

Study on the Coordination and Optimization of Power Grid Investment Demand and Investment Capacity under Under the Environment of Electricity Marketization

Shuo Yin¹, Yao Lu¹, Qinchen Yang^{1,*}, Chunjiao He²

¹State Grid Henan Economic Research Institute, Zhengzhou, China

²Henan University of Technology, Zhengzhou, China

*Corresponding author e-mail: yinshuo1111@163.com

Abstract. Under the influence of the reform of transmission and distribution price, the profit model and operation mode of power grid enterprises have undergone major changes and changes, and it is urgent to transform the operation concept and investment decision of enterprises. The reformed power grid investment demand and investment capacity coordination optimization model provides a direction that can be optimized for power grid investment decision-making. The first step is to analyze the investment demand of the power grid, and divide the power grid investment capacity into distributable profits, financing funds, and depreciation costs, and then build a power grid investment capacity calculation model based on the transmission and distribution price reform. Then, the coordination coefficient of power grid investment capacity and investment demand is calculated, considering multiple constraints, an optimization model of power grid investment demand and investment capacity is established, and particle swarm optimization algorithm is introduced for coordination optimization. Finally, the simulation analysis is carried out considering whether the investment demand and investment ability are coordinated, and the corresponding investment management strategy is proposed according to the simulation results. The verification of the example shows that the model can provide a more effective reference for power grid enterprises to formulate a reasonable investment plan.

Key words: transmission and distribution prices; grid investment demand; investment capacity; particle swarm optimization algorithm

1. Introduction

Due to the reform of transmission and distribution prices, the source of income of power grid enterprises has changed, and the profit model of transmission and distribution has also changed. From earning the purchase and sale price difference to obtaining investment. From earning the price difference between purchase and sale to obtaining reasonable compensation for investment and operation of transmission and distribution assets - allowed costs and permitted benefits[1], which to some extent affects the investment of power grid projects[2]. In this context, the coordinated optimization of investment demand and investment capacity of power grid enterprises is conducive to improving the investment efficiency and operating income of power grid enterprises[3], thus promoting the orderly development of power market[4]. Nowadays, the main factors affecting the investment of power grid are analyzed from the aspects of macro economic development and power grid development, the development needs of all aspects of power grid are summarized, and the investment plan of power grid development in various regions is constructed according to local conditions. This research idea has certain guiding significance. However, due to the lack of constraints on power grid investment, it is difficult to evaluate the benefits of power grid investment, and it is impossible to form suggestions for investment plans[5].

The investment environment of power grid company is complex, and its investment ability is affected by many factors, such as power grid operation efficiency, enterprise benefit, social benefit and power grid security. References [6] introduced the feedback machine of investment behavior to investment ability, established the investment timing optimization model of power grid planning project and considered various influencing factors, and established the model of transmission and

distribution price and power grid investment capacity evolving with time; References [7] considered many factors, such as profit, cost and other external factors. They established a quantifiable investment capacity model, combined with the influence points and analysis conclusions of the new pricing rules, and established a three-optimization and precise investment strategy system for the power grid to adapt to the transmission and distribution price reform. Based on the policy environment faced by transmission and distribution prices, References [8] studied the impact of different sources of funds under the new power system reform, and established a model considering the maximum investment capacity of the power grid.

At present, the research on power grid investment mostly focuses on investment benefit evaluation, and there are few studies on the quantitative calculation method of differentiated power grid investment [9]. In [10], considering the difference of time and space, the quantitative relationship between power grid investment and the difference index of power grid development path is established, and the correlation between power grid investment demand and its influencing factors is analyzed by using the correlation coefficient method. Based on the theory of grey correlation analysis, a prediction model of power grid investment demand is constructed. References [11] analyzed the impact of different aspects of investment management, and established a power grid investment demand forecasting model, which introduced the co-arrangement theory and error correction model. The method of describing the power grid investment demand is based on the adaptive bell curve considering environmental factors.

