Evaluation of the Impact of Wind Farm Grid Connection on Power Quality

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Abstract

In order to evaluate the impact of wind farms on power quality when connected to the power grid, this paper proposes a new comprehensive evaluation method based on the Improved Analytic Hierarchy Process (IAHP) and Criteria Importance Though Intercrieria Correlation(CRITIC). Firstly, for small wind turbines, the method uses the IAHP and CRITIC Method to calculate the subjective and objective weights of each index. Then, it combines the two weights to obtain the comprehensive weights. Finally, the ten-level system based on probability statistics is used to evaluate case analysis, and to verify the effectiveness of the method. When selecting indicators, this paper considers the effects of wind energy utilization coefficient, grid voltage and current.

Keywords

IAHP; CRITIC; Wind Energy Utilization Coefficient; Power Quality.

1. Introduction

1.1 Project Background and Research Significance

The operation characteristics of wind turbines, as well as the intermittent and fluctuating characteristics of wind energy, are the main reasons for the fluctuation of the output power of wind turbines. The larger the installed capacity of wind power generation and the larger the proportion of wind farms in the grid capacity, the greater the impact of wind farms on the power quality of the grid when connected to the grid. Therefore, it is necessary to study the impact of wind farm access on the power grid. In addition, considering the economic benefit, the comprehensive power quality index will be used as a basis for power pricing. Therefore, a reasonable evaluation method should be established to comprehensively evaluate the power quality indicators of wind farms after being connected to the power grid. the quantitative indicators of power quality should be given, so that local power departments can timely grasp the actual situation of the power quality of wind farms.

1.2 The Main Research Content

Firstly, according to China's power quality standards, the power quality evaluation standard for small wind turbines is established. In this paper, wind turbine utilization coefficient (C_p), current harmonic distortion rate (THD_i), voltage harmonic distortion rate (THD_u) and voltage negative sequence unbalance (epsilon and epsilon U_2) are selected as power quality evaluation indexes. [1]The degree of balance (εu2) is used as an indicator of power quality evaluation. Secondly, the CRITIC method and the improved AHP method have higher applicability in the determination of objective and subjective weights respectively. if the subjective and objective weights are combined, the subjective and objective factors will be fully utilized, making the empowerment process more reasonable. This is in line with the idea of attaching importance to subjective and objective factors in the evaluation of wind farm integration. Therefore, this paper attempts to combine the weights obtained by the CRITIC method and the improved AHP method to make a more accurate evaluation of the impact of wind farm integration on power quality.

2. Improved multi-objective evaluation method

2.1 AHP calculation subjective weight based on scale construction method

When the traditional AHP is used for weight calculation, it is often necessary to reconstruct the matrix because the judgment matrix does not satisfy the consistency test. This brings a lot of trouble. Therefore, the scale structure method is used to determine the judgment matrix, and the judgment matrix obtained is satisfied. Consistency and reduced computation.

There are n indicators r_1, r_2, ..., r_n, which are first sorted according to the importance of each index. The result is $r_1 \geq r_2 \geq \ldots \geq r_n$. [2]Compare the importance relationship between r_i and r_{i+1} according to Table 1, and determine the scale value. The corresponding scale is recorded as c_i, and finally the scale values c_1, c_2, ..., c_{n-1} between all adjacent indicators are obtained. According to the transferability of the importance degree, other elements in the judgment matrix are obtained, and then the final judgment matrix R is as shown in the formula (1).

Table 1 Meaning of scale value

Scale value	meaning
1.0	Equally important
1.2	Slightly important
1.4	Strongly important
1.6	Obviously important
1.8	Absolutely important

$$R=\begin{bmatrix} 1 & c_1 & c_1c_2 & \cdots & \prod_{i=1}^{n-1} c_i \\ \frac{1}{c_1} & 1 & c_2 & \cdots & \prod_{i=2}^{n-1} c_i \\ \frac{1}{c_1c_2} & \frac{1}{c_2} & 1 & \cdots & \prod_{i=3}^{n-1} c_i \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ \frac{1}{\prod_{i=1}^{n-1} c_i} & \frac{1}{\prod_{i=2}^{n-1} c_i} & \frac{1}{\prod_{i=3}^{n-1} c_i} & \cdots & 1 \end{bmatrix} \tag{1}$$

The judgment matrix obtained in this way satisfies the consistency and can be directly used for the calculation of the weight without checking.

