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A novel investment strategy for renewable-dominated power distribution networks

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Aiming at the problem of insufficient adaptability to the new elements of the new power system in the current distribution network investment method, this paper innovatively proposes a distribution network investment method based on the new power system. By constructing a source-grid-load-storage-side investment calculation model, the investment in the new power system can be accurately calculated. First, the distributed power investment is calculated from the two aspects of new construction and renovation. Secondly, construct the grid investment demand and grid investment capacity measurement model, and obtain the grid side investment model by weighted summation. Then, a model for calculating the scale of investment that can be saved due to demand-side response is constructed, and the cost of demand response is subtracted to obtain a model for calculating the scale of investment that can be saved on the load side. Finally, the energy storage side investment calculation model is constructed from the power supply side, grid side, user-side energy storage investment, and energy storage investment benefit. The research results are applied to the empirical area, and scientific guidance is provided to realize the precise investment in the area.

KEYWORDS
new power system, distribution network investment, source network load-storage, calculation model, precise investment

1 Introduction

Building a new type of power system is an all-round change, a very challenging and pioneering strategic project (Sánchez et al., 2022). From the perspective of power grid investment, the investment structure and focus will undergo major changes (He et al., 2022). Power grid enterprises should actively implement the reform of management methods (Zhu et al., 2022), change investment concepts and thinking in a timely manner, accurately grasp the focus and direction of investment, optimize investment strategies (Zhang et al., 2022), and provide sufficient and accurate investment support for the construction of new power systems.

At present, experts and scholars have conducted much research on distribution network investment methods. Reference (Ren et al., 2019)estimates the size of the distribution network based on the current situation and load growth of the distribution network, and proposes a model strategy for distribution network investment allocation in combination with regional development needs, economic and social benefits of investment. Reference (Zheng et al., 2021) establishes an improved comprehensive evaluation method and evaluation model of distribution network investment benefit based on the individual evaluation results of investment benefit of distribution network reconstruction project, combined with information entropy and fuzzy analysis method. Reference (Wu et al., 2019)starts from technology, benefit, and project maturity, and builds an index system for investment ranking and evaluation of power grid planning projects under the new power reform environment. The precise investment decision of the distribution network in the above literature is mainly aimed at the traditional power system and has insufficient adaptability to the new elements of the new power system.

In order to implement the dual carbon goal, the state proposes to build a new power system with new energy as the main body. Compared with the traditional power system, its core feature is that new energy occupies a dominant position. In the future, wind power, photovoltaics, and energy storage will show explosive growth. Reference (Elkadeem et al., 2019) proposes an optimal investment model for a distribution network with renewable energy that considers efficiency, benefit, and carbon emission reduction. Based on the research of regional multi-energy system model, reference (Nazir et al., 2021) proposes a regional renewable energy generation capacity planning and investment benefit optimization model based on different dispatch time scales. Reference (Gao and Zhao, 2018) used system dynamics and evolutionary game methods to study the willingness of all parties to photovoltaic projects under the contract energy management model. Although the above references all add new elements related to renewable energy and storage, they do not fully consider the impact of new elements on the investment and construction of the new power system on the four sides of the source, network, load and storage.

In order to adapt to the new elements of the new power system, this paper proposes a distribution network investment method based on the new power system. By constructing the four-side investment model of source, network, load, and storage, and predicting and analyzing the investment data of each side, the asset investment strategy of power grid enterprises can be adjusted., It is of great significance to realize precise investment and improve market competitiveness.

2 Research ideas for new power system investment methods

The general idea of research on new power system investment methods is shown in Figure 1.

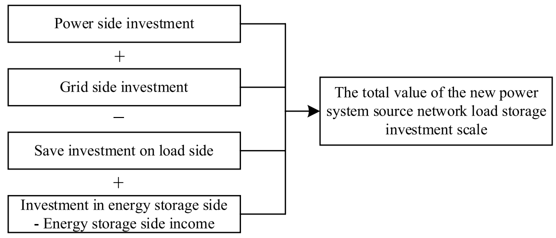

FIGURE 1
Research idea of new power system investment method.

The formula for calculating the total investment scale of the source, grid, load, and storage side of the new power system is shown in Eq. 1:

$$T = C + G - L + (W - I) \tag{1}$$

In the formula, $C$is the power supply-side investment. G is the grid side investment. $L$is the investment on the energy storage side. $W$is the energy storage side investment. $I$is the energy storage side investment, respectively.

Investment on the power supply side: In response to the need of accelerating the construction of a clean, low-carbon, safe and efficient modern energy system, taking clean development as the direction, and investing in optimizing the power supply structure on the basis of ensuring energy security.

Grid-side investment: In order to accelerate the transformation of the distribution network from a single power supply to an intelligent and interactive energy Internet, realize a first-class modern distribution network with high reliability, good interaction, economic efficiency, and reasonably and effectively meet the demand for load growth and safe and reliable power saving on the load side: the investment in the construction of high, medium, and low voltage distribution networks that can be saved due to interruptible load response, etc. Minus the cost of demand response.

Energy storage side investment: the initial cost investment of energy storage on the power supply side, the grid side, and the user side, and the operation cost investment minus the energy storage subsidy.

Energy storage side income: The income from increasing on-grid electricity, reducing the deviation of power generation plant, and providing auxiliary services is the energy storage income on the power supply side; the income such as delaying the investment in grid construction is the energy storage income on the grid side; the income such as peak-valley arbitrage is the energy storage income on the user side.

