

**ARTICLE**

Sustainability Intelligent Evaluation of Regional Microgrid Interconnection System Based on Combination Entropy Weight Rank Order-TOPSIS and NILA-KELM

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ABSTRACT

Sustainability evaluation of regional microgrid interconnection system is conducive to a profound and comprehensive understanding of the impact of interconnection system projects. In order to realize the comprehensive and scientific intelligent evaluation of the system, this paper proposes an evaluation model based on combination entropy weight rank order-technique for order preference by similarity to an ideal solution (TOPSIS) and Niche Immune Lion Algorithm-Extreme Learning Machine with Kernel (NILA-KELM). Firstly, the sustainability evaluation indicator system of the regional microgrid interconnection system is constructed from four aspects of economic, environmental, social, and technical characteristics, and the evaluation indicators are explained. Then, the classical evaluation model based on TOPSIS is constructed, and the entropy weight method and rank order method (RO) are coupled to obtain the indicator weight. The niche immune algorithm is used to improve the lion algorithm, and the improved lion algorithm is used to optimize the parameters of KELM, and the intelligent evaluation model based on NILA-KELM is obtained to realize fast real-time calculation. Finally, the scientificity and accuracy of the model proposed in this paper are verified. The model proposed in this paper has the lowest RMSE, MAE and RE values, indicating that its intelligent evaluation results are the most accurate. This study is conducive to the horizontal comparison of the overall performance of regional microgrid interconnection system projects, helps investors to choose the most promising project scheme, and helps the government to find feasible project.

KEYWORDS

Regional microgrid interconnection system; intelligent evaluation of sustainability; combination entropy weight rank order; TOPSIS; NILA; KELM



1 Introduction

Different from the traditional centralized power supply mode, the microgrid power supply mode is more flexible, and its unique duality of electricity and power supply can play a very important role in the power system [1]. When the distribution density of microgrid in a certain area is high, the interconnection between microgrids forms a regional microgrid interconnection system. As one of the effective means to realize smart grid, regional microgrid interconnection system has a positive role in cost-saving, environmental protection, social development and technological innovation [2]. With the increasing attention to sustainable development, more and more energy companies have begun to shift from the simple pursuit of economic growth in the past to the coordinated development of economy, environment, society, and technology [3]. Therefore, the sustainability evaluation of regional microgrid interconnection system is conducive to a profound and comprehensive understanding of the impact of various aspects of the interconnection system project. However, due to the particularity of its own structure, the regional microgrid interconnection system presents different characteristics from the traditional independent microgrid [4]. Therefore, how to evaluate the sustainability of regional microgrid interconnection system in all aspects to select the most investment potential of regional microgrid interconnection system project is also a focus of future research.

The definition of sustainability can be understood from four relevant dimensions: economy, environmental protection, technology, and society [5]. The concept has received increasing attention in the development of renewable energy projects [6]. However, compared with the independent microgrid structure, the regional microgrid interconnection system structure is more complex, and its characteristics are also different from those of a single microgrid [7]. At present, the research on the sustainability evaluation of regional microgrid interconnection systems is still quite limited, and most literature studies only focus on part of the sustainability benefits. Aghdam et al. [8] proposed a stochastic energy management method for a multi-microgrid system considering all network constraints, which was used to evaluate the influence of active power loss on each individual in energy management. The results show that incorporating active power loss into the objective function of energy management is helpful to reduce active power loss [8]. Zhang et al. [9] studied the online dynamic security assessment of the future distribution system under the framework of a multi-microgrid system. A new interface control strategy for ideal load sharing of the multi-microgrid systems is proposed, and the effectiveness of this strategy is verified by taking a multi-microgrid system as an example [9]. Wang et al. [10] proposed a series of new indicators and multistep performance evaluation methods to evaluate the performance of the multi-microgrid system from a quantitative perspective. The indicator system includes power generation permeability indicator, reliability indicator, and economic indicator. The practice has proved that the indicator system and multistep performance evaluation method are effective [10]. Most of the existing research literature focuses on measuring the reliability and economy of the independent microgrid system. In terms of reliability, some scholars have studied the reliability of microgrids from the aspects of equivalent power/load reliability indicator, off-grid operation reliability indicator, and microgrid benefit indicator [11]. In terms of economy, some literature studied the economy of microgrid systems from the aspects of overall operation benefit of microgrids, comprehensive evaluation indicator of social economy, and life cycle cost [12].

As a necessary link in the development and construction of regional microgrid interconnection system projects, sustainability evaluation is an important part of the whole project life cycle management process. Due to the development of regional microgrid interconnection systems in China is not yet mature, the research on the sustainability evaluation of regional microgrid interconnection systems is very limited. The performance of regional microgrid interconnection systems in environmental,

social, economic, and technological aspects has become the core concern of local governments and potential investors [13]. Therefore, the establishment of an effective sustainability evaluation model for regional microgrid interconnection systems can help investors to choose the most promising project scheme and help the government to find practical project performance improvement measures to attract more social investment by obtaining the various aspects of the sustainability benefits of different regional microgrid interconnection systems projects to achieve horizontal comparison of overall project performance.

The construction of the evaluation model has an important influence on the accuracy of evaluation. Ideal point order preference by similarity to ideal solution (TOPSIS) is a multi-objective decision-making method, which has been widely used in different areas of comprehensive evaluation research [14]. The research results show that this method can obtain a more reasonable and effective evaluation result that is suitable for practice. This method calculates the distance between the evaluation object and the positive ideal solution and the negative ideal solution for the multi-objective decision-making problem and sorts them accordingly [15]. The TOPSIS method can reflect the differences among various schemes. Compared with other methods, this method is more intuitive, and its evaluation results will not be affected by the number of indicators. The TOPSIS method can input all the evaluation indicator data into the evaluation calculation model to maximize the role of indicator data, which can fully reflect the impact of each evaluation indicator data on the evaluation results. Therefore, its evaluation performance is better than other methods, and it can output evaluation results closer to the real state of the project [16]. The determination of indicator weight in the TOPSIS model is particularly important and worthy of further discussion. The entropy weight method reflects the amount of information according to the information entropy of the evaluation indicator, so as to determine the weight of each indicator in the evaluation system, but sometimes the random interference of the data itself will lead to the lack of real reliability of the calculated weight [17]. The Rank order (RO) method can rank the normalized mean values of each indicator from large to small, and the weight obtained by rank can objectively reflect the influence degree of evaluation indicator on evaluation objects [18]. In this paper, the entropy weight method and RO are combined, and the combination entropy weight RO method is proposed, and the weight obtained is more realistic.

The extreme learning machine theory was proposed by Huang et al. in 2006, based on which the basic extreme learning machine, online sequential extreme learning machine, extreme learning machine with the kernel (KELM), and other related algorithms have been derived [19]. KELM is a single-layer feedforward neural network algorithm. Compared with the basic extreme learning machine (ELM) algorithm, it has a stronger ability to solve the regression prediction problem [20]. Compared with back propagation neural network (BPNN) and support vector machines (SVM), it has a faster calculation speed and greatly improves the generalization ability of the network when obtaining better or similar prediction accuracy [21]. The KELM algorithm has been proved to have excellent prediction performance in many fields [22], but its performance is vulnerable to the influence of penalty coefficient C and kernel parameter σ . For the problem that these two parameters are difficult to select, it is necessary to solve the problem with intelligent algorithms. Compared with other intelligent algorithms [23], the lion algorithm proposed by Rajakumar of B. R. has strong robustness in solving performance and the ability to search for better solutions. It is easy to be implemented in parallel and has fast convergence speed. However, in the process of multiple iterations of the lion swarm algorithm, individuals with large fitness in the population will form "inbreeding", resulting in premature convergence and reduced diversity [24]. Therefore, this paper decides to use the niche immune algorithm to improve the lion algorithm and apply the improved lion algorithm to optimize the parameters of KELM.

