Power quality evaluation based on the fusion of improved entropy and analytic hierarchy process

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Abstract. With the increasing of Distributed Generation (DG), the traditional distribution network has changed from a passive mode to an active mode. Under such background, the evaluation of power quality has become a research hotspot. In order to quantify the harm of power quality problems and control the operation of power quality, this paper firstly proposes an improved entropy weight method, which focuses on solving the unreasonable problem of entropy value close to the value of 1 and the entropy weight changes drastically. Secondly, the weight calculation can be computed through fusion the analytic hierarchy process and the improved entropy weight method. Finally, compared with the traditional method, the simulation experiment shows the method in this paper is more suitable for the situation where the power quality index fluctuates greatly after the introduction of DG.

Keywords: Power quality, Improved entropy weight method, Analytic hierarchy process, Weight calculation.

1 Introduction

With the continuous growth of electricity demand, the shortage problem of traditional energy is very serious, which prompting the construction of the power grid to high efficiency, intelligence and sustainability. Under this background, DG are gradually introduced into the power energy market, such as photovoltaic power generation, wind power generation, etc. and their proportion is also increasing. However, the high penetration rate of DG connected to the distribution network may lead to a series of problems such as Short-circuit current rise, Reliability of power supply drops, and Power quality deterioration.

In 2008, the International Power Grid Conference was held in Paris, and it was concluded that the traditional passive distribution network model has not been able to deal with the above problems well, and a brand-new active distribution network technology was released for the first time. The so-called active distribution network can adjust and control the distribution of power flow through the network topology, realize the active management of the distribution network through the optimized of DG, and realize the supporting role of DG on the system under the supporting supervision environment and agreements [1].

The power quality level of the power system is affected by many factors, and its operation status is usually described by multiple indicators. A single independent power quality indicator cannot reflect the level of power quality systematically. Therefore, the core content of power quality evaluation research is to weight and merge a multi-index problem into a single index problem. In the active distribution network, DG has many types, randomness, volatility and intermittent characteristics, which will cause the power flow fluctuation of the power grid system and bring difficulties to the optimization control of the distribution network. In addition, due to the use of a large number of power equipment such as grid-connected inverter devices and solid-state switching devices, the power quality and reliability problem in active distribution networks have become increasingly complex and prominent [2-5].

There are a variety of methods for power quality evaluation, including: fuzzy mathematics[6-8], artificial neural networks and deep learning methods[9,10], user demand methods [11], extension cloud Theory [12], analytic hierarchy process [13,14] and entropy weight methods [15] and combination methods [16,17], probability statistics and vector algebra method [18,19]. Although these mathematical analysis methods are of great significance to the evaluation of power quality, there are still some points to be improved. Among these methods, the methods based on fuzzy mathematics, user demand methods, and the analytic hierarchy process are expert weighting methods. The evaluation results are greatly affected by subjective factors. Experts may have large differences in the discrimination of various indicators. The judgment matrix needs to be tested for consistency. Based on entropy weight method, extension cloud theory, probability statistics and vector algebra method generally do not need expert subjective weighting, only the actual fluctuation of electric energy index is considered, and the expert's engineering experience is completely ignored, so it is not very well. Reflect the actual power quality situation. The inconsistent selection of the benchmark value in the probability and statistics method will lead to a large difference in the results. Based on the artificial neural network method, deep learning method, etc., which need to collect a large number of samples for evaluate the network model. At the same time, the relevant feature extraction will also be combined with some method above. For training, if the number of samples is not enough, the final evaluation will also have a large error.

After researching the existing power quality evaluation methods and their application scenarios, this paper proposes an improvement strategy for the entropy weight method, which can avoid some of the shortcomings of the traditional entropy weight method. In the power quality evaluation, this paper fully considers the complex factors that affect power quality, combines the improved entropy weight method with the analytic hierarchy process to distributes the weights of the importance of different indicators in the DG. Combined with the experimental verification, it is possible to judge the pros and cons of the power quality of the DG-containing system.

2 Traditional entropy method

According to the basic principles of information theory, the amount of information can be measured by information entropy. The entropy has been widely used in engineering technology, social economy and other fields. Information entropy can judge the degree of dispersion of some given index. For example, the smaller of information entropy, the greater of indicator dispersion. If the values of a certain index are all equal, Then this indicator has no effect in comprehensive assessment. Therefore, the information entropy can be used to calculate the indicator weight coefficient, which can provide a theoretical basis for the comprehensive evaluation of multiple indicators.