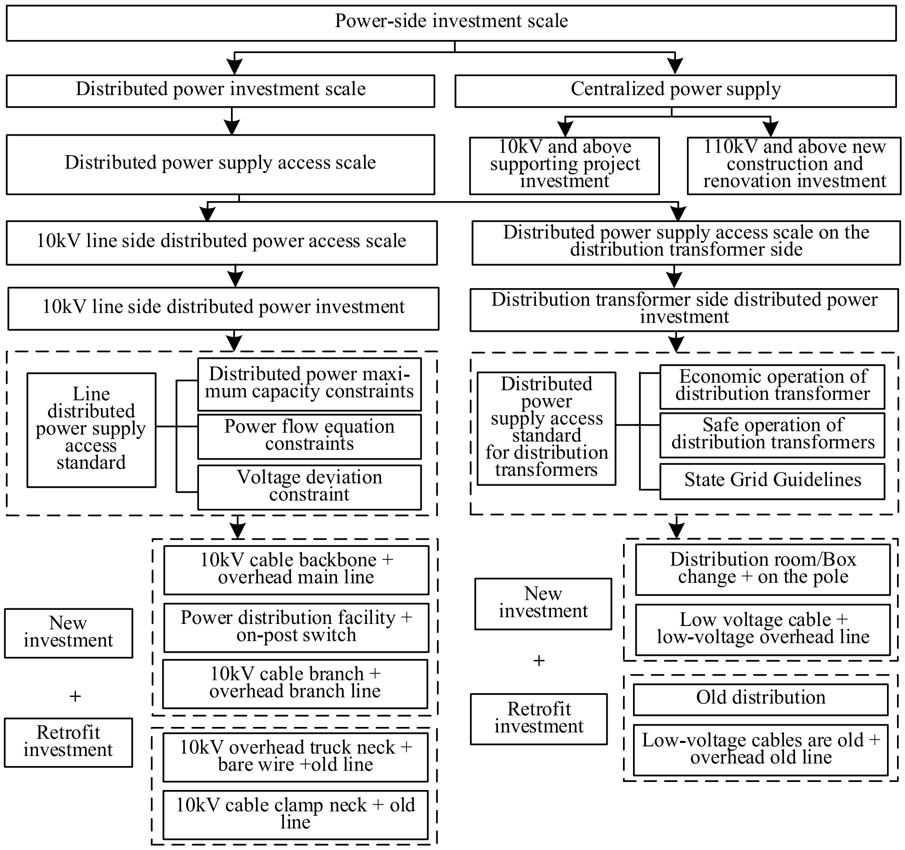

FIGURE 2
Flow chart of investment scale calculation of power supply side in future years.

3 Research on calculation model of new power system power supply side investment

Figure 2 shows the calculation process of the investment scale of the power supply side in the future.

The total investment scale of the power supply side is the sum of the investment in the centralized power supply and the investment in the distributed power supply. This paper mainly studies the calculation method of the investment scale of the distributed power supply (Abdelkader et al., 2018). The calculation formula is shown in Eqs. 2–3:

$$C = C_{fb} + C_{jz} \tag{2}$$

$$C_{fb} = C_1 + C_2 + C_3 + C_4 \tag{3}$$

In the formula, $C_{fb}$is the total investment in distributed power. $C_{jz}$the investment in centralized power. $C_1$and $C_2$are the investment in the construction and reconstruction of 10 kV lines to meet the needs of distributed power supply access. $C_3$and $C_4$are t the construction and reconstruction of distribution transformers, respectively.

3.1 10 kV line-side distributed power investment

Considering that the tie line satisfies the N-1 check and the maximum load rate of the single radiation line does not exceed 70%, the maximum access capacity of the single-circuit 10 kV line distributed power supply is 6 MW.

1) Investment in new 10 kV lines and power distribution facilities

The calculation formula is shown in Eq. 4:

$$C_1 = \frac{a(S_{LDGZ} - \lambda S_{LDGZ})}{6}\left(r_{dz}P_{dzx} + y_1 P_{zpd} + y_2 r_{dfz} P_{dfz}\right) + \frac{b(S_{LDGZ} - \lambda S_{LDGZ})}{6}\left(r_{jz}P_{jzx} + y_3 P_{zzs} + y_4 r_{jfz} P_{jfz}\right) \tag{4}$$

In the formula, $S_{LDGZ}$is the total installed capacity of the distributed power supply on the 10 kV line side; $a$and $b$are the proportions of cables and overhead lines in newly built lines respectively; λ is the current 10 kV line consumption proportion of distributed power. r_{dz}andP_{dzx} are the length and cost of the newly-built single-circuit 10 kV cable trunk line respectively; $y_1$and $P_{zpd}$are the number and cost of the newly-built power distribution facilities (ring network room, branch-box) of the single-circuit cable line respectively; $y_2$is a single distribution Number of newly-built cable branch lines for electrical facilities; $r_{dfz}$and $P_{dfz}$are the unit length and cost of 10 kV cable branch lines; $r_{jz}$and $P_{jzx}$are the length and cost of newly-built single-circuit 10 kV overhead main lines respectively; $y_3$andP_{zzs} are newly-built pole switches for single-circuit overhead lines quantity and cost; y_4,r_{jfz}, $P_{jfz}$are the number, length, and cost of newly-built branch lines of a single-circuit 10 kV overhead line, respectively.

2) Investment in transforming 10 kV lines

The calculation formula is shown in Eq. 5:

$$C_2 = \left(r_{zjk} + r_{zjlj} + r_{zld}\right)P_{jzx} + \left(r_{zdk} + r_{zdlj}\right)P_{dzx} \tag{5}$$

In the formula, r_{zjk},r_{zjlj},$r_{zld}$are the current 10 kV overhead clamp neck, old and bare conductor line length respectively; $r_{zdk}$and $r_{zdlj}$are the current 10 kV cable clamp neck and old-line length,respectively.

3.2 Distribution and transformation side distributed power investment

After calculation, the maximum distributed power access capacity S_{PDG} of a single distribution transformer is 0.8 times the capacity of the distribution transformer.