In summary, this paper constructs a regional microgrid interconnection system sustainability intelligent evaluation model based on combination entropy weight rank order-TOPSIS and NILA-KELM. The rest of the paper is arranged as follows. The second part designs the evaluation indicator system of regional microgrid interconnection system sustainability from four aspects of economic, environmental, social, and technical characteristics, and explains the evaluation indicators. The third part constructs the classical evaluation model based on the combination entropy weight rank order method and TOPSIS and constructs the intelligent evaluation model based on NILA optimized KELM. The fourth part selects practical cases to verify the accuracy and effectiveness of the model proposed in this paper. The fifth part summarizes the research results. The fifth part summarizes the research results.

2 Construction of the Evaluation Indicator System

2.1 Principle of Determining Evaluation Indicator

Establishing a scientific and reasonable evaluation indicator system is the premise of regional microgrid interconnection system sustainability evaluation. The established indicator system should include various factors that have a key impact on the sustainability of regional microgrid interconnection system. The evaluation indicator system should be established on the basis of the following selection principles [25]:

1. The comprehensive principle

The establishment of the evaluation indicator system aims to comprehensively measure the performance of various aspects involved in the regional microgrid inter-connection system project, so as to provide reference for potential investors to judge the advantages and disadvantages of the regional microgrid interconnection system project and the local government to formulate relevant policies. The Regional microgrid interconnection system project consists of multiple sub-microgrids, and each sub-microgrid contains a variety of distributed power, energy storage and other facilities. The operation management and related impacts of these system components will affect the benefit performance of regional microgrid interconnection system projects. The evaluation indicator system established in a specific environment should include economic impact, environmental impact and social impact. Therefore, to have a more profound and specific understanding of the research object, a more comprehensive evaluation indicator system should be established.

2. Hierarchical principle

The Hierarchical structure is one of the most widely used structures in both theory and practice among many benefit evaluation structures. Establishing an evaluation indicator system, hierarchical structure can systematically, accurately and comprehensively show the subordinate relationship and correlation between the sub-level evaluation indicator and each level.

3. Scientific principle

The selection of evaluation indicators should be based on the objective laws and related theories, supported by corresponding scientific theories, and studied from the perspectives of practical experience and theoretical knowledge. The selection of evaluation indicators should fully consider the objective environment, to scientifically express the essential characteristics of the research object.

4. Representative principle

The evaluation indicator system consists of a series of sub-level indicators at different levels. Using a large number of indicators to construct the evaluation indicator system may not necessarily improve

the accuracy of system evaluation. Therefore, representative indicators closely related to the research object should be selected to describe the characteristics of various aspects, fully reflecting the purpose and significance of the selection of indicators. If excessive evaluation indicators are selected in the research process, it may reduce and weaken the influence of important indicators and reduce the reliability of evaluation results.

5. Independence principle

The evaluation system is a hierarchical expression set of multiple representative single indicators. In the selection of indicators, repeated or highly correlated indicators should be avoided. Each indicator should be independent, and each indicator can express all aspects of the research problem from different perspectives, so as to improve the scientificity and effectiveness of the evaluation results.

2.2 Determination of Evaluation Indicators

This section takes the selection criteria of indicators listed in [Section 2.1](#) as the principle, and fully considers the objective environment of the project and the difficulty of data acquisition and other factors to construct the sustainability evaluation indicator system of regional microgrid interconnection system projects. Project sustainability can be defined from four related aspects: economy, environmental protection, technology and sociality. The constructed sustainability evaluation indicator system contains 15 sub-level evaluation indicators, as shown in [Table 1](#). Cost-type indicators are those where the smaller the value the better the evaluation result. Benefit type indicators are those where the larger the value of the index the better the evaluation result. The specific meaning of the indicators is as follows:

Table 1: Sustainability evaluation indicator system of regional interconnected microgrid system

Target level	Criterion layer	Project hierarchy	Indicator number	Indicator type I	Indicator type II
Sustainability benefit evaluation of regional microgrid interconnected multi-microgrid system	Economic indicators	Investment cost	E ₁	Quantitative	Cost
		Operation and maintenance costs	E ₂	Quantitative	Cost
		Payback period	E ₃	Quantitative	Cost
		The levelized cost of electricity	E ₄	Quantitative	Cost
	Environmental protection indicators	CO ₂ emission reduction	P ₁	Quantitative	Benefit
		PM2.5 emission reduction	P ₂	Quantitative	Benefit
		Polluted gas emissions	P ₃	Qualitative	Cost
		Space occupancy	P ₄	Quantitative	Cost
	Social indicators	Resident satisfaction	S ₁	Quantitative	Benefit

(Continued)

Table 1 (continued)

Target level	Criterion layer	Project hierarchy	Indicator number	Indicator type I	Indicator type II
		Job opportunities	S ₂	Qualitative	Benefit
		Poverty rate decreases	S ₃	Quantitative	Benefit
	Technical indicator	Technological innovation	T ₁	Qualitative	Benefit
		Electricity consumption reliability	T ₂	Quantitative	Benefit
		Renewable energy utilization ratio	T ₃	Quantitative	Benefit
		System expansibility	T ₄	Quantitative	Benefit

2.3 Explanation of Evaluation Indicators

2.3.1 Economic Indicators

The economic indicators mainly investigate the economic performance of regional microgrid interconnection system, including four sub-level indicators, namely construction cost, operation and maintenance cost, investment payback period and unit power cost.

1. Investment cost

The investment cost of the project mainly refers to the cost of obtaining land and related equipment in the initial construction process of the regional microgrid interconnection system project. Mainly includes land costs, equipment (such as wind turbines, photovoltaic panels, diesel generators, energy storage systems and related ancillary facilities) acquisition costs and labor costs.

2. Operation and maintenance costs

The operation and maintenance cost mainly refers to the cost needed to maintain the normal operation of the system and ensure the continuous operation of the equipment in the daily management of the regional microgrid interconnection system. Mainly includes the salary of operation management personnel, the cost of parts or spare parts for regular maintenance.

3. Payback period

The payback period of investment refers to the number of years used when the accumulated economic benefits of regional microgrid interconnection system projects are equal to the initial investment costs. Investment payback period is one of the most concerned economic indicators for project investors. By calculating the investment payback period, the time for capital recovery can be clarified, thereby reducing investment risks.

4. The levelized cost of electricity

The normalized electricity cost is an evaluation indicator for the net present value of unit electricity cost in the whole life cycle of the regional microgrid interconnection system project. From the perspective of the project life cycle, this indicator evaluates the economic benefits of regional microgrid interconnection system project, which is one of the important reference indicators in the energy industry.

2.3.2 Environmental Indicators

The development of the regional microgrid interconnection system has a certain degree of complexity in its environmental impact. On the one hand, wind power and photovoltaic power generation in the regional microgrid interconnection system are clean power sources, which are of positive significance to environmental protection; On the other hand, when the system is in the peak load period, the use of diesel generators equipped in the system for energy supply will produce carbon dioxide and polluting gases, adversely affecting the environment.

1. CO₂ emission reduction

Carbon dioxide emission reduction refers to the reduction of greenhouse gas emissions by the system through the use of renewable energy power plants in the life cycle of regional microgrid interconnection system, compared with the use of traditional power generation forms of thermal power plants. The reduction of carbon dioxide emissions is of positive significance to alleviate global warming. The reduction of carbon dioxide emissions is of positive significance to alleviate global warming.

2. PM_{2.5} emission reduction

PM_{2.5} emission reduction refers to the reduction of particulate matter less than 2.5 mm in diameter in the atmosphere through the use of renewable energy in the regional microgrid interconnection system compared with the use of traditional power generation in thermal power plants. This indicator is one of the key indicators to evaluate the quality of air quality.

3. Pollutant gas emission

The emission of polluting gases is mainly used to evaluate the emission of polluting gases generated by burning fossil fuels such as sulfur dioxide and nitrogen oxides during the life cycle of regional microgrid interconnection system when the load is in the peak period when the diesel generator in the system works. Pollutant gas emissions will have a bad impact on the environment, such as acid rain, which will damage the ecology and seriously affect the sustainability of the system.

