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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 for power quality specific to high-dimensional index system issue of comprehensive evaluation for power quality to realize continuous evaluation for 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 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, which provides a new method and thought for decision of comprehensive evaluation for power quality.

Key Words: Power quality; comprehensive evaluation; projection pursuit; RAGA; least variance method; temporal dynamics

1 INTRODUCTION

In the electricity market environment, the quantified description from 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 current research focuses, possesses great significance in assessing power sector, investigating customer satisfaction to utility industry, and determining the electricity price. The traditional Power Quality Evaluation (PQE) method with a single index to evaluate power quality should be changed [7-9]. At present, most of the researches are based on qualitative analysis to evaluate the power system. In [10], after normalization dividing an index by its maximum accept-able value and consolidation combines all the normalized values for one disturbance type into a single index, we got six individuation indices for voltage variations. The indices are easy to understand and manipulate because the value equals to the per-cent of contractual limit or standards limit. But as a result of many service indicators can't qualitative calculation, this method has limitations in index selection. In [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 not only obtains the level of power quality but also provides the credibility information of the evaluation result. The method is simple, accurate and reliable, and has better practicability. In [13], based on the Radial Basis Function RBF (Radial Basis Function) neural network to evaluate the power quality, this model has a universal applicability and advantages. But it hard to evaluate process of the empowerment weight given by the various power quality, lowered the credibility evaluation results. In [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 proportion of indexes. However, the model is subjective. In [15], a new method is presented to quantify and evaluate the power quality by selected the day cycle. The indexes showing an aspect of power quality are qualified and unified using probability and mathematical statistics and vector algebra. The evaluation is presented to evaluate the global unique power quality index, which makes it possible that a class of quality for power has a corresponding price.

Due to the power quality comprehensive assessment is to multi-index integrated into a single index, the multidimensional data down to the process of one dimensional data, so the projection pursuit method will be good solution to this problem [16, 17]. This paper proposes RAGA-PPE comprehensive assessment model for power quality specific to such high-dimensional index system issue of comprehensive evaluation for power quality to realize continuous 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

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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.

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 [18,19,20], 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, find out can reflect the characteristics of the original high-dimensional data structure or Projection, 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 have the following steps:

1) According to the energy gained by the data, the data pretreated;

2) The PPE model is set up;

3) Using RAGA to optimize the best projection direction;

4) Using the minimum variance method to calculate weight system time vector;

5) To determine the time series of the comprehensive evaluation value of each system.

2.1 Electricity Standardized treatment

Because all power quality index type and dimension is not unified, which can't directly use. In order to avoid the unreasonable phenomena occur, dimensionless evaluate power quality index [19]. Here by using evaluation index method of poor raw data standardize processing, the need for indexes are inverse direction judgement, then processing respectively, the specific process is as follows:

Set 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}

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

Reverse index u_{ij}

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

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

2.2 The projection index function

Projection is essentially to observe data from different angles, looking for can reflect the characteristics of the data to the greatest extent and can make the best of the best viewing Angle mining data information is the optimal projection direction [20, 21]. The high-dimensional data into low dimension space by using the method of projection information, not only intuitive image, and convenient to use the conventional methods for high-dimensional data analysis and processing. Here choose linear projection, the high-dimensional data projected to one dimension linear space for research. Set a is m unit vector projection direction. The one dimensional projection characteristic value z_i is

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

$z_{ij}=a_j\times x_{ij}^{*}$ 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, It was integrated projection for projection value z_i as much as possible variation information extraction x_{ij} , In one dimensional space z_i spread class space S_z as large as possible; Projection values z_i of the local density D_z maximum at the same time, the same projection index focus as far as possible in the space. Build a projection objective function is:

$$Q(a)=S_z\times D_z \quad (4)$$

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

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

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

E_z is the average value of a projection characteristics z_i; R is local density window width, and the data characteristics, the selection of it included in the window as the projection point of the average number of too little, not avoid moving average deviation is too big, 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 value; u is unit step function.

2.4 To optimize the projection direction

When the sample values of evaluation indexes for timing, projection index function only changes over the direction of the projection. Different projection direction reflect 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, maximize by solving the projection index function to estimate the optimal projection direction [22]:

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

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

2.5 Determine the projection value

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

3 RAGA—PPE Model

Projection index function structure and its optimization is 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 and widely used. At present commonly used projection pursuit regression model is set up Friedman and Stuetzle multiple smoothing regression technique is put forward, given the method involves many complicated mathematical knowledge, not easy programming, and the large amount of calculation, this is largely limits the widely application of projection pursuit technique. Therefore can consider to use Genetic Algorithm (GA) to convenient [23,24,25], but the standard Genetic Algorithm (also known as the Simple Genetic Algorithm, Simple based Algorithm, referred to as SGA) premature convergence, large amount of calculation and the accuracy is poor, can lead to poor convergence results. To this end, this paper puts forward a kind of Accelerating Genetic Algorithm based on Real number encoding is [26, 27] of 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 influence the convergence speed of SGA, and the search space is wider, goal area is narrower, search time is longer and training speed is slower. RAGA, one Use the excellent individual subgroups to adjust the search scope, 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 serial, which could worsen fitness of offspring, however the choice of RAGA, hybridization and mutation operation was conducted in parallel. So overall, the scope of search of RAGA is larger than SGA's , so getting to the global optimal point might be a little easier.

