Comprehensive quality evaluation method of smart meters based on AHP-Critic

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ABSTRACT: The quality of smart meters directly affects the stability, security and economy of information gather system and power grid. This paper proposes a comprehensive quality evaluation method of smart meters based on AHP-Critic theory. In this method, firstly, the hierarchy of AHP is established to determine the contents of target layer, rule layer and scheme layer; secondly, the judgment matrix is constructed to calculate the hierarchical single ranking value and carry out consistency test; thirdly, the objective weight of rule layer is calculated by using Critic theory; finally, the comprehensive weight of rule layer is obtained by combining AHP and Critic, and the hierarchical total ranking of target layer to scheme layer is calculated. The experimental analysis takes three types of smart meters as evaluation objects, and the results effectively evaluate the quality of each meter.

1. Introduction

The construction of smart grid in China is speeding up [1]. As the metering terminal equipment of smart grid, the quality of smart meters has a direct impact on the safe and stable operation of power grid, and also directly related to the power supply reliability and safety of power users [2]. Although there are many researches on product quality evaluation methods at home and abroad, the quality evaluation models for the smart meters are still very rare, and are still in the initial stage. At present, the quality evaluation methods applied to smart meters mainly include analytic hierarchy process [3], triangular fuzzy number analytic hierarchy process [4], multi-objective evaluation method [5], comprehensive evaluation method [6] and fuzzy optimal membership comprehensive evaluation method [7]. However, most of these methods rely on the subjective experience of experts to evaluate the quality of smart meters. This paper deeply considers the role of the life cycle data of smart meters in the comprehensive quality evaluation, and uses objective data to correct the lack of subjective experience to scientifically evaluate the comprehensive quality of smart meters.

2. Selection of comprehensive quality evaluation index of smart meters

According to the characteristics of smart meters, combined with the different stages of smart meters life cycle, this paper extracts six evaluation indexes to complete the comprehensive quality evaluation of smart meters. The following is the establishment and definition of each quality evaluation index.

(1) The failure rate of smart meters, $\lambda$. According to the use demand of smart meters of State Grid,
the service life of smart meter needs 15 years. In this paper, the failure rate of smart meters is chosen as reliability index, and its value is the sum of failure rate of each component that constitutes the meter.

(2) The basic error of smart meters, $e$. After the smart meters are produced, the supplier carries out a series of tests and gets the test report. Because this process is the supplier's quality supervision and management of its products, we can select basic error as the evaluation index according to its test report. Basic error refers to the indication error of smart meters under reference conditions, which can well reflect the accuracy of smart meters in various tests.

(3) The problem rectification rate of smart meter, $rr$. The product supervision of smart meters can strengthen the quality control of smart meters production, and urge the winning suppliers to strengthen the quality control of smart meters. According to the particularity of this stage, the problem rectification rate of smart meters is selected as the evaluation index.

(4) The test pass rate of smart meter, $pr$. According to the requirements of the State Grid, the pre arrival sample comparison and sampling full performance test shall be carried out for each winning batch of smart meters. At this stage, we select the most representative sample sampling full performance test pass rate as the evaluation index.

(5) The acceptance rate of smart meters, $ar$. The quality management of smart meters after arrival consists of sample comparison, sampling acceptance test and full acceptance test. We select the quality evaluation index of this stage as the acceptance rate of smart meters.

(6) The operation fault rate of smart meters, $f$. The quality supervision of smart meters in operation stage can only be completed through the sampling inspection of smart meters. In the sampling inspection process, we select the operation fault rate of smart meters as the quality evaluation index.

3. AHP-Critic model

When using the analytic hierarchy process, the hierarchy structure should be established first, as shown in Figure 1. The target layer is established as the comprehensive quality evaluation of smart meters, the rule layer is established as the failure rate, basic error, problem rectification rate, test pass rate, acceptance rate and operation fault rate of smart meters, and the scheme layer is established as different types of smart meters.

