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Adaptability Evaluation of Distributed Power Sources Connected to Distribution Network

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ABSTRACT At present, the distribution network is in an important opportunity period of rapid development and improvement of efficiency. A large amount of new energy and distributed energy are connected to the distribution network, which is beyond the capacity of some power grids. Therefore, the influence of nearby access of distributed power sources such as wind power and solar power on the distribution network is taken into account. This paper evaluates and studies the adaptability of distribution network after distributed power supply is connected to distribution network. Firstly, a new definition of the adaptability of distribution network is given. and the adaptability evaluation system of distribution network is sorted out and identified based on this, and the index system of adaptability evaluation of distribution network is constructed. Then the combined weight of the evaluation model is determined by the Analytic Hierarchy Process (AHP) and Entropy Weight method (EM). Then, a distribution network adaptability evaluation model based on quantum adaptive particle swarm optimization support vector machine (QAPSO-SVM) is constructed. Finally, through the comparative analysis of examples and the sensitivity analysis of the results, the superiority of the quantum adaptive particle swarm optimization support vector machine model in the adaptability evaluation of distribution network is proved.

INDEX TERMS Distribution network adaptability, analytic hierarchy process, entropy weight method, combined weight, sensitivity analysis, QAPSO-SVM.

I. INTRODUCTION

In recent years, in order to adapt to the economic development and the adjustment of energy structure, new energy power generation represented by photovoltaic and wind power is gradually becoming an important part of the energy development strategy [1], [2]. Compared with the traditional distribution network structure, distributed grid structure including wind power and solar energy has the characteristics of dispersion and instability [3]. Meanwhile, it is also affected by the randomness and volatility of photovoltaic and wind power, as well as the uncertainty of power supply caused by them and the uncertainty of user load end [4]–[7]. Under the background of energy revolution, the previous evaluation methods of distribution network adaptability take traditional energy supply as the object. It cannot fully cover the new features in the distribution network system. Therefore, an accurate analysis of the impact of new energy grid connection on the distribution network has a certain guiding significance for the scientific transformation of the distribution network.

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II. RELATED WORK

This part mainly carries on the comparative analysis to the relevant work of this paper from two aspects. This paper mainly introduces the research object and research method of traditional distribution network.

A. DIFFERENT SUBJECTS

Compared with the traditional power distribution network, the power distribution network with new energy generation is different in many aspects. The adaptability evaluation of traditional energy access to distribution network is mainly based on the characteristics of distribution network, such as power supply reliability of urban distribution network [8]–[11], household power supply demand characteristics [10], economic analysis [12]–[14] and power system elasticity [15], [16]. The traditional research object is based on the stability of distribution network. The stability of the distribution network is measured by the elasticity of the distribution network in the case of natural disasters [17]. At the same time, it also measures the stability of the distribution network by studying how to reduce the loss and improve the load capacity [18]. However, with the development of traditional distribution network research. The research object becomes the extension method of the new power distribution system [19]. In addition, the power supply reliability of the power grid is studied according to the dynamic behavior and energy exchange of the micro grid [20]. Many papers have studied the single characteristic problem such as the stability of distribution network. However, after the new energy is connected to the distribution network, the research on the overall adaptability of the distribution network is relatively lacking. Therefore, the evaluation object of this paper is the adaptability of distribution network.

B. DIFFERENT RESEARCH METHODS

The evaluation method for the related research of distribution network is usually the traditional and single subjective or objective evaluation method. At the beginning, the most widely used methods include Delphi method and analytic hierarchy process (AHP) to calculate the weight. In [21], the evaluation of wind power grid-connection capacity is studied. By using Delphi method to calculate the weight of the main evaluation index, the final comprehensive evaluation index is obtained. In [22], it adopts the comprehensive weighting method combined with analytic hierarchy process and entropy weight coefficient method, and applies grey relational analysis (GRA) in the comprehensive evaluation of power quality. But because of the evaluation research of distribution network, there is no absolute distinction boundary, so. Fuzzy analytic hierarchy process (FAHP) and Monte Carlo method are increasingly applied to quantitative comprehensive evaluation results [23]–[25]. In [26], The insufficient ramping resource expectation (IRRE) metric is proposed to measure power system flexibility for use in long-term planning, and is derived from traditional generation adequacy metrics. In [27], Based on the mechanisms of the cascading failures caused by geomagnetic storms, the technical requirements for the power system safety assessment of geomagnetic storm disasters are analyzed, and an evaluation method is proposed. Through the improvement of research methods, the comprehensiveness of distribution network research has been improved. However, the literature on the application of intelligent algorithm to distribution network is very rare. Therefore, this paper uses the quantum adaptive particle swarm optimization algorithm to study the adaptability of distribution network.

Based on the above research. In view of the traditional distribution network, its evaluation is mainly for a certain characteristic or several special new distribution network evaluation, such as reliability, economic evaluation, etc. It does not reflect its interrelationship with the external environment. Therefore, this paper firstly gives a new connotation definition of the adaptability of new energy after it is connected to the distribution network. That is, the adaptability of the distribution network is an evaluation that takes into account the distribution network itself and its interaction with the external environment. It is an important content to analyze and judge the quality of power grid construction. It also serves as a feedback for the subsequent construction quality and operation status of the power grid planning system.

The main innovations of this paper are as follows:1) In this paper, the adaptability of distributed energy after access to the distribution network is defined in a new connotation, and it is taken as the research object. 2) This paper combines reliability, load rate, relay protection equipment, power quality, operating life and new energy utilization rate for the first time. Then the evaluation index system is constructed. In this paper, the combination weight of the evaluation model is determined by the analytic hierarchy process and entropy weight method. 3) A distribution network adaptability evaluation model based on quantum adaptive particle swarm optimization support vector machine (QAPSO-SVM) is constructed in this paper. Finally, the superiority of QAPSO-SVM in the adaptability evaluation of distribution network is proved through the example analysis and the sensitivity analysis of the first-level index. It has laid a solid foundation for realizing the predictability, control and dispatching of new energy. It provides a guiding basis for the transformation of new energy grid connection in the distribution network.

III. ESTABLISH AN EVALUATION INDEX SYSTEM FOR THE ADAPTABILITY OF THE DISTRIBUTION NETWORK

The reasonable evaluation index system is the foundation of the adaptability evaluation of distribution network. Therefore, the evaluation index system constructed should comprehensively reflect the changes after distributed energy access and distribution network. According to the principle of constructing the evaluation index system, and through consulting relevant documents and experts' opinions, the index system of adaptability evaluation of distribution network is finally established. The operating life index reflects the time cost and depreciation cost of equipment, which is caused by the external environment of distribution network. The new energy utilization index reflects the contribution of new energy power generation to the total load of the power grid under the background of energy revolution. It reflects factors other than the traditional coal-fired power generation system. Therefore, the operating life index and the new energy efficiency index are called external indicators.

A. ESTABLISHMENT OF INDICATOR SYSTEM

In order to fully reflect the operating state and changes of distributed power supply after it is connected to the distribution network. This paper constructs an evaluation index system from six aspects: reliability, load rate, relay protection equipment, power quality, service life and new energy utilization rate. The indexes are divided into 16 specific evaluation indexes. As shown in the Tab.1.

TABLE 1. Evaluation index system for adaptability of distribution network.

