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Design of data-driven optimization method and multidimensional benefit evaluation system for power grid project investment decision-making

Guozhen Ma[1] ✉, Xiangming Wu[2], Po Hu[1], Hangtian Li[1]

[1] *Economic and Technology Research Institute, State Grid Hebei Electric Power Co., Ltd., Shijiazhuang, Hebei, 050000, China*

[2] *State Grid Hebei Electric Power Co., Ltd., Shijiazhuang, Hebei, 050000, China*

ABSTRACT

According to the decision-making process of power grid investment, this paper sets the objective function and constraints, realizes the construction of optimization model, and selects genetic algorithm as the solution algorithm of optimization model. Under the requirement of evaluation index principle, 16 secondary indexes and 4 primary indexes are screened, thus forming the evaluation index system of power grid project investment efficiency. The experimental conditions are set to evaluate and analyze the optimization of investment decision and multidimensional benefits of power grid project respectively. Along with the reduction of voltage data, the diversity of optimal solutions for grid project benefits begins to materialize, and the diversity of optimal solutions of GA algorithm is higher than that of PSO algorithm, indicating that the use of genetic algorithm to calculate optimal solutions for grid investment benefits is more effective. In addition, the closeness of the seven projects to the optimal solution is 0.4613, 0.5044, 0.4681, 0.5398, 0.6342, 0.5759, 0.4116, respectively, of which project 5 has the best investment benefit.

Keywords: Genetic algorithm, constraints, objective function, investment decision optimization model

1. Introduction

With the growing demand for electricity, power grid construction projects have become one of the key areas of national development, and the investment decision of power grid construction projects is of great significance to the national power supply and economic development. The goal of investment decision of grid construction project is to realize the minimum investment cost under the premise of meeting power demand [1-4]. In the investment decision of grid construction projects, the factors to be considered include power demand forecast, grid planning, transmission line siting and capacity, substation construction, etc. The purpose of optimization analysis is to optimize the investment cost

✉ Corresponding author.
E-mail address: wenjuan-wenjuan@163.com (G. Ma).
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in these decisions. The purpose of optimization analysis is to find the optimal solution to minimize the investment cost and improve the investment efficiency in these decision-making links [5-8].

Distribution network project investment in the current power grid construction occupies an important position, and reasonable evaluation of distribution network project investment, guide the construction and development of distribution network is a major issue of power grid enterprises need to solve [9-11]. Currently, there are not many studies on the evaluation of investment in distribution network projects, and there is a lack of effective analysis and evaluation, and the methods of evaluation of investment in distribution network projects mainly include fuzzy comprehensive evaluation method, hierarchical analysis method, logical framework method, multilevel fuzzy evaluation method, and the improvement of the above methods [12-15]. The investment scale of the main network infrastructure projects of power grid enterprises is huge and involves multiple interests, which is of great significance for promoting economic development, improving people's living standards and building a modernized energy system [16-18]. Therefore, the establishment and application of the investment efficiency evaluation system can provide a scientific basis for the investment decision-making of power grid enterprises, reduce the investment risk, improve the efficiency of capital utilization, and promote the construction and operation of power grids to the direction of high-quality and high-efficiency [19-22].

Optimization of investment decision of power grid construction project is of great significance to realize the reliability and economy of power supply. Through reasonable power demand forecasting, grid planning, transmission line siting and capacity, substation construction and other decisions, investment costs can be minimized and investment benefits can be improved. Literature [23] analyzed the application of multi-objective optimization model in power grid investment. The objective factors of grid investment were discussed, and a multi-objective optimization model was established, and NSGA-II was used to solve the model, and several conclusions were obtained, including "Based on the conventional steps of NSGA-II, suitable steps can be established to search for the optimal solution of the objective set of grid investment", and so on. Literature [24] proposed a hybrid PGI optimization model to synergistically consider risk and return. The risk and benefit indicator system of PGl was established, and a comprehensive evaluation model as well as a PGI optimization model were proposed. Based on the empirical analysis of grid companies, the optimal investment plan and differentiated portfolio strategy are derived. Literature [25] analyzed the factors affecting the investment capacity of grid companies from internal and external sources, calculated the investment demand of grid companies by using the gray prediction model, and constructed a coordinated optimization model, which effectively improves the effectiveness and precision of grid investment and ensures the efficiency of grid investment. Literature [26] proposed an investment optimization decision-making method for multiple grid construction projects under a certain investment scale. Based on the risk assessment of grid projects, a risk assessment index system was constructed. And the effectiveness and applicability of the proposed method is verified. Literature [27] constructed a combinatorial optimization model based on adaptive particle swarm optimization algorithm, which provides an applicable decision-making method for complex grid optimization investment decision-making, and builds a complex grid optimization investment decision-making management process based on power demand and investment capacity. Literature [28] combines SD and BN to establish a security investment optimization model for power grid enterprises, and identifies key security investment factors, which constitute a subsystem of the SD model. The simulation results reveal that the established model has certain practicality and has certain reference and utilization value.

For power grid enterprises, it is particularly important to reasonably assess the efficiency and benefits of power grid investment projects. By strengthening the effective assessment of the efficiency and benefits of power grid investment projects, and formulating perfect efficiency and benefits assessment indexes of power grid investment projects under the regulation of transmission and distribution, the economic benefits of power grid enterprises can be better enhanced. Literature [29] used the MCDM method to evaluate the comprehensive efficiency of grid investment. A number of grid-connected renewable energy generation grid investment projects were studied, and the results showed the robustness of the proposed method, and the MCDM method identified excellent projects that could promote the sustainable development of the power industry. Literature [30] proposes a system of indicators for evaluating the effectiveness and efficiency of grid investment projects, which takes into account the overall economic, technological and social efficiency. Example analysis points out that the proposed efficiency evaluation method has practical value for grid investment project evaluation. Literature [31], based on a series of adequate investigation and research, conducted a comprehensive investigation and analysis of the current grid efficiency and efficiency evaluation index system, and studied the current grid efficiency and efficiency single indexes, and unfolded a comprehensive evaluation of grid efficiency and effectiveness. Literature [32] constructed the evaluation index system of transmission grid projects and calculated the weights of each index by using the graph model method according to the characteristics of project functions. The analysis results show that the graph model method realizes objective weights by reflecting the original evaluation information and can be used for investment benefit evaluation. Literature [33] designed a comprehensive evaluation index system for the investment efficiency of grid projects under transmission and distribution tariff reform, aiming to improve the investment efficiency of grid projects after China's power reform. Literature [34] proposed a grid input-output benefit evaluation method and established a comprehensive evaluation model of grid input-output benefit, and analyzed the benefits. It is emphasized that the method can overcome the shortcomings of traditional methods and realize the accurate reflection of grid stock assets.

Combined with the actual development of the current power grid investment projects, maximizing the benefits of investment decision-making as the objective function, dividing the constraints, completing the construction of the optimization model, and proposing the use of genetic algorithm to calculate the optimal solution of the optimization model. In order to make the research results more convincing, based on the principle of indicator selection, the multidimensional effect evaluation index system is determined, and the ANP algorithm and the AEW algorithm are used to calculate the subjective and objective weights of the evaluation indexes respectively, and the combination weights of the evaluation indexes are further calculated according to the principle of combination weights. Under the known variables, use TOPISI algorithm to evaluate and analyze the multidimensional benefits of power grid investment projects.