![AHP hierarchical structure](image)

Then the judgment matrix $A = (a_{ij})_{p \times p}$ of rule layer is constructed. $a_{ij}$ is the ratio of the influence of any two different indexes in failure rate, basic error, problem rectification rate, test pass rate, acceptance rate and operation fault rate on the comprehensive quality evaluation of smart meters at the target layer, $p$ is the number of indexes in the rule layer, in this paper, $p=6$.

The eigenvector corresponding to the maximum eigenvalue $\lambda_{\text{max}}$ of the judgment matrix is normalized and recorded as $w$. The elements of the vector are hierarchical single ranking of target layer to rule layer, recorded as $(w_1, w_2, \ldots, w_q)$. Finally, the consistency test of judgment matrix is required, and the steps are as follows:

1) Calculate The consistency index CI, formula is as follows:
(1) Look up the table to find out the random consistency index RI. When \( p = 6 \), \( RI = 1.24 \).

3) Calculate the consistency ratio CR, formula is as follows:

\[
CR = \frac{CI}{RI}
\]

When \( CR < 0.1 \), the judgment matrix passes the consistency test, otherwise the judgment matrix is adjusted and tested again.

In the same way, the judgment matrix \( A_2 = (a_{ij})_{n \times n} \) of the scheme layer is constructed and the consistency is tested. \( n \) represents the number of smart meters to be evaluated in the scheme layer. The hierarchical single ranking of rule layer index \( a_j \) to scheme layer is recorded as \( (s_{ij_1}, s_{ij_2}, \ldots, s_{ij_n}) \).

Critic is a comprehensive measure of the objective weight of indexes based on the contrast strength within indexes and the conflict between indexes. It is an objective evaluation method that makes full use of data.

For \( n \) types of smart meters to be evaluated, \( p \) types of evaluation indexes, form the original index data matrix:

\[
X = \begin{pmatrix}
x_{i1} & \cdots & x_{ip} \\
\vdots & \ddots & \vdots \\
x_{ni} & \cdots & x_{np}
\end{pmatrix}
\]

Where \( x_{ij} \) is the value of the \( j \) evaluation index of the \( i \) smart meter.

In order to eliminate the influence of different dimensions on the evaluation results, Critic uses forward and reverse methods to dimensionless the indexes.

If the larger the index value is, the better it is, then the index value will be forward processed, formula is as follows:

\[
x'_{ij} = \frac{x_{ij} - x_{\min}}{x_{\max} - x_{\min}}
\]

The test pass rate and acceptance rate are positive indexes.

If the smaller the index value is, the better it is, then reverse the index value, formula is as follows:

\[
x'_{ij} = \frac{x_{\max} - x_{ij}}{x_{\max} - x_{\min}}
\]

Failure rate, basic error, problem rectification rate and operation fault rate are the reverse indexes.

Critic uses standard deviation to express the fluctuation of the value in the index. The larger the standard deviation is, the greater the numerical difference of the index is, the more information can be reflected, and the stronger the evaluation intensity is. Therefore, the index should be assigned a higher weight. The standard deviation of the index is calculated as follows:

\[
S_j = \sqrt{\frac{\sum_{i=1}^{n}(x_{ij} - \bar{x}_j)^2}{n-1}}
\]

\( S_j \) is the standard deviation of the \( j \) indicator, \( \bar{x}_j = \frac{1}{n} \sum_{i=1}^{n} x_{ij} \).