1) Investment in new distribution transformers

The calculation formula is shown in Eq. 6:

$$C_3 = \frac{pg\left(S_{PDGZ} - \rho S_{PDGZ}\right)}{0.5 \times 0.6 S_{xb}}\left(P_{xb} + z_1 r_{dd} P_{ddx}\right) + \frac{qg\left(S_{PDGZ} - \rho S_{PDGZ}\right)}{0.5 \times 0.6 S_p}\left(P_P + z_2 r_{dj} P_{djx}\right) \tag{6}$$

In the formula, $S_{PDGZ}$is the total installed capacity of 10 kV distribution transformer side distributed power; $p$is the proportion of power distribution room/box substation in newly built low-voltage equipment; $g$is the proportion of the current number of public transformers to the total number of distribution transformers;ρ is the proportion of distributed power supply consumed by the current distribution transformer; $S_{xb}$is the capacity of a single power distribution room/box substation. $P_{xb}$is the cost of a single power distribution room/box substation; z_1,r_{dd} andP_{ddx} are the single power distribution room/box substation, respectively the number, length, and cost of newly built low-voltage cable lines; $q$is the proportion of pole-mounted transformers in newly built low-voltage equipment.$S_P$and $P_P$are the capacity and investment of a single distribution transformer respectively; z_2,r_{dj}andP_{djx} are the newly built low-voltage overhead lines of a single distribution transformer number, length, and cost.

2) Investment in the transformation of distribution transformers

The calculation formula is shown in Eq. 7:

$$C_4 = t_{lj} P_p + r_{djlj} P_{djx} + r_{ddlj} P_{ddx} \tag{7}$$

In the formula, $t_{lj}$is the number of old distribution transformers; $r_{djlj}$and $r_{ddlj}$are the lengths of the old lines of low-voltage overhead and cables, respectively.

4 Research on calculation model of grid side investment in new power system

Figure 3 shows the calculation process of the investment scale on the grid side in the future.

The calculation formula for the investment scale on the grid side is shown in Eq. 8:

$$G = \mu_g\left(\alpha G_{xq} + \beta G_{nl}\right) \tag{8}$$

In the formula,$G_{xq}$is the power grid investment demand. $\mu_g$is the correction factor. $G_{nl}$is the power grid investment capacity. $\alpha$and$\beta$are the investment demand of the power grid and the proportion of investment capacity, respectively, which can be determined by the analytic hierarchy process.

4.1 Grid investment demand estimation

The idea of investment demand estimation is shown in Figure 4.

1) Influencing factor system of power grid investment demand

The indicator system is shown in Figure 5.

4.2 Correlation analysis

The selection of key impact indicators is carried out through correlation analysis (Gao et al., 2022). Correlation analysis refers

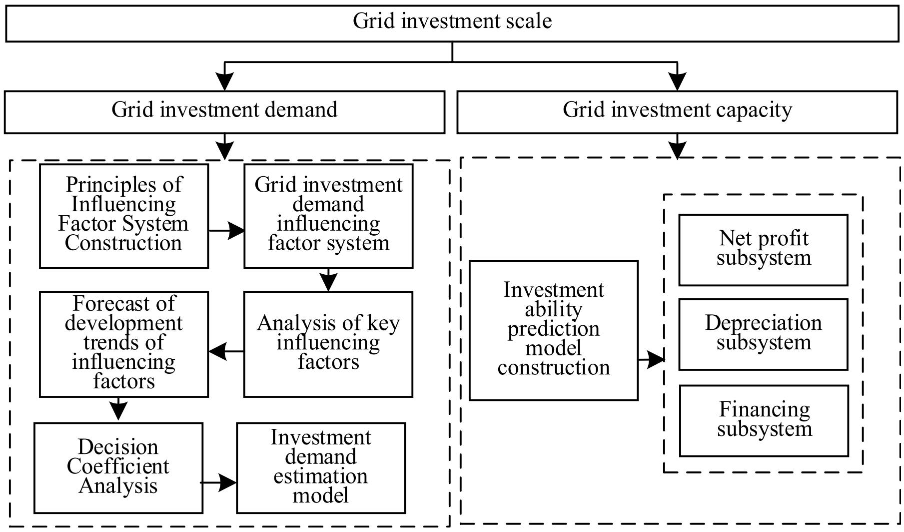

FIGURE 3
Calculation flow chart of investment scale of grid side in future years.

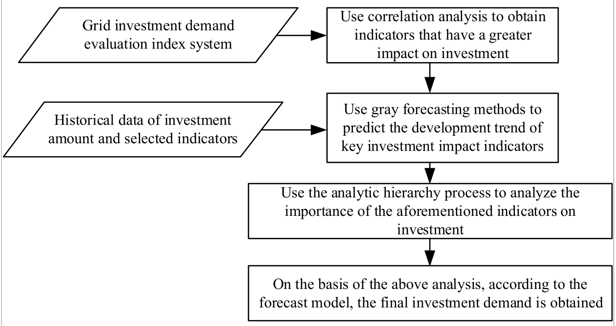

FIGURE 4
Investment demand forecasting ideas.

to the analysis of two or more related variable elements to measure the closeness of the correlation between the two variable factors.

The calculation of the correlation coefficient is shown in Eq. 9:

$$r = \frac{\frac{\sum (x-\bar{x})(y-\bar{y})}{n}}{\sqrt{\frac{\sum (x-\bar{x})^2}{n}}\sqrt{\frac{\sum (y-\bar{y})^2}{n}}} = \frac{\sum (x-\bar{x})(y-\bar{y})}{\sqrt{\sum (x-\bar{x})^2 \sum (y-\bar{y})^2}} \tag{9}$$

In the formula, $r$is the correlation coefficient,$n$is the number of data items; $\bar{x}$is the arithmetic mean of the independent variable series$x$;$\bar{y}$is the arithmetic mean of the dependent variable series$y$.

From the correlation analysis, the key impact indicators are GDP, the number of power supply households, electricity sales, total profit, and the highest load of the whole society.

3) Forecast of the development trend of influencing factors based on gray forecast

The amount of data required for gray prediction is small. When processing the data, it does not seek the probability distribution and statistical law of the data but uses the “gray generation method” to seek a new sequence with weakened randomness and strengthened regularity. The GM (1, 1)model is used for the prediction of the development trend of the influencing factors.