4. Space occupancy

Space occupancy refers to the relevant equipment units in the regional microgrid interconnection system, such as wind turbines, photovoltaic panels, diesel generators, energy storage batteries, and the layout of corresponding transmission lines and control equipment will occupy a certain user area, which will have a certain impact on the residents and the surrounding environment and landscape.

2.3.3 *Social Indicators*

The implementation of the regional microgrid interconnection system project can bring about positive social effects, such as increasing residents' satisfaction, increasing employment opportunities, and reducing poverty rates.

1. Increase resident satisfaction

Residents' satisfaction is the degree of satisfaction to local residents through the use of regional microgrid interconnection system for energy supply. The improvement of residents' satisfaction is one of the necessary indicators for system implementation. The level of residents' satisfaction has a direct impact on their enthusiasm to participate in regional microgrid interconnection system and project implementation.

2. Increase employment opportunities

Increased employment opportunities refer to direct and indirect employment opportunities arising from the implementation and management of regional microgrid interconnection system projects. Direct employment refers to the staff created by the project itself, such as those engaged in manufacturing, installation or operation and maintenance of the system. Indirect employment refers to the increase in job opportunities for relevant personnel who provide investment and knowledge for regional microgrid interconnection systems, such as banks providing funds for project construction and suppliers providing necessary materials.

3. Reduce poverty rate

The construction and implementation of regional microgrid interconnection system can not only create local employment opportunities, but also play a positive role in promoting local economic development. These impacts have a positive impact on poverty reduction, particularly in remote areas. Current society is paying more and more attention to human development. On 03 November 2013, the concept of "targeted poverty alleviation" first proposed poverty reduction as a policy. Therefore, taking poverty reduction as a project evaluation indicator has responded well to the Government's policy call.

2.3.4 *Technical Indicators*

As an emerging technology, the construction of a new regional microgrid interconnection system project can actively explore the actual practice of the project, promote the accumulation of experience and theory at the technical level, and provide effective reference for the gradual maturity of relevant technologies, which is conducive to the further development of intelligent power grid layout.

1. Technological innovation

The construction, operation and management technology of regional microgrid interconnection system is not fully mature. The development of new regional microgrid interconnection system will play a positive role in promoting the accumulation of relevant experience and is conducive to the formation of relevant technological innovation.

2. Electricity consumption reliability

The intermittent of renewable energy in regional microgrid interconnection system poses a serious challenge to the reliability of users' electricity consumption and the frequent access of renewable energy will also threaten the stability of power system. The energy storage system in the regional microgrid interconnection system and the power mutual assistance mechanism in the system can effectively buffer the intermittent characteristics of renewable energy, improve the reliability of power supply, reduce the

dependence of regional microgrid interconnection system on large power grid, and effectively improve the safety and stability of power system.

3. Renewable energy utilization ratio

Due to the randomness of renewable energy power output, a single microgrid has certain limitations on the consumption ability of renewable energy. Through the regional microgrid interconnection system, the excess renewable energy power that cannot be consumed in the sublevel microgrid can be traded to the sublevel microgrid with energy shortage in the form of mutual assistance within the system, so as to reduce the operation cost of the supply and demand sides, improve the utilization rate of renewable energy, and reduce the interference on the distribution network side.

4. System expansibility

Regional microgrid interconnection system is a joint optimal dispatching system composed of several separate sub-microgrids. With the continuous development of power system intelligence, there may be new sub-level microgrids merging into the regional microgrid interconnection system in the future, or realizing system-level interconnection between regional microgrid interconnection systems. In addition, in special cases, such as system failures, in order to ensure the stability of the overall operation of the interconnected microgrid system, the system structure needs to have the possibility of flexible integration and removal of the sub-level microgrid.

3 Construction of Evaluation Model

3.1 In-Line Style

3.2 Weight Calculation Model Based on Combination Entropy Weight Rank Order Method

3.2.1 RO Method

The specific steps of RO method are as follows [26]:

1. Data normalization processing

There are various types of indicators, including maximal indicators, minimal indicators and interval indicators. Maximal indicators reflect the development trend of evaluation indicators. The larger the indicator, the higher the level of sustainable development; On the contrary, minimal indicators indicate that the larger the indicator, the lower the level of sustainable development. To facilitate the calculation and analysis, the values of each index must be consistent, so as to facilitate the comparison and selection of each scheme, and then get the evaluation results of each scheme. After analyzing the index system constructed in this paper, it is found that all evaluation indexes are maximal indicators.

Since the attribute and quantity level of the original data are quite different, it is necessary to normalize each index. Set the evaluation sample set as $\{x_{ij}|i = 1, 2, \dots, m; j = 1, 2, \dots, n\}$. The calculation formula is as follows:

$$x'_{ij} = \frac{x_{ij} - \min\{x_{ij}\}}{\max\{x_{ij}\} - \min\{x_{ij}\}} \quad (1)$$

where x'_{ij} is the normalized value of x_{ij} ; $\max\{x_{ij}\}$, $\min\{x_{ij}\}$ are the maximum and minimum values of the sample set, respectively.

2. The average value of each evaluation index sample $\bar{x}_i (i = 1, 2, \dots, m)$ is calculated by x'_{ij} and sorted by size, with the serial number R'_i . The maximum number corresponds to number m , and the minimum number corresponds to number 1. Order number R'_i is rank, and the greater the value, the greater the impact of the index on the evaluation object.
3. Calculate the weight of each index $\omega_{(1)i} (i = 1, 2, \dots, m)$ namely:

$$\omega_{(1)i} = R'_i / \sum_{i=1}^m R'_i \quad (2)$$

3.2.2 Entropy Weight Method

Calculate the information entropy and weight of each indicator separately [27], namely:

$$k = 1 / \ln n \quad (3)$$

$$f_{ij} = x'_{ij} / \sum_{j=1}^n x'_{ij} \quad (4)$$

$$H_i = - \left(k \sum_{j=1}^n f_{ij} \right) \ln f_{ij} \quad (5)$$

$$\omega_{(2)i} = (1 - H_i) / \left(m - \sum_{i=1}^m H_i \right) \quad (6)$$

where, when $f_{ij} = 0, f_{ij} \ln f_{ij} = 0$.

3.2.3 Combined Weight Calculation

Combined weights ω_i calculated by weights $\omega_{(1)i}$ and $\omega_{(2)i}$:

$$\omega_i = \omega_{(1)i} \omega_{(2)i} / \sum_{i=1}^m \omega_{(1)i} \omega_{(2)i} \quad (7)$$

3.3 TOPSIS

After the weight value of the evaluation index is obtained by the combination weight calculation method mentioned above, the sustainability of the regional microgrid interconnection system project can be evaluated and analyzed by the ideal point sorting method. The specific steps are as follows [28]:

1. Weighted processing of evaluation data

According to the original evaluation data, the weighted normalization matrix needed for the operation of the evaluation model can be obtained by the following formula:

$$R = \begin{pmatrix} P_{11}w_1 & \dots & P_{1n}w_n \\ \vdots & \ddots & \vdots \\ P_{m1}w_1 & \dots & P_{mn}w_n \end{pmatrix} = \begin{pmatrix} r_{11} & \dots & r_{1n} \\ \vdots & \ddots & \vdots \\ r_{m1} & \dots & r_{mn} \end{pmatrix} \quad (8)$$

where, m refers to the evaluation index level, n refers to the number of evaluation indexes.

2. Obtaining positive ideal solution and negative ideal solution by operation

The positive ideal solution refers to the hypothetical value of the optimal value in the ideal situation, while the negative ideal solution refers to the virtual solution of the worst value. The specific calculation formula is:

$$r_j^+ = \{(\max_{1 \leq j \leq m} r_{ij} | j \in J_1), (\min_{1 \leq j \leq m} r_{ij} | j \in J_2) | i = 1, 2, \dots, m\} \tag{9}$$

$$r_j^- = \{(\min_{1 \leq j \leq m} r_{ij} | j \in J_1), (\max_{1 \leq j \leq m} r_{ij} | j \in J_2) | i = 1, 2, \dots, m\} \tag{10}$$

In the above formula, J_1 refers to the set of indicators that the larger the value is, the better the evaluation result is, namely, the so-called set of benefit indicators. V^+ refers to the set of positive ideal solution and negative ideal solution of each index; J_2 refers to the set of indicators that the smaller the value is, the better the evaluation results are, that is, the so-called cost-based indicator set, V^- refers to the set of positive and negative ideal solutions of each indicator in this set.