The relationship between indexes is described by conflict. The greater the conflict is, the weaker the correlation between the two indexes is, the less the information repetition is, and the higher the weight should be assigned. The calculation formula of conflict coefficient is as follows:

\[
R_j = \sum_{k=1}^{p}(1 - r_{kj})
\]

\( R_j \) is the conflict coefficient of the \( j \) indicator, \( r_{kj} \) is the correlation coefficient between index \( k \) and
\[ j, \text{ formula is as follows:} \]
\[
 r_{ij} = \frac{\sum_{i=1}^{n} (x_{ia} - \overline{x_i})(x_{ja} - \overline{x_j})}{\sqrt{\sum_{i=1}^{n} (x_{ia} - \overline{x_i})^2} \sqrt{\sum_{j=1}^{n} (x_{ja} - \overline{x_j})^2}} 
\]

Make
\[
 C_j = S_j \times R_j = S \sum_{i=1}^{n} (1 - r_{ij}) 
\]

The larger \( C_j \) is, the greater the role of the index \( j \) in the whole evaluation index system is, and the higher the weight is.

The objective weight \( w_{ij} \) of the \( j \) index is:
\[
w_{ij} = \frac{C_j}{\sum_{j=1}^{n} C_j} 
\]

Combined with AHP and Critic, the comprehensive weight of the \( j \) index is
\[
w_j = \frac{w_{ij} w_{ij}}{\sum_{j=1}^{n} w_{ij} w_{ij}} 
\]

Finally, the hierarchical total ranking of target layer to scheme layer is:
\[
z_i = \sum_{j=1}^{n} s_{ij} w_j, \quad i=1,2...n 
\]

It is also necessary to check the consistency of the hierarchical total ranking. If the single ranking consistency index of judgment matrices \( A_j \) is \( CI(j) \), and the corresponding random consistency index is \( RI(j) \), then the total ranking consistency ratio is:
\[
 CR = \frac{\sum_{j=1}^{n} CI(j) w_j}{\sum_{j=1}^{n} RI(j) w_j} 
\]

When \( CR < 0.1 \), the judgment matrix passes the consistency test.

4. Experimental analysis
In this paper, X, Y, Z three different types of smart meters are selected to carry out the comprehensive quality evaluation. Table 1 is the rule layer judgment matrix constructed in this paper. The consistency ratio is 0.0996, less than 0.1, which has passed the test. The eigenvector corresponding to the maximum eigenvalue of the matrix is normalized to (0.1507, 0.1792, 0.1886, 0.0472, 0.1464, 0.2879), and the index weight calculated by Critic is (0.1253, 0.1876, 0.1631, 0.0885, 0.1929, 0.2426). According to formula (10), the comprehensive weight of rule layer index is shown in Figure 2.

| Evaluation |  |  |  |  |  |  |
|------------|---|---|---|---|---|---|
| \( \lambda \) | 1 | 1 | 1 | 4 | 1 | 1/2 |
| \( e \) | 1 | 1 | 2 | 4 | 1 | 1/2 |
| \( rr \) | 1 | 1/2 | 1 | 5 | 3 | 1/2 |
| \( pr \) | 1/4 | 1/4 | 1/5 | 1 | 1/3 | 1/3 |
| \( ar \) | 1 | 1 | 1/3 | 3 | 1 | 1 |
| \( f \) | 2 | 2 | 3 | 3 | 1 | 1 |
Table 2 shows the six judgment matrices of the scheme layer constructed in this paper, and the consistency ratios are 0.0158, 0.0212, 0.0061, 0.0559, 0 and 0.0061 respectively, which are all less than 0.1 and pass the test. The six eigenvector values are listed in Figure 3.

According to formula (11), the total ranking weight of the target layer is (0.4497, 0.2637, 0.2866). According to formula (12), the total consistency ratio is 0.0173, which is less than 0.1 and pass the test. The results show that the comprehensive quality of X is the best, Z is the second, and Y is the worst.

5. Conclusion
In this paper, a comprehensive quality evaluation method of smart meters based on AHP-Critic is proposed. This method combines the objective index data deeply and corrects the shortcomings of traditional methods which rely on the subjective experience of experts. Finally, the comprehensive quality of the three types of smart meters is evaluated by experiments, which is in line with the expected results and verifies the effectiveness of the proposed method.
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