/5	1/3	3	1
I_7	1	1	5	5	3	3	1	3	1/3	2	5	1/3
I_8	2	2	1	1	1/3	1/3	1/3	1	1/7	1/4	1	1/4
I_9	6	5	6	6	5	5	3	7	1	3	5	4
I_{10}	7	7	5	5	3	3	1/2	4	1/3	1	5	3
I_{11}	3	3	1	1	1/3	1/3	1/5	1	1/5	1/5	1	1/4
I_{12}	5	5	2	2	1	1	3	4	1/4	1/3	4	1

Quantitatively evaluate the secondary indicators of the new energy consumption constraint factor indicator system using the AHP method, and establish a judgment matrix based on the important correlation between the indicators using the aforementioned method, as shown in Table 2.

Based on this judgment matrix, using the aforementioned indicator weight calculation method, the corresponding weights of 12 secondary indicators can be obtained, which are: 0.217 (I_9), 0.141 (I_{10}), 0.138 (I_7), 0.099 (I_{12}), 0.085 (I_5), 0.068 (I_8), 0.050 (I_3), 0.050 (I_{14}), 0.046 (I_{11}), 0.043 (I_6), 0.033 (I_2), 0.032 (I_1). Draw a visualization chart of 12 secondary indicator weights in descending order based on their weights, as shown in Figure 2.

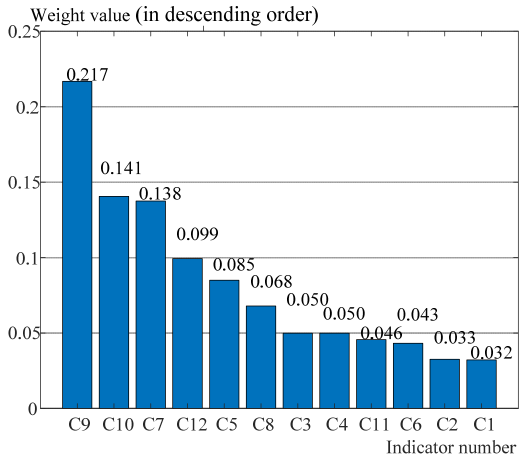

Figure2 Visualization of Weights of Consumption Constraints Indicators

In Figure 2, according to the weight of the indicators, the importance ranking of 12 secondary indicators can be derived as follows: load rate (C9), peak valley difference rate (C10), voltage qualification rate (C7), backup capacity (C12), line overload rate (C5), power flow reversal rate (C8), output fluctuation rate (C3), output simultaneity rate (C4), new energy penetration rate (C11), main transformer overload rate (C6), weather characteristics (C2), and seasonal characteristics (C1).

6. Conclusion

With the comprehensive promotion of various key tasks of China's dual carbon goals, vigorously developing renewable energy will become the direction of China's energy development. As more and more randomly fluctuating renewable energy generation units are put into use, the penetration rate of wind and photovoltaic energy will further increase, and the issue of new energy consumption in the power grid will become increasingly prominent. In order to solve practical problems such as unreasonable geographical distribution of renewable energy, mismatched seasonal and daily power generation characteristics, and mismatched electricity load, it is necessary to comprehensively optimize the operation of renewable energy power generation from the perspective of "source network negative storage" integration, improve its consumption and utilization efficiency, and ensure the safety of power grid operation.This article establishes an effective indicator system for the constraints of new energy consumption through the Analytic Hierarchy Process, including 4 primary indicators and 12 secondary indicators. It comprehensively and systematically describes the constraints of renewable energy consumption, and fully studies and optimizes this system, which can play a positive role in improving new energy consumption and improving the dynamic control ability of the power grid. The method has universal applicability and can provide beneficial auxiliary analysis for similar regions.

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References

[1] Shan Baoguo, Jia Dexiang, Li Shihao, et al. A dynamic comprehensive evaluation method for provincial energy conservation and emission reduction based on AHP entropy weight method [J]. Power Grid and Clean Energy, 2019,35 (01): 54-61

[2] Wang Xiangyan, Zhang Lei, Yang Libin, et al. Analysis of the impact of energy storage systems on the grid connection characteristics of intermittent new energy power plants [J]. Power Grid and Clean Energy, 2016, 32 (9): 107-111

[3] Kui W ,Yifan X ,Wumin Z , et al. Research on optimal dispatch of distributed energy considering new energy consumption[J]. Energy Reports,2023,10.

[4] Jingliao S ,Changhong H ,Fuxian M , et al. Analysis of New Energy Consumption Capacity Considering Photovoltaic Uncertainty[J]. Journal of Physics: Conference Series,2023,2474(1).

[5] Ganggang W ,Zixin Z ,Wenliang T . Construction and application of decision support indicator system for new energy development in Hexi Corridor[J]. Energy Reports,2022,8(S8).

[6] Ganggang W ,Peng D ,Yangying L . Research on the evaluation system of new energy development decision in Dunhuang city based on analytic hierarchy process[J]. Energy Reports,2022,8(S8).

[7] Huiyuan C ,Hua Z ,Qiqi D , et al. A Low-Carbon Planning Model for Regional Power Systems with Generation-Load-Storage Coordination considering New Energy Resources' Consumption[J]. Mathematical Problems in Engineering,2022,2022.

[8] W Z C ,M L ,Q Y G , et al. Research on Risk Early Warning of New Energy Consumption Based on Weight of Differentiated Indicators[J]. Journal of Physics: Conference Series,2022,2186(1).

[9] Chengkun L ,Jiwei S ,Congyu W . Research on the scheduling of unit operation mode for combined heat and power plants considering new energy consumption in heating season[J]. IOP Conference Series: Earth and Environmental Science,2022,983(1).

[10] Mingjun J ,Xiang W ,Fengjiao D , et al. Operation control strategy of load aggregator based on new energy consumption in power grid[J]. Journal of Physics: Conference Series,2021,1894(1)