2. Optimization of investment decisions for power grid projects

Grid construction projects provide protection for the daily needs of users and play a crucial role in the development process and comprehensive benefits of the entire power grid. In recent years, the scale and proportion of investment in the power company network has increased year by year, and there are many grid construction projects, so under the constraints of limited resources, it is urgent to propose a set of practical investment decision-making methods for distribution network projects, which can be used to realize the goal of scientifically selecting investment projects and ensuring the maximization of benefits. Combined with the historical construction and renovation investment project data of the power grid, based on three types of projects, namely key projects, main network projects and distribution network projects, respectively, three project libraries are generated for power grid projects, and the project reserve will randomly generate a project set. The investment decision optimization model of the grid planning project takes the maximum comprehensive benefit score of the project set as the objective function, and carries out the preferential selection of the project portfolio through genetic algorithms, so as to reach the goal of preferential investment in the grid construction projects. The purpose of preferential investment.

2.1. Investment decision-making process

1) Determination of basic project status. Various types of projects for power grid construction are screened to form a reserve pool of projects to be evaluated and ranked. Each project needs to provide the basic information mainly includes: project name, number, voltage level, project type and total project investment, etc. Projects of special significance need to be labeled.
2) Investment Demand Forecasting. Load forecasting is the basic work of investment demand forecasting, which needs to consider historical data, regional economic development and electricity level, etc. The method is to multiply the investment scale by the unit investment to get the proposed investment funds.
3) Measurement of investment capacity. By accounting for the company's profits, to determine the total profit; at the same time through the company's annual financial plan to determine the amount of future annual loans and other sources of funds, and ultimately approved the company's total investment capacity.

The constraint on the investment capacity of the grid is the gearing ratio, and the annual investment capacity of the grid can be calculated through this constraint, thus ensuring that the investment scale of the grid is within the economic capacity of the grid company. The investment capacity of the grid can be simply understood as how much money the grid has available for investment.

The amount of loan repayment for the grid company is determined by the company's repayment plan, and the gearing constraint can be set at an annual increase of 1 percentage point and a maximum of 80%. The gearing ratio can be expressed as:

$$R_a = \frac{L_t + L_m - P_l}{A_t + P_n + L_m} \tag{1}$$

The maximum loan amount can be obtained by the above equation:

$$L_m = \frac{R_a(A_t + P_n) + P_l - L_t}{1 - R_a} \tag{2}$$

Where, R_a represents the gearing ratio of the grid enterprise, L_t represents the total liabilities at the beginning of the year, L_m represents the maximum loan amount of the enterprise in one year, P_l represents the amount of the loan that the enterprise should repay, A_t represents the total assets of the enterprise at the beginning of the year, and P_n represents the net profit of the grid enterprise in one year.

Therefore, the annual real investment capacity of the grid enterprise is:

$$C = \pi_t + D + L_m \tag{3}$$

where C represents the actual annual investment capacity of the grid enterprise, π_i represents the expected minimum return, D represents depreciation, and L_m represents the maximum loan amount available to the grid enterprise.
4) Investment decision-making. In the decision-making module, first of all, according to the project situation will be divided into key projects in the reserve pool, non-key project pool (divided into the main grid project and distribution network project), the key projects in the reserve pool do not need to score sorting, can be prioritized for investment. Then in the investment budget will be the budget amount of the key projects will be subtracted to get the investment funds of other projects. For the non-priority project pool can be categorized according to the voltage level, mainly including 400kV investment projects, 200kV investment projects, 100kV investment projects, 30kV and below investment projects, and so on. Based on the amount of conventional infrastructure investment in different voltage levels and other constraints, investment decisions are made separately.

2.2. Objective function

The general mathematical planning problem can be described as:

$$\begin{cases} \max f(x_{1,}x_2 x_i \ldots, x_n) \\ s.t. g(x_1, x_2, x_i \ldots, x_n) = 0 \\ h(x_{1,}x_{2,}x_i \ldots, x_n) \le 0 \end{cases} \tag{4}$$

In this case, the equality constraints and inequality constraints may not exist, and both contain multiple expressions. When the variable x_1 can only take the value 0 or 1 is called 0/1 planning, 0 indicates that the event is eliminated; 1 indicates that the event is selected.

1) Events are mutually exclusive. Then only one event is selected, then the constraint equation can be expressed as:

$$\sum_{j \in J} x_i \le 1 \tag{5}$$

2) Dependent events. Of two events, the occurrence of one must be predicated on the occurrence of the other then the constraint equation can be expressed as:

$$x_l \le x_k \tag{6}$$

$$x_l, x_k = 0,1 \tag{7}$$

3) Constraints can be substituted. There exist 2 constraints $\sum_{j=1}^{n} a_{1j} x_j \le b_1$ and $\sum_{j=1}^{n} a_{2j} x_j \le b_2$ respectively, satisfy any one of them can be, then the constraint equation can be expressed as:

$$\begin{cases} \sum_{j=1}^{n} a_{1j} x_j \le b_1 + \alpha M \\ \sum_{j=1}^{n} a_{2j} x_j \le b_2 + (1-\alpha) M \end{cases} \tag{8}$$

where M is a very large number.

The decision optimization in this paper is to choose whether to invest or abandon this project, so define the 0-1 vector D. i.e:

$$D=[d_1, d_2, \ldots, d_n] \tag{9}$$

Where D indicates the total number of projects in the project library of dimension n; d_i is the investment status of the project numbered i If d_i is 1, then the project is invested; if d_i is 0, then the project is not invested.

Based on the above definition, when the grid enterprise has sufficient funds, take $a_i = y_i$, y_i for the i th project based on the index system to get the comprehensive evaluation value, that is, infrastructure projects in accordance with the project score optimal decision-making, then the decision-making model is:

$$\max A_o = \sum_{i=1}^{m} a_i \times x_i \tag{10}$$

In the formula, m is selected for investment projects, A_o indicates the total value of the comprehensive evaluation of the project, a_i indicates the i th project scoring, x_i has two values of 0 and 1, the value of x_i is 0, indicating that the i th project is not invested, and the value of x_i is 1, indicating that the i th project investment.

2.3. Constraints

In this paper, we consider the constraints established by the proposed investment in the grid (total capital grid investment capacity) and the constraints on how the investment in each type of project is allocated.

1) The funding constraints are:

$$s.t.\sum_{i=1}^{n} b_i x_i \leq S \tag{11}$$

In the formula, x_i has two values of 0 and 1, when the value of x_i is 0, it means that the i project is not invested, and when the value of x_i is 1, it means that the i th project is invested; S indicates the investment budget of the grid company;

2) Investment allocation ratio constraint. The first step is to analyze the relationship between various types of operational indicators and investment based on the historical development of the regional power grid; the second step is to determine the target value by combining the current situation and expectations; the third step is to determine the contribution of different categories of projects and grid development indicators based on the corresponding relationship between them, and determine the contribution of the projects to the development of the grid. (T_σ), according to the project categories of the investment allocation ratio, (δ_λ), and increase the investment of project categories of great significance for the development of the power grid, i.e., the allocation ratio is equal to the ratio of the contribution to the improvement of reliability indexes. The ratio of contribution to reliability indicator improvement is calculated as follows:

$$\delta_\sigma' : \delta_2' : \ldots \delta_\sigma' = T_1' : T_2' : \ldots T_\sigma' \tag{12}$$

In summary, the constraints are:

$$s.t.\begin{cases} T_t \leq T_m \\ \delta_\sigma' : \delta_2' : \ldots \delta_\sigma' = T_1' : T_2' : \ldots T_\sigma' \end{cases} \tag{13}$$

2.4. Genetic Algorithm Based Model Solving

Due to the large number of items in the planning library, the enumeration method is efficient and takes a long time to compute. Considering the characteristics of the optimization variables - as fixed-length 0-1 vectors, it meets the input requirements of the genetic algorithm (GA), and at the same time, the discrete nature of the model coincides with the characteristics of the GA. A genetic algorithm is proposed to be used for the optimization, and the flowchart of the genetic algorithm is shown in Fig. 1.

