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Application of Grey Correlation Degree and TOPSIS Method in Evaluation of Power Quality

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Abstract

Aiming at solving multi-criteria decision problems in power quality, a new decision-making method based on grey correlation degree and TOPSIS is proposed. On the basis of introducing the concept of grey correlation degree into traditional TOPSIS, a new relative similarity degree is established to decide power quality by combining Euclidean distance with grey correlation degree. Error originated from biased thinking due to subjective and objective factors in decision-making problem when using single method could be overcome by using the method and reliability of evaluation result in electric material tendering can be boosted up. Example shows that power quality could be effectively estimated by use the method and the method is an effective instruction for PQ evaluation.

Keywords: *power quality, TOPSIS, grey correlation degree, Euclidean distance*

1. Introduction

Along with the progressing of innovation of power market, customers tend to obtain power service of high quality and low price. Because of specialty of power commodity and multiplicity of quality index it makes difficult to quantize and evaluate quality index. We need a effective method of comprehensive evaluation [1-3], it can supply gist for two-way selection of power service between power supply corporations and customers.

In recent years many experts and scholars have tended to focus on the methods of power quality comprehensive evaluation (PQCE). Some advance fuzzy model and comprehensive indexs based on fuzzy principle are used to evaluate power quality [4]. Some advance evaluation methods are based on combination weighing [5-7] and could overcome deficiency of single weighing methods. Another apply fuzzy mathematics and fuzzy AHP in PQCE and resolve fuzzy uncertainty of subjective judgment.

A power quality comprehensive evaluation method based on grey correlation degree and TOPSIS is proposed in the paper. Example shows that the method could effectively evaluate power quality problems.

2. Combination Weighing Method

The weights of indices of power quality comprehensive evaluation are decided by FAHP and entropy methods. The deficiency of single weighing methods is overcome and the weights are decided rationally.

2.1. Decision of Subjective Weights

Fuzzy judgement matrix is formed by introducing triangular fuzzy numbers [8] in consideration of uncertainty of subjective judgement formation. Indices seqencing and weight are decided by using fuzzy numbers compare principle.

Judgement matrix is indicated by 1~9 scale and reciprocal according to relative important level of each level element.

The quantity of power quality indices that is related with upper index is setted m and index assemblage is setted as $X=\left\{x_1,x_2,\cdots,x_m\right\}$. Triangular fuzzy numbers $b_{ij}=\left[l_{ij},e_{ij},p_{ij}\right]$

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of fuzzy judgement is decided to important level of index i comparing with index j. Left and right extension l_{ij} and p_{ij} is indicated fuzzy level of judgement. The value of $p_{ij} - l_{ij}$ is bigger, fuzzy level of comparing judgement is higher. Fuzzy comparing judgement matrix B is obtained by comparing finally:

$$B = \left(b_{ij}\right)_{m\times n} = \begin{bmatrix} [l_{11}, e_{11}, p_{11}] & \cdots & \cdots & [l_{1m}, e_{1m}, p_{1m}] \\ [l_{21}, e_{21}, p_{21}] & \cdots & \cdots & [l_{2m}, e_{2m}, p_{2m}] \\ \vdots & \vdots & \vdots & \vdots \\ [l_{m1}, e_{m1}, p_{m1}] & \cdots & \cdots & [l_{mm}, e_{mm}, p_{mm}] \end{bmatrix} \quad (1)$$

Fuzzy relative weight vector of index i comparing with other indices is decided in Fuzzy comparing judgement matrix:

$$Q_i = \left[\frac{\sum_{j=1}^{m} l_{ij}}{\sum_{i=1}^{m}\sum_{j=1}^{m} p_{ij}}, \frac{\sum_{j=1}^{m} e_{ij}}{\sum_{i=1}^{m}\sum_{j=1}^{m} e_{ij}}, \frac{\sum_{j=1}^{m} p_{ij}}{\sum_{i=1}^{m}\sum_{j=1}^{m} l_{ij}} \right]^{-1} \quad (2)$$

Triangular fuzzy numbers of fuzzy relative weight vector are defined clearly in order to sequence. Subjective weight of Q_i is decided:

$$w_i = \frac{l_i + 2e_i + p_i}{4} \quad (3)$$

2.2. Decision of Objective Weights

Objective weight based on entropy is applied in the paper. Information entropy is indicated uncertainty magnitude for a random event or occurrence probability of some specified information. Entropy is bigger, degree of out-of-order is higher. Otherwise, degree of in-order is higher. Weights are decided by comparing entropy value of indices according to entropy value in PQCE. Entropy value of indices is smaller, degree of variation of indices data series is bigger, weight of indices is bigger.

Entropy value S_i of index i :

$$S_i = -k\sum_{j=1}^{n} P_{ij}\ln P_{ij}, \left(i = 1, \cdots, m;\ j = 1, \cdots, n\right) \quad (4)$$

Where $k = \frac{1}{\ln n}$, when $P_{ij} = 0$, $P_{ij}\ln P_{ij} = 0$.

