An autonomous decision making algorithm applied for the evaluation of power quality

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Abstract

An autonomous decision making algorithm applied for the evaluation of the field power quality is proposed. This algorithm can reflect to the characteristics of evaluation objects, develop evaluation objects initiatives, weakens the influence of the subjective weight of index on evaluation results and implements the comparison of different power qualities of the assessed in the area. The paper introduces the implementation steps of autonomous decision making algorithm, analyses the competition scope of the power quality of the assessed with this algorithm. The competition model is established, which output the comprehensive evaluation results of the assessed. The simulation demonstrates the effectiveness and practicability of this method.

Keywords: power quality, autonomous decision, algorithm, evaluation

1 Introduction

With the increasing concern about power quality, many power quality assessment methods have been put forward. Actually, we often need to assess the power quality in a certain region, so as to compare the result with those of other parts in that region. At present, many assessment methods about power quality have been proposed by science researchers, including Entropy Weight Analysis [1], Neural Network Analysis [2], Extentics Cloud Theory [3], Fuzzy Mathematics [4, 5], Analytic Hierarchy Process [6, 7]. Such methods are easy to use and simple in principle [8]. But for the determination of subjective weights of the evaluation indexes, some controversies are still needed to be resolved:

1) When assessing power quality, the characteristics of the objects have been omitted [9];
2) Subjective preferences influence the weights determination of the assessment criteria [10].

In allusion to the problems mentioned above, an autonomous decision making algorithm applied for the evaluation of the field power quality is proposed in the paper. This algorithm can reflect the characteristics of evaluation objects, develop evaluation objects initiatives, weakens the influence of the subjective weight of index on evaluation results, which maintains algorithm implementation steps, Evaluation model is established. Simulation results illustrate the efficiency of this autonomous decision making algorithm.

2 Algorithm

2.1 DESIGN STEPS OF THE ALGORITHM

1) Decide the technical and non-technical indicators of the electric energy first.
2) Convert the historical energy data into a matrix with certain rules.
3) Through the judgment of property weight value, get the non-authoritarian conditions to constrain weight.
4) Establish the optimized rules of competition range to reflect the autonomous decision-making of evaluators.
5) Construct models in accordance with the above rules, and work out the competitive range of the evaluate.
6) Finally, obtain the evaluated conclusions which can reflect the independently decision-making of evaluate.

2.2 ESTABLISH THE RULES OF THE POWER QUALITY MATRIX

1) The indexes of power quality are considered in the paper is Frequency offset, Voltage deviation, Short-term flicker, Unbalanced three-phase, Harmonic distortion rate, Power supply reliability, Long flicker [11].
2) Using the method of extremum of historical electricity data regularization processing rules matrix A Maximization of index formula:

$$x_{ij\_M} = \frac{M_j - x_{ij}}{M_j - m_j}, \quad (1)$$

Minimization of the index formula:

$$x_{ij\_m} = \frac{x_{ij} - m_j}{M_j - m_j}, \quad (2)$$

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x_{ij_M} - maximization of index; x_{ij_m} - minimization of the index; x_{ij} - the assessed sample; M_j - maximum value in sample; m_j - the minimum value in sample.

2.3 COMPETITION MODEL

2.3.1 Condition of weights nondictatorship

Condition of weights nondictatorship refers to the circumstance when any indicator does not play a leading role in terms of all the relatively insignificant indicators within domain [12, 13]. M represents the total number of samples, and $x \in M, w_j$ denotes the weight of x_i. When the condition that $w_1 \geq w_2 \geq w_3 \geq ... \geq w_m$ is satisfied, the satisfiable Equation (3) is named condition of weak weights nondictatorship [14].