Genetic algorithm is a parallel global search method for efficient problem solving, which simulates a series of evolutionary processes of genetic selection and natural elimination of organisms in natural environment, that is to say, GA essentially deals with the discrete optimization search problem, which does not require the continuity of the problem space, and has the advantages of convenience and strong global search ability, which can be widely used in optimizing complex systems, especially in solving larger-scale network planning multi-objective comprehensive optimization problems, has the advantages that other methods can not be compared [35-36].

1) Selection. It embodies Darwin's principle of survival of the fittest, in order to let the excellent individuals selected in the group to reproduce the next generation. That is to say, it can be based on the degree of adaptation of the individual, through specific methods and principles from the parent group to inherit a portion of the next generation.GA is to increase the chances of the high degree of adaptation of the best individuals to provide offspring through the selection algorithm.

2) Crossover. It is one of the most important aspects of GA that can provide a new generation of individuals that combines the characteristics of the previous generation of individuals. Individuals are randomly paired and swap a portion of their chromosomes. Crossover embodies the idea of information exchange.
3) Mutation. Mutation simulates the process by which organisms undergo genetic mutation. The first step of the mutation operation requires the selection of individuals, and then for the selected individuals to change one of their genes with the probability of mutation, by repeating these three basic operations to improve the degree of adaptation of individuals. Mutation provides an opportunity for the creation of new individuals.

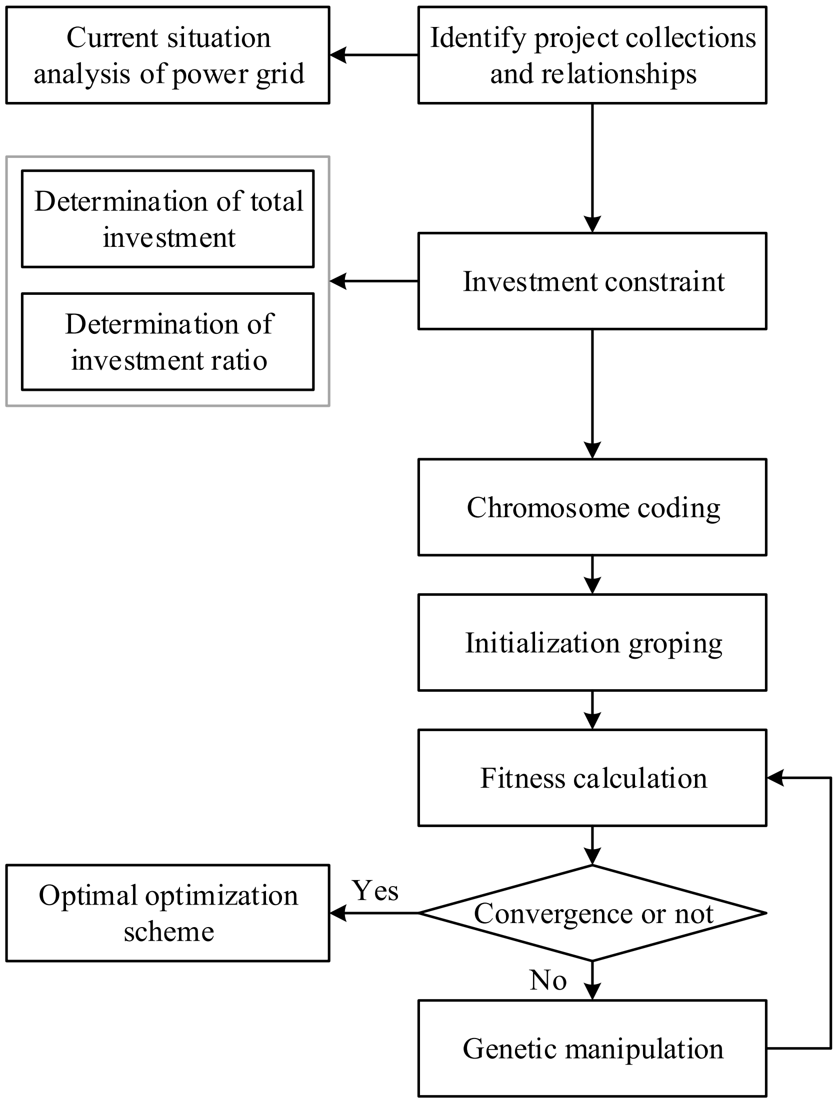


Fig.1. Flow chart of genetic algorithm

3. Cultidimensional benefits assessment design

On the basis of the optimization model of grid project investment decision, the comprehensive evaluation of grid project is carried out. The chapter constructs a comprehensive benefit evaluation index system for power grid projects from four aspects, namely, technical benefits, economic benefits, social benefits, and environmental benefits, and evaluates them by using the ANP (Network Hierarchical Analysis) - AEW (Anti-Entropy) - TOPSIS (Approximation of Ideal Solution Sorting) method. It helps to improve the coordination capacity of energy supply and demand, promote clean energy production and nearby consumption, reduce wind, light and water abandonment and limit power, and promote the consumption of renewable energy, and is an important means to improve the comprehensive efficiency of the energy system, which is of great practical significance and far-reaching strategic significance for the construction of a modern energy system that is clean, low-carbon, safe and efficient.

3.1. Principles for the selection of indicators

1) Systematic principle. The evaluation indexes selected should systematically and comprehensively reflect the overall characteristics of the grid project under the framework of multi-energy complementarity, including the evaluation indexes of benefits in technology, economy, society and environment.
2) Quantitative principle. The data sources of the indicators for the comprehensive benefit evaluation of the grid project should be as objective as possible, and at the same time, they should be quantized in order to be calculated and evaluated, and for some indicators that are not easy to obtain real statistics and have significance, they can be quantified through expert scoring.
3) Principle of simplicity. The evaluation indexes should be simple and clear, and should be closely centered on the comprehensive benefit evaluation field of the power grid project, and some evaluation indexes in line with the professional representativeness should be selected for the core links (technical benefits, economic benefits, social benefits and environmental benefits).
4) Principle of comparability. The index data and calculation method of the comprehensive benefit evaluation of power grid project should be standardized and rigorous, and can be compared and analyzed in different time and space.

3.2. Construction of the evaluation system

On the basis of relevant studies at home and abroad, a multi-dimensional benefit evaluation index system for grid project investment is constructed from four aspects: technical benefit, economic benefit, social benefit and environmental benefit. The multi-dimensional benefit evaluation index system of grid project investment is shown in Table 1, which is mainly composed of four first-level indicators and 16 second-level indicators.

Table 1. Multidimensional benefit evaluation index system

Primary index	Symbol	Secondary index	Symbol
Technical benefit	A1	Technology maturity	B1
		Equipment maintainability	B2
		Average power outage time of users	B3
		Comprehensive voltage pass rate	B4
		Combined line loss ratio	B5
Economic benefit	A2	Net present value	B6
		Internal rate of return	B7
		Dynamic payback period	B8
Social benefit	A3	Consistent with national policy	B9
		Demonstration of technology	B10
		User satisfaction	B11
Environmental benefit	A4	Utilization rate of renewable energy	B12
		New energy access ratio	B13
		CO2 emission reduction	B14
		NOX Emission reduction	B15
		SO2 reduce emission	B16

3.3. ANP-AEW calculation of weights

1) ANP

(a) Constructing the network hierarchy of the indicator system. The ANP structure is shown in Figure 2, which constructs the evaluation indicators (elements) of the object to be evaluated, determines the elements in the control layer and the network layer, and analyzes the relationship between influencing and being influenced between the elements of the control layer and all the elements of the network layer, i.e., it determines the mutual influencing relationship between the guidelines and the indicators of the network layer and the elements of the network layer [37-38].

