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RAGA-PPE Model for Power Quality Comprehensive Evaluation

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Abstract: This paper proposes RAGA-PPE comprehensive assessment model specifically for high-dimensional index system issue in order to conduct comprehensive evaluation of the power quality of multi-index regional power grid from three dimensions of index, time and region through adjustment of time factor size. The model adopts PPE to convert power index of multidimensional data to lower-dimensional subspace and compress multiple power indexes to single power index for systematic comprehensive evaluation, which overcomes shortcomings such as influences of human and subjective factors and local optimization in conventional assessment methods. Improved RAGA based on real coding is used for optimization of target function to reduce optimization workload and search out the optimal projection direction rapidly. The optimal projection direction subject to optimization reflects the degree of importance of various power indexes for comprehensive evaluation of power quality. Examples prove that the evaluation model is simple in computation, good in applicability, and accurate and objective in evaluation result, providing a new method and thought for decision of comprehensive evaluation for power quality.

Keywords: Power quality, comprehensive evaluation, projection pursuit, RAGA, least variance method, temporal dynamics.

1. INTRODUCTION

In the electricity market environment, the quantified description of power quality synthetic evaluation is a vital basis for Power Quality Evaluation (PQE) and electricity pricing. Reliable and comprehensive evaluation of power quality, as one of the current research focuses, possesses great significance in assessing power sector, investigating customer satisfaction for utility industry, and determining the electricity price Shao *et al.* [1-6]. The traditional Power Quality Evaluation (PQE) method with a single index to evaluate power quality should be changed Lin *et al.* [7-9]. At present, most of the researches are based on qualitative analysis to evaluate the power system. In Tao and Xiao [10], after normalization dividing, an index by its maximum acceptable value and consolidation combines all the normalized values for one disturbance type into a single index, obtaining six individuation indices for voltage variations. The indices are easy to understand and manipulate because the value equals to the percent of contractual limit or standard limit. Since many service indicators cannot carry out qualitative calculation, this method has limitations in index selection. In Li *et al.,* Xia *et al.* [11, 12], by establishing the standard cloud matter element model of power quality comprehensive evaluation and calculating the association degree between the matter element to be evaluated and standard cloud matter element model, the coefficient of credible degree is defined, which allows the model to not only obtain the level of power quality but also provides credible information of the evaluation result. The method is simple, accurate and reliable, and has better practicability. In Liu *et al.* [13], based on the Radial Basis Function (RBF) neural network to evaluate the power quality, this model has a universal applicability and advantages. But it is hard to evaluate the process of empowerment weight given by the various power qualities, which in turn lowers the credibility of the evaluation results. In Chen *et al.* [14], the Attribute Recognition Theory is adopted here firstly, and a new attribute recognition theoretical model used in evaluation system of quality electrical energy is established. Analysis of Hierarchy Process (AHP) is used to acquire the proportion of each index; as a result, subjective unilateralism could be avoided effectively in judging the proportion of indexes. However, the model is subjective. In Jiang *et al.* [15], a new method is presented to quantify and evaluate the power quality by selecting the day cycle. The indexes showing an aspect of power quality are quantified and unified using probability and mathematical statistics and vector algebra. The evaluation is presented to evaluate global unique power quality index, which makes it possible that a class of quality for power possesses a corresponding price.

Due to the power quality comprehensive assessment being multi-index integrated into a single index, the multi-dimensional data steps down to the process of one dimensional data, therefore, the projection pursuit method is a good solution to this problem Fu *et al*., Feng *et al.* [16, 17]. This paper proposes RAGA-PPE comprehensive assessment model specific to such high-dimensional index system issue of conducting comprehensive evaluation for power quality of multi-index regional power grid from three dimensions of index, time and region through adjustment of time factor size. Examples prove that the evaluation model is simple in computation, good in applicability, and accurate and objective in evaluation result, which provides a new method and thought for decision of comprehensive evaluation for power quality.