Objective weight υ_i is decided:

$$\upsilon_i = \frac{1 - S_i}{\sum_{i=1}^{m}\left(1 - S_i\right)} = \frac{1 - S_i}{m - \sum_{i=1}^{m} S_i}, \left(i = 1, \cdots, m;\ j = 1, \cdots, n\right) \quad (5)$$

2.3. Decision of Combination Weights

$$\omega_i = \frac{w_i v_i}{\sum_{j=1}^{n} w_j v_j}, i = 1, \cdots, n \quad (6)$$

3. Decision Model Based on TOPSIS and Grey Correlation Degree

TOPSIS [9] is one of the multi-criteria decision-making methods. The method is to assess judgment gist by constructing ideal solution and negative ideal solution and judgmenting the distance of indices and ideal solution and negative ideal solution.

The basic idea of classical grey correlative [10-12] decision making is to analyze and compare similarity degree of geometrical relationship of data sequence and geometry of curve of indices. It takes the size of similarity degree of curves as weigh scale of correlation degree. The closer the curves are, the bigger the correlation degree sequences are. Conversely, the smaller.

A new relative similarity degree that is a standard of judging power quality is established by integrating grey correlation degree with traditional TOPSIS in the paper. The method based on analyzing distance relation among data sequence could reflect position relation among data curves by using distance as scale and embody situation change of data sequence.

Supposed there are m indices and n criteria. The value of criterion is $X_{ij}\left(1\le i\le m,1\le j\le n\right)$. Supposed decision matrix $X=\left(x_{ij}\right)_{m\times n}$ and criteria weight vector $W=\left(\omega_1,\omega_2,\cdots,\omega_n\right)$ in the method.

3.1. Standardizing Decision Matrix and Calculating Weighted Matrix

Firstly, standardizing decision matrix $X=\left(x_{ij}\right)_{m\times n}$ and achieving a standardized matrix $Y=\left(y_{ij}\right)_{m\times n}$.

$$y_{ij}=\frac{x_{ij}}{\sqrt{\sum_{i=1}^{m}x_{ij}^2}}\left(i=1,2,\cdots,m;\ j=1,2,\cdots,n\right) \tag{7}$$

$$U=\left(u_{ij}\right)_{m\times n}=\left(\omega_j y_{ij}\right)_{m\times n} \tag{8}$$

3.2. Determining Ideal Solution and Negative Ideal Solution

$$U_0^+=\left\{\left(\max_{1\le i\le m}u_i(j)\right)j\in J^+,\left(\min_{1\le i\le m}u_i(j)\right)j\in J^-\right\}=\left(u_0^+(1),u_0^+(2),\cdots,u_0^+(j),\cdots u_0^+(n)\right) \tag{9}$$

$$U_0^-=\left\{\left(\min_{1\le i\le m}u_i(j)\right)j\in J^+,\left(\max_{1\le i\le m}u_i(j)\right)j\in J^-\right\}=\left(u_0^-(1),u_0^-(2),\cdots,u_0^-(j),\cdots u_0^-(n)\right) \tag{10}$$

3.3. Calculating Distance

$$D_i^+=\sqrt{\sum_{j=1}^{n}\left[u_i(j)-u_0^+(j)\right]^2},\left(i=1,2,\cdots,m\right) \tag{11}$$

$$D_i^-=\sqrt{\sum_{j=1}^{n}\left[u_i(j)-u_0^-(j)\right]^2},\left(i=1,2,\cdots,m\right) \tag{12}$$

3.4. Calculating Grey Correlation Coefficient

Calculating grey correlation coefficient of the alternative i and the ideal sample concerning the index j based on weighted standardized matrix mentioned above.

$$r_{ij}^+=\frac{\min_i\min_k\Delta_i(k)+\zeta\max_i\max_k\Delta_i(k)}{\Delta_i(k)+\zeta\max_i\max_k\Delta_i(k)} \tag{13}$$

$$r_{ij}^{-}=\frac{\min_i\min_k\Delta_i(k)+\zeta\max_i\max_k\Delta_i(k)}{\Delta_i(k)+\zeta\max_i\max_k\Delta_i(k)} \quad (14)$$

Where $\Delta_i(k)=\left|u_0^+(k)-u_i(k)\right|$, $\Delta_i(k)=\left|u_0^-(k)-u_i(k)\right|$. ζ is resolution coefficient $\zeta=0.5$.

3.5. Calculating Grey Correlation Degree

The grey correlation matrix are:

$$R^+=\begin{bmatrix} r_{11}^+ & r_{12}^+ & \cdots & r_{1n}^+ \\ r_{21}^+ & r_{22}^+ & \cdots & r_{2n}^+ \\ \vdots & \vdots & \vdots & \vdots \\ r_{m1}^+ & r_{m2}^+ & \cdots & r_{mn}^+ \end{bmatrix},\ R^-=\begin{bmatrix} r_{11}^- & r_{12}^- & \cdots & r_{1n}^- \\ r_{21}^- & r_{22}^- & \cdots & r_{2n}^- \\ \vdots & \vdots & \vdots & \vdots \\ r_{m1}^- & r_{m2}^- & \cdots & r_{mn}^- \end{bmatrix} \quad (15)$$