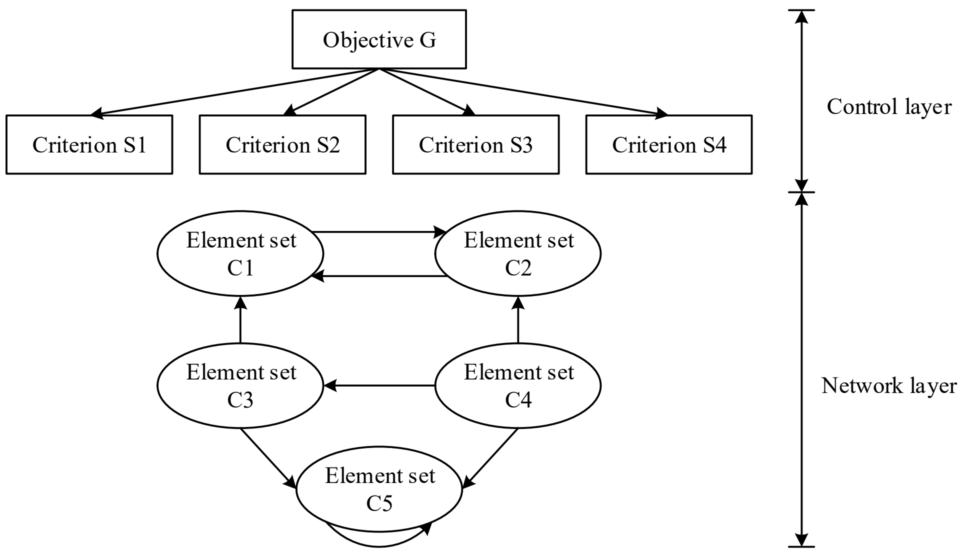


Fig. 2. ANP structure

(b) Constructing the supermatrix for network hierarchy analysis. Assuming that the elements of the control layer of the ANP are $S_1, S_2, ..., S_m$ and the elements of the network layer are $C_1, C_2, ..., C_n$, where there is an element $c_{ji}(i=1,2,...,n_i)$ in C_j. Taking the element $S_s(s=1,2,...,m)$ of the control layer as the criterion, and the element $c_{jk}(k=1,2,...,n_j)$ in C_j as the sub-criterion, the elements in the group of elements C_i are compared in terms of their influence on c_jk, i.e., the judgment matrix is constructed under the criterion S_s, and the weight vector $w_{il}^{(jk)}, w_{i2}^{(jk)}, ..., w_{in_i}^{(jk)}$ is solved by the method of the eigenroots, and the matrix is obtained by repeating the above steps for $k=1,2,...,n_j$:

$$W_{ij} = \begin{pmatrix} w_{i1}^{(j1)} & w_{i1}^{(j2)} & \cdots & w_{i1}^{(jn_j)} \\ w_{i2}^{(j1)} & w_{i2}^{(j2)} & \cdots & w_{i2}^{(jn_j)} \\ \vdots & \vdots & \ddots & \vdots \\ w_{in_i}^{(j1)} & w_{in_i}^{(j2)} & \cdots & w_{in_i}^{(jn_j)} \end{pmatrix} \tag{14}$$

where the column vector of W_i represents the ordering vector of the degree of influence of all the elements in C_i on the element c_{jk} in C_j. If ε_{ik} is not affected by element $c_{ip}(p=1,2,...,n_i)$ in C_i, then $w_{ip}^{(jk)}=0$. Repeat the above steps for each C_i and $C_j(i,j=1,2,...,n)$ to obtain a supermatrix under the S_s criterion. According to the number of elements in the control layer, there are m supermatrices in total and all of them are non-negative matrices with the general form:

$$W^{(s)} = \begin{pmatrix} W_{11}^{(s)} & W_{12}^{(s)} & \cdots & W_{1n}^{(s)} \\ W_{21}^{(s)} & W_{22}^{(s)} & \cdots & W_{2n}^{(s)} \\ \vdots & \vdots & \ddots & \vdots \\ W_{n1}^{(s)} & W_{n2}^{(s)} & \cdots & W_{nn}^{(s)} \end{pmatrix} \tag{15}$$

(c) The weighted supermatrix of the ANP. Each element of supermatrix $W^{(s)}(s=1,2,...,m)$ is a matrix whose submatrix $W_{ij}^{(s)}$ is column normalized, but $W^{(s)}$ is not column normalized. The column normalization is performed on $W^{(s)}$ to obtain the weighted supermatrix in the following steps: take S_s as the criterion and the element group $C_j(j=1,2,...,n)$ as the sub-criterion, compare the relative importance magnitude of all the element groups, and obtain the weight vector $A_j^{(s)}=(a_{j1}^{(s)},a_{j2}^{(s)},...,a_{jn}^{(s)})^T$ according to the eigenvalue method, and repeat the above steps for all the $j=1,2,\ldots,n$ to obtain the weighted matrix as shown in Eq. (16):

$$A^{(s)} = \left(A_1^{(s)}, A_2^{(s)}, \ldots, A_n^{(s)}\right)^T = \begin{pmatrix} a_{11}^{(s)} & a_{12}^{(s)} & \cdots & a_{1n}^{(s)} \\ a_{21}^{(s)} & a_{22}^{(s)} & \cdots & a_{2n}^{(s)} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1}^{(s)} & a_{n2}^{(s)} & \cdots & a_{nn}^{(s)} \end{pmatrix} \tag{16}$$

To weight the submatrices in supermatrix W in this way, the column normalized weighted supermatrix under the S_s-criterion is obtained as shown in equation (16). Similarly, there should be m such weighted supermatrices. Namely:

$$W^{(As)} = (W_{ij}^{(As)})_{n\times n} \tag{17}$$

where $W_{ij}^{(As)} = a_{ij}^{(s)} \times W_{ij}^{(s)}$.

(d) Stabilization of the supermatrix. In order to accurately reflect the interdependence between the elements, it is necessary to stabilize the supermatrix. By calculating the limit relative ranking vector of each supermatrix: $\lim_{k\to+\infty} W^{(s)k}$, if the limit converges and is unique, the value of the corresponding row of the original matrix is the stabilized weight of each evaluation index. The core of network hierarchical analysis method is to solve the supermatrix, and this paper utilizes the super decision-making software for calculation.

2) Anti-entropy weight method. In the entropy value method, the variability of the indicators is inversely proportional to the entropy value and directly proportional to the weight coefficients. If anti-entropy weights are used, the objective weight vector ω_0 is calculated by the anti-entropy weight method (AEW). The concept of entropy originates from system thermodynamics and is used to characterize the degree of disorder in a system. If the system may have m different states, $p_j(j=1,2,...,m)$ represents the probability of the j th state, then the entropy is defined as:

$$h = -\sum_{j=1}^{m} p_j \ln p_j \tag{18}$$

In the formula, $0 \le p_j \le 1$ and $\sum_j =1^m p_j = 1$.

It is possible to avoid the situation that the indicator is too small when weights are assigned due to the high variability of the indicator, which is proportional to both the anti-entropy value and the weight coefficient, as defined in equation (19):

$$h = -\sum_{j=1}^{m} p_j \ln(1-p_j) \tag{19}$$

where $0 \le p_j \le 1$ and $\sum_j =1^m p_j = 1$.