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2. THE PPE MODEL OF POWER QUALITY

The Projection Pursuit Evaluation Model (PPE) is a kind of nonlinear high-dimensional data to deal with many factors of new comprehensive Evaluation method Fu *et al.* [18-20], its basic idea is: the high-dimensional data through some combination of Projection to the low-dimensional subspace (1 ~ 3D), and by minimizing a Projection index, can reflect the characteristics of the original high-dimensional data structure or Projection, and analyze the data structure in low dimensional space in order to achieve the purpose of the research and analysis of high dimensional data.

The power quality comprehensive evaluation generally has the following steps:

1) According to the energy gained by the data, the data is pretreated;
2) The PPE model is set up;
3) RAGA is used to optimize the best projection direction;
4) The minimum variance method is used to calculate the weight system time vector;
5) Determines the time series of the comprehensive evaluation value of each system.

2.1. Electricity Standardized Treatment

As all power quality index types and dimensions are not unified, this treatment cannot be directly used. In order to avoid the occurrence of the unreasonable phenomena, dimensionless evaluation of power quality index can be carried out Guo and Yi [19]. Here, by using evaluation index method of poor raw data standardize processing, the need of indexes is for inverse direction judgement, and then for processing respectively. The specific process is as follows:

Setting Indicators j in the sample i as x_{ij}, $i=1,2,\cdots,n$, $j=1,2,\cdots,m$, n is samples, m is indicators, positive index u_{ij}

$$x_{ij}^* = \left[\frac{x_{ij} - x_{j\min}}{x_{j\max} - x_{j\min}}\right] \tag{1}$$

Reverse index u_{ij}

$$x_{ij}^* = \left[\frac{x_{j\max} - x_{ij}}{x_{j\max} - x_{j\min}}\right] \tag{2}$$

$x_{j\max}$ and $x_{j\min}$ are the original data of the maximum and the minimum as for evaluation and j, x_{ij}^* is dimensionless, and $0 \le x_{ij}^* \le 1$.

2.2. The Projection Index Function

Projection involves essentially the observation of data from different angles, looking for the reflection of the characteristics of the data to a great extent, which can make the best viewing Angle mining data information as the optimal projection direction Fan *et al.*, Si *et al.* [20, 21]. The high-dimensional data can be transferred into low dimension space by using the method of projection information, which involves not only intuitive image but also is a convenient way to use the conventional methods for high-dimensional data analysis and processing. Here, linear projection and the high-dimensional data projected to one dimension linear space are chosen for research. Setting a as m unit vector projection direction, the one dimensional projection characteristic value z_i is

$$z_i = \sum_{j=1}^{m} a_j \times x_{ij}^*,\ \left(i = 1,2,\cdots,n\right) \tag{3}$$

$z_{ij} = a_j \times x_{ij}^*$ is Component as i sample j index of projection, $z = \left(z_1, z_2, \cdots, z_n\right)$ is Projection eigenvalue vector.

2.3. Construct the Objective Function

In order to find the data in multidimensional index structure combination characteristic, the projection is integrated for projection value z_i as much as possible and for variation information extraction x_{ij}, in one dimensional space z_i, class space S_z is spread as largely as possible; Projection values z_i of the local density D_z if maximum at the same time, the same projection index focuses as far as possible on the space. Building a projection objective function as:

$$Q(a) = S_z \times D_z \tag{4}$$

S_z are projection values z of the standard deviation, D_z for the projection values z of the local density.

$$S_z = \sqrt{\frac{\sum_{i=1}^{n}\left(z_i - E_z\right)^2}{\left(n-1\right)}} \tag{5}$$

$$D_z = \sum_{i=1}^{n}\sum_{j=1}^{n}\left(R - r_{ij}\right) \times u\left(R - r_{ij}\right) \tag{6}$$

E_z is the average value of a projection characteristic z_i; R is the local density window width, and the data characteristics, the selection of which includes the window as the projection point of an average number which is too insignificant , not to be avoided that moving average deviation is too large, R is αS_z, α is 0.1, 0.01 and 0.001. According to the projection point z_{ij} on the distribution of regional appropriate adjustments,

$r_{ij} = \left|z_i - z_k\right|$ $\left(k = 1,2,\cdots,n\right)$ is the distance between two projection characteristic values; u is unit step function.