At the same time, in terms of investment strategy, Reference [12] established the function relationship between power grid investment and transmission and distribution price, and proposed investment strategies according to different investment strategy scenarios. References [13] analyzed the transmission and distribution price approval and the differentiated investment strategy of provincial power grid. Based on the traditional investment decision-making optimization and provide reference. Reference [14] combed the relationship between transmission and distribution price and investment capacity, and studied the investment strategy to adapt to the development of power grid, so as to promote the healthy and sustainable development of power grid.

Based on this, this paper fully considers the coordination relationship between power grid investment capacity and investment demand, and establishes a coordinated optimization model between the two, which provides decision support for power enterprises to maximize investment benefits.

2. Coordinated optimization of power grid investment demand and investment capacity

2.1 Power grid investment demand and power grid investment capacity

The investment demand of power grid refers to the investment made by provincial power grid companies in order to ensure the steady progress of strategic projects and decisions, and to build a safe and reliable power grid according to the needs of social and economic development. With reference to social development, user-side demand and resource use, a certain stage of investment demand is proposed. The deficiency is that it lacks consideration of grid investment capacity and related aspects, and it is difficult to determine a reasonable investment scale.

Power grid investment capacity refers to the ability of provincial power grid companies to meet the needs of power grid investment, which is realized by cash flow generated by general enterprises on the basis of operation and financing activities. After the reform of the transmission and distribution price, the supervision method of the income of the provincial power grid company is implemented according to the internationally accepted nuclear price method, and the cost constraints of the enterprise are also stricter, so that the profit model of the transmission and distribution business of the power grid company has changed, thus affecting the change of the investment capacity of the power grid. By analyzing the calculation method of transmission and distribution price, this paper

puts forward the calculation method of power grid investment capacity under the reform of transmission and distribution price.

2.1.1 Transmission and distribution price calculation

The transmission and distribution price reform follows the "Several Opinions of the Central Committee of the Communist Party of China and the State Council on Further Deepening the Reform of the Electric Power System" (Zhongfa (2015) No. 9). According to the principle of "allowable cost plus reasonable income," the overall allowable income and average transmission and distribution price of power grid enterprises are approved, and then the supervision mode of power grid enterprises is changed, as shown in Formula (1-5):

$$P_{td} = \frac{I_a}{L \times h} \quad (1)$$

$$I_a = C_a + R_a + T \quad (2)$$

$$C_a = D + F_{om} \quad (3)$$

$$R_a = E_i \cdot \mu \quad (4)$$

$$T = T_{in} + T_{ur} + T_{ed} \quad (5)$$

In the formula, P_{td} represents the average transmission and distribution price; I_a represents permitted income; L represents the power demand of grid users, h represents the maximum load utilization hours; C_a represents the allowable cost; R_a represents the allowable income; T represents tax; D represents depreciation expense; F_{om} is the operation and maintenance cost including material cost, operation and maintenance cost and labor cost; E_i represents the effective assets that can be accrued; μ represents the return on capital; T_{in} , T_{ur} and T_{ed} represent income tax, urban maintenance and construction tax and education surcharge respectively.

2.1.2 Calculation method of power grid investment capacity

Based on the perspective of cash flow, the business activities and financing activities of power grid enterprises play a decisive role in investment capacity. According to different sources of funds, this paper divides the investment capacity of power grid into distributable profit, financing capital and depreciation cost, so as to establish a calculation model of power grid investment capacity suitable for the reform of transmission and distribution price. As shown in formula (6) :

$$I_c = P_d + F + D \quad (6)$$

$$P_d = P_t \times \alpha - P_r \quad (7)$$

$$F = \frac{\eta \times (Z_{tp} + P_t) - L_{tp}}{1 - \eta} \quad (8)$$

$$D = \sum_{i=1}^n Z_{s_i} \times \beta_1 + \sum_{j=1}^m Z_{t_j} \times \beta_2 \quad (9)$$