After the above steps, the Euclidean distance can be calculated according to the following formula:

$$d_1^+ = \sqrt{\sum_{j=1}^n (r_{ij} - r_j^+)^2} \quad (i = 1, 2, \dots, m) \tag{11}$$

$$d_1^- = \sqrt{\sum_{j=1}^n (r_{ij} - r_j^-)^2} \quad (i = 1, 2, \dots, m) \tag{12}$$

3. Calculating relative approach degree

Relative approach degree is calculated according to the following formula:

$$C_i = \frac{d_i^+}{d_i^+ + d_i^-} \quad (i = 1, 2, \dots, m) \tag{13}$$

In the calculation process discussed above, the distance between each index and positive and negative ideal solutions in the evaluation index system can be calculated, and the corresponding Euclidean distance represents the degree of closeness of the sustainability and ideal level of the regional microgrid interconnection system project. Therefore, the sustainability of regional microgrid interconnection system projects can be described by the operational distance and then sorted by the calculated distance. The smaller the distance is, the closer the sustainability of the regional microgrid interconnection system project is to the ideal degree. At the same time, it indicates that the regional microgrid interconnection system project has better sustainability and the rank ordering will be at the top.

3.3.1 Lion Algorithm (LA)

LA is a bionic algorithm based on the social behavior of lions, which was proposed by Rajakumar of B. R. in 2012 [29]. The LA realizes the iteration and generation of the optimal solution through the breeding and evolution of territorial lions or the defense competition of territorial lions against mobile lions. Each lion represents a solution. The solution is continuously optimized through the change of the lion population, and the optimal solution is finally generated. The LA simulates the social behavior of the lion group. The main steps include the generation of the initial population, mating variation, territorial defense, and territorial takeover. The algorithm optimizes the objective function through continuous iteration and search, and finally obtains the optimal solution. The objective function is set as:

$$\min f(x_1, x_2, \dots, x_n), (n \geq 1) \quad (14)$$

1. Generate population

In the initial stage of the algorithm, the lion group is initialized as $2n$ lion and divided into two groups equally to obtain a candidate population. Where, the male lion structure is $A^m = [\psi_1^m, \psi_2^m, \psi_3^m, \dots, \psi_l^m]$, the female lion structure is $A^f = [\psi_1^f, \psi_2^f, \psi_3^f, \dots, \psi_l^f]$, and l is the length of the solution vector.

2. Mating

In the process of iteration and searching for the optimal solution, mating is a very effective method. It can generate new solutions through existing solutions. Mating operations achieve the purpose of updating the lion group and maintaining the stability of the lion group by crossing, mutation, clustering, killing sick, weak cubs and other steps.

The mating step introduces the crossover method based on double probabilities (crossover with two different probabilities).

By mating, the generated A^m and A^f produce new $A^{cub} = [\psi_1^{cub}, \psi_2^{cub}, \psi_3^{cub}, \dots, \psi_l^{cub}]$ offspring. By randomly selecting two crossing points ψ_i^m and ψ_j^f for double probability crossover, four baby groups $A_{1\sim4}^{cub}$ can be generated.

Mutation operation is to use probability for random mutation to produce pups. After the crossover and mutation were completed, the number of cub species was 8. Clustering uses the K-means method to group the existing 8 solutions into gender groups: male cubs (A^{m_cub}) and female cubs (A^{f_cub}).

Finally, by testing the health status (or target), kill a larger group of thin individuals to ensure the balance of the two groups of cubs, and finally achieve the purpose of renewing the population. And after the population update is completed, the age of the cubs is initialized to 0.

3. Territorial defense

In the breeding process of lion groups, they will be attacked by nomadic lions. At this point, in order to protect the cubs and continue to occupy the territory, the lion will defend the attack of the nomadic lions, as shown in Fig. 1.

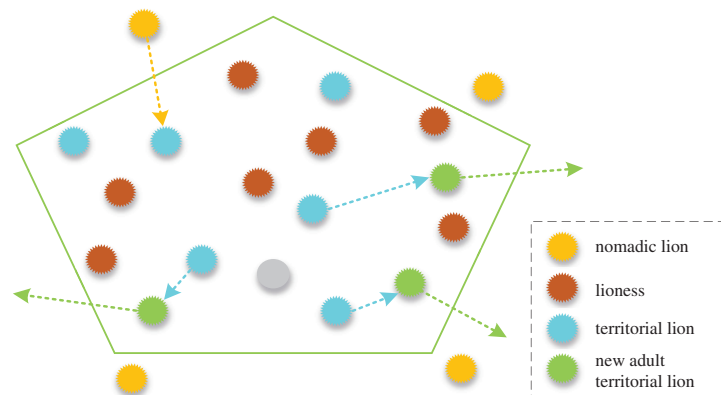


Figure 1: Lion defense illustration

In the process of territorial defense, first use the method of generating territorial lions to generate nomadic lions ψ^{nomad} , use the new solution (ψ^{nomad}) to attack the male lions (ψ_i^m), if the new solution is better, compare it with the solution of the entire lion group; If the new solution is still better, this solution (ψ^{nomad}) will replace the original lion (ψ_i^m). The new lion will continue to mate, and the original lion and cub will be killed; otherwise the original lion will continue the territorial defense and the cub will grow up to one year old until the cub becomes an adult.

Let $f(\cdot)$ be the objective function, $f(\psi^{pride})$ is the value of the entire population, the calculation formula is as follows:

$$f(\psi^{pride}) = \frac{1}{2(1 + \|\psi^{m_cub}\|)} \left\{ f(\psi^m) + f(\psi^f) + \frac{age_{mat}}{age_{cub} + 1} \sum_{k=1}^{\|\psi^{m_cub}\|} \frac{f(\psi_k^{m_cub}) + f(\psi_k^{f_cub})}{\|\psi^{m_cub}\|} \right\} \quad (15)$$

where, $f(\psi^m)$ and $f(\psi^f)$ are the values of male and female lions, $f(\psi^f)$ and $f(\psi_k^{f_cub})$ are the values of male and female cubs, $\|\psi^{m_cub}\|$ represents the number of male cubs in the population and age_{mat} is the age at which mating requirements are met.

4. Territorial takeover

In the territorial takeover stage, the best solution between the female lion and the male lion is searched for, replacing the inferior solution, and mating until the termination conditions are reached. The replacement process is as follows:

First follow the following criteria:

$$f(\psi_{best}^m) < f(\psi_{pride}^m), \psi_{best}^m \neq \psi_{pride}^m, \psi_{pride}^m = \{\psi^m, \psi^{m_cub}\} \quad (16)$$

$$f(\psi_{best}^f) < f(\psi_{pride}^f), \psi_{best}^f \neq \psi_{pride}^f, \psi_{pride}^f = \{\psi^f, \psi^{f_cub}\} \quad (17)$$

Choose the best male lion (ψ_{best}^m) and the best female lion (ψ_{best}^f).

Let κ be the breeding number and $\kappa_{strength}$ the optimal breeding ability of a female lion, usually set to 5, and gradually increase by one with the mating behavior of the lion group (set to 0 when the lion group is initialized). If the lioness is replaced, κ is initialized to 0. If the original lioness is replaced, add up on the original basis.

After completing the above steps, return to Step 2 until the termination condition. The best lion in the repeating population of the whole process is selected as the optimal solution.

3.3.2 Niche Immune Lion Algorithm (NILA)

Lion swarm algorithm is a parallel search method that does not depend on specific problems. It has the characteristics of self-adaptability, group search and heuristic random search. However, in the process of multiple iterations, the individuals with large fitness in the population will form ‘inbreeding’, resulting in premature and reduced diversity. To solve this problem, the niche immune algorithm is introduced to limit the excessive replication of similar individuals, so as to ensure the diversity of population. The detailed steps of niche immune algorithm are shown in reference [30]. The following is the improvement process of lion swarm algorithm based on niche immune thought.