Subjective weight is directly calculated by equation (2)

$$\omega_i = \left(\prod_{j=1}^{n} r_{ij} \right)^{1/n} / \sum_{i=1}^{n} \left(\prod_{j=1}^{n} r_{ij} \right)^{1/n} \tag{2}$$

Where ω_i is the weight value of the i-th index; $\prod_{j=1}^{n} r_{ij}$ represents the product of all elements of the i-th row in the matrix R.

2.2 CRITIC method to calculate objective weights

The CRITIC method[3] is an objective weighting method based on indicator data. When using this method to determine the weight, it not only considers the amount of information contained in the indicator, but also considers the contrast between different schemes and the conflict between indicators. The calculation results are more objective and reasonable.

Assuming a total of m planning schemes, each with n indicators, the evaluation matrix can be expressed as:

$$X=\begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1m} \\ x_{21} & x_{22} & \cdots & x_{2m} \\ \vdots & \vdots & & \vdots \\ x_{n1} & x_{n2} & \cdots & x_{nm} \end{bmatrix} \quad (3)$$

The calculation steps of the objective weights are as follows.

Indicators are the same.

$$x'_{ij}=\frac{1}{p+\max|X_i|+x_{ij}} \quad (4)$$

Usually, the negative indicators are converted into positive indicators, and the conversion method is as shown in equation (4).

Where max $|X_i|$ is the maximum value of the i-th index, that is, the maximum value of the matrix X row; p is the coordination coefficient, and is generally taken as 0.1. After the above processing, the normalized evaluation matrix X' is obtained.

b. Indicator data is dimensionless.

The meanings of the indicators in the matrix X' are different, and the units are different. It needs to be dimensionlessly processed. The processing method is as shown in equation (5), and the standard matrix X″ is obtained.

$$x''_{ij}=\frac{x'_{ij}}{\sqrt{\sum_{j=1}^{m}(x'_{ij})^2}} \qquad i=1,2,\dots,n \quad (5)$$

c. Calculate the objective weight of the indicator.

In the CRITIC method, the standard deviation of the indicators is used to characterize the difference of the value of the same indicator in different schemes, that is, the contrast between the schemes; based on the correlation coefficient between the indicators, construct a quantitative expression that characterizes the conflict, Reflect the conflict between indicators. From the standard matrix X", the standard deviation s_i of each index data and the correlation coefficient ρ_{ij} between the indicators are respectively:

$$s_i=\sqrt{\frac{1}{m}\sum_{j=1}^{m}(x''_{ij}-\overline{x''_i})^2}, \qquad i=1,2,\dots,n \quad (6)$$

$$\rho_{ij}=\left|\mathrm{cov}\left(X''_i, X''_j\right)\right|/\left(s_i s_j\right), \quad i,j=1,2,\dots,n \quad (7)$$

Where $\overline{x''_i}$ is the mean of the i-th index, that is, the mean of the elements of the i-th row of the matrix X″; cov (X″$_i$, X″$_j$) is the covariance of the i-th row and the j-th row of the standard matrix X″.Calculate the amount of information Gi contained in each indicator according to the CRITIC method, as shown in equation (8).

$$G_i=s_i\sum_{j=1}^{n}(1-\rho_{ij}) \quad (8)$$

Among them, $s_i\sum_{j=1}^{n}\left(1-\rho_{ij}\right)$ is the quantitative index of the conflict between the i-th indicator and other indicators. The larger the G_i, the larger the amount of information contained in the i-th indicator, the more important the indicator is, and the greater the empowerment. The calculation formula of the objective weight υ_i is:

$$v_i = \frac{G_i}{\sum_{j=1}^{n} G_j} \tag{9}$$

2.3 Comprehensive weight and comprehensive evaluation

The index weights in the paper use the subjective and objective combination weights, $\alpha = [\alpha_1, \alpha_2 ..., \alpha_n]$[4], then

$$\alpha_i = \frac{\omega_i v_i}{\sum_{i=1}^{n} \omega_i v_i}, \qquad i=1,2,...,n \tag{10}$$

After determining the weight of each individual indicator of power quality, a comprehensive assessment of power quality can be performed. This paper uses a combination of probability theory and fuzzy mathematics to comprehensively evaluate power quality. This article uses a ten-layer classification system.