The initial year index value is recorded as $X^{(0)}$, and the initial number column is$X^{(0)} = (X^{(0)}(1), X^{(0)}(2), \cdots, X^{(0)}(n))$. Reference (Luo et al., 2021) builds a model by the cumulative generation of the grey generation method, then the model is:

$$\hat{X}^{(1)}(k+1) = \left[X^{(0)}(1) - \frac{u}{a}\right]e^{-ak} + \frac{u}{a}, k = 0, 1, \cdots, n-1 \tag{10}$$

By reducing the above formula, the gray prediction model of the original sequence can be obtained as:

$$\hat{X}^{(0)}(k) = \hat{X}^{(1)}(k) - \hat{X}^{(1)}(k-1), k = 2, 3, \cdots, n \tag{11}$$

4) Decision coefficient analysis based on AHP (Wang et al., 2021)

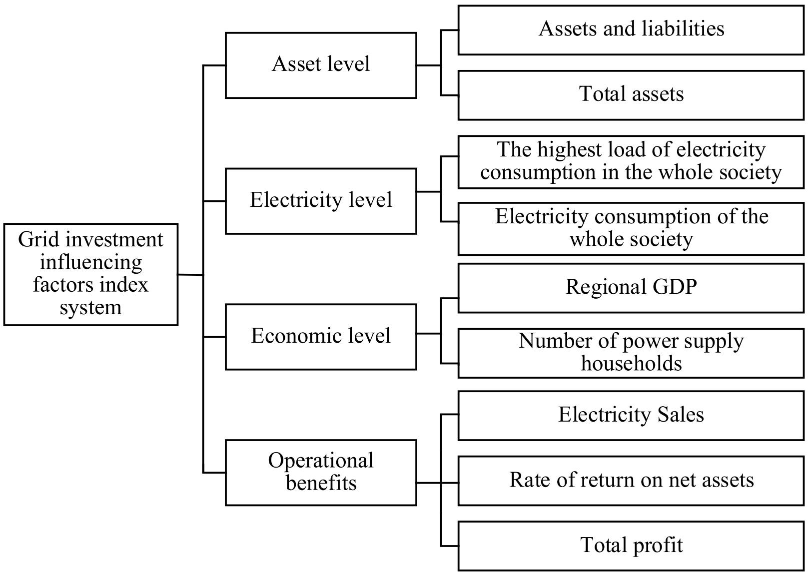

FIGURE 5
Investment scale forecast influencing factors.

The analytic hierarchy process is used to analyze and predict the decision coefficient of key impact indicators. The calculation steps are as follows:

4.3 Establish a judgment matrix

Generally, the judgment matrix is established by the reciprocal 1–9 scale scaling method. Assuming that the judgment matrix is: $A = \begin{bmatrix} a_{11} & \dots & a_{1m} \\ \dots & \dots & \dots \\ a_{m1} & \dots & a_{mm} \end{bmatrix}$, then the element $a_{ij}$of the judgment matrix A corresponds to the relative importance of the two elements $a_i$and $a_j$in the hierarchy.

4.4 Calculation method of decision coefficient

Assuming that the judgment moment is $A = \begin{bmatrix} a_{11} & \dots & a_{1m} \\ \dots & \dots & \dots \\ a_{m1} & \dots & a_{mm} \end{bmatrix}$, firstly multiply each element by row and raise it to the power$m$, that is, to obtain the geometric mean of the elements in each row, as shown in Eq. 12:

$$b_i = \left(\prod_{j=1}^{m} a_{ij} \right)^{1/m} \quad (i = 1, 2, \cdots, m) \tag{12}$$

TABLE 1 Average stochastic consistency indicator parameters.

m	1	2	3	4	5	6	7	8	9
R.I.	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45

By normalizing $b_i\,(i = 1, 2, \cdots, m)$again, the decision coefficient of each element of the criterion layer or the scheme layer can be obtained, as shown in Eq. 13:

$$\omega_j = \frac{b_j}{\sum_{k=1}^{m} b_k} \; (j = 1, 2, \cdots, m) \tag{13}$$

4.5 Consistency check of judgment matrix

The rationality of the decision coefficient can be verified by the consistency of the judgment matrix. If the judgment matrix can pass the consistency check, it means that the decision coefficient is reasonable; otherwise, the decision coefficient is unreasonable.

Calculate the maximum eigenvalue $\lambda_{\max}$of the judgment matrix, as shown in Eq. 14:

$$\lambda_{\max} = \frac{1}{m}\sum_{i=1}^{m}\frac{\sum_{j=1}^{m} a_{ij}\omega_j}{\omega_j} \tag{14}$$

To calculate the consistency index $C.I.$, the formula is shown in Eq. 15:

$$C.I. = \frac{\lambda_{\max} - m}{m-1} \tag{15}$$

Define the mean consistency metric $R.I.$.

4) Calculate the random consistency ratio $C.R.$, the formula is shown in Eq. 16:

$$C.R. = \frac{C.I.}{R.I.} \tag{16}$$

The average random consistency index $R.I.$ can be found from the Table 1 according to the matrix order m.

4.6 Check the consistency of the judgment matrix, as follows

When $C.R. = \frac{C.I.}{R.I.} < 0.1$, it is considered that the judgment matrix has acceptable inconsistency, otherwise, it is considered that the initially established judgment matrix is unsatisfactory and needs to be re-assigned and carefully revised until the consistency check is passed.

5) Grid investment demand estimation

Construct an investment demand estimation model as shown in Eq. 17:

$$G_{xq} = \sum_{i=1}^{n} u_i \times \left[\frac{y_i(k+1) - y_i(k)}{y_i(k) - y_i(k-1)}\right] \times x(k) \tag{17}$$

In the formula, $G_{xq}$is the investment demand of the regional distribution network in the next year; $u$is the factor's decision-making coefficient; $y_i(k+1)$is the value of the next year's factor; $y_i(k)$is the value of the current year's factor; $y_i(k-1)$is the value of the previous year's factor; $x(k)$is the amount of grid input for this year.