In the formula, I_c represents the investment ability of the grid company; P_d represents distributable profits; F represents the cash flow generated by the financing activities of the power grid company; P_t represents the total profit; α represents the income tax rate; P_r represents retained profits, which refers to the after-tax profits retained by the company to the country in order to achieve turnover; Z_{tp} represents the total value of assets last year; L_{tp} represents the total liabilities of last year; η represents the asset-liability ratio; Z_{s_i} represents the total value of stock

fixed assets ; Z_{ij} represents the total value of incremental fixed assets ; β_1 and β_1 represent the depreciation rate of stock fixed assets and incremental fixed assets respectively.

2.2 Determine the coordination coefficient

The coordination of investment demand and investment capacity of power grid ensures the sustainable development of power grid enterprises. In order to measure the corresponding relationship between investment demand and investment capacity of power grid and judge its coordination, this paper evaluates and analyzes the ratio of the difference I_x between investment demand and investment capacity to investment capacity.

Power grid investment demand can be divided into rigid investment and flexible investment. Rigid investment includes policy investment and mandatory investment. Flexible investment refers to self-development investment. Therefore, the evaluation index of coordination between power grid investment demand and investment capacity is given by Formula (10). At the same time, in order to further determine the standard of coordination between power grid investment capacity and investment demand, the historical investment demand and investment capacity of power grid companies in 25 provinces and cities are calculated and analyzed. The scatter diagram of coordination degree is shown in figure 1, and then the normal distribution theory is used to determine the coordination standard of demand and capacity.

$$CO = \frac{I_x}{I_c} \quad (10)$$

$$I_x = I_c - I_d \quad (11)$$

$$I_d = I_r + I_f \quad (12)$$

In the formula, CO represents the coordination coefficient, indicating that the investment capacity and investment demand coordination degree are positively correlated ; I_d represents the investment demand of the power grid company ; I_x represents the difference between investment capacity and investment demand ; I_r represents the total rigid investment ; I_f represents the total flexible investment.

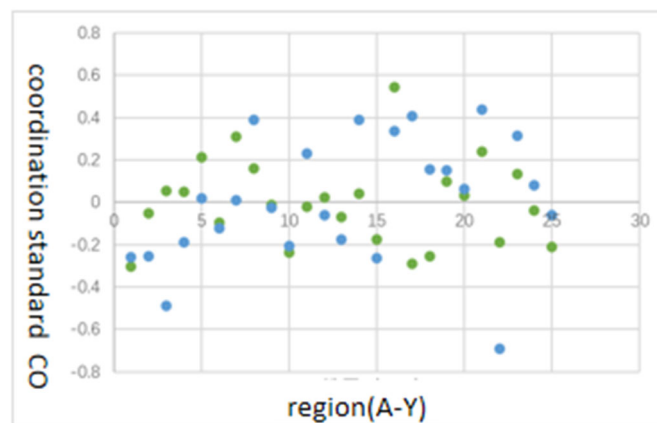


Fig.1 Scatterplot of the degree of coordinated correspondence between investment demand and investment capacity

Based on the research of investment demand measurement and investment capacity measurement, according to the comparative analysis of investment demand and investment capacity of 25 provincial companies over the years. It is found that the sample data is normally distributed, as shown in Figure 2. The main distribution interval of the sample data is $[-0.25, 0.25]$. It can be considered that when the coordination coefficient $CO \geq -0.25$, the investment capacity and investment demand are coordinated.