$$w_j \in \left[0.5^{m-1}, 0.5\right], \quad (3)$$

and the satisfiable Equation (4) is named condition of strong weights nondictatorship:

$$\begin{cases} w_1 + w_2 + w_3 + ... + w_m = 1 \\ 0.5^{m-1} \leq w_m \leq 0.5 \\ w_1 \leq w_2 + w_3 + ... + w_m \\ w_2 \leq w_3 + ... + w_m \\ ... \\ ... \\ w_{m-1} \leq w_m \end{cases} . \quad (4)$$

When weights are assigned to the maximum indicator value after being sorted by indicator value as far as possible under constraint condition, evaluation value would reach the maximum; when weights are assigned the other way around, evaluation value would reach the minimum. Based on such principles, the following conclusions are drawn: under condition of weak weights nondictatorship, comprehensive evaluation value y_i achieves its maximum and minimum value, when the optimal descending weight vector and the worst descending weight vector are w_{i_u} and w_{i_f} respectively, and it can be seen in Equations (5), (6) under condition of strong weights nondictatorship, the comprehensive evaluation value y_i achieves its maximum and minimum value when the optimal descending weight vector and the worst descending weight vector are w_{i_u} and w_{i_f} respectively, and it can be seen in Equations (7), (8).

$$w_{i\_u} = (0.5, 0.5 - (m-2)0.5^{m-1}, 0.5^{m-1}, ..., 0.5^{m-1}), \quad (5)$$

$$w_{i\_f} = (0.5^{m-1}, 0.5^{m-1}, ..., 0.5 - (m-2)0.5^{m-1}, 0.5), \quad (6)$$

$$w_{u\_u} = (0.5^1, 0.5^2, 0.5^3, ...0.5^{m-2}, 0.5(1 - \sum_{j=1}^{m-2} 0.5^j)), \quad (7)$$

$$w_{u\_f} = (0.5(1 - \sum_{j=1}^{m-2} 0.5^j), 0.5^{m-2}, ...0.5^3, 0.5^2, 0.5^1). \quad (8)$$

The research question in this paper using two rules mentioned above to get the comprehensive evaluation value range Y under certain conditions.

2.3.2 Optimality principle of competition range

Competition range refers to the set of objects evaluated and those who may compete with the evaluated. In the above, the object evaluated can be represented by $r(r \in N)$, where N represents the total number of the objects evaluated. When the following two conditions are met, the objects will lie in the competition range.

1) $x_{ik} \geq x_{jk} (i, j \in N, i \neq j)$ is false. As $k \in M$ for at least one k there is strict inequality established.

2) $Y_i \cap Y_j \neq \varnothing$, where Y_i refers to the value range of power quality evaluation of r_i, and Y_j refers to that of r_j.

From the optimality principle of competition range, it can be found that all the objects evaluated want to enhance their competitiveness and weaken that of their competitors. When competition range is *C:*

$$C = \{r_1^i, r_2^i, r_3^i, ..., r_m^i\}, \quad N_i = (1, 2, 3, ..., n_i),$$

$$i \in N, x_{ij}^i \in x_j(r_l^i), j \in M, l \in N_i$$

the expected weight value w_i is the solution of the following multi-objective linear programming.

$$\max\left[\gamma_1 \sum_{j=1}^{m} x_{ij} w_j^i - \gamma_2 \sum_{j=1}^{m} u_l^i \sum_{j=1}^{n} x_i^j w_j^i\right],$$

$$\sum_{j=1}^{m} w_j^i = 1, \; w_j^i \geq 0, \; w_j \in \alpha, \; j \in M, \; l \in N_i \quad , \quad (9)$$

α represents the constraint set of weight vector w_i meeting with weights non-dictatorship condition; $\gamma_1 + \gamma_2 = 1$, among them γ_1 refers to the weight coefficient of enhancing their own competitiveness, γ_2 that of weakening the competitiveness of their competitor u_l^i is the competitiveness-focused coefficient of r_i to competitiveness evaluation objects r_l^i in competition range C; $\sum_{l=1}^{n_i} u_l^i = 1$ stands for the competitiveness-focused coefficient vector of $u_i = (u_1^i, u_2^i, u_3^i, ..., u_m^i)$.