The specific steps for determining the weights of indicators by the anti-entropy weight method are as follows:

Let the evaluation problem have m evaluation objects, n evaluation indexes, the index value is $x_{ij}(i=1,2,...,n, j=1,2...,m)$, and the evaluation matrix is $X=(x_{ij})_{n\times m}$. According to the evaluation matrix X, determine the anti-entropy of each index, see the following formula:

$$h_i = -\sum_{j=1}^{m} r_{ij} \ln(1-r_{ij}) \tag{20}$$

In the formula, $r_{ij} = x_{ij} / \sum_{j=1}^{m} x_{ij}$.

Then normalize the anti-entropy value of each indicator and the result is the objective weight of each indicator ω_0, i.e.:

$$\omega_{0i} = h_i / \sum_{i=1}^{n} h_i \tag{21}$$

3) Calculation of combined weights by ANP-AEW method

The subjective weight set $\omega_s = \{\omega_{si} \mid 1 \le i \le n\}$ of each indicator is calculated by ANP method, and then the objective weight set $\omega_o = \{\omega_{oi} \mid 1 \le i \le n\}$ of each indicator is calculated by AEW method, and the difference of indicators will affect the relative importance of subjective and objective weights. Setting α to represent the relative importance of subjective weights and β to represent the relative importance of objective weights, the moment estimation theory is introduced to obtain the relative importance coefficients of subjective and objective weights of each indicator, α and β, which are expressed by the formula:

$$\alpha_i = w_{si} / (w_{si} + w_{oi}), i = 1,2,...,n \tag{22}$$

$$\beta_i = w_{oi} / (w_{si} + w_{oi}), i = 1,2,...,n \tag{23}$$

Using the subjective weight set, objective weight set and relative importance coefficients of subjective and objective weights that have been obtained, the combination weights ω_i can be calculated as shown in equation (24):

$$\omega_i = \frac{\alpha_i \omega_{si} + \beta_i \omega_{oi}}{\sum_{i=1}^{m} (\alpha_i \omega_{si} + \beta_i \omega_{oi})}, i = 1,2,\dots,n \tag{24}$$

3.4. TOPSIS-based comprehensive evaluation of benefits

Based on the introduction and comparative analysis of the previous article on comprehensive evaluation methods, and combining the characteristics of the evaluation object in this paper, the TOPSIS method is therefore adopted for comprehensive evaluation. The ANP-AEW method is applied to determine the weights and combined with TOPSIS to achieve the purpose of reducing the weighting error and improving the calculation precision. The specific steps are as follows:

1) Construct the standardized decision matrix $R=(r_{ij})_{n\times m}(i=1,2,...,n; j=1,2,...,m)$.
2) Calculate subjective weight vector W_s using ANP.
3) Calculate objective weight vector W_o using AEW method.
4) Calculate the combined weight vector $W = \alpha W_s + \beta W_o$.
5) Determine the indicator weighted evaluation matrix $\overline{V}$, which is calculated by the formula:

$$\overline{V}=(v_{ij})_{n\times m}=W\times R=\begin{pmatrix}\omega_1 r_{11} & \omega_1 r_{12} & \cdots & \omega_1 r_{1m}\\ \omega_2 p_{21} & \omega_2 p_{22} & \cdots & \omega_2 r_{2m}\\ \vdots & \vdots & \ddots & \vdots\\ \omega_n r_{1m} & \omega_n r_{n2} & \cdots & \omega_n r_{nm}\end{pmatrix} \tag{25}$$

Where, v_{ij} represents the weighted evaluation result of alternative j on indicator i.

6) Find the positive and negative ideal alternatives V^+ and V^- based on TOPSIS, i.e:

$$\begin{aligned}V^+&=\{v_1^+,v_2^+,\cdots,v_n^+\}\\ V^-&=\{v_1^-,v_2^-,\cdots,v_n^-\}\end{aligned} \tag{26}$$

Where: $v_i^+=\max_{1\le i<m} v_{ij}$ is the i rd element in the positive ideal program V^+, $v_i^-=\min_{1\le i\le m} v_{ij}$ is the i th element in the negative ideal program V, and there is $i=1,2,\ldots,n$.

7) Calculate the distance between the object of evaluation and the optimal program and the worst program. Let the distance from program j to the positive ideal program is S_i^+, and the distance to the negative ideal program is S_i^-, then:

$$\begin{aligned}S_j^+&=\left[\sum_{i=1}^{n}\left(v_{ij}-v_{ij}^+\right)^2\right]^{1/2}\\ S_j^-&=\left[\sum_{i=1}^{n}\left(v_{ij}-v_{ij}^-\right)^2\right]^{1/2}\end{aligned} \tag{27}$$

Where: v_{ij} is the weighted evaluation value of an evaluation object j in the i indicator, v_{ij}^+ is the value of the optimal indicator, and v_{ij}^- is the value of the worst indicator.

8) Calculate the closeness of evaluation object j to the optimal program δ_j, the formula is:

$$\delta_j=\frac{S_j^-}{S_j^+ + S_j^-} \tag{28}$$

9) Apply the ANP-AEW-TOPSIS combination method to calculate the evaluation value of each program, and rank the evaluation objects based on the evaluation value. The larger the closeness, the closer the program is to the optimal program, and the better the program is in relative terms, which provides guidance for the investment decision of power grid projects.

4. Ptimization and Benefit Analysis of Investment Decisions for Grid Projects

4.1. Optimization Model Arithmetic Analysis

4.1.1. Analysis of the optimal solution of the objective function.The analysis of the optimal solution of the objective function is shown in Table 2. By collecting the relevant historical data of the 220kV grid, the power grid company of Province C assumes that the life of each project (a total of seven projects, respectively, indicated by the numbers from 1 to 7) is 25 years, and that the annual operating cost of each project remains unchanged during the life period, the annual base rate of return also remains unchanged at 6%, and that the average maximum shortfall cost of each year is 200,000 yuan, and that the shortfall costs is directly proportional to the size of the cost. After adopting the above assumptions, the model in the paper is applied to this example, which is realized based on Visual C++7.0 software, and the final calculation result is $X=(1,0,1,1,0,1,1)$, i.e., it is optimal to choose to invest in projects 1, 3, 4, 6 and 7, and the investment amount of its decision-making scheme is 215.6 million yuan, and the value of the objective function is 24.57 million yuan.

Table 2. Optimal solution of objective function

Item	Invest into Cost / 10,000 yuan	Annual operating cost/10,000	Annual revenue / 10,000	Capacity /MVA

		yuan	yuan	
1	4200	69	436	665
2	4275	104.38	467	716
3	6172	145.62	644	979
4	4680	113.7	511	757
5	4910	116.87	515	785
6	3760	94.75	447	684
7	2750	69.47	419	648

4.1.2. Comparative analysis of the effect of optimization model application.In order to further prove the practical application effect of the optimization model in this paper, this subsection adopts different algorithms to solve the optimization problem of grid investment benefit under different voltage levels and analyze its performance.

1) Experimental setup. The voltage level is divided as shown in Table 3, and the research samples have been given above, so we will not repeat them here to compare the differences in the results of the project investment benefit optimization of the four schemes under different voltage levels, and analyze the reasons from several aspects. The specific comparison programs are as follows:

Scenario 1: The optimization model is used for project preference, and the genetic algorithm (GA) is used to select the final investment portfolio.