First level indicator	Secondary indicators	Representation symbol
Reliability index	Transformer reliability	A_1
	Line reliability	A_2
Load rate index	Transformer full load rate	B_1
	Transformer capacity ratio	B_2
	Line full load rate	B_3
Relay protection equipment index	Protection of malfunction rate in case of failure	C_1
	Protection malfunction rate during normal operation	C_2
Power quality index	Voltage deviation exceeding rate	D_1
	Harmonic distortion exceeding rate	D_2
	Harmonic current exceeding rate	D_3
	Voltage fluctuation exceeding rate	D_4
	Over-standard rate of voltage unbalance	D_5
Operating life index	Transformer operating life	E_1
	Line operating life	E_2
New energy utilization rate	New energy penetration rate	F_1
	New energy consumption rate	F_2

B. ANALYSIS OF EVALUATION INDICATORS

1) TRANSFORMER RELIABILITY A_1

Transformer reliability refers to the proportion of transformer equipment in the distribution network that meets the N-1 principle. This indicator reflects the safety and stability of the transformer in the distribution system. The higher the reliability of the transformer, the better the adaptability of the transformer in the distribution network to new energy access. The calculation formula is as follows:

$$A_1 = \frac{a_2}{a_1} \tag{1}$$

In the formula, a_1 is the total number of transformers in the distribution network; a_2 is the number of transformers that meet the N-1 principle.

2) LINE RELIABILITY A_2

Line reliability refers to the proportion of lines that meet N-1 in the total number of lines. This indicator reflects the safety of distribution network lines. The higher the line reliability, the better the adaptability of the distribution line to new energy access. The calculation formula is as follows:

$$A_2 = \frac{a_3}{a_4} \tag{2}$$

In the formula, a_4 is the total number of lines in the distribution network; a_3 is the number of distribution lines that meet the N-1 principle.

3) TRANSFORMER FULL LOAD RATE B_1

Transformer full load rate refers to the increase ratio of full load and overload transformers after distributed power sources are connected to the grid.

4) TRANSFORMER CAPACITY RATIO B_2

Line overload rate is the proportion of overloaded lines in the total number of lines in the distribution network. This indicator reflects the operating status of lines in the distribution network. The lower the overload rate of the line, the better the running condition of the line and the higher the adaptability to new energy access. The calculation formula of line overload rate is as follows:

$$B_2 = \frac{b_1}{a_3} \times 100\% \tag{3}$$

In the formula, b_1 is the number of overloaded lines in the distribution network.

5) LINE FULL LOAD RATE B_3

Transformer capacity ratio refers to the ratio of the total installed capacity of the transformer to the peak load in the distribution network. This index reflects the operating status and utilization efficiency of the transformer. There are different recommended ranges of capacity ratio for substation equipment of different voltage levels. The capacity ratio of 220kV substation is 1.6∼1.9; the capacity ratio of 35∼110kV substation is 1.8∼2.1. The calculation formula is as follows:

$$B_3 = \frac{b_2}{b_3} \tag{4}$$

In the formula, b_3 is the annual peak load of the distribution network; b_2 is the total capacity of transformers in the distribution network.

6) PROTECTION MALFUNCTION RATE IN CASE OF FAILURE C_1

Protection misoperation rate refers to the relay protection equipment when there is no accident. It is a reflection of relay protection equipment operating error index. The protection misoperation rate under fault condition can reflect the weakness of relay protection equipment in distribution system. The calculation formula of protection misoperation rate in the case of fault is as follows:

$$C_1 = \frac{c_2}{c_1} \times 100\% \tag{5}$$

where, c_1 is the total number of relay protection equipment in the distribution network; c_2 is the number of misoperation of relay protection equipment in the distribution system under the condition of failure.

7) PROTECTION MALFUNCTION RATE DURING NORMAL OPERATION C_2

The protection misoperation rate under normal conditions refers to the probability of the occurrence of misoperation when the protection equipment is in normal operation. This index reflects the adaptability of overload protection equipment to new energy access. The calculation formula of this index is as follows:

$$C_2 = \frac{c_3}{c_1} \times 100\% \tag{6}$$

where, c_3 is the number of devices that are misoperated during normal operation of the distribution network.

8) VOLTAGE DEVIATION EXCEEDING RATE D_1

After the distributed power source is connected to the power grid, in actual operation, there will be deviations between the actual voltage and the nominal voltage at each point of the system due to changes in the operation mode, which is called voltage deviation. The voltage deviation exceeding rate refers to the increase ratio of nodes with voltage deviation exceeding the standard.

9) HARMONIC DISTORTION EXCEEDING RATE D_2

The over-standard harmonic distortion rate is the increasing proportion of the nodes whose voltage total harmonic distortion rate exceeds the standard after the distributed power supply is connected to the power grid.

10) HARMONIC CURRENT EXCEEDING RATE D_3

Harmonic current exceeding rate refers to the increasing proportion of nodes with harmonic current exceeding the standard after distributed power sources are connected to the grid.

11) VOLTAGE FLUCTUATION EXCEEDING RATE D_4

The over-standard voltage fluctuation rate refers to the increase ratio of nodes with over-standard voltage fluctuations after the distributed power sources are connected to the power grid, which indicates the rapid change of the effective value of the grid voltage.

12) OVER-STANDARD RATE OF VOLTAGE UNBALANCE D_5

The over-standard voltage unbalance rate refers to the increase ratio of nodes with over-standard negative sequence voltage unbalance after the distributed power sources are connected to the power grid. Voltage unbalance refers to the amplitude difference between the three-phase voltages, or the phase shift relative to the normal voltage phase difference, or both.

13) TRANSFORMER OPERATING LIFE E_1

The operating life of a transformer refers to the operating life of the substation equipment in the distribution network. This indicator reflects the operating conditions and daily operating losses of the substation equipment in the distribution system.

14) LINE OPERATING LIFE E_2

Line operating life refers to the average operating life of lines in the distribution network. This indicator reflects the operating conditions and daily losses of line equipment.

15) NEW ENERGY PENETRATION RATE F_1

New energy penetration rate refers to the ratio of the total installed capacity of new energy to the peak total load in the distribution network. This indicator reflects the relationship between new energy installed capacity and total load.

$$F_1 = \frac{f_1}{f_2} \times 100\% \tag{7}$$

In the formula, f_1 is the total installed capacity of new energy generation in the distribution network; f_2 is the peak value of the total load in the distribution network.

16) NEW ENERGY CONSUMPTION RATE F_2

New energy consumption rate refers to the ratio of the actual output power of new energy absorbed by the distribution network to the peak value of the total load. This indicator reflects the contribution of new energy power generation to the total grid load. The calculation formula is as follows:

$$F_2 = \frac{f_3}{f_2} \times 100\% \tag{8}$$

f_3 is the on-grid power of new energy in the distribution network.

IV. EVALUATION OF ADAPTABILITY OF DISTRIBUTION NETWORK BASED ON QAPSO-SVM MODEL

This section will introduce the analytic hierarchy process, entropy method and particle swarm optimization support vector machine model related theories involved in the evaluation of the adaptability of the distribution network.

A. DETERMINATION OF THE WEIGHT OF THE DISTRIBUTION NETWORK ADAPTABILITY EVALUATION INDEX

There are many typical index weighting methods, which are mainly divided into three categories: subjective weighting method, objective weighting method, and combined weighting method. The characteristic analysis is shown in Tab.2.

Index weight calculation is an important part of the evaluation model. From the analysis in Tab.2, it is concluded that no matter whether it is subjective or objective weighting method, there is a risk of losing information, which will affect the accuracy of the evaluation results. Therefore, this paper uses the combination weighting method to replace the individual objective weighting or subjective weighting to improve the accuracy of the evaluation system. This article will combine the analytic hierarchy process to obtain the subjective weights, and use the effective entropy weights method to calculate the objective weights. Finally, the two results will be integrated to build a combined weighting model for the adaptive evaluation of new energy consumption in distribution networks. The weight of the performance evaluation index combination.

B. ANALYTIC HIERARCHY PROCESS

Analytic Hierarchy Process (AHP) is a systematic and hierarchical multi-objective decision analysis method [28]. This

TABLE 2. Index weighting method classification.