1. In the iteration, each certain algebra dl is centered on the position of each lion, and M lion is cloned according to the size of its objective function value. The cloning formula is as follows:

$$M_j = M_{\max} \times \left(1 - \frac{\rho_j}{\sum_{j=1}^N \rho_j}\right) \quad (18)$$

In the formula, M_j is the number of clones of the j lion, M_{\max} is the maximum number of clones, and take 40 here, ρ_j as the objective function value of the j lion.

2. After cloning, do single parent mutation for M lion, for the lion with lower objective function value, use monosexual reproduction lion to mutation operation, the mathematical formula is as follows:

$$x_{i+1} = x_i + r \times \text{randn}(1) \quad (19)$$

$$r = \frac{2 \times P_{\max}}{N}, \quad (20)$$

In the formula, x_i is the lion individual, x_{i+1} is the offspring population after parthenogenesis, P_{\max} is the maximum position of the lion, N is the number of lion.

3. After cloning and mutating the lion, M mutating lion and this lion are selected, and the lion with high objective function value is selected as the new lion.

3.4 Extreme Learning Machine with Kernel

First, briefly explain the neural network construction mechanism of the basic ELM algorithm, and its neural network function is as follows [31]:

$$g(x) = h_i(x) \cdot \beta_i \quad (21)$$

where: $g(x)$ is the network output value, $h_i(x)$ is the output of the i – th hidden layer neuron corresponding to the input x ; β_i is the connection weight between the i – th hidden layer neuron and the output neuron value.

ELM ensures the accuracy of regression prediction by minimizing the output error, as shown below:

$$\lim_{L \rightarrow \infty} \|g(x) - g_o(x)\| = \lim_{L \rightarrow \infty} \left\| \sum_{i=1}^L \beta_i h_i(x) - g_o(x) \right\| = 0 \quad (22)$$

where: L is the number of hidden layer neurons; $g_o(x)$ is a function to be predicted for the target value.

At the same time, ELM algorithm ensures the generalization ability of neural network by minimizing the output weight β . usually β takes its least square solution; the calculation method is as follows:

$$\begin{aligned} \beta &= H^+ O = H^T (HH^T)^{-1} O \\ &= H^T \left(\frac{1}{C} + HH^T \right)^{-1} O \end{aligned} \quad (23)$$

In the formula: H is the hidden layer matrix of neural network; H^+ is the generalized inverse matrix of H matrix; O is the prediction target value vector. According to ridge regression theory, by increasing the normal number $1/C$, the results will be more stable and have better generalization ability.

For KELM algorithm, the kernel function is introduced to obtain better regression prediction accuracy. Mercer's condition is used to define the kernel matrix, as follows:

$$\begin{cases} \Omega_{ELM} = HH^T \\ \Omega_{ij} = h(x_i) \cdot h(x_j) = K(x_i, x_j) \end{cases} \quad (24)$$

The kernel matrix Ω replaces the random matrix HH^T in ELM, and uses the kernel function to map all input samples from the n-dimensional input space to the high-dimensional hidden layer feature space. After the kernel parameter setting is completed, the mapping value of the kernel matrix Ω is a fixed value. Kernel functions, including RBF kernel functions, linear kernel functions, polynomial kernel functions, etc., are usually set as RBF kernels:

$$K(\mu, \nu) = \exp[-(\mu - \nu)^2/\sigma] \quad (25)$$

The parameter $1/C$ is added to the main diagonal in the unit diagonal matrix HH^T so that the characteristic root is not zero, and then the weight vector β^* is obtained. This makes ELM more stable and its generalization is better. At this time, the output weight of the ELM network becomes:

$$\beta^* = H^T(I/C + HH^T)^{-1}O \quad (26)$$

where, I is the diagonal matrix; C is the penalty coefficient, used to weigh the ratio between structural risk and empirical risk. HH^T is generated by mapping input samples through a kernel function.

From the above formula, the output of the KELM model is:

$$\begin{aligned} f(x) &= h(x)H^T(I/C + HH^T)^{-1}O \\ &= \begin{bmatrix} K(x, x_1) \\ \vdots \\ K(x, x_N) \end{bmatrix}^T (I/C + \Omega_{ELM})^{-1}O, \end{aligned} \quad (27)$$

In the kernel-based KELM algorithm, the specific form of the feature mapping function $h(x)$ of the hidden layer node is not specifically given, but the value of the output function can be obtained by knowing the specific form of the kernel function. At the same time, because the kernel function directly adopts the form of inner product, there is no need to set the number of hidden layer nodes when solving the output function value, so there is no need to set the initial weight and bias of the hidden layer.

3.5 Evaluation Process Based on Combined Entropy Weight Rank Order-TOPSIS and NILA-KELM

Based on the establishment of the evaluation index system, this section proposes a new hybrid evaluation method based on combined entropy weight rank order-TOPSIS and NILA-KELM, which uses combined entropy weight rank order-TOPSIS to obtain classic evaluation results. Then use the NILA algorithm to optimize KELM, so as to obtain the optimal value of the KELM model parameters, and finally get the evaluation result and analyze the result. The proposed hybrid evaluation framework is shown in Fig. 2.

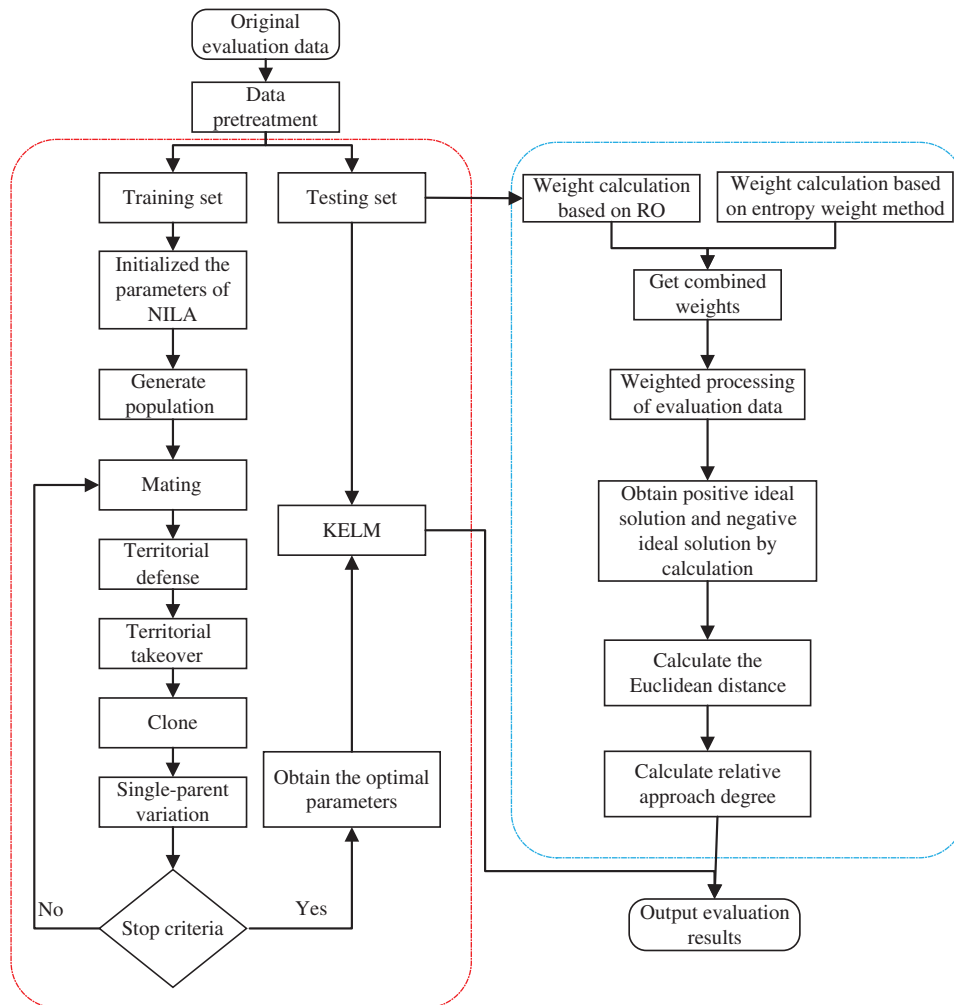


Figure 2: Evaluation process

The specific steps are as follows:

Step 1: Carry out initial input variable selection and data preprocessing. Based on the established evaluation index system, an initial set of input variables is formed, and the original data of each input factor is quantified and standardized.