Scheme 2: Project selection based on the optimization model and selecting the final portfolio using particle swarm algorithm (PSO).

Option 3: Select the final portfolio by manual optimization method in accordance with the comprehensive score ranking.

Option 4: Create 0/1 decision variables through YALMIP and call CPLEX optimization solver for project selection to maximize the comprehensive benefits.

Table 3. Voltage classification

Voltage level	400kv	200kv	100kv	30kv	Total
Number of items/pieces	26	47	106	106	285
Planned investment / 100 million yuan	19.69	32.54	25.68	7.96	85.87
Total investment in feasibility research / 100 million yuan	87.68	64.86	39.92	11.33	203.79

Different voltage level constraint values are set as shown in Table 4, according to the actual grid project investment reality, set different voltage level constraint values to lay the theoretical foundation for the subsequent analysis of the research results.

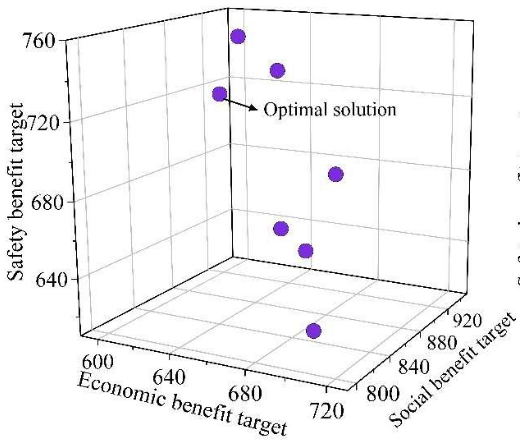
Table 4. Different voltage level constraint value setting

Voltage level	400kv	200kv	100kv	30kv	Total
Total investment scale / 100 million yuan	32	22	22	12	88
Newly started investment scale / 100 million yuan	10	10	7	3	30
Winter kurtosis constraint /MVA	1500	1200	800	500	-
Kurtosis summer constraint /MVA	2000	1300	1000	700	-
Ratio of new opening/research	[0.15,0.25]	[0.3,0.5]	[0.4,0.7]	[0.4,0.9]	[0.35,0.75]
Ratio of new opening to continued construction	[0.45,0.65]	[0.45,0.75]	[0.3,0.6]	[0.2,0.4]	[0.25,0.55]

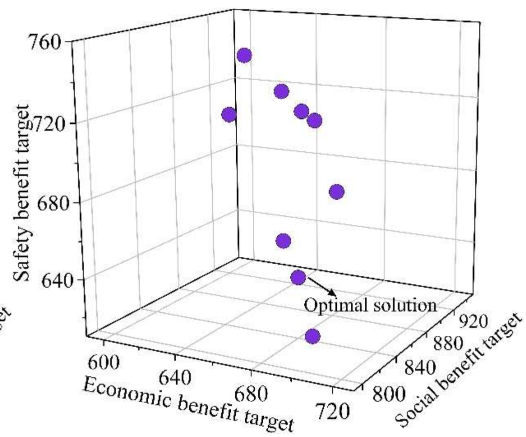
2) Evaluation indicators. Inverse generational distance (IGD) and spatial distribution diversity (SSP) are used as the indicators for judging the convergence and diversity of the Pareto frontier solutions obtained from the project investment decision optimization model based on genetic algorithm and particle swarm algorithm. IGD is obtained by calculating the minimum distance between the target solution set and the uniformly distributed solution set of the ideal Pareto frontier and taking the average value, and the smaller the value is, the closer to the ideal Pareto frontier the solution set is, and the better the convergence is. IGD is obtained by calculating the minimum distance between the target solution set and the uniformly distributed ideal Pareto front solution set and finding the average value, the smaller its value is, the closer the solution set is to the ideal Pareto front solution set and the better the convergence of the solution set is.

3) Comparative analysis of results. In order to more intuitively observe the changes in the multidimensional benefits of grid project investment, it is divided into economic benefits, social benefits, and security benefits on the basis of the original. Next, the application effectiveness of the algorithm and the preferred effect of different optimization schemes 400kv, 200kv, 100kv, 30kv are compared with the distribution of Pareto frontier solution sets for projects of different voltage levels and the distribution of final decision solutions obtained by using optimization solution algorithms (GA, PSO).

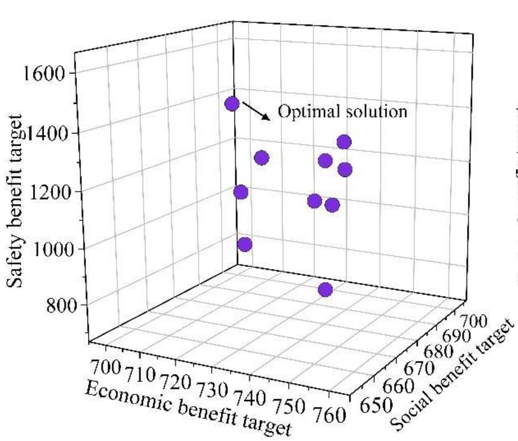
In order to visually compare the performance of GA and PSO algorithms in solving the decision optimization problems of grid projects, a comparison of the solution effectiveness of different algorithms at different voltage levels is shown in Fig. 3, where (a) ~ (h) are the preferred effects of GA~PSO at 400kv, 200kv, 100kv, and 30kv, respectively. Due to the small number of 400kV grid infrastructure projects resulting in a small range of solution selection in the feasible domain, the optimal solution set of 400kV grid project benefits obtained by the two algorithms is basically the same in the three-dimensional spatial distribution. As the voltage level decreases and the number of projects to be selected increases, the diversity of the optimal solution set of grid project benefits gradually appears. From Figures (c)-(h), it can be seen that the spatial distribution and diversity of the GA algorithm is better, avoiding the shortcomings of the optimal solution set of the grid project benefits falling into the local optimization, and realizing a more uniform spatial distribution as well as a wider distribution.