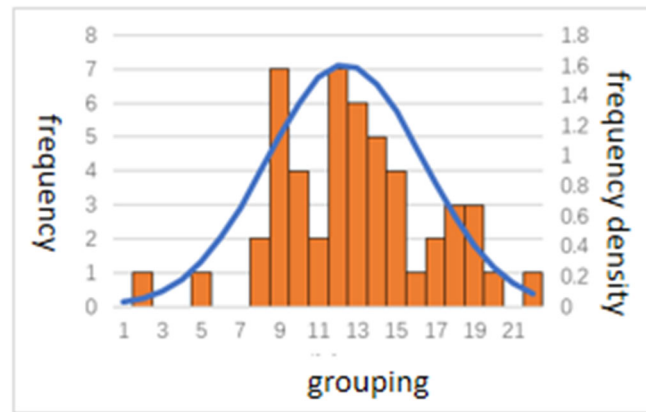


Fig.2 Normal distribution curve of coordination coefficient

2.3 Power grid investment demand and investment capacity coordination optimization model

2.3.1 Objective function

The objective function of the coordinated optimization model is given by Formula (13), which is based on the minimum difference between investment capacity and investment demand.

$$F = \min |I_{c_oc} - I_d| \quad (13)$$

$$I_{c_oc} = P_{t_oc} \times \alpha - P_r + \frac{\eta_{oc} \times (Z_{ip} + P_t) - L_{ip}}{1 - \eta_{oc}} + D \quad (14)$$

$$P_{t_oc} = (L_{s_oc} \times P_s + L_{td} \times P_{td} + R_{ob_oc}) \times (1 - \varepsilon_{oc} - \delta_{oc}) - F_{om_oc} - D - L_{s_oc} \times (1 + \phi) \times P_p \quad (15)$$

In the formula, I_{c_oc} represents the power grid investment capacity after coordinated optimization ; P_{t_oc} , R_{ob_oc} and F_{om_oc} represent the total profit after coordinated optimization, other business income and operation and maintenance costs respectively ; L_{td} represents the amount of transmission ; h is the coordinated optimization of electricity sales ; η_{oc} , ε_{oc} and δ_{oc} represent the asset-liability ratio, management expense ratio and operating expense ratio after coordination and optimization. ϕ represents the line loss rate.

2.3.2 Constraint condition

Considering the adjustability of indicators and the difficulty of adjustment, this paper adjusts the calculation index of investment ability as a strategic index, and establishes the constraints of relevant indicators.

(1) Asset-liability ratio constraint

By increasing the asset-liability ratio, the cash flow of financing activities can be increased to a certain extent, thereby improving the investment capacity of the power grid. According to the " guidance on strengthening the asset-liability constraints of state-owned enterprises ", power grid companies set 70 % as the highest value of their asset-liability ratio.

$$\eta \leq \eta_{oc} \leq 70\% \quad (16)$$

(2) Management expense rate and operating expense rate constraints

The cost rate affects the cost, profit and investment ability.

$$\varepsilon_{\min} \leq \varepsilon_{oc} \leq \varepsilon_{\max} \quad (17)$$

$$\delta_{\min} \leq \delta_{oc} \leq \delta_{\max} \quad (18)$$

In the formula, $\varepsilon_{\min}$ and $\varepsilon_{\max}$ represent the minimum and maximum management cost rate of the grid company respectively; $\delta_{\min}$ and $\delta_{\max}$ represent the minimum and maximum operating cost rates of the grid company.

(3) Other business revenue constraints

According to the change of external environment, the power grid company expands the income source and profit level of other businesses through the integration and optimization of management, so as to improve the business investment ability.

$$R_{ob} \leq R_{ob_oc} \leq R_{ob} \times (1 + \theta_{R_{ob}}) \quad (19)$$

In the formula, $\theta_{R_{ob}}$ means the degree to which the grid company adjusts other business income.

(4) Operating maintenance cost constraints

The operation and maintenance cost will affect the transmission and distribution cost to a certain extent, thus affecting the investment capacity. Provincial power grid companies can reduce daily maintenance costs by strengthening the monitoring of equipment status and improving the quality of technological transformation.

$$F_{om} \times (1 - \theta_{F_{om}}) \leq F_{om_oc} \leq F_{om} \quad (20)$$

In the formula, $\theta_{F_{om}}$ represents the degree of adjustment in operating and maintenance costs.

