Power quality assessment based on combinatorial weight method of variance maximizing

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Abstract. In order to improve the limitation of the existing wind power grid connection quality assessment methods, a more reasonable combinatorial weight method considering the advantages of both subjective and objective is proposed. The objective function is to maximize the variance of the evaluation object under the combined weight, and to optimize the optimal solution of the model as the index weight. On this basis, an adaptive fuzzy neural network is used to evaluate the power quality evaluation method based on the combination weight of the maximization of variance. This method is used to evaluate the 220KV bus power quality of the Weifang power grid. The results not only verify the reasonableness of the proposed variance maximization combination weight weighting, but also verify the effectiveness of the proposed adaptive fuzzy neural network power quality comprehensive evaluation method, which provides a new method for the study of the evaluation method.

1. Introduction

In recent years, the permeability of wind power generation in the distribution network is increasing gradually. As an unstable power supply mode, the wind power has a negative impact on the power quality after the wind power is connected to the distribution network. Therefore, it is of great significance and practical value to evaluate the impact of wind power on the quality of the power. According to the various indicators of power quality after wind power integration, comprehensive assessment and classification are carried out, so as to get the actual situation of power quality in time, and take corresponding measures [1].

The existing combination weighting method uses simple linear weighting or multiplication to normalize the combination of subjective and objective weights, and its combination principle and rationality still have some problems. For example, the adjustment weight of the linear weighting method is difficult to solve, and the combination method can not distinguish the superior information and the bad information from the subjective and objective information. Multiplicative synthesis leads to the multiplier effect of weight, and the meaning of product of subjective weight and objective weight is difficult to give a reasonable explanation.

In order to reduce the impact of human factors in the evaluation process and overcome the shortcomings of the existing combination method, a combination weighting method based on the
maximization of variance is proposed. The combination of the weighting method is reasonable, and the subjectivity of the decision-maker and the characteristics of the objective weight change with the degree of distinction can be taken into account simultaneously. On this basis, the neural network evaluation method based on the weighting method is further studied to achieve more detailed and comprehensive evaluation.

2. Calculation of subjective and objective weight

2.1. Subjective weight calculation based on improved AHP algorithm
Analytic hierarchy process (AHP) can solve complex nonlinear problems by qualitative and quantitative analysis of specific problems. In order to avoid the consistency detection of the traditional AHP algorithm, an improved method proposed by is adopted [2]. According to the expert opinion, the 6 evaluation indexes are compared to each other, and the relative importance index is determined. The judgment matrix is consistent. By obtaining the eigenvector corresponding to the maximum eigenvalue of the judgment matrix R, and the normalization process, the subjective weight vector based on the improved AHP method can be obtained.

2.2. Calculation of subjective weight based on expert investigation method
The method of expert investigation is simple and intuitive, and it is realized. The specific steps are: hire an expert to fill in the survey form, and the experts identify the selected indexes independently according to their own opinions, determine the weight value of each index, and ensure that the sum of the index weight values is 1, assuming that there are n indicators, and the M experts are required to assign rights to them, then the result is a matrix (m, n) [3], then for a single index I, the weight values can be summarized as

\[
C_i = \frac{\sum_{j=1}^{m} a_{ij}}{\sum_{i=1}^{n} (\sum_{j=1}^{m} a_{ij})}, \quad i = 1, 2, \ldots, n
\]

2.3. Calculation of objective weight based on entropy weight
The basic idea of determining the objective weight by entropy weight method is [2]: the entropy value of each evaluation index is calculated based on the measured data. According to entropy, the weight coefficient of each index is determined by the principle that the weight coefficient is small and the information entropy is small according to the entropy value.

2.4. Objective weight calculation based on variation coefficient method
The coefficient of variation is used to calculate the corresponding weight value [4]. The higher the degree of variation, the greater the weight. By calculating the standard deviation coefficient of each index data, the normalized index standard deviation is used as the coefficient of variation to calculate the weight.

3. Combinatorial empowerment based on maximization of variance
In order to reflect the subjectivity of decision-making and reflect the objectivity of decision-making, we need to integrate the subjective and objective weights of the above indicators.

First, according to the different weights of each index, the reasonable interval of index combination weight is determined. Suppose that the weighting method of M is used to weight the K index, and its weight matrix can be expressed by matrix A

\[
A = [\alpha_{ij}]_{k \times m} = \begin{pmatrix}
\alpha_{i1} & \cdots & \alpha_{im} \\
\vdots & \ddots & \vdots \\
\alpha_{k1} & \cdots & \alpha_{km}
\end{pmatrix}
\]

where j represents an empowerment method, and i represents the empowerment of the index, i=1,2,...
K; j=1,2,..., M.