In power quality evaluation , the entropy weight method is used to construct a model for the comprehensive evaluation of power quality. The basic calculation steps are shown in Figure 1:

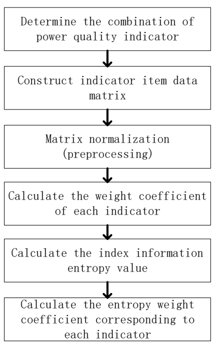

Fig. 1 The basic steps of traditional entropy method for power quality evaluation

2.1 Indicator data matrix and standardization

There are n available energy indicators to form the original index data matrix X , which can be represented by the following matrix:

$$X = \begin{pmatrix} X_{11} & \cdots & X_{1m} \\ \vdots & \vdots & \vdots \\ X_{n1} & \cdots & X_{nm} \end{pmatrix}_{n\times m} \quad (1)$$

In matrix (1), X_{ij} is the value of the j-th index of the i-th scheme. For a certain x_j, the greater X_{ij}, the greater role of the index in the comprehensive evaluation. If all the indicator values are equal, the indicator does not play a role in comprehensive evaluation.

2.2 Data non-negative processing

After standardizing the index items, if there are negative numbers in the data, the data needs to be non-negative. In addition, in order to avoid the meaningless situation of the logarithm when calculating the entropy value, it is necessary to perform the matrix translation operation. The specific operation is divided into two cases:

For large indicators, use the translation operation of formula (2):

$$X_{ij}^{'} = \frac{X_{ij} - \min(X_{1j}, \cdots, X_{nj})}{\max(X_{1j}, \cdots, X_{nj}) - \min(X_{1j}, \cdots, X_{nj})} + 1, i = 1, 2, \cdots, n;\ j = 1, 2, \cdots, m \quad (2)$$

For small indicators, use the translation operation of formula (3):

$$X_{ij}^{'} = \frac{\max(X_{1j}, \cdots, X_{nj}) - X_{ij}}{\max(X_{1j}, \cdots, X_{nj}) - \min(X_{1j}, \cdots, X_{nj})} + 1, i = 1, 2, \cdots, n;\ j = 1, 2, \cdots, m \quad (3)$$

Regardless of the kind of data translation operation, they are all recorded as X_{ij}.

2.3 Calculating Entropy Coefficient

Calculate the proportion of the first scheme under the j-th index in the index as shown in formula (4) to formula (7):

$$P_{ij} = \frac{X_{ij}}{\sum_{i=1}^{n} X_{ij}} \quad (j = 1, 2, \cdots m) \quad (4)$$

$$e_j = -\frac{1}{\log(m)} * \sum_{i=1}^{n} P_{ij} \log(P_{ij}) \quad (5)$$

Where log represents the logarithm with the constant e as the base, satisfying: $0 \le e_j \le 1$.

$$g_j = 1 - e_j \quad (6)$$

$$W_j = \frac{g_j}{\sum_{j=1}^{m} g_j}, \ j = 1, 2 \cdots m \quad (7)$$

3. Improve the entropy method

From the calculation of formulas (6) and (7), it can be seen that when the calculated value of entropy e_j is closer to 1, the difference coefficient g_j tends to 0, and the calculation of w_j value is too sensitive, that is, the entropy value calculated between the two indicators tends to When it is close to 1, a small change in the entropy result will lead to an excessive change in the final weight, which is not in line with the conventional understanding of people.

In [20],the author improved the calculation of the entropy weight coefficient in response to the above problems, and changed the formula (7) to the formula (8):

$$W_j = \frac{\sum_{j=1}^{m} e_j + 1 - 2e_j}{\sum_{j=1}^{m}(\sum_{j=1}^{m} e_j + 1 - 2e_j)}, \; j = 1, 2 \cdots m \tag{8}$$