(5) Electricity sales constraints

Electricity sales have a great impact on income and profits, thus affecting investment capacity. Provincial power grid companies can win more customers by implementing multi-price strategies and improving service awareness, thereby expanding the scale of electricity sales.

$$L_s \leq L_{s_oc} \leq L_s \times (1 + \theta_{L_s}) \quad (21)$$

In the formula, θ_{L_s} represents the degree of adjustment of electricity sales.

2.3.3 Solving algorithm

Particle swarm optimization (PSO) is derived from the study of bird predation behavior, which aims to find the optimal solution through the cooperation and information sharing among individuals in the group. It has the characteristics of simple parameters, efficient search and fast convergence. In this paper, the algorithm is applied to the coordinated optimization of power grid investment. The process of PSO is shown in Figure 3.

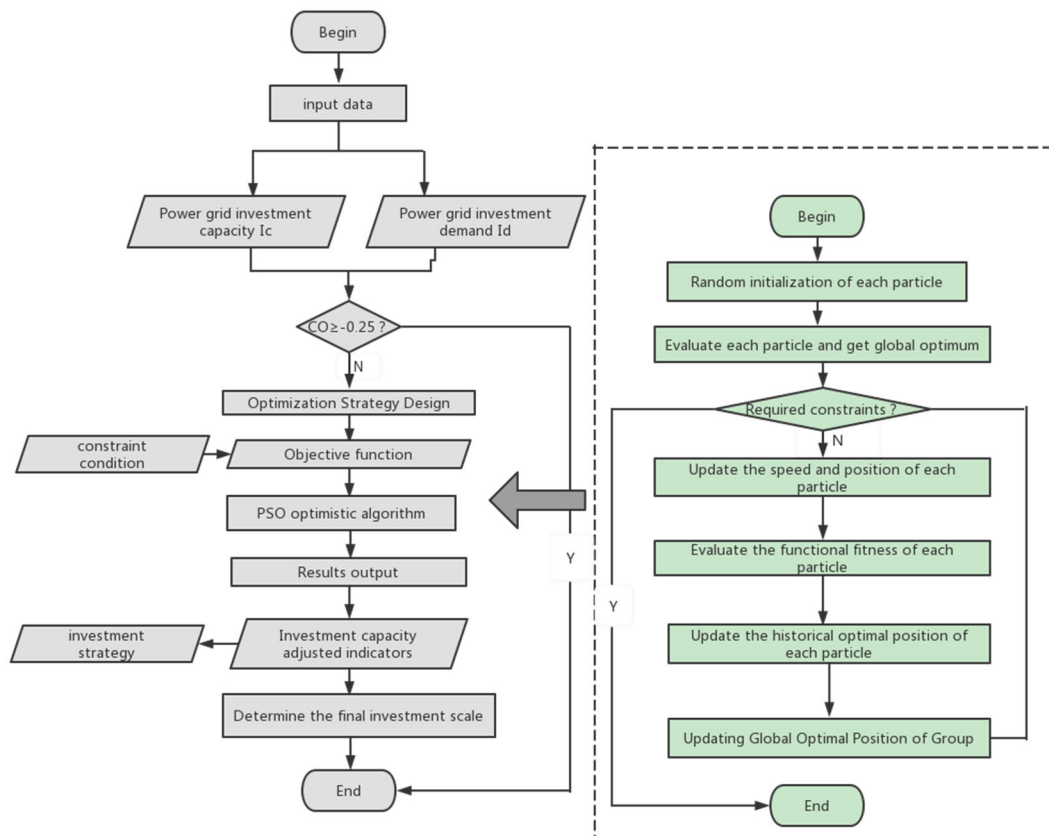


Fig.3 Flowchart for optimization of coordination between power grid investment demand and investment capacity

The steps of using PSO optimization algorithm to solve the coordination optimization problem of power grid investment capacity and investment demand are as follows.