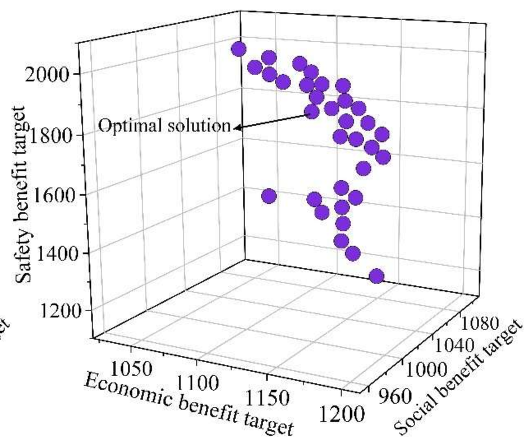
(a)PSO-400kv



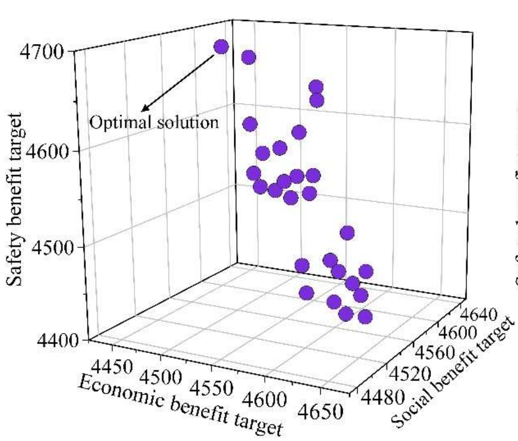
(b)GA-400kv



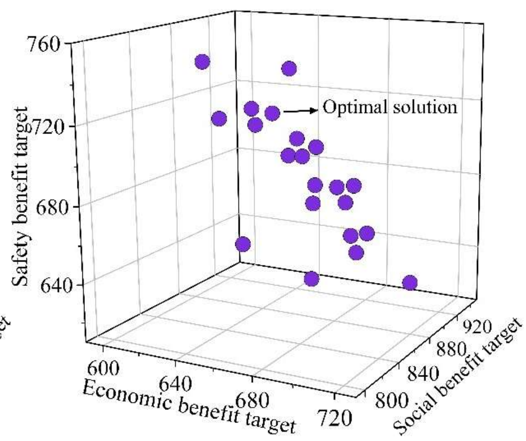
(c)PSO-200kv



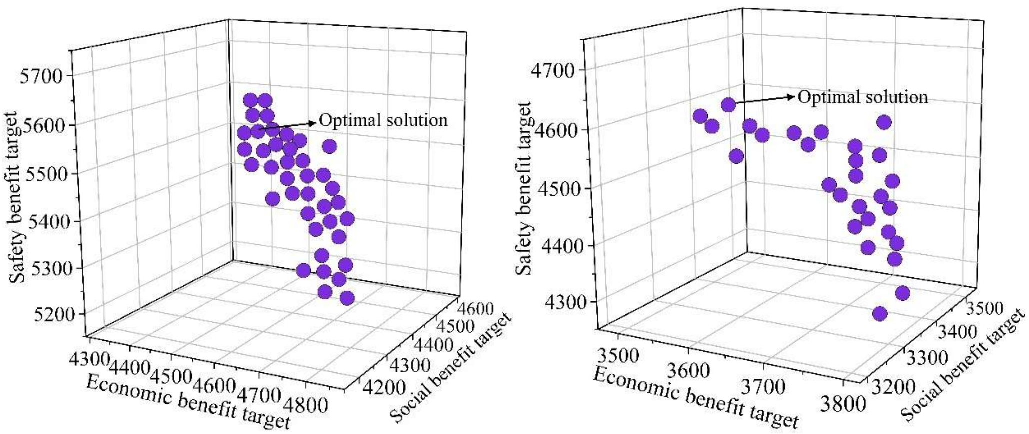
(d)GA-200kv



(e)PSO-100kv



(f)GA-100kv



(g)PSO-30kv (h)GA-30kv

Fig. 3. Comparison of solving efficiency under different voltage levels

Firstly, the total benefit target value under different options is compared, and in order to unify the quantitative preference results, the quantitative benefit target is adopted, and the comparison results of the four options are shown in Fig. 4. Scenario 1 has obvious advantages in economic benefits, social benefits and safety benefits. In terms of economic benefits were higher than the benefits of Scheme II, Scheme III, Scheme IV value of 1417, 7094, 2590, in terms of social benefits and security benefits are in the same situation, indicating that the optimization model in this paper can achieve the maximization of the benefits of the power grid investment project. In terms of project preference characteristics, the overall benefits of Scenario 1 and Scenario 2 are similar, and the benefits of Scenario 3 and Scenario 4 have the same trend. For scheme three manual selection method, usually to grid enterprises to assume social responsibility as a starting point, optimization project benefit target to social benefits and security benefits, favoring the realization of guaranteeing the security and stability of power supply, in order to achieve the protection of people's livelihood. Scenario 4 optimizes a large number of low-voltage infrastructure projects, most of which are substation or line reconstruction projects to solve the heavy overload problem, as well as infrastructure projects to meet the demand for new capacity, and thus generates high values of social benefits and safety benefits. Overall, the optimization model in this paper has superior performance in the optimization of grid project investment decisions.

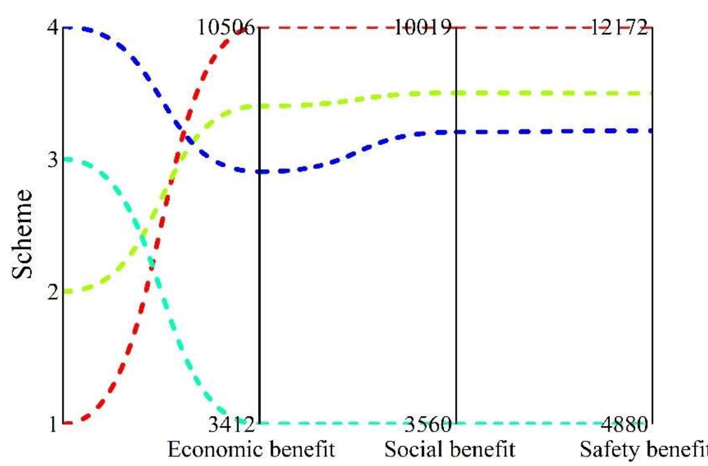


Fig. 4. Comparison results of four schemes

4.2. Multidimensional benefits assessment analysis

Although the above has tested the application efficacy of the model in this paper, considering the rigor of the research results, the next use of ANP (Network Hierarchy Analysis) - AEW (Anti-Entropy Method) - TOPSIS (Approximate Ideal Solution Sorting Method) to analyze the multi-dimensional benefit evaluation index system of the power grid project investment has been realized to assess the multi-dimensional benefits.

4.2.1. Portfolio weighting analysis

1) Subjective weight calculation based on ANP. The original data for subjective weight calculation is obtained through the form of professional scoring of evaluation indicators. According to the above formula, the subjective weights of the indicators in the multi-dimensional benefit evaluation index system of the constructed grid project investment are calculated, and the subjective weights of the evaluation indicators are shown in Table 5. Based on the weight data in the table, it can be seen that the weight of the first-level indicators exists, A4 (0.3211) < A1 (0.2633) < A3 (0.2448) < A4 (0.1708), while the second-level indicators have B14 (0.1094) < B7 (0.1058) < B10 (0.1030) < B3 (0.0936) < B2 (0.0932) < B15 (0.0905) <B13 (0.0818) <B9 (0.0814) <B1 (0.0689) <B8 (0.0611) <B11 (0.0604) <B12 (0.0305) <B16 (0.0089) <B4 (0.0046) <B6 (0.0039) <B5 (0.0030).

Table 5. Subjective weights of parity indicators

Primary index	Weighting	Secondary index	Weighting
A1	0.2633	B1	0.0689
		B2	0.0932
		B3	0.0936
		B4	0.0046
		B5	0.0030
A2	0.1708	B6	0.0039
		B7	0.1058
		B8	0.0611
A3	0.2448	B9	0.0814
		B10	0.1030
		B11	0.0604
A4	0.3211	B12	0.0305
		B13	0.0818
		B14	0.1094
		B15	0.0905
		B16	0.0089

2) Objective weight calculation of evaluation indicators based on AEW. The original data required for the objective weight calculation of evaluation indicators is different from the original data of subjective weight mentioned above, and the data of each indicator on the official website of the grid enterprise is used as the original data. Based on the AEW formula, the objective weights of the evaluation indicators are calculated, and the results of the objective weights of the evaluation indicators based on AEW are shown in Table 6. According to the order of weights from the largest to the smallest, the secondary indicators have B16 (0.0874) > B1 (0.0859) > B14 (0.0849) > B13 (0.081) > B15 (0.0809) > B12 (0.0788) > B6 (0.0657) > B7 (0.0652) > B8 (0.0649) > B3 > (0.0571)B10 (0.0559)>B11 (0.0456)>B2 (0.0443)>B4 (0.0413)>B5 (0.0329)>B9 (0.0282), whereas the first level indicator exists A4 (0.4130)>A1 (0.2615)>A2 (0.1958)>A3 (0.1297).