After formula (8) is modified, it can indeed alleviate the situation when the entropy value tends to 1, but it cannot give a more reasonable entropy value for other situations. In [21], the author gives an example of formula (8) calculation unreasonable, when the entropy value vector of 3 indicators is (0.99, 0.98, 0.1), the entropy weight corresponding to the entropy value 0.1 should be much larger than 0.99 and entropy weight corresponding to 0.98 entropy value. However, the entropy weight vector obtained by the improved method given by equation (8) is (0.215, 0.219, 0.566), which does not reflect the weight between entropy values well. For this reason, the literature [21] modified the formula (7) and changed it to the formula (9) mode:

$$W_j = \frac{1 - e_j + \varepsilon}{\sum_{j=1}^{m}(1 - e_j + \varepsilon)}, \; j = 1, 2 \cdots m \tag{9}$$

ε is a very small value. When the value is $\varepsilon = 0$, it degenerates into the traditional entropy weight method, which is finally determined in the literature [21] after comprehensive consideration. At this time, the entropy vector for the three indicators is (0.99, 0.98, 0.1) When calculating, the final entropy weight obtained is (0.089, 0.098, 0.813), which is indeed alleviated compared to the literature [20], but it is set to a fixed value, which can only perform a fixed stretch on the overall entropy weight coefficient calculation result , Did not fundamentally solve the problem.

From the above problem analysis and improvement strategy, it can be seen that when the value of e_j tends to 1, the calculation of the W_j value is too sensitive, and when the value of e_j tends to 0, the calculation of the W_j value is more reasonable. When the e_j value tends to 1, the same restriction is added to the situation where the value of e_j tends to 0, which will inevitably affect other reasonable values of e_j tending to 0. Therefore, in order to solve this problem, this paper adds a certain limit to e_j on the basis of literature [21], so that it increases the limit when the e_j value tends to 1, and the e_j value tends to 0 reduces the limit. To obtain a more reasonable value distribution of entropy weight, the specific calculation formula is as follows:

$$w_j^{(1)} = \frac{1-e_j+e_j\varepsilon}{\sum_{j=1}^{m}(1-e_j+e_j\varepsilon)} \ , j=1,2\cdots m \tag{10}$$

4. Evaluation Process

The entropy weight method improved in this paper determines the index weights according to the degree of difference between the index values of each index. This is an objective weighting method that avoids the deviation caused by human factors, but because it ignores the importance of the index itself, Sometimes the determined indicator weights are far from the expected results. In order to better reflect the importance of the indicators themselves, this article uses the improved entropy weight method while introducing the tomographic analysis method to make subjective expert judgments on various indicators. In the end, the fusion method in this paper takes into account the opinions of experts and the actual fluctuation of each power index, and divides the importance of each power quality index.

4.1 Analytic Hierarchy Process

Analytic Hierarchy Process can solve complex nonlinear problems through qualitative and quantitative analysis of specific problems. It is a subjective evaluation method that is currently used more frequently. This method can distinguish the importance of different indicators relative to the evaluation purpose, and give the order of each indicator; in addition, the mathematical processing of this method is more rigorous, and in the process of continuous application and development, many new ideas are constantly infiltrated. A variety of improvement methods have been produced. The steps of using the analytic hierarchy process to obtain the index weight coefficients are shown in Fig. 2:

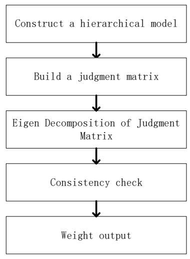

Fig. 2 Calculating index weight coefficient

The structure of the hierarchical structure model is to establish the hierarchical structure among the indicators according to a certain subordination relationship, and it is often analyzed according to the scale of Table 1.

Table 1 Meaning of 1-9 scales in analytic hierarchy process

Different scale	meaning
1	Two elements are equally important
3	The previous element is slightly more important than the next
5	The former element is obviously more important than the latter
7	The former element is more important than the latter
9	The former element is extremely important than the latter
2、4、6、8	The middle value of the above two adjacent judgments
1/3	The former element is slightly less important than the latter
1/5	The former element is obviously less important than the latter
1/7	The former element is stronger than the latter element is not important
1/9	The former element is extremely unimportant than the latter
1/2、1/4、1/6、1/8	The middle value of the above two adjacent judgments

In general, the more complex the research problem, the more various considerations, and the more levels established, the more difficult it is to analyze and process. For the 9-scale method, more information is required, and it is difficult to grasp the importance of indicators. 3 The scaling method requires less information, and it is easy to judge the importance of the indicators, but there is a loss of judgment information, a loss of cumulative dominance, and a loss of consistency [22]. Therefore, this article refers to [21], using the 5-scale method to divide the index hierarchy to form a judgment matrix. First, confirm the importance of each index based on expert opinions, and then construct a judgment matrix A based on the importance of each index.