(1) Input data. According to the investment ability calculation method, the investment ability is predicted.

(2) Determine whether investment demand and investment capacity are coordinated. According to the coordination coefficient of investment demand and investment capacity, it is judged whether the two are coordinated. If $CO \geq -0.25$, it is considered coordinated and the analysis is over. Otherwise, begin to optimize the coordination of investment.

(3) Combined with the actual management situation, determine the adjustment range of indicators. Accordingly, the objective function is established to consider the minimum gap between investment capacity and investment demand. The constraint conditions are constructed, and the constraint conditions include the fluctuation range of the relevant indicators. Finally, the particle swarm optimization is used to solve the above objectives and determine the optimal investment plan.

(4) Output results. The content of the output results contains the solution of the objective function and constraint conditions established by the above steps.

(5) Determine the final investment scale. For provincial power grid companies, the optimized and coordinated model has certain reference significance for the implementation of the final investment project, and based on this, relevant strategies are formulated to adapt to the transmission and distribution price reform policy.

3. Simulation analysis

Based on the above research and analysis of the coordinated optimization model of power grid investment demand and investment capacity, this section calculates the investment capacity of provincial power grid companies under two different scenarios, and formulates a certain adaptability and matching business investment strategy, which can effectively guide the high-quality development of power grid enterprises. The scenario is set as follows :

Table1 Scenario set-up table

serial number	concrete contents
Scenario 1	Power grid investment demand and investment capacity can be coordinated.
Scenario 2	Power grid investment demand and investment capacity can not be coordinated.

3.1 Scenario 1: Power grid investment demand and investment capacity can be coordinated

3.1.1 Base data

Taking a provincial power grid company A as the research object, the main input data is shown in table 2. Through the transmission and distribution price accounting method and the calculation formula of the power grid investment capacity related model established above, the investment data of the power grid company A can be obtained, as shown in Table 3.

Table2 Main input data sheet

Data name	Data value
Average selling price	0.5225yuan/kWh
Average purchase price	0.3191yuan/kWh
Average transmission and distribution price	0.2144yuan/kWh
Management cost rate	7%
Operating cost rate	5%
Asset-liability ratio	58%
Depreciation rate of stock fixed assets	5.5%
Incremental depreciation rate of fixed assets	4.8%
Income tax rate	15%
Line loss rate	20%
Electricity sales	82500000000kWh
Electricity purchase	88400000000kWh
Transmission capacity	6562000000kWh
Other business income	230000000yuan
Operating maintenance costs	100000000yuan

Table3 Investment Data Sheet

Data name	Data value
Investment demand	9200000000yuan
Investment capacity	7241999500yuan
Distributable profits	87359800yuan
Financing amount	120639700yuan
Depreciation fee	7034000000yuan

3.1.2 Simulation and Result Analysis

(1) Determine whether the demand and ability are coordinated.

According to the data in Table 3, the coordination coefficient of investment demand and investment capacity of power grid company A is 0.27, which is less than the coordination standard value, indicating that the two are not coordinated. Using the model constructed in this paper, the problem is optimized and solved, and finally the reasonable and feasible investment scale is calculated.

(2) Determine the adjustable index range

Power grid company A has a large scale of electricity sales. According to the external conditions and actual operation of power grid company A, the changes of each adjustable index are analyzed. The specific adjustable index range setting is shown in Table 4.

Table4 Adjustable index range setting table

Adjustable index	Adjusting range
Asset-liability ratio	$\leq 4\%$
Management cost rate	5%-12%
Operating cost rate	4%-10%
Other business income	$\leq 5\%$
Operating maintenance costs	$\leq 5\%$
Electricity sales	$\leq 1\%$

(2) Algorithm solution and result analysis

The PSO optimization algorithm is used to iteratively optimize each adjustable index, and the three optimization algorithms of Cuckoo Search algorithm (CS), Genetic Algorithm (GA) and Artificial bee colony algorithm (ABC) are set up for comparison. The superiority and robustness of PSO optimization algorithm in solving the problem of coordinated optimization of investment demand and investment capacity are proved. The fitness curve is shown in Figure 4.