Category	Concept	Methods	Characteristics
subjective weighting	Experts make judgments on the relative weights of each indicator based on experience and assign weights to each indicator accordingly.	Delphi method[32], analytic hierarchy process, factor pair comparison method[33], set value iteration method[34] and so on.	It can well reflect the background conditions of the evaluation object and the intention of the evaluator, but the accuracy of the weight coefficient of each indicator depends on the accumulation of experts' experience and knowledge, which has a large degree of subjective arbitrariness.
Objective weighting	According to certain rules, according to the actual data situation to sort out and analyze, give weight to each index.	Factor analysis method[35], entropy weight method, maximum deviation method[36], coefficient of variation method[37] and so on.	Objectivity is strong, but sometimes it is easy to appear with the reality of the relatively important degree of each index big difference unreasonable phenomenon.
Combinatorial weighting	Combining the characteristics of subjective weighting method and objective weighting method.	A combination of subjective and objective weighting[38].	It not only reflects the subjective information of the decision-maker but also can use the original data and mathematical model to make the weight coefficient objective.

theory was proposed by American operations researcher T.L Saaty and others in the mid1970s. The complicated evaluation system, according to its internal logical relationship, combine evaluation indicators into an orderly hierarchical structure and then use the expertise and experience of experts or managers to compare pairs of indicators at the same level and follow the prescribed scale Value construction discriminant matrix [29]. This method is based on the expert's experience judgment and changes the expert's experience judgment from directly facing many factors at the same time, to judge the two factors, and uses mathematical methods to quantitatively measure the experience judgment results of each expert [30], [31].

The specific operation steps of the analytic hierarchy process are as follows:

1) ESTABLISHING A HIERARCHICAL STRUCTURE MODEL

The first step of the analytic hierarchy process is to establish a hierarchical structure model, as shown in the Fig 1 below. Generally speaking, the model includes three levels: the first layer is called the goal layer, which describes the overall goal to be achieved for the entire decision problem; the second layer is called the criterion layer, which describes the various criteria and factors that need to be considered to achieve the overall goal; If the problem structure is more complex, it usually includes multiple criteria layers; the third layer is called the indicator layer, which describes the indicators or schemes for measuring each criterion. The hierarchy structure of analytic hierarchy process is shown in Fig.1.

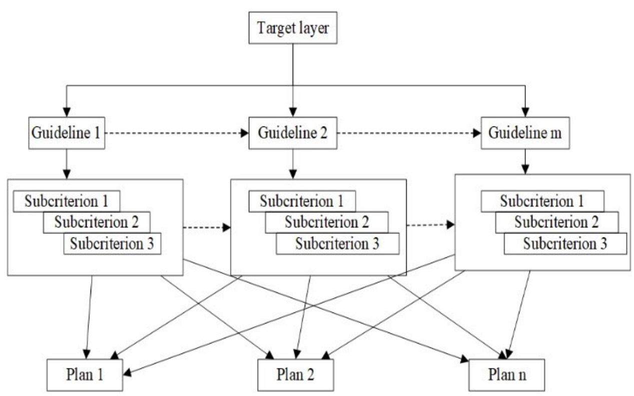

FIGURE 1. Hierarchical structure diagram of AHP.

2) CONSTRUCTION OF JUDGMENT MATRIX

The judgment matrix indicates the relative importance of the indicators of this layer compared to the indicators of the upper layer. The values are generally given according to the nine-level scale method, which is shown in Tab.3.

3) HIERARCHICAL ORDERING AND CONSISTENCY CHECK

Hierarchical single ordering is to calculate the relative value (that is, the weight value) of the importance of this level of an index to the upper-level index according to the judgment matrix. For each judgment matrix, it can correspond to a characteristic equation A, can correspond to a characteristic equation:

$$AW = \lambda W \tag{9}$$

Among them, λ Is the eigenvalue of the judgment matrix, W As with the λ corresponding eigenvectors; Take the judgment matrix A Maximum eigenvector $\lambda_{\max}$ s corresponding eigenvectors are normalized and the consistency test of the

TABLE 3. 9-grade scale method of AHP.

scale	Description
1	The two factors are equally important
3	One factor is slightly more important than the other
5	One factor is more important than the other
7	One factor is more important than the other
9	One factor is more important than the other
2、4、6、8	The median of the above pairwise judgments
The bottom	indicators x_i with x_j Judgment by comparison λ_{ij} , x_j with x_i comparative judgment $1/\lambda_{ij}$

judgment matrix is carried out according to the formula.

$$CR = \frac{\frac{\lambda_{\max}-n}{n-1}}{RI} \tag{10}$$

Among them CR Is the consistency ratio coefficient of the judgment matrix, $\lambda_{\max}$ is the maximum characteristic root of the judgment matrix, RI Is the random consistency index $CR \leq 0.1$, it is considered that the judgment matrix has satisfactory consistency, the calculated index is feasible, and the obtained vector is the weight vector of the importance of the lower index relative to the upper index, that is, the weight vector of the hierarchical judgment matrix. Otherwise, it is not feasible and needs to be adjusted.

4) TOTAL HIERARCHICAL SORTING

The calculation of the importance scale of all elements in a layer relative to the highest level is called the total order of the hierarchy $k-1$ weight vector of the layer relative to the top layer $\alpha^{k-1}k$ and layer relative to the $k-1$ weight vector of the layer β^k, k The rank vector of the layer element concerning the highest rank

$$\alpha^k = \beta^k \alpha^{k-1} \tag{11}$$

Among them, the ranking weight formula is:

$$\alpha^k = \beta^k \beta^{k-1} \cdots \beta^3 \alpha^2, \quad 3 \leq k \leq h \tag{12}$$

Type, α^2 Is the weight vector of the second layer of factors, h Is the number of levels of the importance weight of each evaluation index.

C. ENTROPY WEIGHT METHOD

Entropy method (EM) is a method that introduces the concept of "Entropy" in physics into information theory to measure information uncertainty. On the contrary, the smaller the entropy value is, the stronger the orderliness is, the more effective the information is, and the larger the index weight is. This method is to determine the entropy value of each index by analyzing the changing trend of each index, and then use the entropy weight to correct the weight of each index, to obtain a more objective index weight [32].

Specific operation steps are as follows:

1) ESTABLISH THE INDEX MATRIX

Let the evaluation object be m, the evaluation index be n, and each index value be $x_{ij}(i = 1, 2, \ldots, m; j = 1, 2, \ldots, n)$, then the index matrix is:

$$X = \begin{pmatrix} x_{11} & \cdots & x_{1n} \\ \vdots & \ddots & \vdots \\ x_{m1} & \cdots & x_{mn} \end{pmatrix} \tag{13}$$

2) NORMALIZED PROCESSING OF INDICATOR MATRIX

Pair index matrix X after normalization, the normalized index matrix is obtained $G = (g_{ij})_{m*n}$ where the normalized index values g_{ij},

$$g_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{n} (x_{ij})^2}} \tag{14}$$

3) CALCULATE THE CHARACTERISTIC PROPORTION OF THE INDEX

The characteristic proportion of each index in the normalized matrix h_{ij} There's a formula for that.

$$h_{ij} = \frac{1 + g_{ij}}{\sum_{i=1}^{m} (1 + g_{ij})} \tag{15}$$

4) CALCULATE THE ENTROPY WEIGHT OF THE INDEX

The first j Entropy weight of terms k_j

$$k_j = \frac{\sum_{i=1}^{m} h_{ij} \ln h_{ij}}{\ln n} \tag{16}$$

5) CALCULATE THE DIFFERENTIATION COEFFICIENT OF INDICATORS

Differentiation coefficient $p_j = 1 - k_j$

6) CALCULATE THE INDEX WEIGHT

The weight q_j

$$q_j = \frac{p_j}{\sum_{i=1}^{n} p_j} \tag{17}$$

D. THE COMBINED WEIGHT CALCULATION MODEL

According to the principle of minimum information recognition, in order to make the weight of evaluation index more rigorous and scientific, the executive weight and objective weight should be appropriately combined to minimize the distribution distance of the two weights. In this chapter, the combination weight in formula (18) is used to calculate the combination weight of adaptability evaluation index of distribution network.

$$w_j = \frac{\sqrt{w_{1j} \times w_{2j}}}{\sum_{j=1}^{n} \sqrt{w_{1j} \times w_{2j}}} \tag{18}$$

Among them w_j is the combined weight of index $j, j = 1, 2, \ldots, n$; w_{1j} Is the subjective weight of AHP of item j; w_{2j} Is the objective weight of EM in item $j, j = 1, 2, \ldots, n$.