4.7 Grid investment capacity calculation model

Figure 6 shows the calculation idea of investment capacity.

The power grid investment capacity prediction model (Yi et al., 2021) can be divided into profit subsystem, depreciation subsystem, and financing subsystem.

The investment ability prediction formula is shown in Eq. 18:

$$G_{nl} = N_p - T_p + D + F \tag{18}$$

In the formula, $G_{nl}$is the investment capacity of the power grid company. $N_p$is the net profit of the power grid company. $T_p$is the profit turned over by the power grid company. $D$is the depreciation amount. $F$is the financing amount.

1) The net profit subsystem is shown in Eq. 19:

$$N_p = S_D + TZ_p + Y_p + Q_p - CB_Z - S_p \tag{19}$$

In the formula, $S_D$is the income from electricity sales. $TZ_P$is the investment income. $Y_P$is the income from the outside business. $Q_P$is the income from other businesses. $CB_Z$is the total cost and expense. $S_P$is the income tax.

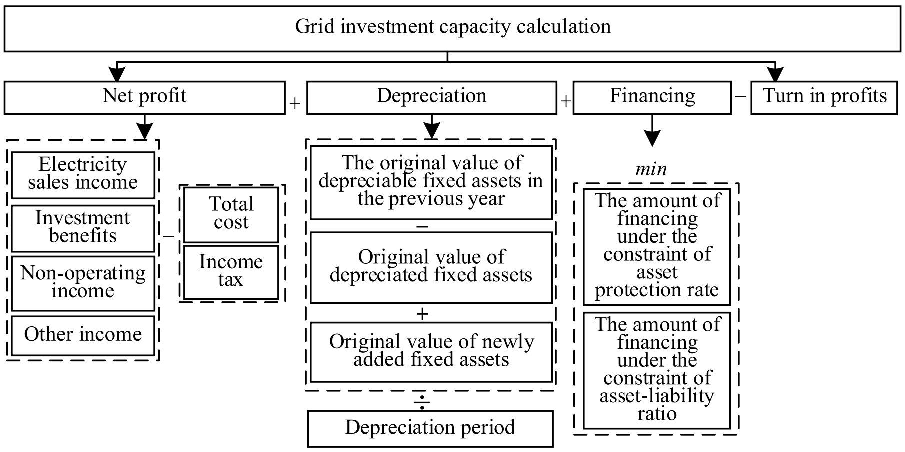

FIGURE 6
Investment capability forecast flow chart.

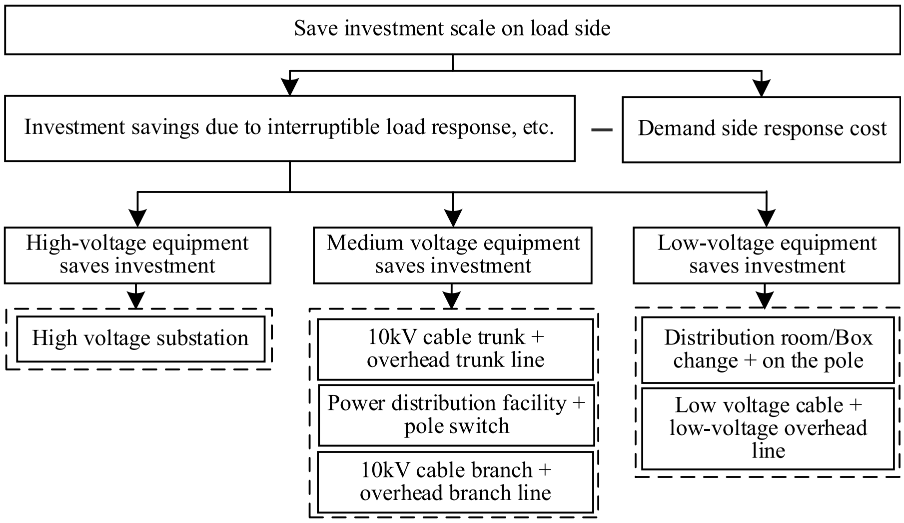

FIGURE 7
Flow chart of the scale of investment savings on the load side in the coming years.

2) The depreciation subsystem is shown in Eq. 20:

$$D = (D_{ZCL} - D_{ZCT} + \Delta D_{ZC})/N \tag{20}$$

In the formula, $N$is the depreciation period. $D_{ZCL}$is the original value of depreciable fixed assets in the previous year. $D_{ZCT}$is the original value of depreciable fixed assets. $\Delta D_{ZC}$is the original value of newly added fixed assets.

3) The financing subsystem is shown in Eqs. 21–23:

$$F = \min(F_{BZ}, F_{FZ}) \tag{21}$$

$$F_{BZ} = \left(N_p - T_p + D\right) \times \varepsilon \times (1 - \lambda_{BZ})/\lambda_{BZ} \tag{22}$$

$$F_{FZ} = \frac{\lambda_{FZ}\left(F_{ZCL} + N_p - T_p - F_{HK}\right) - F_{FZL} + F_{HK}}{1 - \lambda_{FZ}} \tag{23}$$

In the formula, $F_{BZ}$and $F_{FZ}$are respectively the financing amount under the constraints of capital security rate and debt ratio. $\varepsilon$is the cash flow coefficient; $\lambda_{BZ}$is the capital security rate. $\lambda_{FZ}$is the asset-liability ratio. $F_{HK}$is the repayment amount. $F_{ZCL}$and $F_{FZL}$are the assets and assets total liabilities.

5 Research on the calculation model of new power system load-side saving investment

Figure 7 shows the calculation process of the scale of investment savings on the load side in the coming years.