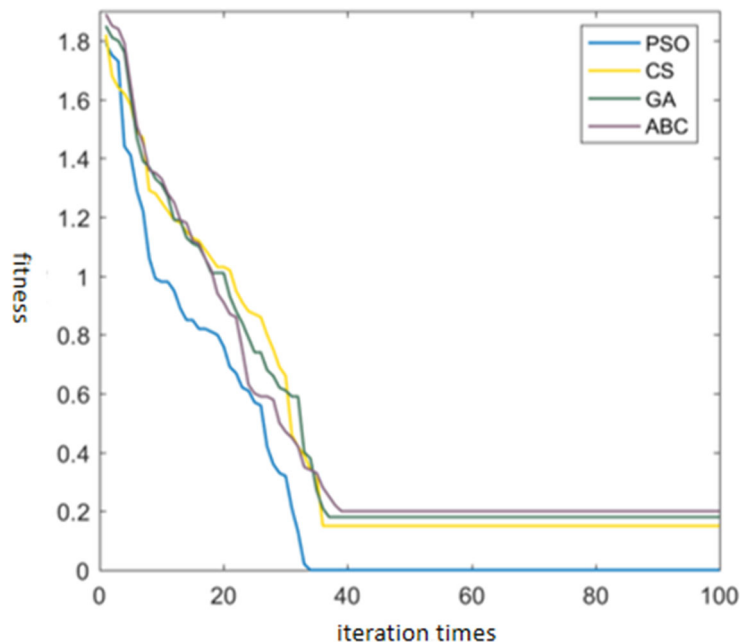


Fig.4 Algorithm adaptation curve

As shown in Figure 4, the curve gradually converges and reaches a stable value after about 34 iterations. The coordinated investment capacity is 9274.52 million yuan, and the coordination index $CO = 0.008 \geq -0.25$, indicating that the power grid company A can effectively coordinate the relationship between investment capacity and investment demand. The specific data is shown in table 5.

Table5 Optimal value of each index after coordination and optimization

Index Name	Investment Capacity	Asset-liability ratio	Management cost ratio	Operating cost ratio	Other business income	Operation and maintenance costs	Electricity sales
optimal value	9274520000yuan	58.94%	5%	4.5%	280000000yuan	96000000yuan	82800000000 kWh

It can be seen from the table that all indicators are within the expected range. After coordination and optimization, the asset-liability ratio increased from 58 % to 58.94 %, increased by 0.94 %, the management cost rate decreased from 7 % to 5 %, and the operating cost rate decreased from 5 % to 4.5 %, decreased by 2 % and 0.5 % respectively. Electricity sales increased by 30 million kilowatt hours, other business income increased by 50 million yuan, and operation and maintenance costs decreased by 4 million yuan.

(4) Put forward the corresponding investment management strategy

The simulation results show that the grid company A can achieve the optimal coordination of investment capacity and investment demand. Therefore, the final investment can be identified as 9274.52 million yuan. In order to achieve this goal, the Grid Company A should adopt the following investment strategies : 1) Under the premise of controlling the asset-liability ratio, bear moderate financing debt ; 2) Ensure reasonable cost and optimal management efficiency ; 3) Take a multi-price strategy and improve service awareness; 4) Actively expand other business.

3.2 Scenario 2: Power grid investment demand and investment capacity can not be coordinated

3.2.1 Base data

Taking a provincial power grid company B as the research object, the main input data is shown in table 6, and the investment data of power grid company B is shown in table 7.