E. QUANTUM ADAPTIVE PARTICLE SWARM OPTIMIZATION SUPPORT VECTOR MACHINE MODEL

1) PARTICLE SWARM OPTIMIZATION SUPPORT VECTOR MACHINE MODEL

The basic steps are as follows [33]–[35], please refer to the flowchart for details.

(1) First, set the number of population particles to m.

(2) Initialize the speed and position of each particle in the population to obtain the first generation population:

$$u^{(1)} = [u_1^{(1)} + u_2^{(1)} \ldots, u_j^{(1)}, \ldots + u_m^{(1)}] \tag{19}$$

Set the historical optimal position p_{best} of each particle as the initial position, and take the optimal value g_{best} in the global optimal position of the particle swarm.

(3) According to the obtained population, update the penalty coefficient C and kernel function g width in the SVM algorithm.

(4) Use training samples to train the SVM algorithm model.

(5) Use test samples to test the accuracy of the SVM algorithm, that is, the fitness function value. The calculation expression of fitness function value is as follows:

$$Z = \frac{1}{n}\sum_{i=1}^{n}(Z_{rec} == Z_{act}) \tag{20}$$

In formula (18), Z_{rec} is the recognized working condition type; Z_{act} is the actual working condition type; n is the number of test samples.

(6) Update the particle velocity and position, the expressions are as follows:

$$v^{k+1} = wv^k + c_1 r_1(p_{best}^{(k)} - u^{(k)}) + c_2 r_2(g_{best}^{(k)} - u^{(k)}) \tag{21}$$

$$u^{(k+1)} = u^{(k)} + v^{(k+1)} \tag{22}$$

where w is the inertia weight; $r1$ and $r2$ are random numbers located in [0, 1]; k represents the current iteration number, the initial value is 1, $p_{best}^{(k)}$ represents the position of the k-th individual optimal particle; $g_{best}^{(k)}$ represents the k Substituting the position of the global optimal particle; c_1 and c_2 are constants, v is the velocity of the particle, u is the position of the particle.

(7) After each calculation update, calculate the fitness of each particle and compare it with the optimal position p_{best} experienced before. If the particle is now in a better position, then the current particle position is taken as p_{best}.

(8) Set the fitness of each particle to the optimal position of all particles g_{best}. If the position of the particle swarm is better now, then the position of the current particle is taken as g_{best}.

(9) Check the final value condition, if the precision meets the preset condition, stop the iteration; if the precision does not meet the preset condition, return to step 3; if the maximum number of iterations is exceeded, stop the iteration.

(10) Output the optimal solution.

2) QUANTUM ADAPTIVE PARTICLE SWARM OPTIMIZATION

Although the basic particle swarm optimization algorithm is simple to use and has a fast optimization speed, it is also easy to fall into local minimum value and convergence accuracy.

Therefore, it is necessary to improve it [43].

a: SETTING THE INITIAL POSITION OF THE QUANTUM PARTICLE SWARM

The quantum bit is used to replace the particles in the elementary particle swarm, in which the position state of the quantum bit is composed of two parts: $|0>$ and $|1>$:

$$|\varphi >= \alpha|0> +\beta|1> \tag{23}$$

where α and β is a pair of complex numbers satisfying the following relation:

$$|\alpha|^2 + |\beta|^2 = 1 \tag{24}$$

Therefore, we take x^α to represent the position in the state of $|0>$ and x^β to represent the position in the state of $|1>$, and then the position of the particle at the conventional position x in the quantum bit is expressed as:

$$x = x^\alpha + x^\beta \tag{25}$$

The initial position of standard particle swarm to quantum particle swarm is:

$$X_i = \begin{bmatrix} x_{i,1}^a x_{i,2}^a \cdots x_{i,j}^a \cdots x_{i,N}^a \\ x_{i,1}^\beta x_{i,2}^\beta \cdots x_{i,j}^\beta \cdots x_{i,N}^\beta \end{bmatrix} \tag{26}$$

In the formula $i = 1, 2, \cdots, M; j = 1, 2, \cdots, \text{N}_i$, N represents the dimension of the search space;

M represents the population size of the particle swarm.

b: THE UPDATING PROCESS OF PARTICLES

For the i-th particle, the average distance and velocity compared with other particles are:

$$D_{i,x} = \frac{1}{M-1}\sum_{j=1, j\neq i}^{M}\sqrt{\sum_{k=1}^{N}(x_{i,k} - x_{j,k})^2} \tag{27}$$

$$D_{i,v} = \frac{1}{M-1}\sum_{j=1, j\neq i}^{M}\sqrt{\sum_{k=1}^{N}(v_{i,k} - v_{j,k})^2} \tag{28}$$

The difference in particle trajectories determined by average distance and average velocity is denoted as $D_{i,c}$

$$D_{i,c} = D_{i,x} + \rho_{x_i,v_i} \cdot D_{i,v} \tag{29}$$

$$\rho_{x_i v_i} = \frac{E(x_i v_i) - E(x_i)E(v_i)}{\sqrt{E^2(x_i^2) - E^2(v_i^2)} \cdot \sqrt{E(x_i^2) - E^2(x_i)}}$$

$$= \frac{\sum_{j=1}^{N} x_{i,j}v_{i,j} - \frac{1}{N}\sum_{j=1}^{N} x_{i,j}\sum_{j=1}^{N} v_{i,j}}{\sqrt{\sum_{j=1}^{N} x_{i,j}^2 - \frac{1}{N}\left(\sum_{j=1}^{N} x_{i,j}\right)^2} \cdot \sqrt{\sum_{j=1}^{N} v_{i,j}^2 - \frac{1}{N}\left(\sum_{j=1}^{N} v_{i,j}\right)^2}} \tag{30}$$

In the formula, $\rho_{x_i v_i}$ represents Pearson correlation coefficient with v.

According to the above formula $D_{i,c}$, the largest particle trajectory difference is denoted as $D_{c,\max}$, the smallest is denoted as $D_{c,\min}$, and the optimal particle trajectory difference is denoted as $D_{c,g}$, then the evolution factor of particle trajectory is:

$$f_c = \frac{D_{c,g} - D_{c,\min}}{D_{c,\max} - D_{c,\min}} \in [0, 1] \tag{31}$$

c: ADAPTIVE DYNAMIC CONTROL OF INERTIA WEIGHT

The local and global optimization abilities of particles vary with the setting of inertia weights. Therefore, in the process of particle iteration, the layout optimization ability and global optimization ability of particle should be adjusted dynamically. On this basis, the following dynamic weight method is proposed to keep the dynamic balance between global and local, that is:

$$w_c(f_c) = \frac{1}{1 + 1.5e^{-2.6f_c}} \tag{32}$$

d: VARIATION OPERATION

In order to make the particle jump out of the global extremum point, into a larger space to find a new global extremum. At the same time, in order to ensure the population diversity of particles in a larger search space, the mutation idea of genetic algorithm is used to exchange some qubit states. Achieve variation effect namely. The operation is as follows:

$$C(k) \cdot x_{g,i} = C(1) \cdot \begin{bmatrix} x_{i,p}^{\alpha} \\ x_{i,p}^{\beta} \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix} \begin{bmatrix} x_{i,p}^{\alpha} \\ x_{i,p}^{\beta} \end{bmatrix} = \begin{bmatrix} x_{i,p}^{\alpha} \\ x_{i,p}^{\beta} \end{bmatrix} \tag{33}$$

3) QAPSO OPTIMIZATION OF SUPPORT VECTOR MACHINE

QAPSO-SVM is mainly divided into two parts: the QAPSO optimization part on the left and the SVM part on the right.