2.4. To Optimize the Projection Direction

When the sample values of evaluation index for timing, projection index function only changes over the direction of the projection. Different projection direction reflects the characteristics of the different data structure. The optimal projection direction is the largest possible exposure to certain types of high-dimensional data characteristic of the structure of the projection direction, which is maximized by solving the projection index function to estimate the optimal projection direction Zhou *et al.* [22]:

$$\begin{cases} Max: Q(a) = S_z \times D_z \\ s.t.: \quad \left\| a_j \right\| = 1 \end{cases} \tag{7}$$

This is a thought that if nonlinear optimization problem of optimized variables a_j is complicated, it is difficult to use conventional optimization methods for the processes.

2.5. Determine the Projection Value

The optimal projection direction value a_j generation into the projection value of projection index functions to get the sample z_i , the projection value is the best projection direction of each evaluation index and evaluation standard of weighting. Moreover, the sample and analysis can be evaluated according to the size of the projection value.

3. RAGA—PPE MODEL

Projection index function structure and its optimization are the key factors of the success of the PPE method. Its complexity to a certain extent limits the in-depth study of the PPE method. At present, commonly used projection pursuit regression model has been set up and Friedman and Stuetzle multiple smoothing regression technique is put forward, given that the method involves much complicated mathematical knowledge, difficult programming, and large amount of calculation. This largely limits the wide application of projection pursuit technique. Therefore, it can be considered to use Genetic Algorithm (GA) for convenience Hou *et al.* [23-25], but the standard Genetic Algorithm (also known as the Simple Genetic Algorithm, Simple based Algorithm, referred to as SGA) possesses premature convergence and large amount of calculation having poor accuracy which can lead to poor convergence results. To this end, this paper puts forward a kind of Accelerating Genetic Algorithm based on Real number encoding Juliang *et al.*, Lei *et al.* [26, 27] from projection pursuit evaluation model.

3.1. Theoretical Analysis of RAGA

3.1.1. The Space of Compression Solution

The change of the size of the optimization variable search space influences the convergence speed of SGA, with the search space being wider, goal area being narrower, search time being longer and training speed being slower. RAGA uses excellent individual subgroups to adjust the search scope which are integrated in the system to enhance optimization robustness and accelerate convergence.

3.1.2. Parallel Search

SGA selection, cross and mutation operation is often done in series, which could worsen the fitness of offspring, however the choice of RAGA, hybridization and mutation operation is conducted in parallel. So overall, the scope of search of RAGA is larger than SGA's, to facilitate global optimal point..

3.1.3. Increasing the Approximate Probability

The researcher attempts to make an analysis that the probability of excellent individual surrounded by the global optimal point decides global optimization performance through RAGA. It is assumed that excellent individuals randomly distribute the optimal point, and which is uniformly distributed. So when evolutionary iteration is conducted twice, the probability of the number of 2 s optimal points surrounded by excellent individual can be calculated by

$$P_{o1} = 1 - 0.5^{2s} \tag{8}$$

Similarly, problems of p optimized variables and the situation of q accelerating returns used by RAGA, the probability of the number of optimal points surrounded by excellent individual can be calculated by

$$P_{op} = \left(1 - 0.5^{2s}\right)^{pq} \tag{9}$$

From this, it can be seen that RAGA gradually compresses search space generally has great probability when presenting the most advantages.

3.2. Modeling Steps

The flow chart to optimization problem is shown below.

Step 1: N group of random variable of uniform distribution is generated at the change interval of each decision variable value is expressed as:

$$V_i^{(0)}\left(a_1, a_2, ..., a_j, ..., a_p\right) \; i = 1 \sim N, j = 1 \sim p \tag{10}$$

$V_i^{(0)}$ represents parent chromosomes; N represents population size; p represents the number of optimization variables.