3.1.3 Increasing the approximate probability

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

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

From this, we can see, RAGA in gradually compress search space generally still has great probability when surrounded by the most advantages.

3.2 Modeling steps

The flow chart of the way to optimization problem is showed below.

Step 1: N group of random variable of uniform distribution are generated at the change interval of each decision variable values , Shorthand for

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

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

Step 2:Calculate the objective function value. Take $V_i^{(0)}$ to the objective function, get $Q^{(0)}\left(V_i^{(0)}\right)$,then according to the size of the function value will be ordered by chromosome, get $V_i^{(1)}$.

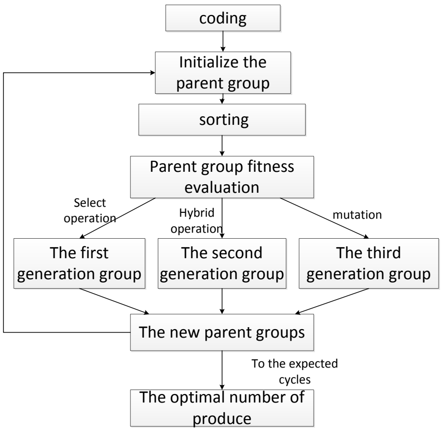

Fig.(1). genetic algorithm process

Step 3: Calculate evaluation function $eval\ (V)$.

Evaluation function is used to set the probability of V . The stronger Chromosome adaptability ,the greater the possibility should be selected. Then set $\alpha \in (0,\ 1)$, the evaluation function can be calculate

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

Step 4:Taking selection operation, which generate the first offspring. according to the fitness of each chromosome to select chromosomes .after several selection of the chromosome,we can get a new kind of chromosome $V_i^{(2)}$

Step 5: A new species that generated in step 4 is crossover operated .first, set P_c as the probability of crossover operation, then generate a random number from $[0,\ 1]$, if $r<P_c, V_i$ will be used as a parent. Using $V_1^{'}, V_2^{'},...$as Selected parent. $\left(V_1^{'},V_2^{'}\right)$ $\left(V_3^{'},V_4^{'}\right)$,$\left(V_5^{'},V_6^{'}\right)$ Selected to use arithmetic crossover method, which were generated the random number c from $(0,\ 1)$.

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

Step 6: Generate the new $V_i^{(3)}$;

Step 7: Evolutionary iteration.

Step 8:Accelerate circulation

Step 9:It is concluded that the best projection direction and the corresponding projection values.

4 The comprehensive evaluation value of time series

Adjusting the size of the time factor can achieve outstanding role of power quality in different periods [28,29,30,31].In this paper Determine the evaluation system in each period value is introduced. Comprehensive evaluation value can be calculated as

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

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

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

Time weight vector will be defined by Minimum variance method, which have 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 $W=\left(\frac{1}{N},\frac{1}{N},...,\frac{1}{N}\right)$, $\lambda = 0.5$.

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

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

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

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

5 Case study

Continuous power quality event is selected as object of study. Data is from power supply bureau in a given area of six 220 kV substation, which included 9 index 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 95% probability values in each month. The index system can be constructed evaluation system according to the actual demand and index data covering degree.

Table 1. Evaluation indicator system of the regional power quality

The 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	3-th harmonic	x6
7	The 5th harmonic	x7
8	The 7th harmonic	x8
9	The 9th harmonic	x9

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

Index data $t_1, t_2, t_3, ..., t_{12}$ of electric power are respectively formula (3), (5), (6), (4) in turn. The projection index function are derived. Then according to the identified problems, namely formula (7). And the solution is optimized by RAGA. The best projection directions are found. The results are shown in Table 2.

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

The best projection directions $a(t_k)$ are back in formula (7), and each substation projection values $z_i(t_k)$ can be got.

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

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

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

6 Conclusions

From the result point of view, the evaluation results and the conclusion of literature [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 realized distinguish 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 period 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 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 bigger 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 later decreased. When the time factor is greater than 0.5, the contrary is the case.

Regional power grid power quality evaluations are recalculated from the view of time, space index of three dimensions in table 5. The power quality of different regions can be in the horizontal comparison or in longitudinal comparison. And comparison of longitudinal and transverse can be made in different regions.

CONFLICT OF INTEREST

The author confirms that this article content has no conflict of interest.

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