Step 2: Classical evaluation calculation. The combined entropy weight rank order is used to obtain the evaluation index weight, and then it is substituted into the TOPSIS evaluation model to obtain the classic evaluation result.

Step 3: Use NILA algorithm optimization to obtain the optimal value of the KELM model parameters. The key parameters of the KELM model will have a significant impact on its final evaluation effect, and it is related to the accuracy of the sustainability evaluation of the regional microgrid interconnection system project. If the stop condition is not reached, the algorithm needs to be rerun to obtain the corresponding optimized solution set.

Step 4: Output intelligent evaluation results and compare and analyze the results. Based on the above-obtained intelligent evaluation model for the sustainability of the regional microgrid

interconnection system project, the simulation calculation is carried out, and the obtained intelligent evaluation results are compared with the classical evaluation model calculation results.

4 Case Analysis

4.1 Classical Evaluation Calculation and Analysis

Through field research and data collection, the relevant data of 30 regional microgrid interconnection system projects were collected and sorted out. At the same time, 25 experts were invited to score the indicators based on the interval scores, and then the scores were summarized and averaged.

According to the evaluation index preprocessing method in [formula \(1\)](#), the raw data of sustainability evaluation index of 30 regional microgrid interconnection system projects were standardized. The processing results of some data are shown in [Table 2](#).

Table 2: Standardized processing results of sustainability evaluation index data for regional microgrid interconnection system projects

Index	M1	M2	M3	...	M15	M16	...	M28	M29	M30
E ₁	1.0000	0.7143	0.5306	...	0.8163	0.4490	...	0.5714	0.1224	0.3265
E ₂	0.7400	0.7600	0.1000	...	0.2200	0.7000	...	0.8000	0.5200	0.3200
E ₃	0.9545	0.8182	0.6364	...	0.6818	0.8409	...	0.6136	0.0909	0.8409
E ₄	0.0000	0.3913	0.9783	...	0.1087	0.9565	...	0.7174	0.8261	0.0000
P ₁	0.8800	0.9800	0.8600	...	0.9600	0.0000	...	0.3600	0.5600	0.9600
P ₂	0.3231	1.0000	0.8000	...	0.8615	0.3692	...	0.0000	0.0154	0.9846
P ₃	1.0000	0.7872	0.5957	...	0.7660	0.3830	...	0.7234	0.3404	0.9149
P ₄	0.8200	0.4800	0.7800	...	0.2200	0.4200	...	0.4400	0.7200	0.8600
S ₁	0.0625	0.8333	0.2083	...	0.9792	0.2292	...	0.3750	0.8958	1.0000
S ₂	0.3556	0.7111	0.4222	...	0.4667	0.7556	...	0.0444	0.4000	0.5556
S ₃	0.0426	0.1702	0.1489	...	0.9362	0.6383	...	0.7234	0.8936	0.4894
T ₁	0.7708	0.8542	0.1875	...	0.2083	0.5625	...	0.0000	0.2708	0.6875
T ₂	0.7083	0.7083	1.0000	...	0.1667	0.0000	...	0.2708	0.8958	0.8958
T ₃	0.1042	0.3542	0.7292	...	0.8958	0.9583	...	0.3750	0.5417	0.0833
T ₄	0.2600	0.3800	0.8200	...	0.3400	0.0400	...	0.5400	0.7400	0.4200

[Table 2](#) Standardized processing results of sustainability evaluation index data for regional microgrid interconnection system projects.

According to the weight determination method described in [3.1](#), the sustainability evaluation index weights of regional microgrid interconnection system projects can be obtained as shown in [Table 3](#). The weight ratio of each evaluation index is shown in [Fig. 3](#).

Table 3: Calculation results of evaluation index weights

Index number	RO weight	Entropy weight	Combination weight
E1	0.0167	0.0733	0.0190
E2	0.0083	0.0693	0.0090
E3	0.1083	0.0608	0.1027
E4	0.0417	0.0686	0.0445
P1	0.1167	0.0653	0.1186
P2	0.1250	0.0540	0.1052
P3	0.0833	0.0684	0.0889
P4	0.0333	0.0690	0.0359
S1	0.0500	0.0891	0.0694
S2	0.1000	0.0513	0.0800
S3	0.0750	0.0786	0.0918
T1	0.0250	0.0693	0.0270
T2	0.0917	0.0637	0.0910
T3	0.0667	0.0663	0.0688
T4	0.0583	0.0530	0.0482

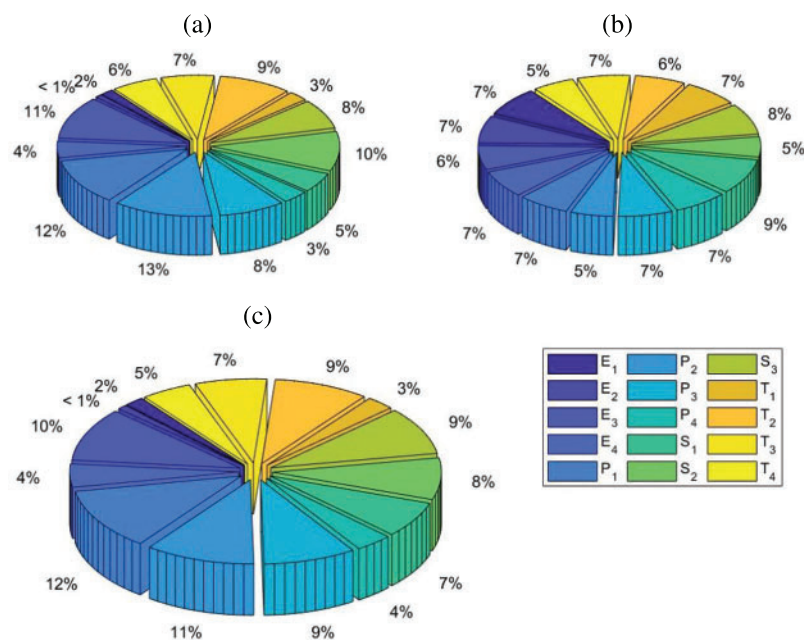


Figure 3: Distribution of the weights of sustainability evaluation indicators. (a) RO weight (b) Entropy weight (c) Combination weight

As can be seen from the data in Fig. 3, among all sustainability evaluation indicators, environmental protection indicators CO₂ emission reduction and PM2.5 emission reduction account for a larger proportion of weight. The performance of these two indicators has a significant impact on the results of sustainability evaluation. Because in recent years, under the call of relevant government policies, China's economy has gradually changed from the rough development in the past to the green and sustainable de-development mode, so as to achieve a more harmonious coexistence of human and natural environment, and the environmental protection benefit is an important reference standard for measuring the sustainable benefit of projects. At the same time, with the development of the social economy and the continuous improvement of residents' living standards, people's demands for a better living environment have also made environmental protection an important indicator of social development. In addition, the impact of social indicators in the sustainability evaluation of the project is also worthy of attention, such as employment creation and poverty reduction indicators, which play a key role in the willingness of local residents to accept the implementation of the project.

Then, the initial data are weighted to obtain the weighted normalization matrix, and the calculation results are shown in Table 4.