The weight matrix A can be used to determine the interval range of the combined weight \( \theta = (\theta_j, \theta_j, \ldots, \theta_j) \), and the reasonable interval of the combined weights of the i index is \( [\theta_i^-, \theta_i^+] \) expressed as

\[
\theta_i^+ = \max\{\alpha_{ij}, \alpha_{ij}, \ldots, \alpha_{im}\}
\]

\[
\theta_i^- = \min\{\alpha_{ij}, \alpha_{ij}, \ldots, \alpha_{im}\}
\]

By introducing an unknown weight vector, the maximum variance of the score of the evaluated object is the objective function. Calculate the K index n evaluation object X negative matrix normalization matrix as shown below.

\[
X = \begin{bmatrix} x_1 & \ldots & x_n \end{bmatrix}_{k \times n} = \begin{bmatrix} x_{11} & \ldots & x_{1n} \\ \vdots & \ddots & \vdots \\ x_{k1} & \ldots & x_{kn} \end{bmatrix} = \begin{bmatrix} x_1, x_2, \ldots, x_n \end{bmatrix}
\]

(5)

The results of the comprehensive evaluation Z are as follows.

\[ Z = \theta X = (\theta x_1, \theta x_2, \ldots, \theta x_n) \]

(6)

The variance of the comprehensive evaluation results is as follows:

\[
S^2 = \frac{1}{n-1} \sum_{i=1}^{n} (\theta \bar{x}_i - \bar{x})^2
\]

\[
= \frac{1}{n-1} \sum_{i=1}^{n} (\theta y_i)^2
\]

\[
= \frac{1}{n-1} \sum_{i=1}^{n} \theta (y_i^r)^T \theta^T
\]

\[
= \frac{1}{n-1} \sum_{i=1}^{n} \theta H \theta^T
\]

(7)

For the convenience of calculation and representation, in the calculation of variance \( y_i = x_i - \bar{x} \),

\[ H = y_i y_i^T. \]

The idea of determining the combined weights by variance maximization can be calculated and the combined weight optimization model is as follows.

\[
\max \frac{1}{n-1} \sum_{i=1}^{n} \theta H \theta^T(a)
\]

\[
\text{s.t.}\ \sum_{i=1}^{n} \theta_i = 1(b)
\]

\[
\theta_i^- \leq \theta_i \leq \theta_i^+(c)
\]

(8)

The objective function (a) ensures that the combined weight can make the final variance of the evaluation result maximum, and the discrimination effect of the evaluation object is good. The constraint condition (b) ensures that the sum of all elements of the combined weight vector is 1, which is also the basic feature of combinatorial weighting. The weight of each index is guaranteed in a reasonable range by the constraint condition (c), and the weight of the weight \( \theta = (\theta_j, \theta_j, \ldots, \theta_j) \) of the main objective weight and the combination weight of the i index are finally calculated.

4. Fuzzy evaluation method based on improved membership function

4.1. Construction of index fuzzy model
Based on the ridge membership function, the power quality is divided into 5 grades, and on the basis of the quality grade division of the power quality evaluation index, the fuzzy area between the two grades is quantified to make it a parameter adjustable membership function [5]. For the 5 quality grades, the membership function is shown in Figure 1. The values of $X_1$ and $X_2$ in the diagram are determined by the actual situation, and $\bar{X}$ is the limit value of the national standard.

![Figure 1. Membership function of indexes relative to all level](image)

The membership function of the index corresponding to the superior quality grade is

$$
\mu(\Delta X) = \begin{cases} 
1, & 0 \leq \Delta X \leq X_1 + C \\
\frac{1}{2} - \frac{1}{2} \sin \varphi, & X_1 + C \leq \Delta X \leq X_2 + C \\
0, & \Delta X \geq X_2 + C 
\end{cases} \tag{9}
$$

where $\varphi = \frac{\pi}{X_2 - X_1} \left( \frac{X_2 + X_1}{2} \right) ; \quad C = \frac{1}{8} \bar{X}$.

The index corresponds to the membership function of good, medium and acceptable grade is

$$
\mu(\Delta X) = \begin{cases} 
0, & \Delta X \leq -X_2 + (nk + C) \\
\frac{1}{2} + \frac{1}{2} \sin \varphi, & -X_2 + (nk + C) < \Delta X < -X_1 + (nk + C) \\
1, & -X_1 + (nk + C) \leq \Delta X \leq X_1 + (nk + C) \\
\frac{1}{2} + \frac{1}{2} \sin \varphi, & X_1 + (nk + C) \leq \Delta X \leq X_2 + (nk + C) \\
0, & \Delta X \geq X_2 + (nk + C) 
\end{cases} \tag{10}
$$

where $k = \frac{1}{4} \bar{X}$.