Therefore, the value range of r_i is $Y_i = [y_i^L, y_i^U]$ and that of r_l^i is $Y_l^i = [y_{il}^L, y_{il}^U]$.

If $Y_i \cap Y_l^i \neq \varnothing$ and C_i is the competitive interval, $C_i = Y_i \cap Y_l^i$.

If d_{il} is the competitive intensity of r_i and r_l^i,

$$d_{il} = \frac{e(Y_i \cap Y_l^i)}{e(Y_i \cup Y_l^i)};$$

competitiveness-focused-coefficient $u_l^i = dil / \sum_{l=1}^{n_i} d_l^i$; and stands for the calculation function of interval width.

In the constraint set of weight vector w_i meeting with weights non-dictatorship condition, the above method can be adopted to solve the linear programming problem and the weight vector in the weights non-dictatorship condition. In the same way, the weight vectors in the competitive view of other objects can be determined and finally the optimal weight vector matrix W can be combined.

2.4 ESTABLISH COMPREHENSIVE EVALUATION MATRIX

Comprehensive evaluation matrix B:

$$B=AW^T. \quad (10)$$

Based on comprehensive evaluation matrix B, comprehensive evaluation conclusion m is proposed:

$$m = [m_1, m_2, m_3, ..., m_m].$$

3 Case study

This paper conducts simulation based on the monitoring data, which is provided in reference [15], of eight quality indexes of power in the 12 months of 2009 from six 220kV transformer substations of the Power Supply Bureau of some region. The regularization matrix obtained according to Equations (1) and (2) is as shown in Table 1.

TABLE 1 The regularization matrix of power quality indices at each spot

Monitoring point	Frequency offset	Voltage deviation	Short-term flicker	Unbalanced three-phase	Harmonic distortion rate	Power supply reliability	Long flicker
1	0	0.53	0.92	0.49	0.00	0.50	0.90
2	1	0.28	1.00	0.28	0.58	0.00	1.00
3	0	1.00	0.47	0.70	1.00	1.00	0.44
4	1	0.00	0.75	0.00	0.00	0.00	0.56
5	1	0.00	0.75	0.84	0.84	0.49	0.69
6	0	0.10	0.58	1.00	1.00	0.50	0.50

According to the competition model of autonomous decision-making, regularized matrix is given. Under the condition of non- dictatorship weight, the optimized competition model is built. Specific steps are as follows.

1) Selecting the non-dictatorship weight as the rule for autonomous decision-making algorithm.

2) According to the Equation (7), optimal descending weight vector w_{u_u} is:

$$w_{u\_u} = (0.5, 0.25, 0.125, 0.0625, 0.03125, 0.015625)$$

3) Comprehensive evaluation value range of the assessed $r_1, r_2, r_3, r_4, r_5, r_6,$:

$Y_1 = [0.13, 0.83]$,

$Y_2 = [0.10, 0.92]$,

$Y_3 = [0.22, 0.94]$,

$Y_4 = [0.04, 0.79]$,

$Y_5 = [0.29, 0.88]$.

4) Competition intensity matrix D:

$$D = \begin{bmatrix} 0.75 & 0.71 & 0.84 & 0.93 & 0.83 & 0 & 0.77 & 0.59 \\ 0.84 & 0.71 & 0 & 0.93 & 0 & 0.84 & 0.72 & 0.67 \\ 0 & 0.81 & 0.84 & 0.80 & 0.77 & 0.75 & 0.57 & 0,76 \\ 0.62 & 0.58 & 0 & 0.77 & 0 & 0.83 & 0 & 0.48 \\ 0.81 & 0 & 0.71 & 0.77 & 0.58 & 0.71 & 0.52 & 0.83 \\ 0.81 & 0.77 & 0.83 & 0 & 0.77 & 0.93 & 0.92 & 0.64 \end{bmatrix}$$