The formula for calculating the scale of saving investment on the load side is shown in Eqs. 24–25:

$$L = L_{xq} - L_{cb} \tag{24}$$

$$L_{xq} = L_{gxq} + L_{zxq} + L_{dxq} \tag{25}$$

In the formula, $L_{xq}$is the saving investment on the demand side. $L_{cb}$is the cost of demand response. $L_{gxq}$is the high-voltage substation to save investment. $L_{zxq}$is the saving of investment in medium voltage equipment. $L_{dxq}$is for low-voltage equipment to save investment.

The cost of demand-side response (Yang et al., 2021) is calculated according to the regional demand response subsidy price scheme.

6 Research on investment calculation model of energy storage side of new power system

6.1 Energy storage side investment calculation model

Figure 8 shows the calculation process of the investment scale of the energy storage side in the future.

The total investment cost of the energy storage system is shown in Eqs. 26–28:

$$W = W_1 + W_2 \tag{26}$$

$$W_1 = W_{ps}P_{EN} + W_{es}E_N \tag{27}$$

$$W_2 = W_{omp}P_{EN} + W_{ome}E_N \tag{28}$$

In the formula, $W_1$is the initial energy storage system cost. $W_2$is the operation and maintenance cost. $W_{ps}$is the

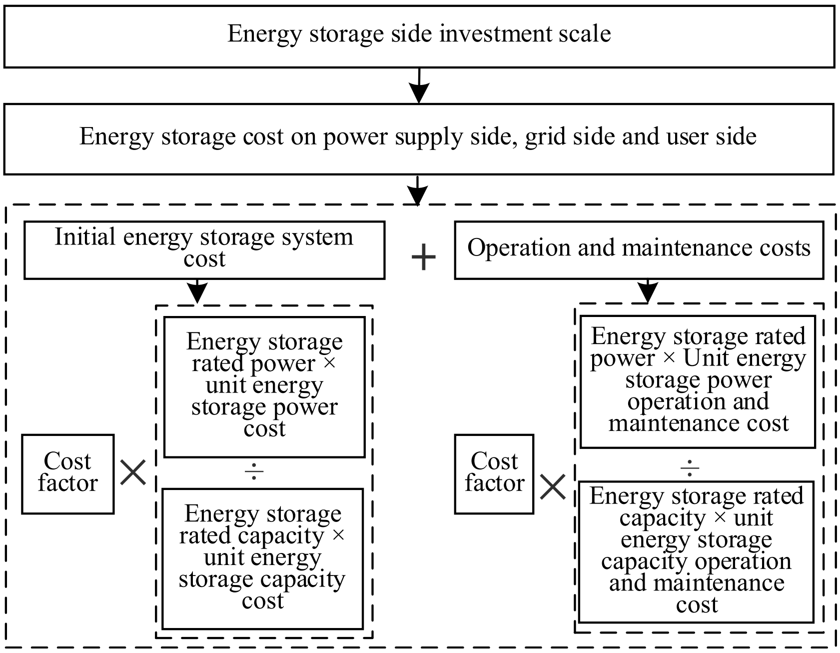

FIGURE 8
Calculation flow chart of investment scale of energy storage side in the future.

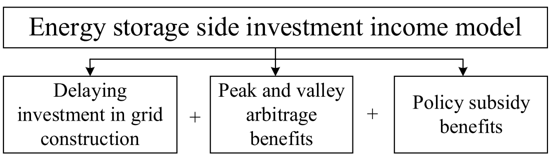

FIGURE 9
Flow chart of future annual investment income calculation of energy storage side.

unit energy storage power cost. $P_{EN}$is the energy storage rated power. $W_{es}$is the unit energy storage capacity cost. $E_N$is the rated capacity of energy storage. $W_{omp}$is the operation and maintenance cost of unit energy storage power. $W_{ome}$is the operation and maintenance cost of unit energy storage capacity

6.2 Energy storage side investment income model

Figure 9 shows the calculation process of the investment income of the energy storage side in the future.

The future annual investment income of the energy storage side is shown in Eq. 29:

$$I = I_{dw} + I_{tl} + I_{bt} \tag{29}$$

1) Delaying investment in grid construction

The economic benefits of reducing investment in grid expansion and reconstruction by installing energy storage can avoid fixed capacity costs, which can be determined according to the average cost of substations, transformers, transmission lines, and their supporting equipment that are less or delayed in construction, as shown in Eq. 30:

$$I_{dw} = A_t \varphi \eta P_{\max} \tag{30}$$

In the formula: $I_{dw}$is the investment in grid construction that can be delayed. $A_t$unit power cost of distribution network. $\varphi$is the fixed asset depreciation rate of power distribution equipment. $\eta$is the charge-discharge efficiency. $P_{\max}$is the rated power of the energy storage.

2) Peak and valley arbitrage income

Under the premise of charging and discharging twice a day, the main benefits of user-side energy storage projects are the peak-valley price difference and the peak-to-parity price difference arbitrage.

Assuming two charges and two discharges per day, the peak electricity price under special circumstances is not considered,

TABLE 2 Comparison of calculation results of two grid investment calculation methods.

Year	Actual grid investment scale (ten thousand dollars)	Calculation method of power grid investment based on historical investment effect			Calculation method of distribution network investment based on new power system		
		Investment scale (ten thousand dollars)	Deviation rate (%)	Average deviation rate (%)	Investment scale (ten thousand dollars)	Deviation rate (%)	Average deviation rate (%)
2018	17.68	17.08	3.44	7.46	18.17	2.79	2.33
2019	28.75	31.01	7.86		28.57	0.61	
2020	26.09	23.63	9.42		25.62	1.79	
2021	18.41	16.73	9.13		19.17	4.14	

and only the peak, flat, and valley electricity prices are considered, and the daily charge and discharge income is calculated as shown in Eqs. 31–33:

$$I_{tl} = P_f - P_c \tag{31}$$

$$P_c = S\left(p_m + p_l\right) \tag{32}$$

$$P_f = 2S\eta p_h \tag{33}$$

In the formula: $I_{tl}$is the peak-valley arbitrage income. $P_f$is the discharged income. $P_c$is the charging fee. $S$is the rated capacity of energy storage on the user side. $p_h$is the peak electricity price. $p_m$is the flat section electricity price. $p_l$is the low price of electricity. $\eta$is the charge-discharge efficiency.