The particle of QAPSO is used to represent the penalty factor of SVN and the parameters of the radial basis function. The accuracy of M on the right was taken as the fitness of QAPSO, and the fitness value was used to optimize the particle according to the steps of QAPSO to find the optimal position. As the penalty factor, radial basis function parameter and relaxation factor of SVM. The algorithm implementation is shown in Fig.2

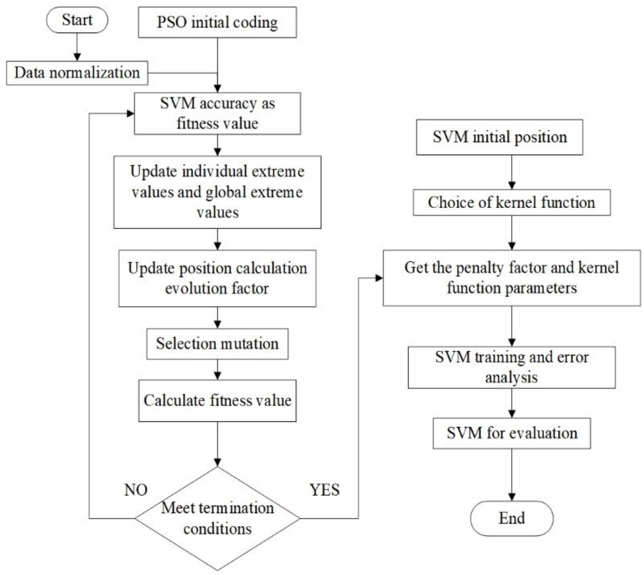

FIGURE 2. **QAPSO optimization of support vector machine.**

F. STEPS TO EVALUATE THE ADAPTABILITY OF DISTRIBUTION NETWORK BASED ON PSO-SVM

Considering that the single weight determination method has certain limitations, this paper adopts two weighting methods to combine and get the combined weight. Then, the normalized raw data matrix and the combined weight are multiplied and summed to obtain the expected output value of the evaluation model. Finally, PSO-SVM evaluation model is used to evaluate and analyze the adaptability of distribution network.

Step 1: AHP method is used to calculate the subjective weight of each index. According to the adaptability evaluation index system of distribution network in Table 1, 10 experts were invited to give scores by means of questionnaire, and the evaluation results of 10 experts were aggregated by means of geometric mean method, and the judgment matrix of indicators at all levels was finally constructed. Check whether it passes the consistency test one by one, and finally determine the subjective weight of the three-level index on the target scheme w_{1j}

Step 2: Use the entropy method to calculate the objective weight of each indicator w_{2j}. The specific method is to first normalize the index matrix to obtain the normalized matrix $G = (g_{ij})_{m*n}$. Use the combination weight in formula (16) to calculate the combination weight of the evaluation index.

Step 3: Determine the expected output value of the evaluation model. Referring to the method of distribution network adaptability evaluation in QGDW11619-2017 "Evaluation guidelines for connecting distributed generation to power grid" in this guideline, the weight is obtained by analytic hierarchy process and combined with the expert score. The expected output value of this paper is an improved method of power network evaluation guide. The expected output value of the evaluation model is obtained by multiplying and adding combination weights. Establish a standardized decision matrix $Z = [z_{ij}]$, $z_{ij} = a_{ij}/(\sum_{i=1}^{m} a_{ij}^2)$, $i = 1, 2, \ldots m; j = 1, 2, \ldots n$ where a_{ij} is the value of the j factor of the i alternative. Establish a weighted standardized decision matrix $X = [x_{ij}]$, the weight vector is $W_j = [\mathrm{w}_1, \mathrm{w}_{2,\ldots}\mathrm{w}_n]^T$,

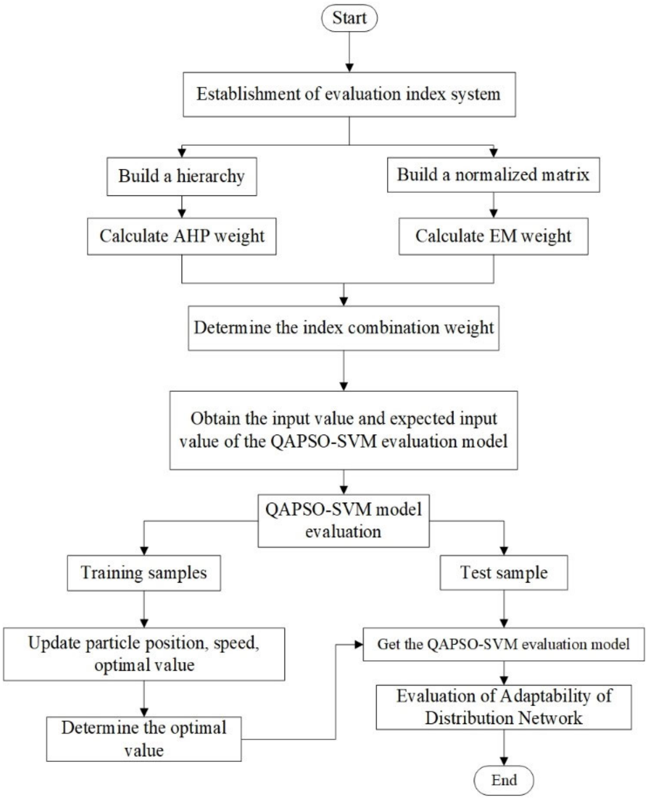

FIGURE 3. Evaluation flowchart based on AHP-EM-QAPSO-SVM.

W_j is the combined weight vector, where $x_{ij} = w_j z_{ij}$, and the expected output value of the PSO-SVM evaluation model is obtained.

Step 4: QAPSO-SVM combination evaluation model was used for evaluation. According to the original data of the index system as the input value of the evaluation model, the results determined in Step 2 as the expected output value of the model. 20 groups of data were randomly selected for model training, and the remaining 5 groups of data were tested for sample, and finally the model evaluation results were obtained. The specific steps can refer to the above QAPSO-SVM model optimization steps.

This paper constructs a distribution network adaptability evaluation model based on the QAPSO-SVM model for evaluation. The specific framework process is shown in Fig. 3.

V. CASE ANALYSIS

Ningxia is the first national new energy demonstration area in China. Therefore, this paper selects the distribution network data of five regions in Ningxia from 2015 to 2019 for analysis. They are Yinchuan area, ShiZuishan area, Wuzhong area, Ningdong area and Zhongwei area respectively. In this paper, A, B, C, D and E are used to replace the above five areas respectively. In order to explain the evaluation process in more detail and clearly, this paper takes the 5-year data of area A as an example and explains the evaluation steps in detail, including the determination of weights, sample training and test results. The process is as follows.

TABLE 4. Weight values of the evaluation index system.

Number	AHP weight	EM weight	Combination weight
A_1	0.160700	0.000029	0.000096
A_2	0.160700	0.000110	0.000366
B_1	0.078400	0.077346	0.125354
B_2	0.039200	0.111579	0.090418
B_3	0.039200	0.077155	0.062522
C_1	0.079200	0.000036	0.000060
C_2	0.039600	0.107523	0.088020
D_1	0.103600	0.065611	0.140515
D_2	0.037400	0.093454	0.072253
D_3	0.058000	0.100939	0.121025
D_4	0.063000	0.138452	0.180313
D_5	0.024100	0.138452	0.068977
E_1	0.047300	0.000883	0.000863
E_2	0.015800	0.000581	0.000190
F_1	0.036100	0.043669	0.032589
F_2	0.018000	0.044180	0.016439

A. DETERMINATION OF INDEX WEIGHT

According to the evaluation index system established in this article, data collection is carried out through the official website of the enterprise and the authoritative website of the industry and consulting the corresponding staff. First, AHP is used to determine the subjective weight of the evaluation index, and the objective weight is obtained using the EM method, and the index combination weight is calculated according to formula (16). The results are shown in Tab.4 below.