Table6 Main input data sheet

Data name	Data value
Average selling price	0.5106yuan/kWh
Average purchase price	0.3215yuam/kWh
Average transmission and distribution price	0.1706yuan/kWh
Management cost rate	8%
Operating cost rate	8%
Asset-liability ratio	60%
Depreciation rate of stock fixed assets	6.5%
Incremental depreciation rate of fixed assets	5.8%
Income tax rate	15%
Line loss rate	20%
Electricity sales	29880000000kWh
Electricity purchase	308860850000kWh
Transmission capacity	9562000000kWh
Other business income	205270000yuan
Operating maintenance costs	350000000yuan

Table7 Investment Data Sheet

Data name	Data value
Investment demand	53600000000yuan
Investment capacity	32447680000yuan
Distributable profits	240700000yuan
Financing amount	17406980000yuan
Depreciation fee	14800000000yuan

3.2.2 Simulation and Result Analysis

Consistent with the scenario 1 steps, the coordination coefficient of grid company B is -0.65, which is less than the coordination standard value, and the two are not coordinated. Then determine the adjustment range of the adjustable index, as shown in Table 8. The PSO algorithm is used to optimize the results as shown in Figure 5. The coordinated investment capacity is 38979.3 million yuan, and the coordination index $CO = -0.37 < -0.25$, indicating that the power grid company B cannot achieve the coordination of investment demand and investment capacity.

Table8 Adjustable index range setting table

Adjustable index	Adjusting range
Asset-liability ratio	$\leq 4\%$
Management cost rate	5%-12%
Operating cost rate	4%-10%
Other business income	$\leq 5\%$
Operating maintenance costs	$\leq 5\%$
Electricity sales	$\leq 1\%$

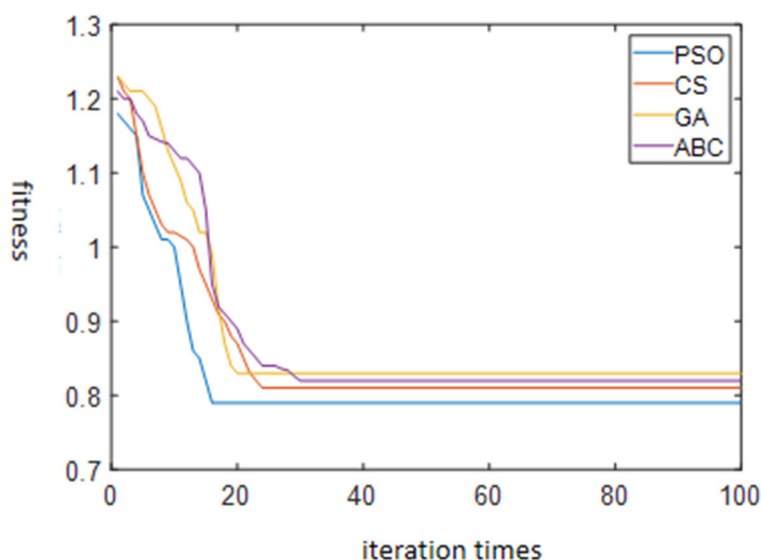


Fig.5 Algorithm adaptation curve

In the case of limited investment capacity, power grid company B should adopt the following investment strategy to deal with the reform of transmission and distribution price. 1) Reduce the scale of investment under the premise of meeting the load and safety ; 2) Strictly control expenditure, improve investment returns from many aspects ; 3) Pay attention to relevant policies and carry out the implementation of the project accordingly. With the help of government support, reduce investment pressure. 4) Improve service capabilities and strengthen user loyalty.

4. Conclusion

The current external environment is complex and changeable. Coordinated optimization of investment demand and investment capacity of power grid enterprises can achieve the effectiveness of power grid investment and enhance the profitability of enterprises. Based on the background of transmission and distribution price reform, this paper introduces the coordination coefficient to measure the relationship between investment demand and investment ability, and establishes a coordinated optimization model of power grid investment demand and investment ability. According to the simulation results, the corresponding investment and management strategies are proposed to provide decision support for power grid enterprises to adapt to the national power system reform and maximize investment benefits.

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