Grey correlation degree of sample i and ideal sample are:

$$R_i^+=\frac{1}{n}\sum_{j=1}^{n}r_{ij}^+,(i=1,2,\cdots,m),\ R_i^-=\frac{1}{n}\sum_{j=1}^{n}r_{ij}^-,(i=1,2,\cdots,m) \quad (16)$$

3.6. Calculating Relative Similarity Degree

Since the bigger value D_i^- and R_i^+ are, the closer the samples are from the ideal solution and the bigger value D_i^+ and R_i^- are, the further the samples are from the ideal solution. The formula could be derived as follow.

$$S_i^+=\alpha_1 D_i^-+\alpha_2 R_i^+\ (i=1,2,\cdots,m) \quad (17)$$

$$S_i^-=\alpha_1 D_i^+ +\alpha_2 R_i^-\ (i=1,2,\cdots,m) \quad (18)$$

Where α_1 and α_2 reflect the preference degree of decision makers for situation and shape, and $\alpha_1+\alpha_2=1$. S_i^+ reflects the proximity of the sample to ideal sample, and the bigger the value is, the better the sample is. With S_i^- the opposite is the case.

Relative similarity degree is calculated as follow:

$$C_i^*=\frac{S_i^+}{S_i^-+S_i^+}(i=1,2,\cdots,m) \quad (19)$$

4. Case Study

The paper simulates and analyzes field data of power quality from five observation point of some area according to the method. Field data of power quality from five observation point of the area are shown as Table 1.

The paper establishes indices weight by using subjective weighing based on fuzzy AHP method [13-14] firstly, then by using objective weighing based on entropy-right method. Finally combination weights are formed.

Table 1. Field Data of Power Quality from Observation Point

Observation point	point 1	point 2	point 3	point 4	point 5
Voltage deviation /%	4.130	5.680	6.560	3.580	4.350
Voltage fluctuation /%	1.420	1.640	1.960	1.360	1.480
Voltage sag	1.745	0.965	1.405	2.128	2.855
Unbalance %	0.400	0.680	1.360	1.080	1.890
Harmonics /%	1.680	4.300	2.690	3.260	4.070
Frequence deviation /Hz	0.090	0.093	0.099	0.097	0.095
Interruption（h/a）	172	206	155	210.2	176.4

According to Fuzzy comparison judgment matrix subjective weight about single index of power quality which is solved is shown as Table 2. According to Equation (4), Equation (5) and Equation (6), objective weight and combination weight are shown as Table 3.

Table 2. Subjective Weight of Indices

Indices	Subjective weight vector	Subjective weight
Voltage deviation	[0.131,0.182,0.247]	0.186
Voltage fluctuation	[0.081,0.108,0.143]	0.110
Voltage sag	[0.107,0.145,0.211]	0.152
Unbalance	[0.055,0.073,0.095]	0.074
Harmonics	[0.110,0.148,0.196]	0.151
Frequence deviation	[0.215,0.282,0.363]	0.286
Interruption	[0.048,0.062,0.082]	0.064

Table 3. Entropy Values, Objective Weight and Combination Weight of Indices

Indices	Entropy	Objective weight	Combination weight
Voltage deviation	0.830	0.128	0.163
Voltage fluctuation	0.847	0.106	0.080
Voltage sag	0.831	0.119	0.124
Unbalance	0.795	0.125	0.063
Harmonics	0.733	0.192	0.198
Frequence deviation	0.796	0.149	0.292
Interruption	0.736	0.182	0.080

According to above calculating process, TOPSIS similarity degree, grey correlation similarity degree and comprehensive similarity degree and their sequencing results are shown as Table 4.

Table 4. Comparison of References and Sequencing Results

Observation point	D^{+}	D^{-}	R^{+}	R^{-}	S^{+}	S^{-}	TOPSIS	Grey correlation similarity	Comprehensive
1	0.2623	1.0000	1.0000	0.7116	1.0000	0.4870	0.7922 (1)	0.5842 (1)	0.6725 (1)
2	0.8437	0.6821	0.8302	0.9056	0.7562	0.8747	0.4470 (4)	0.4783 (3)	0.4637 (4)
3	0.6579	0.6638	0.7639	0.9261	0.7139	0.7920	0.5022 (2)	0.4520 (4)	0.4741 (3)
4	0.6470	0.6402	0.8232	0.8479	0.7317	0.7475	0.4974 (3)	0.4926 (2)	0.4947 (2)
5	1.0000	0.3835	0.7396	1.0000	0.5616	1.0000	0.2772 (5)	0.4252 (5)	0.3596 (5)

Comprehensive sequencing result corresponds with sequencing results of TOPSIS and grey correlation degree method in Table 4. It is obvious that sequencing result of the method is not in accord with sequencing result of TOPSIS or grey correlation degree method. The characteristic of TOPSIS and grey correlation degree method could be embodied better by the comprehensive method.

5. Conclusion

A new PQCE method based on grey correlation degree and TOPSIS is proved effective by case study. We can adjust α_1 and α_2 to strengthen situation variation of data or distance relationship of data, reflecting decision-makers's knowledge and experience about power quality. Example result shows that the method is feasible and universal.

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