Step 2: Calculating the objective function value by taking $V_i^{(0)}$ as the objective function, $Q^{(0)}\left(V_i^{(0)}\right)$ is obtained. Then according to the size of the function value ordered by chromosome, $V_i^{(1)}$ is obtained.

Step 3: Evaluation function $eval\ (V)$ is calculated. Evaluation function is used to set the probability of V . The stronger the chromosome adaptability, the greater the selected possibility. Then setting $\alpha \in (0,\ 1)$, the evaluation function can be calculated as:

$$eval\ \left(V_i\right) = \alpha\left(1-\alpha\right)^{i-1}, i = 1,\ 2, ..., N \tag{11}$$

Step 4: Taking selection operation into consideration generates the first offspring. According to the fitness of each chromosome to select chromosomes after varied selection of the chromosome, a new kind of chromosome $V_i^{(2)}$. can be obtained.

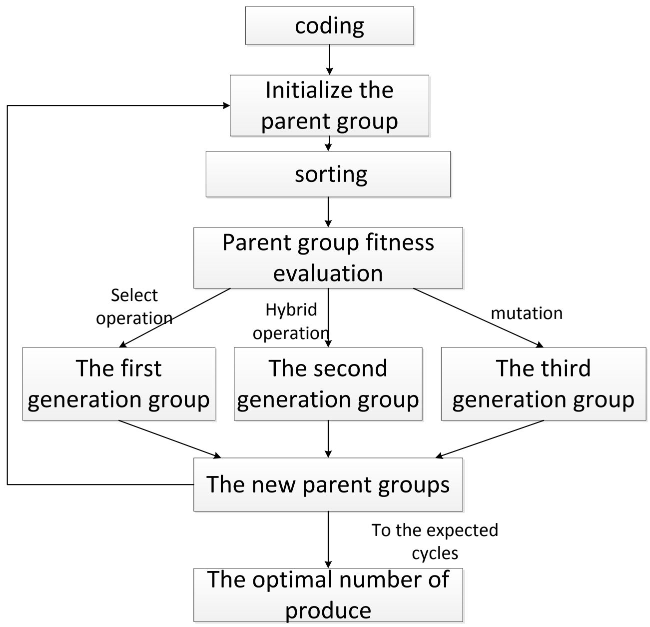

Fig. (1). Genetic algorithm process.

Step 5: A new species generated in step 4 is crossover operated first, setting P_c as the probability of crossover operation, thereby generating a random number from $[0, 1]$, if $r < P_c$, V_i is used as a parent. Using $V_1^{'}, V_2^{'}, ...$ as the selected parent, $(V_1^{'}, V_2^{'})$ $(V_3^{'}, V_4^{'})$, $(V_5^{'}, V_6^{'})$ are selected to use arithmetic crossover method, generated as the random number c from $(0, 1)$.

$$\begin{cases} X = c \times V_1^{'} + (1-c) \times V_2^{'} \\ Y = (1-c) \times V_1^{'} + c \times V_2^{'}, \end{cases} \tag{12}$$

Step 6: Generating the new $V_i^{(3)}$.

Step 7: Evolutionary iteration.

Step 8: Circulation is accelerated.

Step 9: The best projection direction and the corresponding projection values are assessed.

4. THE COMPREHENSIVE EVALUATION VALUE OF TIME SERIES

Adjusting the size of the time factor can achieve outstanding role of power quality in different time periods Wang *et al.* [28-31]. In this paper, the evaluation system is determined and each period value is introduced. Comprehensive evaluation value can be calculated as:

$$z_i = \sum_{k=1}^{N} w_{k\_time} z_i(t_k) \times 100 \tag{13}$$

w_{k_time} is time weight at the period of t_k.