For judgment matrix A, calculate the maximum eigenvalue and eigenvector using formula (11) :

$$A\varpi = \lambda_{\max}\varpi \tag{12}$$

In (12), $\lambda_{\max}$ is the largest eigenvalue of matrix A, and ϖ is the eigenvector corresponding to $[w_1^{(2)}, w_2^{(2)}, ..., w_m^{(2)}]$.

The consistency test can be carried out according to formula (13):

$$\theta = {(\lambda_{\max} \text{-} m)}/{(m-1)} \quad , \ m \geq 1 \tag{13}$$

In (13), m is the order of matrix A

4.2 Algorithm fusion

Two different weights of the same index can be obtained after two power quality evaluation methods are calculated. The fusion adopts a simple linear combination form. The specific formula is as follows:

$$w_j = \alpha w_j^{(1)} + \beta w_j^{(2)} \tag{14}$$

In (14), α、β is linear coefficient.

5. Experimental results

5.1 Improved Entropy Method Experiment

In order to complete the algorithm experiment, this paper uses the simulated entropy data used in literature [21] for comparison, and the test results using different methods are shown in Table 2:

Table 2 Comparison between different entropy methods

No.	Entropy	Traditional entropy weight method	The method of Literature [21]	Improved method in this study
1	(0.999,0.998,0.997)	(0.167,0.333,0.5)	(0.330,0.333,0.337)	(0.243,0.247,0.249)
2	(0.3,0.2,0.1)	(0.292,0.333,0.375)	(0.296,0.333,0.371)	(0.121,0.130,0.143)
3	(0.003,0.002,0.001)	(0.33,0.333,0.337)	(0.333,0.333,0.334)	(0.242,0.247,0.248)
4	(0.9,0.5,0.1)	(0.067,0.333,0.6)	(0.111,0.333,0.555)	(0.104,0.163,0.143)
5	(0.99,0.98,0.1)	(0.011,0.022,0.968)	(0.089,0.098,0.813)	(0.211,0.226,0.143)

Through algorithm experiments, when the e_j value tends to 1, the entropy weight coefficient calculated by the algorithm in this paper is very close, which is better than the traditional method and the method in [21]. For the case where the e_j value tends to 0, the algorithm in this paper can also be very good. To adapt to the change of information entropy value, obtain a more reasonable value distribution of entropy weight.

5.2 Electric energy evaluation experiment

In order to complete the algorithm experiment, this paper selects five indicators, including voltage flicker, voltage fluctuation, harmonic voltage, and Three electrical unbalance. In order to obtain the above data, two data collection points are set up in the two substations of a power supply company, which are recorded as collection point 1 and collection point 2. Each access point collects data for 100 consecutive days of indicators, and the percentage of statistics is shown in the table 3 shows:

Table 3 Samples of collected data for different indicators

Collection point	Voltage flicker	Voltage fluctuation	Harmonic voltage	Three electrical unbalance
Collection point 1	0.25	1.02	1.11	0.62
Collection point 2	0.27	3.18	0.92	0.96

The power quality evaluation is carried out for the above two access points, and the evaluation results are shown in table 4:

Table 4 Power quality assessment results of different access points

Collection point	Analytic Hierarchy Process	Entropy method	Our method
Collection point 1	1.65	1.97	1.75
Collection point 2	2.17	2.58	3.66

For the collection point 1, since the fluctuation of the electric energy index is not large, the final evaluation result value is not much different. For collection point 2, because the voltage fluctuation index changes drastically, the weight coefficient should be increased, but the separate analytic hierarchy process and entropy weight method do not conform to the objective situation.

6 Conclusion

In order to quantify the harm of power quality problems and control the power quality, this paper firstly proposes an improved entropy weight method, which focuses on solving the unreasonable problem of the entropy value close to the value of 1 and the entropy weight changes drastically, and keeps it under other conditions. Consistent result with traditional entropy method. Secondly, the fusion of analytic hierarchy process and improved entropy method is introduced for weight calculation. Finally, the effectiveness of this method is proved by experiments.

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