B. DETERMINATION OF THE EXPECTED OUTPUT VALUE OF THE SAMPLE

Due to the different unit level of each index, the dimensionless data was processed before the comprehensive evaluation, and the standardized matrix was obtained. Refer to the method of distribution network adaptability evaluation in QGDW11619-2017 ''Evaluation guidelines for connecting distributed generation to power grid''. Sum the normalized matrix by multiplying the combined weights. The result is determined as the expected output value of the QAPSO-SVM model.

C. EVALUATION PROCESS OF ADAPTABILITY OF DISTRIBUTION NETWORK BASED ON QAPSO-SVM MODEL

According to the sample data of distribution networks in 5 regions of Ningxia, 20 groups are randomly selected as training samples and the remaining 5 groups are selected as test samples. In order to verify the validity of the model, quantum particle swarm optimization support vector

TABLE 5. Parameter setting of PSO algorithm in each model.

Model	Parameter Settings
QAPSO	$\omega: 0.9 \sim 0.4, c_1: 1.5 \sim 2.5, c_2: 1.5 \sim 2.5,$ $\delta: 0.05 \sim 0.1, r_{1d}: 0 \sim 1, r_{2d}: 0 \sim 1, V_{\max d} = Range$
QPSO	$\omega: 0.9 \sim 0.4, c_1: 1.5 \sim 2.5, c_2: 1.5 \sim 2.5,$ $\delta: 0.05 \sim 0.1, r_{1d}: 0 \sim 1, r_{2d}: 0 \sim 1, V_{\max d} = Range$
PSO	$\omega: 0.9 \sim 0.4, c_1 = c_2 = 2$

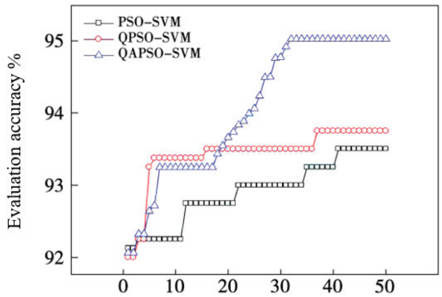

FIGURE 4. Relationship between evolution times and Evaluation accuracy.

machine (QPSO-SVM), conventional PSO-SVM, genetic algorithm optimization support vector machine (GA-SVM) and conventional support vector machine (SVM) are introduced for comparative analysis.

1) PARAMETER SETTING

According to the data of distribution network adaptability in 5 regions, 20 groups were randomly selected as the training data. And it is used for parameter estimation and model establishment. The remaining 5 groups of data were used as test data to verify the evaluation accuracy. The calculations of the 5 method models used in this paper are all carried out on Matlab2018 (a). The initial parameter Settings of PSO algorithm in each evaluation model are shown in Tab.5. In order to ensure the fairness of the evaluation results of the model, all PSOs were adopted: particle number N = 30, space dimension 2, and maximum iteration number 200. Initialize the penalty factor C and the width of the kernel function δ are [1.2]

In Fig.4, the accuracy of the three optimized SVM for the adaptability evaluation of the distribution network increases with the increase of the number of particle swarm evolution at the beginning. The accuracy does not change after a certain number of times. The optimization effect of QAPSO on SVM is obviously better than that of the other two methods.

In the iteration process of QAPSO-SVM, the algorithm began to converge when the iteration reached 34 times, and the width of the kernel function quickly dropped to around 1.14. However, QPSO-SVM rapidly begins to converge around the 42 times. PSO-SVM begins to converge around the 48th time, and GA-SVM begins to converge around the 93rd time. Therefore, the convergence rate of

TABLE 6. QAPSO algorithm results.

Algorithm	Average number of iterations	Convergence time	Global optimization probability
QAPSO	34	66	74.66
QPSO	42	85	73.41
PSO	48	90	72.03
GA	93	102	70.50

TABLE 7. SVM parameter setting.

Algorithm	Penalty factor C	Kernel parameter g
QAPSO-SVM	25	1.04
QPSO-SVM	67	1.59
PSO-SVM	93	2
GA-SVM	30	1.25
Human experience setting values	100	2.5

QAPSO-SVM is optimal when calculating parameters. This is shown in Fig. 4, Tab.6, and Tab. 7.

2) TRAINING AND TESTING OF QAPSO-SVM MODEL

Considering the randomness of particle swarm optimization algorithm, the code is run for 10 times, and the average value of the result is taken. The training results based on the QAPSO-SVM evaluation model are shown in Tab.8.

According to the training results of the model, 5 groups of test sets were substituted into the trained QAPSO-SVM evaluation model, and the evaluation results of 5 groups of test samples were obtained. The results are shown in Tab.6. The results and errors of the training process are compared in Tab.5. From the perspective of relative error, the range of relative error of QAPSO-SVM model training is between [−1.96%, 2.04%], and the mean absolute value of relative error is 0.827%, indicating that QAPSO-SVM has a good training effect.

As shown in Tab.9, the test output obtained by QAPSO-SVM is compared to the expected output. The maximum relative error range between the test output value and the expected output value is [−0.54%, 0.05%], and the mean absolute value of the relative error is 0.37%. It can be seen that it has a high evaluation accuracy, and the fluctuation range of relative error is very small.

In Tab.10, the execution efficiency parameters and precision of QAPSO-SVM algorithm, QPSO-SVM algorithm, PSO-SVM algorithm, GA-SVM algorithm and SVM algorithm are compared. Among them, QAPSO-SVM can meet the needs of distribution network adaptability evaluation. By comparing the results in Tab.10, compared with QPSO-SVM, PSO-SVM, GA-SVM and SVM, the modified QAPSO-SVM method can improve the training time by 34.4%, 58.7%, 64.1% and 68.1% respectively. The test time can be increased by 20%, 50.7%, 59.1% and 65.7% respectively. The experimental results show that QAPSO-SVM

TABLE 8. Training results of QAPSO-SVM evaluation model.

Sample number	Expected output value	QAPSO-SVM model training output	Relative error
1	0.4356	0.4329	-0.62%
2	0.5154	0.5201	0.91%
3	0.7135	0.7182	0.66%
4	0.3429	0.3466	1.08%
5	0.5659	0.5623	-0.64%
6	0.3912	0.3926	0.36%
7	0.5831	0.5889	0.99%
8	0.7454	0.7408	-0.62%
9	0.199	0.1966	-1.21%
10	0.6108	0.5988	-1.96%
11	0.4574	0.4602	0.61%
12	0.5619	0.5632	0.23%
13	0.5193	0.5299	2.04%
14	0.5689	0.5646	-0.76%
15	0.5187	0.5203	0.31%
16	0.3974	0.4006	0.81%
17	0.4298	0.4262	-0.84%
18	0.4999	0.5052	1.06%
19	0.6497	0.6533	0.55%
20	0.6408	0.6389	-0.30%
Relative error absolute value average			0.827%

TABLE 9. Test results of QAPSO-SVM evaluation model.

Sample number	Expected output value	QAPSO-SVM test output value	QAPSO-SVM relative error
1	0.3911	0.3922	0.0028
2	0.4309	0.4311	0.0005
3	0.5067	0.5044	-0.0045
4	0.7051	0.7088	0.0052
5	0.6429	0.6394	-0.0054
Relative error absolute value average			0.0037

method is superior to the other four methods in training time and testing time.

3) ERROR ANALYSIS

According to the index data of 5 regions in Ningxia in 5 years, 20 items were used as training data for parameter estimation and model establishment. The remaining 5 items were used as test data to detect the difference between the evaluation value and the actual value. The relative error is used to analyze the error. Then, Mean Absolute Error (MAE), Mean Square Error (MSE) and Normalized Mean Square Error (NMSE) were used to evaluate the performance. Its definition is as follows:

$$MSE = \frac{1}{n}\sum_{i=1}^{n}\left(x_i - \hat{x}_i\right)^2 \tag{34}$$

TABLE 10. Comparison of QAPSO-SVM, QPSO-SVM, PSO-SVM, GA-SVM and SVM.