Then

$$W_{time} = (w_{1\_time}, w_{2\_time}, ..., w_{N\_time}) \tag{14}$$

Time weight vector is defined by Minimum variance method, which has the advantage of good stability. λ is used as time temperature, when $W = (1,0,...,0)$, $\lambda = 1$; and when $W = (0,0,...,1)$, $\lambda = 0$; when $W = \left(\frac{1}{N}, \frac{1}{N}, ..., \frac{1}{N}\right)$, $\lambda = 0.5$.

$$w_1^* = \frac{2(2N-1) - 6(N-1)(1-\lambda)}{N(N+1)} \tag{15}$$

$$w_N^* = \frac{6(N-1)(1-\lambda) - 2(2N-1)}{N(N+1)} \tag{16}$$

$$w_j^* = \frac{N-j}{N-1} w_1^* + \frac{j-1}{N-1} w_N^* \left(j \in \{2, ..., N-1\}\right) \tag{17}$$

When $\lambda \in \left(\frac{N-2}{3(N-1)}, \frac{2N-1}{3(N-1)}\right)$ the weight of the vector that minimum variance method determined is not 0, otherwise it is 0.

5. CASE STUDY

Continuous power quality event is selected as the object of study. Data is from power supply bureau in a given area of six 220 kV substation, which included 9 indexes of power quality monitoring data in 2009. As shown in Table **1**, the evaluation points are the power quality data collected at 220 kV substation into line. Every index is in the corresponding month with 95% probability values in each month. The index system can be constructed as the evaluation system according to the actual demand and index data covering degree.

Table 1. Evaluation indicator system of the regional power quality.

Serial Number	Evaluation Index	Symbol
1	LONG-TERM FLICKER VALUE	x1
2	SHORT-TERM FLICKER VALUE	x2
3	Voltage deviation	x3
4	Unbalanced three-phase	x4
5	The total distorted rate of the harmonics	x5
6	The 3rd harmonic	x6
7	The 5th harmonic	x7
8	The 7th harmonic	x8
9	The 9th harmonic	x9

Due to the limit of space, data sample is no longer listed here. First, the data sample is dimensionless and consistent by using formula (1) and (2). The unified power quality index is distributed in the standard data between (0, 1).

Index data $t_1, t_2, t_3, ..., t_{12}$ of electric power are respectively formulae (3), (5), (6), (4) in turn. The projection index function is derived. Then according to the identified

Table 2. The best projection directions in every month.

Month	x1	x2	x3	x4	x5	x6	x7	x8	x9
1	0.088	0.0953	0.456	0.235	0.5089	0.5844	0.2539	0.2233	0.0716
2	0.2388	0.3119	0.3789	0.3489	0.4445	0.4711	0.3047	0.0099	0.2608
3	0.0534	0.2535	0.3074	0.015	0.4149	0.5643	0.5694	0.0902	0.1236
4	0.1034	0.2605	0.4052	0.2217	0.4734	0.524	0.4318	0.0665	0.1359
5	0.1621	0.1653	0.4175	0.1189	0.5063	0.5126	0.4598	0.0446	0.1597
6	0.113	0.2281	0.3081	0.0539	0.4835	0.5553	0.4709	0.2182	0.1609
7	0.1496	0.347	0.4624	0.1473	0.468	0.4597	0.3886	0.1607	0.1203
8	0.1241	0.1068	0.4551	0.0114	0.506	0.2896	0.5882	0.2596	0.1124
9	0.223	0.0628	0.3652	0.0221	0.4975	0.4673	0.3608	0.4531	0.1058
10	0.0193	0.1147	0.3433	0.0159	0.5149	0.4456	0.4989	0.3327	0.2123
11	0.2791	0.1685	0.3874	0.0518	0.5495	0.3821	0.4662	0.2374	0.1389
12	0.1236	0.1349	0.3287	0.2363	0.608	0.4967	0.4072	0.016	0.1423

Table 3. Time weight vectors.