The membership function of the index corresponds to the unqualified quality grade is

$$
\mu(\Delta X) = \begin{cases} 
1, & \Delta X \geq -X_1 + (nk + C) \\
\frac{1}{2} + \frac{1}{2} \sin \varphi, & -X_2 + (nk + C) < \Delta X < -X_1 + (nk + C) \\
0, & \Delta X \leq -X_2 + (nk + C) 
\end{cases} \tag{11}
$$

The above model can be used to depict the membership degree of the single evaluation index of power quality relative to each quality grade, and the relationship between two quality grades can be established, rather than the general membership degree of the overall qualification.

### 4.2. Design of power quality evaluation algorithm

The power quality comprehensive evaluation algorithm designed in this paper includes the following steps:
a. According to the structure characteristics of Weifang power grid, the power quality index is
determined. The selected electrical energy quality data is collected by the power quality detection
terminal, and the data collected by the power quality indexes are standardized.
b. Calculate the subjective weight, objective weight and combination weight of \( W \) according to the
data.
c. Application (9) - (11) fuzzing the evaluation index with respect to each quality grade, and
obtaining the membership matrix \( \mu \).
d. The subordinate degree of the total power quality of the point to the fuzzy subset of the quality
grade is evaluated by the following calculation.
\[
B = W \cdot \mu \quad (12)
\]
e. 5 quality grades are assigned to \( c_1, c_2, c_3, c_4, c_5 \), and the distance between adjacent grades is
equal. From high to low, the power quality is from good to poor. Finally, the power quality factor of
the evaluation point \( f_{PQ} \) is obtained by weighted average, and the calculation formula is as follows.
\[
f_{PQ} = \frac{\sum_{j=1}^{n} b_j c_j}{\sum_{j=1}^{n} b_j} \quad (13)
\]
In the formula, the \( b_j \) represents the membership of the integrated power quality relative to the j
quality level.

5. Fuzzy evaluation method of power quality based on combination of variance maximization
weights

5.1. The weight of the evaluation index of power quality
First, the power quality factor set \( U \) is determined. \( U = \{ \text{voltage deviation, harmonic, three-phase}
imbalance, frequency deviation, voltage fluctuation, voltage flicker} \) in this paper. The power quality
is divided into 5 levels, and the 6 power quality of the wind farm access point is detected. As shown in
Table 1, the data is standardized and the subjective and objective weight is calculated according to the
method mentioned above.

| Number | Voltage deviation | Harmonic voltage | Voltage fluctuation | Voltage flicker | Frequency deviation | Three phase unbalance |
|--------|-------------------|------------------|---------------------|----------------|---------------------|---------------------|
| 1      | 3.3               | 0.6              | 0.095               | 0.3            | 0.04                | 0.17                |
| 2      | 3.24              | 0.57             | 0.217               | 0.26           | 0.04                | 0.22                |
| 3      | 3.0               | 1.69             | 0.103               | 0.11           | 0.03                | 0.23                |
| 4      | 2.71              | 1.1              | 0.174               | 0.30           | 0.04                | 0.15                |
| 5      | …                 | …                | …                   | …              | …                   | …                   |
| 6      | 3.47              | 0.75             | 0.125               | 0.21           | 0.04                | 0.11                |

A. Calculation of subjective weight based on improved AHP method. The importance of the
evaluation index is: voltage deviation > harmonic voltage > voltage fluctuation = voltage flicker >
frequency deviation > three-phase unbalance. The relative importance of each index is determined by
experts. It is tentatively defined as \{1.8,1.7,1. 1.8,1.2\}. By obtaining the eigenvector corresponding to
the maximum eigenvalue of the matrix \( R \), and the normalization process, the subjective weight based
on the improved AHP method is \{0.1051,0.2071,0.2071,0.1229,0.2851,0.0727\}, and the result is listed
in Table 2 and second columns.

B. Calculation of subjective weight based on expert investigation method. Taking the results of an
expert as an example, the expert on the importance of each index in the power quality factor is \{0.4,
0.15, 0.05, 0.2, 0.05\}. The results of a number of experts are summed up and the subjective right
based on the method of expert investigation can be obtained according to formula (1). The weight
vector is \{0.35, 0.1333, 0.0667, 0.1416, 0.1917, 0.1167\}, and the results are listed in the third column
of Table 2.
C. Calculation of objective weight based on entropy weight. According to the measured data, the information amount of each index is calculated, and the objective weight of the evaluation index is \{0.1544, 0.211, 0.1512, 0.3361, 0.0255, 0.1218\}. It is known from the measurement data that the voltage flicker and the harmonic voltage fluctuate greatly, while the frequency deviation and the voltage fluctuation data are very small, so the voltage fluctuation and the harmonic voltage are so small. The objective weight reflects the objective characteristics of the data, and the results are listed in the fourth column of Table 2.