Table 4: Calculation results of weighted normalization matrix

Index	M1	M2	M3	...	M15	M16	...	M28	M29	M30
E1	0.0190	0.0136	0.0101	...	0.0155	0.0085	...	0.0109	0.0023	0.0062
E2	0.0067	0.0068	0.0009	...	0.0020	0.0063	...	0.0072	0.0047	0.0029
E3	0.0980	0.0840	0.0653	...	0.0700	0.0863	...	0.0630	0.0093	0.0863
E4	0.0000	0.0174	0.0436	...	0.0048	0.0426	...	0.0320	0.0368	0.0000
P1	0.1044	0.1163	0.1020	...	0.1139	0.0000	...	0.0427	0.0664	0.1139
P2	0.0340	0.1052	0.0841	...	0.0906	0.0388	...	0.0000	0.0016	0.1036
P3	0.0889	0.0700	0.0529	...	0.0681	0.0340	...	0.0643	0.0303	0.0813
P4	0.0294	0.0172	0.0280	...	0.0079	0.0151	...	0.0158	0.0258	0.0308
S1	0.0043	0.0578	0.0145	...	0.0680	0.0159	...	0.0260	0.0622	0.0694
S2	0.0284	0.0569	0.0338	...	0.0373	0.0604	...	0.0036	0.0320	0.0444
S3	0.0039	0.0156	0.0137	...	0.0860	0.0586	...	0.0664	0.0821	0.0449
T1	0.0208	0.0230	0.0051	...	0.0056	0.0152	...	0.0000	0.0073	0.0185
T2	0.0645	0.0645	0.0910	...	0.0152	0.0000	...	0.0246	0.0815	0.0815
T3	0.0072	0.0244	0.0502	...	0.0616	0.0660	...	0.0258	0.0373	0.0057
T4	0.0125	0.0183	0.0395	...	0.0164	0.0019	...	0.0260	0.0357	0.0202

The positive and negative ideal solutions are calculated as shown in Table 5.

Table 5: Calculation results of positive and negative ideal solutions

Index number	Positive	Negative
E1	0.0190	0.0000
E2	0.0090	0.0000

(Continued)

Table 5 (continued)

Index number	Positive	Negative
E3	0.1027	0.0000
E4	0.0445	0.0000
P1	0.1186	0.0000
P2	0.1052	0.0000
P3	0.0889	0.0000
P4	0.0359	0.0000
S1	0.0694	0.0000
S2	0.0800	0.0000
S3	0.0918	0.0000
T1	0.0270	0.0000
T2	0.0910	0.0000
T3	0.0688	0.0000
T4	0.0482	0.0000

The Euclidean distances from the microgrid interconnection system projects in each region to the positive and negative ideal solutions are calculated as shown in [Table 6](#).

Table 6: Euclidean distance from regional microgrid interconnection system project to positive and negative ideal solutions

Regional microgrid interconnection system project	Euclidean distance to positive ideal solution	Euclidean distance to negative ideal solution	Regional microgrid interconnection system project	Euclidean distance to positive ideal solution	Euclidean distance to negative ideal solution
M1	0.1666	0.1910	M16	0.1929	0.1556
M2	0.1090	0.2232	M17	0.1843	0.1711
M3	0.1256	0.2031	M18	0.1705	0.1597
M4	0.1763	0.1987	M19	0.1873	0.1603
M5	0.0741	0.2409	M20	0.1846	0.1590
M6	0.1892	0.1524	M21	0.1703	0.1623
M7	0.0963	0.2406	M22	0.1921	0.1820
M8	0.2014	0.1442	M23	0.1561	0.1608
M9	0.2077	0.1366	M24	0.1957	0.1544
M10	0.1146	0.2156	M25	0.1510	0.1872
M11	0.1759	0.1643	M26	0.1393	0.1706
M12	0.1703	0.1686	M27	0.1682	0.1909
M13	0.1696	0.1590	M28	0.1884	0.1357
M14	0.1544	0.1974	M29	0.1736	0.1687
M15	0.1152	0.2209	M30	0.1046	0.2345

The relative proximity of regional microgrid interconnection system projects can be calculated, and the relative proximity is sorted by size. The greater the relative proximity is, the better the sustainability of regional microgrid interconnection system projects is. Finally, 30 regional microgrid interconnection system project sustainability comprehensive evaluation rank ordering results are shown in [Table 7](#).

Table 7: Comprehensive evaluation results of sustainability

Regional microgrid interconnection system project	Relative approach degree	Rank	Regional microgrid interconnection system project	Relative approach degree	Rank
M1	0.4660	20	M16	0.5536	6
M2	0.3282	27	M17	0.5187	9
M3	0.3821	24	M18	0.5165	11
M4	0.4701	18	M19	0.5389	7
M5	0.2352	30	M20	0.5372	8
M6	0.5538	5	M21	0.5121	14
M7	0.2857	29	M22	0.5135	13
M8	0.5828	2	M23	0.4926	17
M9	0.6033	1	M24	0.5589	4
M10	0.3470	25	M25	0.4464	22
M11	0.5171	10	M26	0.4494	21
M12	0.5024	16	M27	0.4684	19
M13	0.5162	12	M28	0.5812	3
M14	0.4390	23	M29	0.5072	15
M15	0.3428	26	M30	0.3085	28

From the above, based on the combination entropy weight rank order-TOPSIS method, the sustainability of 30 regional microgrid interconnected system projects is comprehensively evaluated. The sustainability of M9 is the best, and the sustainability of M5 is the worst.

4.2 Intelligent Evaluation Calculation and Analysis

In order to verify the effectiveness and feasibility of NILA-KELM model, it is compared with KELM model, ELM model and BPNN model. BPNN, a concept introduced in 1986 by scientists led by Rumelhart and McClelland, is a multilayer feed-forward neural network trained according to an error back propagation algorithm and is one of the most widely used neural network models. Therefore, this model has been chosen for comparison in this paper. The specific test results are shown in [Table 8](#). [Fig. 4](#) shows the comparison between the test results of different models and the actual values. [Fig. 5](#) is the relative error diagram of each intelligent model.

Relative error (RE) refers to the absolute error caused by the measurement and the ratio of the measured (agreed) true value multiplied by 100% of the resulting value, expressed as a percentage. In general, RE better reflects the degree of confidence in the measurement. Root mean square error (RMSE) can eliminate the effect of the magnitude and describe the data better compared to mean

squared error (MSE). Mean absolute error (MAE) is the average of the absolute values of the deviations of all individual observations from the arithmetic mean. The mean absolute error avoids the problem of errors canceling each other out and thus accurately reflects the magnitude of the actual prediction error. In summary, these three indicators are chosen in this paper.

Table 8: Test results of four models

Regional microgrid interconnection system project	Classic evaluation results	NILA-KELM	KELM	ELM	BPNN
M1	0.4660	0.4621	0.5000	0.4802	0.5162
M2	0.3282	0.3116	0.3058	0.3078	0.3469
M3	0.3821	0.3718	0.3947	0.4140	0.4153
M4	0.4701	0.4796	0.4823	0.4575	0.5037
M5	0.2352	0.2285	0.2236	0.2541	0.2461
M6	0.5538	0.5340	0.5792	0.6042	0.5834
M7	0.2857	0.2920	0.2928	0.2738	0.3050
M8	0.5828	0.5873	0.5996	0.5595	0.5615
M9	0.6033	0.5871	0.5866	0.6604	0.6442
M10	0.3470	0.3425	0.3532	0.3281	0.3684
M11	0.5171	0.5003	0.5311	0.4704	0.5542
M12	0.5024	0.5262	0.4863	0.4860	0.5294
M13	0.5162	0.5188	0.5293	0.4898	0.5331
M14	0.4390	0.4318	0.4467	0.4021	0.4108
M15	0.3428	0.3421	0.3687	0.3335	0.3078
M16	0.5536	0.5413	0.5938	0.5012	0.5801
M17	0.5187	0.5145	0.4794	0.5037	0.4820
M18	0.5165	0.4974	0.5474	0.5022	0.4757
M19	0.5389	0.5602	0.5161	0.5902	0.5709
M20	0.5372	0.5246	0.5095	0.5500	0.5001
M21	0.5121	0.5060	0.5217	0.4991	0.5394
M22	0.5135	0.5114	0.5216	0.4758	0.4557
M23	0.4926	0.4776	0.4715	0.4613	0.5290
M24	0.5589	0.5465	0.5168	0.5945	0.5856
M25	0.4464	0.4601	0.4193	0.4826	0.4633
M26	0.4494	0.4512	0.4258	0.4620	0.4146
M27	0.4684	0.4657	0.4342	0.5029	0.5005
M28	0.5812	0.5912	0.5615	0.5545	0.5236
M29	0.5072	0.4870	0.4978	0.4849	0.4810
M30	0.3085	0.3044	0.3024	0.3357	0.2926
RMSE		1.22%	2.27%	3.06%	3.29%
MAE		1.02%	2.01%	2.73%	3.09%