Model	Training time(ms)	Testing time (ms)
QAPSO-SVM	166	36
QPSO-SVM	253	45
PSO-SVM	402	73
GA-SVM	462	88
SVM	520	105

TABLE 11. Test error analysis results of five evaluation models.

Sample number	QAPSO-SVM relative error	QPSO-SVM relative error	PSO-SVM relative error	GA-SVM relative error	SVM relative error
1	0.0028	0.0125	-0.0115	0.0095	0.0601
2	0.0005	-0.0246	0.0007	-0.0053	-0.0107
3	-0.0045	0.0069	0.0022	-0.0073	0.0089
4	0.0052	0.0070	0.0120	-0.0118	0.0070
5	-0.0054	0.0011	0.0011	-0.0104	0.0027
Relative error absolute value average	0.0037	0.0104	0.0055	0.0089	0.0179

$$MAE = \frac{1}{n}\sum_{i=1}^{n}\left|x_i - \hat{x}_i\right| \tag{35}$$

$$NMSE = \frac{\sum_{i=1}^{n}\left(x_i - \hat{x}_i\right)^2}{\sum_{i=1}^{n}\left(x_i - \bar{x}_i\right)^2} \tag{36}$$

where, n is the number of samples; $\bar{x}$ is the average value of the adaptability evaluation of actual distribution network. x_i is the adaptability evaluation value of the i th actual distribution network; $\hat{x}_i$ is the evaluation value of the adaptability of the i th distribution network. Obviously, the smaller the MAE and NMSE values are, the higher the evaluation accuracy is.

The results of the five algorithms are calculated for 10 times, and the average value of the results is taken. According to the output values of the five test samples, the analysis results are shown in Tab.11 and Fig.5.

The test output values of five models are given in this paper. This is shown in Tab.11. It is found that in the 5 groups of test samples, the relative error interval between the test output value and the expected output value of QAPSO-SVM model is [−0.0054, 0.0028], and the mean absolute value of the relative error of QAPSO-SVM is 0.37%. By observing Fig. 5, it is found that among the five test sample points, the relative error of QAPSO-SVM in the three sample points is the smallest, and the fluctuation range of the error is the smallest, with a small error fluctuation range. Therefore, the QAPSO-SVM evaluation model has advantages in both the point evaluation error and the interval error, which shows the high evaluation accuracy of this model.

In addition, the relative error range of QPSO-SVM is [−0.0246, 0.0125], and the mean absolute value of relative error is 0.0104. The relative error range of PSO-SVM is [−0.0115, 0.0120], and the mean absolute value of relative

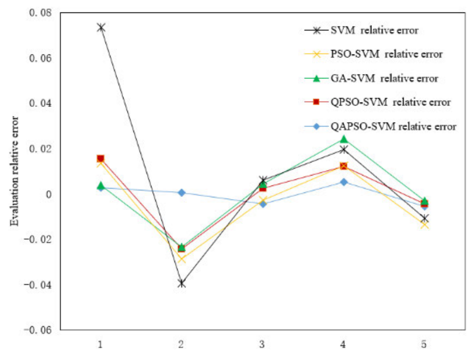

FIGURE 5. Comparison of relative errors of five models.

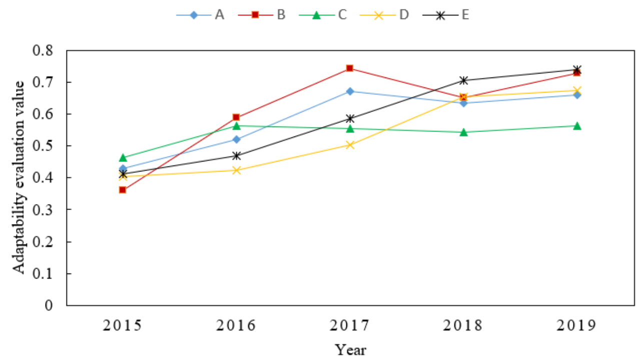

FIGURE 6. Evaluation value of adaptability of distribution network in 5 regions.

TABLE 12. Evaluation performance index of various methods.

Evaluation of error	QAPSO-SVM	QPSO-SVM	PSO-SVM	GA-SVM	SVM
MAE	0.0022	0.0049	0.0052	0.0030	0.0079
MSE	0.0011	0.0026	0.0024	0.0019	0.0050
NMSE	0.0211	0.0480	0.0463	0.0349	0.0945

error is 0.0055. The relative error interval of GA-SVM is [−0.0118, 0.0095], and the mean absolute value of relative error is 0.0089. By comparing the errors of GA-SVM and PSO-SVM, it can be seen that for SVM, the error of PSO optimization is less than that of GA optimization, which is also the reason why particle swarm optimization algorithm is given priority to the optimization of support vector machine.

In order to further illustrate the prediction effect of this method, Tab.12 makes a quantitative analysis and comparison of the specific evaluation performance indexes of the five evaluation models. We found that among the five different performance indexes of evaluation accuracy, the MAE, MSE and NMSE of QAPSO-SVM method were all lower than those of other methods. This indicates that the QAPSO-SVM evaluation model has higher evaluation accuracy compared with the existing four methods.

VI. ANALYSIS OF THE EVALUATION RESULTS OF THE ADAPTABILITY OF THE DISTRIBUTION NETWORK

In order to more intuitively analyze the evaluation results of distribution network adaptability in five regions in five years, the results were analyzed from two perspectives, namely, adaptability evaluation results and sensitivity analysis.

A. ANALYSIS OF ADAPTABILITY OF DISTRIBUTION NETWORK IN 5 REGIONS

In order to compare the adaptability evaluation results of distribution networks in five regions more intuitively, the adaptability results of distribution networks in five regions in the past five years are shown in Fig.6.

As shown in Fig.6, from 2015 to 2019, the ranking of adaptability evaluation value of distribution networks in the five regions has changed. Among them, the evaluation values of D and E have been on the rise continuously in the past five years, and both of them have maintained an increasing trend. This indicates the overall improvement of the adaptability of its distribution network. In addition, the adaptability of distribution network in Region E ranked first in 2019. The evaluation value of A and B maintained an upward trend from 2015 to 2017, but since 2017, it has dropped sharply. The main reason is that the reliability and load rate of the distribution network have dropped sharply due to the connection of distributed energy to the grid. However, with improvements in technology and new energy efficiency throughout the year, 2019 is worth an upgrade. The overall adaptability evaluation value of distribution network in C region is relatively stable. Area C is characterized by solid and reliable network frame, intelligent equipment table, good operation and maintenance effect, and high degree of technological innovation. Therefore, the evaluation value of C region has remained stable for 5 years. However, as distributed energy is connected to the grid, the new energy utilization rate in C region is not high, and its advantages gradually decline. Therefore, the comprehensive ranking of its distribution network adaptability evaluation value decreases year by year. As shown in Fig.6.

B. SENSITIVITY ANALYSIS

Sensitivity analysis method is used to evaluate the uncertainty in the process of adaptability evaluation of distribution networks in different regions. The adaptability of distribution network includes all the first level indicators are analyzed one by one. In this paper, the weight of distribution network adaptability evaluation index system is studied. When the weight changes to a certain extent, whether the comprehensive effect of the adaptability evaluation of distribution networks in each region changes in 2019 is analyzed. Here, the weight range of the established first-level indicators is [0, 1]. As shown in Fig.7.