The Time Factor	Evaluation of Time/Month											
	1	2	3	4	5	6	7	8	9	10	11	12
0.304	0.0004	0.0155	0.0306	0.0456	0.0607	0.0758	0.0909	0.1059	0.121	0.1361	0.1512	0.1663
0.354	0.0216	0.0328	0.044	0.0553	0.0665	0.0777	0.0889	0.1002	0.1114	0.1226	0.1339	0.1451
0.404	0.0427	0.0501	0.0575	0.0649	0.0723	0.0796	0.087	0.0944	0.1018	0.1092	0.1166	0.1239
0.454	0.0639	0.0674	0.0709	0.0745	0.078	0.0816	0.0851	0.0886	0.0922	0.0957	0.0993	0.1028
0.504	0.085	0.0847	0.0844	0.0841	0.0838	0.0835	0.0832	0.0829	0.0826	0.0823	0.0819	0.0816
0.554	0.1062	0.102	0.0979	0.0937	0.0896	0.0854	0.0813	0.0771	0.0729	0.0688	0.0646	0.0605
0.604	0.1273	0.1193	0.1113	0.1033	0.0953	0.0873	0.0793	0.0713	0.0633	0.0553	0.0473	0.0393

problems, formula (7) is obtained. The solution is optimized by RAGA. The best projection directions are found. The results are shown in Table **2**.

The best projection directions $a(t_k)$ are presented in formula (7), and each substation projection value $z_i(t_k)$ can be obtained.

Each substation annual comprehensive evaluation value is calculated by using the principle of the minimum variance method. To study various substations' power quality under different time factor temporal dynamic value changes of the sort, λ selects 7 values from 0.304 to 0.604, which ensures that zero component is not included in weight of each time at the same time. Time weight vectors (14) are obtained by formulae (15), (16) and (17), and are given in Table **3**.

Finally, the annual power quality comprehensive evaluation of percentile substation is calculated by using the formula (13) under the action of factors in different times and the comprehensive values are ranked. The results are shown in Table **4**.

CONCLUSION

From the result point of view, it can be concluded that the evaluation results and the conclusion of literature Yang and Wang [32] are basically identical. From the perspective of the actual situation of substation, the model can be implemented in the dispersion characteristics of dynamic evaluation, because the whole electric power system is dynamic and the most electrical parameters are dynamically changing at any given moment. Overall, this algorithm has distinguished between the evaluation objects power quality level through the evaluation index. In addition, according to the best projection direction, impact degree of each evaluation index can be analyzed which can provide decision-making basis for different regions to further improve the quality of electric energy.

The weights of different periods of power quality can be emphasized by adjusting the size of the time factor. Substation annual value ranking is different under the effect of different time factor. Its change is related to the time

Table 4. Substation ranking under the different time factors.

Ranking	The Time Factor						
	0.304	**0.354**	**0.404**	**0.454**	**0.504**	**0.554**	**0.604**
1	E	E	E	E	E	E	E
	231.55	226.85	222.18	217.48	212.81	208.11	203.35
2	A	A	A	A	A	A	A
	226.62	222.02	217.44	212.84	208.26	203.66	198.99
3	C	C	C	C	C	C	C
	225.07	220.41	215.77	211.12	206.48	201.82	197.09
4	F	F	F	D	D	D	D
	217.43	212.31	207.21	202.69	199.07	195.44	191.74
5	D	D	D	F	F	F	F
	213.57	209.94	206.32	202.09	196.99	191.87	186.69
6	B	B	B	B	B	B	B
	71.68	71.4	71.13	70.85	70.57	70.29	69.99

factor. In this case, when the time factor is less than 0.5, the time weight is a gradual increase. Each substation power quality weight is greater in the second half. When the time factor is increased within the scope, the weight of each time period is increased in the first half of the year and is later decreased. When the time factor is greater than 0.5, contrary is the case.

Regional power grid power quality evaluations are recalculated from the view of time and space index of three dimensions in Table **4**. The power quality of different regions can be in horizontal comparison or in longitudinal comparison. Ccomparison of longitudinal and transverse can be made in different regions.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflict of interest.

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