D. Objective weight calculation based on maximization of standard deviation and mean difference. The standard deviation coefficient and average difference coefficient of each evaluation index are calculated according to [3]. The objective weight of each evaluation index is determined to be \{0.0669, 0.2213, 0.1822, 0.1335, 0.1589, 0.2371\}, and the results are listed in the fifth column of Table 2.

5.2. Calculation of combined weight based on maximization of variance
According to the subjective weight and objective weight of the index in Table 1, the interval range of the combined weight of the evaluation index is determined. Then the measured data are standardized in the negative direction, and the evaluation function \(Z\) is constructed by using the standardized data and combination weight to evaluate the variance of the function \(Z\) as the target function, and the sum of the index weight is \(1\). The reasonable interval of the index is used as the constraint condition to establish the optimization model. The combination weight of the satisfied conditions can be obtained to be \{0.0909, 0.2213, 0.2071, 0.1229, 0.2815, 0.0727\}, and the calculation results are listed in Table 2 sixth columns.

| Subjective weight | Objective weight | Combina-torial weight |
|-------------------|------------------|-----------------------|
| Voltage deviation | 0.1051 0.350 0.1544 0.0669 | 0.0909 |
| Voltage fluctuation | 0.2071 0.1333 0.211 0.2213 | 0.2213 |
| Voltage flicker | 0.2071 0.0667 0.1512 0.1822 | 0.2071 |
| Harmonic voltage | 0.1229 0.1416 0.2361 0.1335 | 0.1229 |
| Frequency deviation | 0.2851 0.1917 0.1255 0.1589 | 0.2815 |
| Three phase unbalance | 0.0727 0.1167 0.1218 0.2371 | 0.0727 |

5.3. Formation of index membership matrix
Taking the power quality provided in Table 1 as an example, the values of the parameters in membership functions are shown in Table 3 [6].

| Voltage deviation | Harmonic voltage | Voltage fluctuation | Voltage flicker | Frequency deviation | Three phase unbalance |
|-------------------|------------------|---------------------|----------------|----------------------|----------------------|
| \(X_1\) | 0.3125 | 0.125 | 0.05 | 0.0375 | 0.025 | 0.125 |
| \(X_2\) | 0.9375 | 0.375 | 0.15 | 0.1125 | 0.075 | 0.375 |

According to formula (9) - (11) the membership matrix \(\mu\) is calculated as

\[
\mu = \begin{bmatrix}
1 & 0 & 0 & 0 & 0 & 0 \\
0.0778 & 0.9222 & 0 & 0 & 0 & 0 \\
0 & 0 & 1 & 0 & 0 & 0 \\
0 & 0.9524 & 0.0476 & 0 & 0 & 0 \\
0 & 0.2417 & 0.7583 & 0 & 0 & 0 \\
1 & 0 & 0 & 0 & 0 & 0
\end{bmatrix}
\]
5.4. Determination of power quality factor

According to formula (12), the composite power quality is calculated with respect to the membership of each grade.

$$B = W \cdot \mu = [0.1808, 0.3892, 0.4264, 0, 0].$$

The 5 grades of power quality are 5, 4, 3, 2 and 1 respectively, and the power quality factor can be calculated from the formula (13).

$$f_{PQ} = \frac{\sum_{j=1}^{m} b_{j} c_{j}}{\sum_{j=1}^{m} b_{j}} = 3.7394$$

The power quality level of the bus can be seen from the power quality factor. The power quality of the bus is between good and medium two quality grades and is closer to the good. Therefore, the electric energy quality evaluation of the bus is good, which is the same as that of the usual grade of the bus, and the evaluation results agree with the actual situation.

Therefore, we should consider the information reflected by each weight synthetically, and calculate the combined weights of indexes. From the description of this article, we can know the reasonable interval of the index given by the combination weighting method of variance maximization. When the combination weight of the index falls in the interval, it can explain the advantage that the combination weight can reflect the objective weight. It can be seen from table 2 that the classification of the combination weighting method is better, and the most important thing is that the combination weighting method is from the point of view. The index layer is combined with the weight, and the combination process does not involve the direct operation of the subjective weight and the objective weight, which shows that the combination weighting method of the variance maximization is reasonable.

6. Conclusion

On the basis of the weighting method of subjective and objective, this paper puts forward a combination weighting method based on the maximization of variance in view of the limitations of the traditional combinatorial weighting method. This method is not only reasonable, but also can take into account the characteristics of subjective weight and objective weight, and study the concept of reasonable interval, which provides a new way of thinking for the rationality discrimination of combination weight. In addition, the fuzzy evaluation method of power quality based on the empowerment method is studied, and a comprehensive evaluation system of power quality is established. The evaluation results of the 220KV bus in Weifang prove the effectiveness of the method. At the same time, it shows that the comprehensive evaluation method has good application value.

Acknowledgments

The authors wish to thank the corporate researchers in the common laboratory for the generous help of simulation program and experiment.

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