6.3 Policy subsidy income

Policy subsidy income $I_{bt}$is calculated according to the regional energy storage subsidy scheme.

6.4 Case analysis

6.4.1 Grid investment scale in historical years

The distribution network investment calculation method based on historical investment results (Li et al., 2019) and based on the new power system are respectively used to calculate the investment scale of the county's power grid in the current year.

Based on the actual power grid investment scale from 2018 to 2021, the maximum deviation rate of the distribution network investment calculation method based on historical investment results is 9.42%, and the average deviation rate is 7.46%. But based on the new power system investment calculation, the maximum deviation rate is 4.14%, and the average deviation rate is 2.33%. The details are shown in Table 2.

The calculation results show that, compared with the distribution network investment calculation method based on historical investment results, the deviation rate of the distribution network investment calculation method based on the new power system is significantly smaller, and the investment scale is closer to the actual investment completion.

6.5 Grid investment scale in the coming years

Taking a county as a demonstration area, the investment scale of the county's distribution network based on the new power system is predicted in 2022.

6.5.1 Investment calculation on the power supply side

The county is a Class C power supply area. In 2022, the installed capacity of distributed power supply in the county will reach 30 MVA, the current line can accommodate an installed capacity of 11.7 MVA, and the remaining capacity needs to be absorbed by new lines and distribution transformers. The variable side distributed installed capacity is 11.9 MV A. In 2022, the county's power supply side investment is 3.6809 million dollars, and the details are shown in Table 3.

6.5.2 Grid side investment calculation

1) Calculation of power grid investment demand

In 2022, the county's power grid investment demand is 18.3998 million dollars, and the specific results are shown in Table 4.

Taking the highest electricity load of the whole society as an example, the sensitivity analysis of the index is carried out. In 2022, the highest electricity load in the whole society will increase by 8% compared with 2021. Assuming other conditions remain

TABLE 3 Calculation results of investment scale on the power supply side.

Category	Project name	Data	Data value	Investment (ten thousand dollars)	Total investment (ten thousand dollars)
Distributed power investment	New investment on the 10 kV line side	Length of overhead line (km)	10	62.76	189.85
		Cable line length (km)	5	70.61	
		Column switch (pcs)	12	11.30	
		Ring network room (box) (seat)	3	23.54	
		Cable branch box (seat)	3	4.71	
		Overhead branch line (km)	2.4	11.30	
		Cable branch line (km)	0.6	5.65	
		Overhead card neckline (km)	0.5	3.14	
		Overhead bare conductor line (km)	1.20	7.53	
	10 kV line side transformation investment	Overhead old line (km)	1.3	8.16	18.83
		Cable card neckline (km)	0	0.00	
		Old cable line (km)	0	0.00	
		Change on the column	12	18.83	
	New investment on the distribution transformer side	Overhead low voltage line (km)	9.6	15.06	107.63
		Power distribution room/box change (block)	5	23.54	
		Cable low-voltage line (km)	8	50.21	
	Distribution transformer side transformation investment	Old distribution transformer (Taiwan)	20	31.38	51.78
		Old low-voltage overhead line (km)	13	20.40	
		Old low-voltage cable line (km)	0	0	
Centralized power investment				0	0
Total					368.09

TABLE 4 Calculated results of power grid investment demand scale.

Key influencing factors	Measured value of decision coefficient	Grid investment in 2021 (ten thousand dollars)	Actual value in 2021	2020 actual value	Forecast for 2022	Forecast value of power grid investment in 2022 (ten thousand dollars)	Power grid investment in 2022 (ten thousand dollars)
GDP (ten thousand dollars)	0.2615	1,753.67	131.03	122.23	140.46	491.60	1,839.98
Number of power supply households (households)	0.0333		50.33	50.32	50.34	372.27	
Electricity sales (100 million kWh)	0.5128		29.78	29.05	30.53	5,875.43	
Total profit (ten thousand dollars)	0.0634		1.97	1.77	2.19	123.75	
The highest load in the whole society (ten thousand kilowatts)	0.129		823.1	762	889.10	1,557.44	

TABLE 5 Sensitivity analysis results of the highest electricity load in the whole society.

Index	Planning scheme (ten thousand dollars)	Change in the growth rate of the highest load in the whole society (%)					
		−20	−10	−5	5	10	20
Predicted value of grid investment in 2022 (ten thousand dollars)	1839.98	137.41	138.44	138.96	139.99	140.51	141.54
Compared with the standard value (ten thousand dollars)		−61.51	−31.04	29.91	60.39	90.87	121.34
Relative change rate (%)		−3.34	−1.69	1.63	3.28	4.94	6.59

TABLE 6 Calculation results of power grid investment capacity.

Data	Data value (ten thousand dollars)
Net profit	45.69
Turn in profits	37.50
Depreciation	1738.44
Financing amount	1,082.92
Investment capacity	2,829.55

unchanged, a sensitivity analysis is carried out on the different growth rates of the highest electricity load in the whole society. The calculation results of the scale of power grid investment demand show that when the growth rate of the highest electricity load in the whole society changes between −20% and 20%, the predicted value of investment demand changes between −3.34% and 6.59%.

The changes in the forecast value of investment demand are shown in Table 5.

After calculation, GDP, electricity sales, and the highest load of the whole society are the most sensitive factors.

2) Calculation of power grid investment capacity

Using the investment capacity prediction model, it is estimated that the county's power grid investment capacity in 2022 will be 28.2955 million dollars. The specific results are shown in Table 6.