Table 6. Objective weights of evaluation indicators based on AEW

Primary index	Weighting	Secondary index	Weighting
A1	0.2615	B1	0.0859
		B2	0.0443
		B3	0.0571
		B4	0.0413
		B5	0.0329
A2	0.1958	B6	0.0657
		B7	0.0652
		B8	0.0649
A3	0.1297	B9	0.0282
		B10	0.0559
		B11	0.0456
A4	0.4130	B12	0.0788
		B13	0.081
		B14	0.0849
		B15	0.0809
		B16	0.0874

3) Calculation of combination weightsFirst, according to the formula (22) and (23) to calculate the important coefficient (α , β) of the subjective and objective weights of the indicators, on the basis of the known subjective and objective weights, the formula (24) is used to calculate the combination weight data of the indicators, and the values of the combination weights of the evaluation indicators are shown in Table 7. It can be seen that B4 (0.0867) > B6 (0.0793) > B3 (0.0759) > B5 (0.0755) > B2 (0.0715) > B9 (0.0703) > B14 (0.07) > B16 (0.0688) > B1 (0.068) > B8 (0.0595) > B11 (0.0574) > B7 (0.0554)>B12 (0.0546)>B10 (0.0474)>B13 (0.033)>B15 (0.0267), and in the tier 1 indicators, A4 (0.3614)>A1 (0.2665)>A2 (0.1893)>A3 (0.1828), which provide data support for the comprehensive multidimensional benefits assessment exercise below.

Table 7. Evaluation index combination weight value

Primary index	Composite weight	Secondary index	Subjective weight	Objective weight	α	β	Composite weight
A1	0.2665	B1	0.0689	0.0859	0.4451	0.5549	0.0688
		B2	0.0932	0.0443	0.6778	0.3222	0.0680
		B3	0.0936	0.0571	0.6211	0.3789	0.0700
		B4	0.0046	0.0413	0.1002	0.8998	0.0330
		B5	0.0030	0.0329	0.0836	0.9164	0.0267
A2	0.1893	B6	0.0039	0.0657	0.0560	0.9440	0.0546
		B7	0.1058	0.0652	0.6187	0.3813	0.0793
		B8	0.0611	0.0649	0.4849	0.5151	0.0554
A3	0.1828	B9	0.0814	0.0282	0.7427	0.2573	0.0595
		B10	0.1030	0.0559	0.6482	0.3518	0.0759
		B11	0.0604	0.0456	0.5698	0.4302	0.0474
A4	0.3614	B12	0.0305	0.0788	0.2790	0.7210	0.0574
		B13	0.0818	0.081	0.5025	0.4975	0.0715
		B14	0.1094	0.0849	0.5630	0.4370	0.0867
		B15	0.0905	0.0809	0.5280	0.4720	0.0755
		B16	0.0089	0.0874	0.0924	0.9076	0.0703

4.2.2. Analysis of assessment results.The designed questionnaires are distributed to ten experts, which include C Grid enterprise employees, CEC employees and university teachers, and during the evaluation process the experts use the investment evaluation index system of the grid construction projects (a total of 7 projects) to score each single index of the project according to the basic information such as project proposal and feasibility study report, (excellent 100-90, good 70-80, General 50-60, poor 30-40, poor 0-20), the standardization of the 7 project indicator scores, and finally get the standardized decision matrix, standardized as shown in Table 8. According to formula (26) get to find out the positive and negative ideal program V^+ and V^-, that is:

$$V^+ = (17.86, 19.51, 18.38, 19.59, 19.72, 19.6719.68, 17.75$$
$$19.32, 19.7, 16.47, 17.99, 19.85, 18.04, 17.63, 17.45)$$

$$V^- = (5.03, 5.92, 5.79, 5.83, 6.52, 5.16, 5.66, 5.2,$$
$$11.98, 9.11, 7.47, 7.9, 6.02, 6.97, 7.89, 6.08)$$

Table 8. Standardized decision matrix

Secondary index	Composite weigh	Weighted evaluation score						
		Item 1	Item 2	Item 3	Item 4	Item 5	Item 6	Item 7
B1	0.0688	8.01	12.98	17.86	12.93	11	13.09	5.03
B2	0.0680	8.71	16.3	5.92	12.28	19.1	19.51	11.92
B3	0.0700	9.79	18.38	6	7.98	12.91	15.79	5.79
B4	0.0330	5.83	9.78	19.59	12.7	15.62	11.15	14.58
B5	0.0267	9.85	11.58	6.98	19.72	19.71	17.79	6.52
B6	0.0546	5.16	18.2	10.75	9.67	19.67	10.51	16.76
B7	0.0793	16.42	8.72	10.86	15.1	18.68	13.04	5.66
B8	0.0554	5.2	17.56	15.03	17.75	9.2	17.71	12.12
B9	0.0595	19.09	17.24	18.65	16.67	19.32	11.98	15.46
B10	0.0759	14.96	11.05	19.7	9.11	18.57	10.74	13.54
B11	0.0474	9.3	16.47	9.55	16.32	8.13	7.47	15.83
B12	0.0574	17.2	7.9	17.16	13.44	10.41	17.99	8.62
B13	0.0715	19.85	7.52	6.02	18.31	8.01	18.9	7.55
B14	0.0867	15.96	7.96	13.72	6.97	18.04	15	9.66
B15	0.0755	13.38	12.85	8.52	7.89	14.56	12.76	17.63
B16	0.0703	17.45	9.21	9.62	15.82	15.84	6.08	16.59

According to formula (27), the distances of the seven projects to the positive and negative ideal points can be calculated separately, and the distances of the seven projects to the positive and negative ideal points are shown in Table 9. It can be seen that the closest distances of the 7 projects to the positive and negative ideal points are project 5 and project 7 respectively.

Table 9. Distance of each item to positive or negative ideal points

Item number	Item 1	Item 2	Item 3	Item 4	Item 5	Item 6	Item 7
S_i^+	32.3156	28.6941	32.4289	26.5963	21.1306	24.4629	35.3651
S_i^-	27.6704	29.2044	28.5363	31.1925	36.6372	33.2131	24.7398

Finally, the proximity of the seven projects to the optimal solution is calculated using equation (28), and the proximity and ranking results of the seven projects to the optimal solution are shown in Table 10. The results obtained according to the TOPSIS method show that project 5 has the best investment efficiency, followed by project 6, and the worst investment efficiency is project 7.

Table 10. The close degree of distance optimal scheme and the ranking result

Item number	Item 1	Item 2	Item 3	Item 4	Item 5	Item 6	Item 7
Close degree δ	0.4613	0.5044	0.4681	0.5398	0.6342	0.5759	0.4116
Rank	6	4	5	3	1	2	7

5. Conclusion

This paper sets the objective function and constraints, thus composing an optimization model of power grid project investment decision-making, and proposes to use genetic algorithm to solve this model. In order to study the scientific nature of the research results, according to the principle of evaluation index construction, a multi-dimensional benefit evaluation index system is constructed, and the index system is evaluated and analyzed with the help of the ANP (network hierarchical analysis) - AEW (anti-entropy method) - TOPSIS (approximation of the ideal solution sorting method). The index system is evaluated and analyzed. Compared with the PSO algorithm, the GA algorithm has better spatial distribution and diversity, and effectively regulates the problem of local optimization, i.e., the GA algorithm has a higher priority in optimizing the investment decision of power grid projects. In addition, in the proximity analysis of the optimal grid distance scheme, there exists project 5>project 6>project 4>project 2>project 3>project 1>project 7, which is an all-round analysis of the actual situation of the current grid project investment decision.

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