As can be seen from Fig.7(a), the adaptability evaluation value of distribution networks in regions A and C decreases with the increase of reliability index weight, showing an inverse change. The evaluation values of B, D and E change in the same direction as the weight of reliability index. There are two changes in the overall order, one at the two vertical blue lines. At this time, the ranking of regions A, B and C

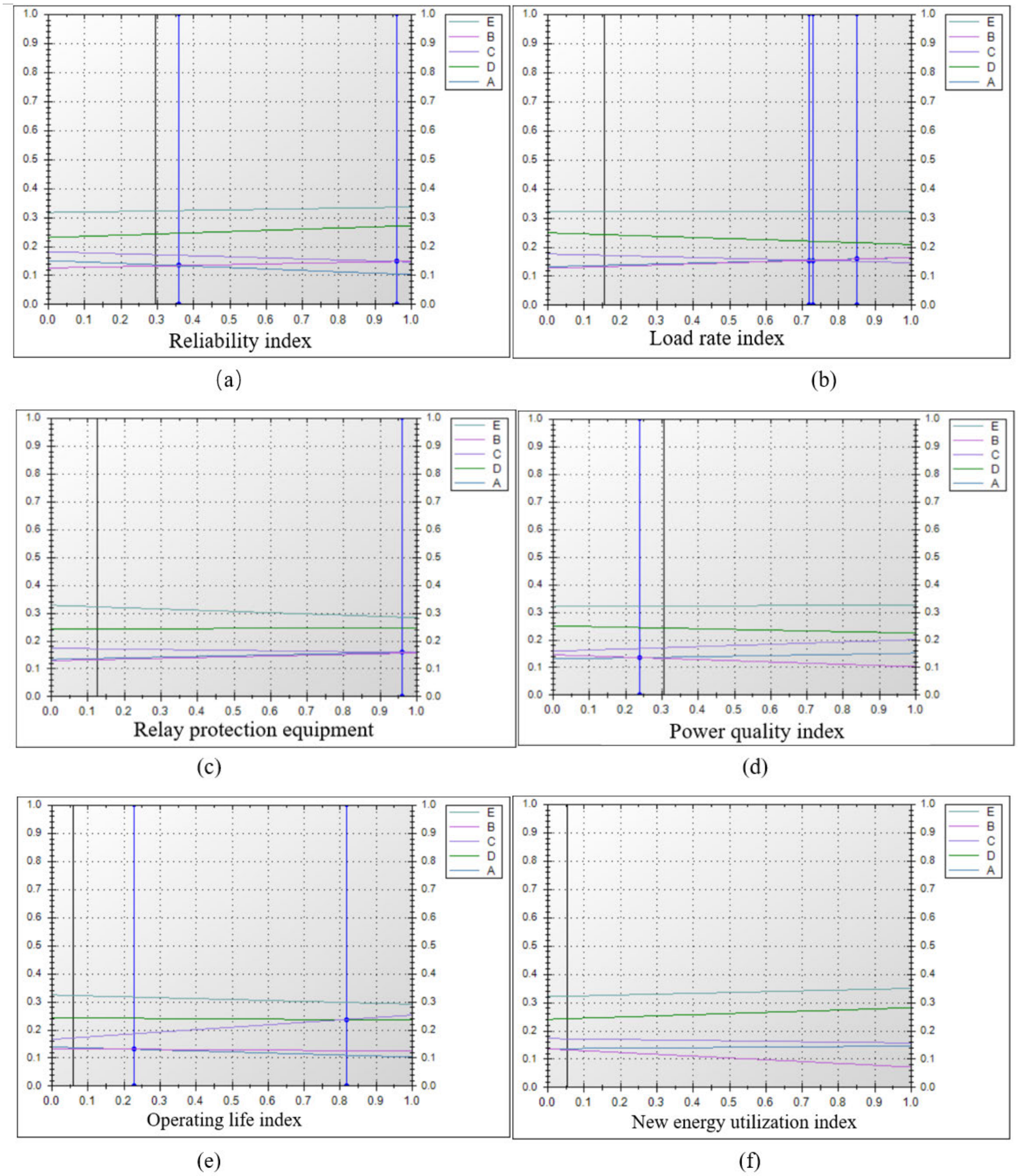

FIGURE 7. Sensitivity analysis of primary indicator.

changed. Therefore, the adaptability of distribution network in each region is more sensitive to the reliability index.

According to Fig.7(b), The evaluation value of distribution network adaptability in A, B and E varies in the same direction with the weight of load rate index. The evaluation values of C and D regions changed in the opposite direction with the weight of the load rate index. At the same time, the order changes three times, at the blue line. Therefore, the adaptability of distribution network in each region is more sensitive to load rate index.

According to Fig.7(c), The adaptability evaluation value of distribution network in A, B and D regions changes in the same direction as the weight of current index. The evaluation value of C and E changes in the opposite direction with the weight of current index. There is a change in the overall order, as shown by the blue line. Therefore, the adaptability of distribution network in each region is more sensitive to the current index.

According to Fig.7(d), The evaluation value of distribution network adaptability in regions A, C and E changes in the same direction as the weight of power quality index; the evaluation value in regions B and D changes in the opposite direction as the weight of power quality index. In terms of the overall order, there is a change, which is shown in the blue line. Therefore, the adaptability of distribution network in each region is more sensitive to power quality.

According to Fig.7(e), The adaptability evaluation value of distribution networks in the four regions A, B, D and E changes in the same direction as the weight of operating life index. The evaluation value of C region changes in the opposite direction with the weight of the operating life index. In terms of the overall ranking, there are two changes in the ranking, which are shown in the blue line. Therefore, the adaptability of distribution network in each region is more sensitive to the operating life index.

According to Fig.7(f), The adaptability evaluation value of distribution networks in A, D and E regions changes in the same direction as the weight of new energy utilization index. The evaluation value of B and C region changes in the opposite direction with the weight of new energy utilization rate index. There is no change in overall ordering. Therefore, the adaptability of distribution networks in different regions is less sensitive to the new energy utilization efficiency index.

In summary, through the sensitivity analysis of the first-level index of the adaptability index system of the distribution network, the following findings are found. The adaptability of distribution network is more sensitive to reliability index, load rate index, power supply index, power quality index and operating life index, but less sensitive to new energy utilization efficiency index. At the same time, in all the regions, D and E distribution network adaptability has superior adaptability evaluation value. It also verifies the effectiveness of the adaptability rating index system of distribution network. At the same time, it proves that the QAPSO-SVM evaluation model adopted in this paper has good robustness in the adaptability evaluation of distribution network.

C. RELATED SUGGESTIONS

(1) Establish a sound distributed power access management system, clarify relevant standards, and ensure the reasonable operation of distributed power.

(2) Perfect the distributed power management system, implement the responsibility mechanism, and ensure the safe operation of distributed power.

(3) Actively carry out research and development of distributed power supply and establish expert group.

(4) Strengthen the control of distributed power supply and do a good job in the monitoring of power quality of distribution network.

(5) Access schemes should be analyzed in combination with specific lines to better guarantee the economic operation, stable operation and safe operation of distribution networks.

(6) In order to reduce the active power loss of distribution wires and effectively improve the utilization efficiency of distributed power supply. The distributed source should be located near the end of the load or distribution line. The final realization of local consumption.

VII. CONCLUSION

This paper first gives a new definition of the adaptability of distribution network with access to distributed energy. At the same time, 16 indexes are combined in this paper for the first time to establish a scientific and reasonable evaluation index system of distribution network adaptability. The combined weight method is used to determine the index weight. At the same time, a distribution network adaptability evaluation model based on QAPSO-SVM is constructed. Then, through case analysis, compare the five models of QAPSO-SVM, QPSO-SVM, GA-SVM, PSO-SVM and SVM. Compared with QPSO-SVM, PSO-SVM, GA-SVM and SVM, QAPSO-SVM can improve the training time by 34.4%, 58.7%, 64.1% and 68.1%, respectively. The test time can be increased by 20%, 50.7%, 59.1% and 65.7% respectively. The MAE, MSE and NMSE of QAPSO-SVM were 0.22%, 0.11% and 2.11%, respectively, which were better than the other four models. It is proved that the model has strong applicability and feasibility in the adaptability evaluation of distribution network. Finally, through sensitivity analysis, it is concluded that the adaptability of distribution network is more sensitive to reliability index, load rate index, power supply index, power quality index and operating life index, but less sensitive to new energy utilization efficiency index. The research of this paper can guide the standardization work of distribution network planning and design in the future, and provide some basis for the decision maker in the future.

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