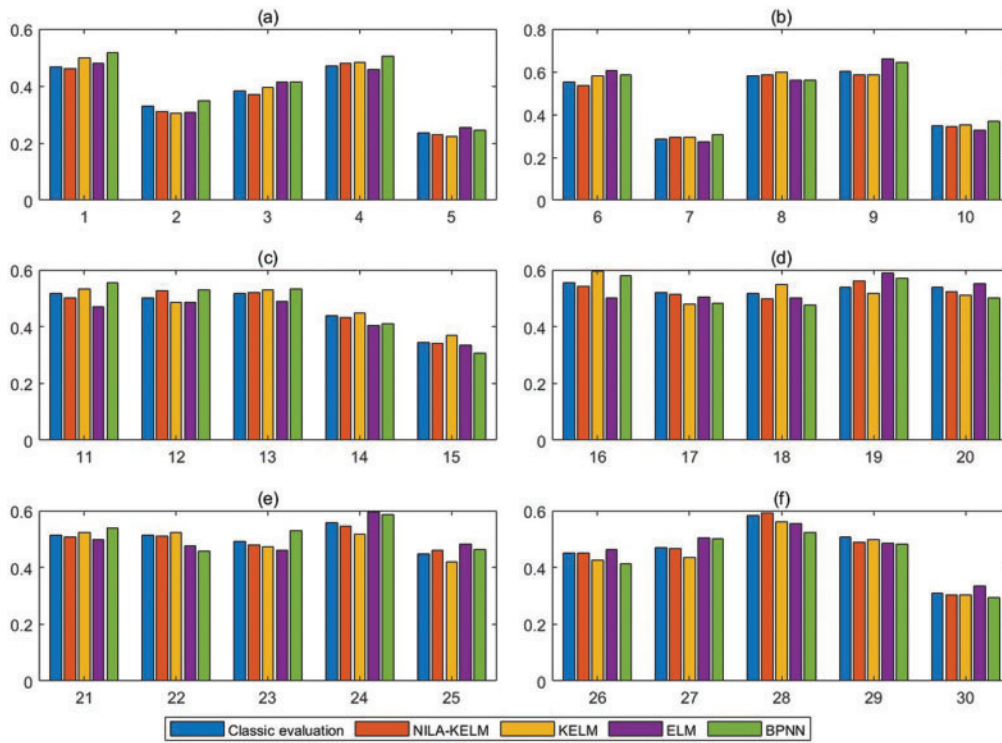


Figure 4: Test results of different models

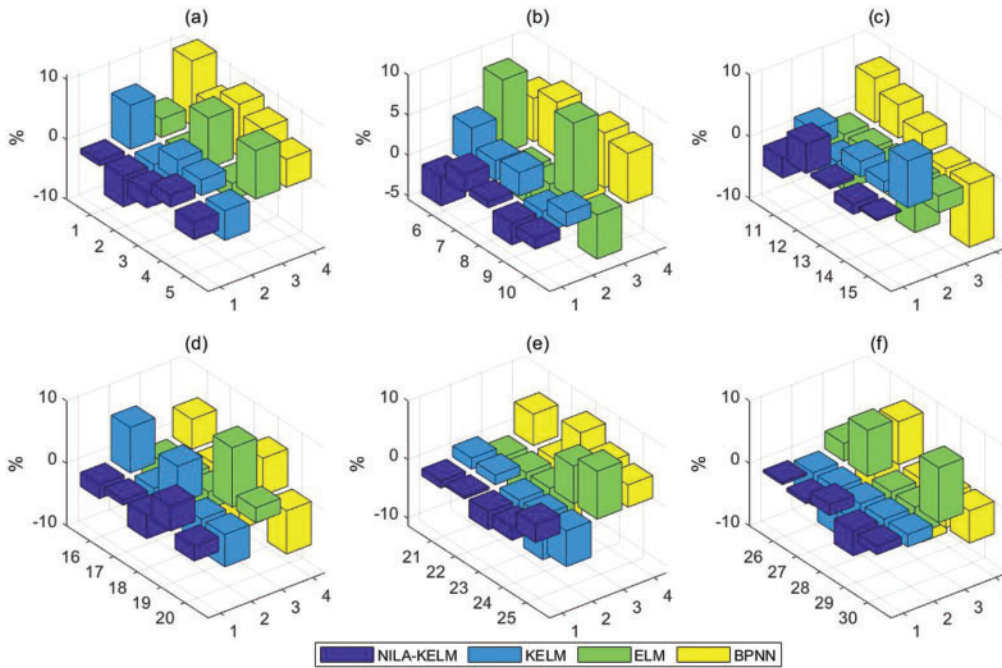


Figure 5: The relative error of each smart model

As shown in [Table 2](#), the RMSE value of the NILA-KELM model is 1.22%, which is smaller than the 2.27%, 3.06% and 3.29% of KELM, ELM and BPNN. In addition, the MAE value of the NILA-KELM model is 1.02%, which is also smaller than the 2.01%, 2.73% and 3.09% of KELM, ELM and BPNN. The smaller the two values, the higher the accuracy and stability of the NILA-KELM model for predicting the output value.

It can be seen from [Fig. 4](#) that the gap between the NILA-KELM model and the actual value is far less than that of KELM, ELM and BPNN, and the correlation between the test value curve and the actual value curve is higher, indicating that the sustainability assessment of regional microgrid interconnection system projects is more accurate and closer to reality. The gap between the test value and the actual value of KELM model is slightly smaller than that of ELM model and BPNN model, indicating that the accuracy of KELM model in the project sustainability assessment of regional microgrid interconnection system is slightly higher than that of ELM model and BPNN model. The relative error results shown in [Fig. 5](#) also verify the above conclusions. As shown in [Fig. 5](#), the relative error of NILA-KELM model is closer to the horizontal axis, and the relative error fluctuation is the smallest, indicating that the overall error is less than the other two models. The relative error of KELM model is slightly lower than that of ELM and BPNN models, and the overall fluctuation of the curve is smaller than that of ELM and BPNN models, indicating that the prediction accuracy of KELM model is slightly higher than that of ELM and BPNN models, but the difference is small.

5 Conclusions

Scientific and reasonable measurement of various benefits of regional microgrid interconnection system in terms of sustainability is conducive to the stable realization of multi-stakeholder mutual benefit and win-win situation, including power system and microgrid. Therefore, this paper designs a set of a sustainability evaluation system for regional microgrid interconnection system, which mainly includes an evaluation index system and a new hybrid intelligent evaluation method. The main research results and conclusions include the following four points:

1. The sustainability evaluation index system of regional microgrid interconnection system is constructed from four aspects of economic, environmental, social and technical characteristics, which solves the problems that the sustainability of regional microgrid interconnection system is mainly reflected in.
2. The weight of evaluation index is obtained based on the combination entropy weight rank order method, and the TOPSIS evaluation model is designed, and the evaluation results are obtained from the perspective of classical evaluation methods.
3. The niche immune algorithm is used to improve the lion algorithm, and a new niche immune lion swarm algorithm is formed. NILA is used to optimize KELM, and an intelligent evaluation model is constructed.
4. The scientificity and accuracy of the evaluation model proposed in this paper are verified by example analysis. The classical evaluation model can obtain accurate reference results, while the modern intelligent evaluation model can achieve the purpose of fast calculation and support for relevant decisions.

In summary, the research results of this paper can provide some reference for local governments and potential investors to make investment decisions in regional microgrid interconnection system projects. However, the paper does not screen the input indicators, which is a shortcoming of the paper and a direction for future research.

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