5) The competitiveness-focused coefficient vector U

$$U = \begin{bmatrix} 0.14 & 0.13 & 0.16 & 0.17 & 0.15 & 0 & 0.14 & 0.11 \\ 0.18 & 0.15 & 0 & 0.18 & 0 & 0.18 & 0.16 & 0.15 \\ 0 & 0.16 & 0.16 & 0.16 & 0.12 & 0.14 & 0.11 & 0,15 \\ 0.19 & 0.18 & 0 & 0 & 0 & 0.25 & 0 & 0.16 \\ 0.16 & 0 & 0.14 & 0.14 & 0.12 & 0.16 & 0.11 & 0.16 \\ 0.14 & 0.13 & 0.15 & 0.15 & 0.13 & 0 & 0.16 & 0.11 \end{bmatrix}$$

6) Assuming that target coefficient $\gamma_1 = \gamma_2 = 0.5$, the optimal weight vector matrix W is:

$$W = \begin{bmatrix} 0.008 & 0.063 & 0.250 & 0.015 & 0.008 & 0.031 & 0.500 & 0.125 \\ 0.500 & 0.031 & 0.125 & 0.016 & 0.063 & 0.008 & 0.250 & 0.008 \\ 0.008 & 0.500 & 0.008 & 0.063 & 0.125 & 0.250 & 0.016 & 0.031 \\ 0.500 & 0.008 & 0.250 & 0.016 & 0.063 & 0.008 & 0.125 & 0.031 \\ 0.500 & 0.008 & 0.250 & 0.063 & 0.016 & 0.008 & 0.125 & 0.031 \\ 0.008 & 0.008 & 0.031 & 0.500 & 0.063 & 0.063 & 0.016 & 0.250 \end{bmatrix}$$

7) $B=AW^T$, comprehensive evaluation matrix B is

$$B = \begin{bmatrix} 0.458 & 0.404 & 0.376 & 0.488 & 0.381 & 0.825 & 0.289 & 0.557 \\ 0.259 & 0.904 & 0.925 & 0.271 & 0.918 & 0.784 & 0.367 & 0.179 \\ 0.940 & 0.257 & 0.284 & 0.650 & 0.271 & 0.491 & 0.772 & 0.852 \\ 0.080 & 0.765 & 0.761 & 0.095 & 0.785 & 0.479 & 0.245 & 0.071 \\ 0.304 & 0.862 & 0.830 & 0.740 & 0.853 & 0.660 & 0.656 & 0.426 \\ 0.374 & 0.309 & 0.278 & 0.827 & 0.301 & 0.542 & 0.745 & 0.430 \end{bmatrix}$$

8) Comprehensive evaluation conclusion m is:

$$m = [0.324, 0.393, 0.192, 0.282, 0.444, 0.229].$$

9) Comprehensive evaluation conclusion is shown in Table 2:

TABLE 2 The result of evaluation of the substations

Monitoring point	r_1 value ranges	r_2 value ranges	r_3 value ranges	r_4 value ranges	r_5 value ranges	r_6 value ranges	comprehensive ordering
1	1	5	5	4	2	4	3
2	5	1	4	5	4	2	4
3	3	6	1	3	6	5	5
4	6	3	6	1	3	6	6
5	4	2	2	6	1	3	2
6	2	4	3	2	5	1	1

From Table 2, it can be seen that

1) the entire accessed can give full play to his superiority within his own competitive scope, getting the highest rank among comparing matters and attaining the goal of weakening the competitors;

2) the Comprehensive Assessment Table is relatively fair, which is able to stand for the features of every competitor.

4 Conclusions

An autonomous decision making algorithm applied for the evaluation of the field power quality is proposed. Using of autonomous decision-making algorithm, the competitive interval and view of power quality the assessed are analysed and an evaluation model is established; finally rational sorting results of the assessed are obtained. Results of the simulation show that the autonomous decision making algorithm can incarnate the autonomous action of the assessed and both fairness and effectiveness of evaluation results can be ensured.

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