3) Calculation results of grid side investment

Taking into account the investment demand and investment capacity of the power grid in the region, the weights of the investment proportion calculated by the AHP method are 0.4 and 0.6 respectively, and considering the grid side investment correction coefficient of 0.95, the final investment on the grid side of the county in 2022 is 23.1204 million dollars.

6.6 Load-side saving investment calculation

In 2022, the maximum demand-side response load in the county is 30MW, and the demand-side load response coefficient is 0.7. Due to the interruptible load response, 30 km of new 10 kV overhead lines, 36 switches on the column, 7.2 km of overhead branch lines, 32 transformers on the column, and 32 km of overhead low-voltage lines can be reduced, saving investment of 3.5648 million dollars as shown in Table 7.

The annual fixed unit price of the electricity subsidy is 62.79 cents/kWh, the single response time is 2 h, and the number of responses in the whole year is 10 times. The demand response load in the county is 65,577kW, and the demand response cost is about 0.8231 million dollars.

To sum up, the load-side saving investment in 2022 is 2.7416 million dollars.

6.6.1 Energy storage side investment calculation

1) Investment scale of energy storage side

In this paper, the unit energy storage power cost is 0.3923 million dollars/MW, the unit energy storage capacity cost is 0.3138 million dollars/MWh, and the unit energy storage power operation and maintenance cost and unit energy storage capacity operation and maintenance cost are 6.276 dollars/kW. In 2022, the county's energy storage side investment will be 4.6741 million dollars, the details are shown in Table 8.

2) Energy storage side investment income

6.7 Delay grid construction

In this paper, the unit power cost of the distribution network is 0.1569 million dollars/MW, the charging and discharging efficiency is 81%, the fixed asset depreciation rate of the distribution equipment is 30%, and the rated power of the energy storage is 5 MW. According to Eq. 30, it can be

TABLE 7 Save investment due to interruptible load response in 2022.

Investment voltage level	Data	Data value	Investment (ten thousand dollars)	Total investment (ten thousand dollars)
Investment in high voltage equipment	Required Transformer Capacity (MW)	0	0	0
	Number of substations (seats)	0		
MV equipment investment	Overhead line length (km)	30	188.28	256.0608
	On-column switch (pcs)	36	33.8904	
	Overhead branch line (km)	7.2	33.8904	
Low-voltage equipment investment	On-column variation (units)	32	50.208	100.416
	Overhead low-voltage lines (km)	32	50.208	
Total				356.4768

TABLE 8 Calculation results of investment scale on the energy storage side.

Energy storage configuration	Energy storage rated power (MW)	Rated capacity of energy storage (MWh)	Investment (ten thousand dollars)
Power side energy storage configuration	0	0	0
Grid-side energy storage configuration	2.5	5	259.6695
User side energy storage configuration	2	4	207.7356
Total			467.4051

obtained that the delay of power grid construction is 0.1906 million dollars.

6.8 Peak and valley arbitrage income

In this paper, the peak electricity price is 14.59 cents/kWh; the trough electricity price is 3.36 cents/kWh, and the flat segment electricity price is 8.34 dollars/kWh. The rated capacity of the user-side energy storage is 4 MWh, the charging and discharging efficiency is 81%, and the energy storage system works 330 days a year. Then the Eqs. 31–33 can be obtained, the peak-valley arbitrage income is 0.1575 million dollars.

6.9 Energy storage subsidy income

The energy storage compensation standard in this area is 31.38 dollars/kW per year. After calculation, the energy storage subsidy income in this area is 0.1412 million dollars.

To sum up, in 2022, the energy storage side income in the region will be about 0.5678 million dollars, and the energy storage side investment in the region 2022 will be 4.1847 million dollars.

6.9.1 Calculation results of new power system investment in the demonstration area

The estimated scale of investment on the power supply side is 3.68 million dollars, the estimated scale of investment on the grid side is 23.1204 million dollars, the scale of saving investment on the load side is 2.7416 million dollars, and the estimated scale of investment on the energy storage side is 4.1847 million dollars.

According to the research idea of the new power system investment method, which can be obtained from Eq. 1, the total investment in the county's new power system in 2022 is estimated to be 28.2443 million dollars.

7 Conclusion

Considering the investment and construction needs of new elements on the source, grid, load, and storage sides, this paper innovatively constructs an investment scale calculation model based on the new power system on the four sides of the source, grid, load, and storage. On the power supply side: Considering factors such as lines, distribution and transformation distributed power access standards, safe and reliable operation, and grid construction standards in different power supply areas, develop a new energy grid investment scale calculation model that takes into account safety and economy. On the grid side: overall consideration of regional investment needs and investment capacity, and research on the investment scale calculation model based on the three major financial statements, economic development and power demand. On the load side: Considering the interruptible load's participation in peak shaving and the corresponding demand subsidy policy, a load-side saving investment scale calculation model that takes into account the benefits of the delay in the construction of the distribution network and the corresponding demand is developed. On the energy storage side: Considering the configuration of energy storage capacity and energy storage subsidy policy, develop an energy storage side investment calculation model that takes into account the costs and benefits of energy storage. The four-side investment calculation method based on the new power system, load and storage, plays an important role in meeting the precision requirements of distribution network investment projects under the new situation and improving the investment efficiency of the power grid.

The research results are applied to the calculation of the investment scale of a new power system in a county in the future, and can accurately predict the investment scale of the next year. From the perspective of historical years, compared with the traditional distribution network investment calculation method, the calculation results of the four-side investment scale calculation method of the source network, load and storage are more accurate and have certain forward-looking results. In the future, the input data optimization model can be revised based on accumulated experience, providing more flexible investment plans for long-term construction investment decisions, continuously improving the accuracy of model prediction, and better adapting to the new energy-based distribution network under the "carbon peaking and carbon neutrality" goals. New power system planning investment decisions.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

ZF was responsible for the specific work of this article. ZF and XL guided the work of this article. CD and FJ did some calculations. FJ and WJ collected data and calculated and compared the plans.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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