3. Small wind turbine power quality comprehensive evaluation case

3.1 Determination of subjective weights

Determine the scale value between the indicators $c_1 = 1.6$, $c_2 = 1$, $c_3 = 1.4$, then the expert judges the score matrix R:

$$R = \begin{bmatrix} 1 & 1.6 & 1.6 & 2.24 \\ \frac{1}{1.6} & 1 & 1 & 1.4 \\ \frac{1}{1.6} & 1 & 1 & 1.4 \\ \frac{1}{2.24} & \frac{1}{1.4} & \frac{1}{1.4} & 1 \end{bmatrix}$$

The subjective weight ω can be obtained from equation (2):

$$\omega = [0.3709 \quad 0.2318 \quad 0.2318 \quad 0.1655]$$

3.2 Determination of objective weights

First, the negative index is converted into a forward indicator, then the matrix is dimensionless, and finally the standard matrix is obtained:

$$X^{"} = \begin{bmatrix} 0.4123 & 0.4618 & 0.4371 & 0.4123 & 0.3629 & 0.2749 & 0.2199 \\ 0.3085 & 0.3174 & 0.3478 & 0.3939 & 0.4087 & 0.4192 & 0.4302 \\ 0.3213 & 0.3423 & 0.3480 & 0.3696 & 0.3977 & 0.4176 & 0.4350 \\ 0.3907 & 0.3885 & 0.3844 & 0.3803 & 0.3744 & 0.3705 & 0.3558 \end{bmatrix}$$

Calculate the objective weights of each indicator according to the CRITIC method:

$$v = [0.4512 \quad 0.2529 \quad 0.2305 \quad 0.0654]$$

3.3 Determination of comprehensive weight

The comprehensive weight α can be obtained from the formula (10):

$$\alpha = [0.5766 \quad 0.2020 \quad 0.1841 \quad 0.0373]$$

This result is the final weight value of each evaluation index obtained by improving the combination of AHP and CRITIC methods.

3.4 Case evaluation

The selected indicators are equally divided into ten levels according to the national standard limit, and the excess is regarded as the eleventh level[5]. The evaluation method for the comprehensive power quality indicator from quantitative to hierarchical qualitative is shown in Figure 1:

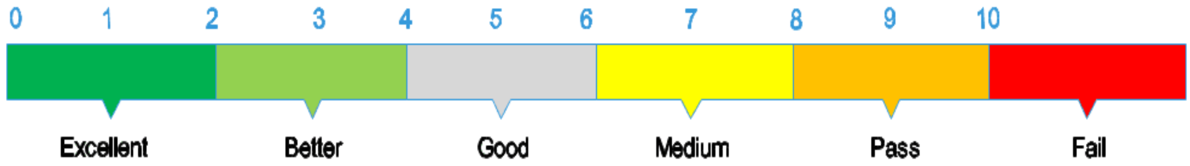

Fig. 1 Evaluation of synthetic power quality value

The probability matrix S of each level of each power quality indicator is obtained by analyzing and processing the original measured data:

$$S=\begin{bmatrix} 0.6534 & 0.3597 & 0.0049 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0.0646 & 0.5632 & 0.2104 & 0.0563 & 0.0389 & 0.0326 & 0.0160 & 0.0111 & 0.0069 \\ 0.7431 & 0.1979 & 0.0375 & 0.0118 & 0.0069 & 0.0014 & 0.0014 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0.0819 & 0.5889 & 0.3014 & 0.0278 & 0.0278 & 0 & 0 & 0 & 0 \end{bmatrix}$$

Where each row of S represents the probability that an indicator is at 11 levels.

Evaluation result vector V=W*S=

$$[0.5032 \quad 0.2439 \quad 0.0258 \quad 0.1379 \quad 0.0550 \quad 0.0127 \quad 0.0081 \quad 0.0066 \quad 0.0032 \quad 0.0022 \quad 0.0014]$$

Calculate the evaluation result Q using the weighted average method:

$$Q=\sum_{i=1}^{11} iV_i / \sum_{i=1}^{11} V_i = 2.1469$$

4. Conclusion

In this paper, the improved AHP and CRITIC methods are used to obtain the main and objective weights, and the primary and objective weights are combined based on the principle of minimum information identification, so that the influence of objective and subjective factors are considered, so that the weight of the index is more reasonable. In addition, the effectiveness of the comprehensive evaluation method proposed in this paper is verified by an example. The results of the example show that the method can not only comprehensively evaluate the impact of wind farms on the power quality of the distribution network, but also reflect the overall closeness between the indicators and the ideal scheme in the scheme. It is an effective method. Comprehensive evaluation method.

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