Investment allocation method for hierarchical classification of distribution networks

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Abstract. This article proposes an investment allocation method for hierarchical classification of distribution network investment under the new situation. Firstly, the total investment amount is determined based on the unit investment effect of the overall planning of the distribution network in historical years. Then determine the allocation ratio for different projects based on the type of project. Further allocate the overall investment amount to each grid within the limits of the power supply grid. The accuracy and effectiveness of the proposed method were verified through case analysis. The proposed method not only achieves investment allocation in the distribution network, but also determines the total investment amount. It has certain engineering practical significance.

Keywords: total investment; project type; layering and zoning; investment allocation.

1 Introduction

There are many research results on investment allocation in the current distribution network. References [1-3] established evaluation indicators for distribution network planning projects and allocation methods based on investment allocation constraints. References [4-5] established a model for investment allocation in distribution networks from the perspectives of investment demand, economic requirements, and demand for electricity growth. References [6-7] consider the different impacts of different factors on investment efficiency and achieve the allocation of investment amounts. References [8-10] established a functional relationship between the investment of medium voltage distribution networks in various regions of local power supply companies and the comprehensive evaluation of indicators.

However, the above literature only considered a certain aspect of investment allocation, resulting in unreasonable allocation results. Therefore, this article proposes a hierarchical classification investment allocation method for distribution networks, which

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horizontally covers various project classifications and vertically connects the city and county grids. It can provide effective support for power supply enterprises to allocate investment directions reasonably and scientifically arrange investment projects.

2 Indicator reflection and weight determination

2.1 Selection of evaluation indicators

According to the Guidelines for Distribution Network Planning and Design, select the investment direction and evaluation indicators for the distribution network as shown in Figure 1.

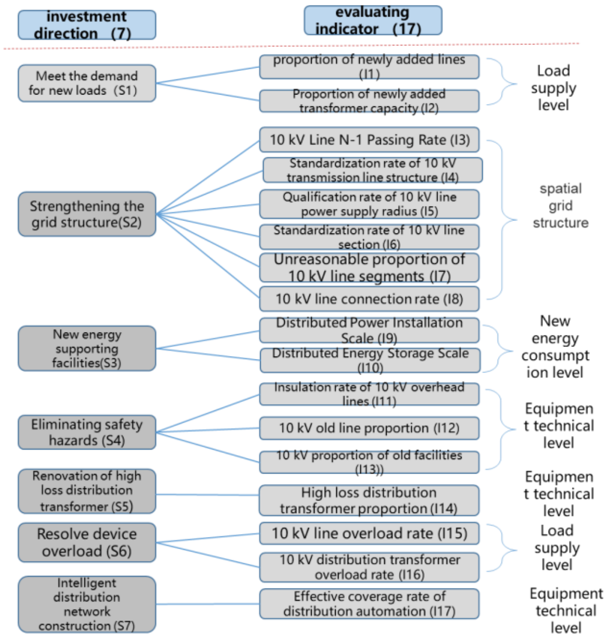

Fig. 1. Mapping relationship between investment direction and evaluation index

2.2 Determination of Dynamic Adaptive Weights

Improvement degree method indicator weight. To decouple the implementation effect of the project from the current situation of the power grid, the ratio of the absolute change degree of the indicators to their potential improvement space is defined as the degree of indicator improvement. Generally speaking, the gap between the current and ideal values of an indicator can reflect the urgency of improvement. The larger the gap between the current and ideal values, the higher the urgency of improvement, and the corresponding weight of the indicator should also be higher. This also solves the problem of different indicators having different characteristics, dimensions, and orders of magnitude.

Set $[I_1^0, I_2^0, \cdots\cdots, I_{16}^0, I_{17}^0]^T$ and $[I_1^1, I_2^1, \cdots\cdots, I_{16}^1, I_{17}^1]^T$ as the indicator values before and after implementation, respectively. The ideal value of the benefit indicator is $I_i^{\max}$, and the degree of improvement of the indicator ΔI_i is proportional to $I_i^{\max}$.

In the formula, ΔI_i represents the improvement degree I_i of the item indicator i, I_i^0 and I_i^1 represents the indicator values before and after project implementation, respectively, $I_i^{\max}$ is the ideal values of the benefit indicator.

The ideal value for cost-based indicators is $I_i^{\min}$, and the degree of improvement in the indicators ΔI_i is proportional to $I_i^{\min}$.

In the formula, ΔI_i represents the improvement degree I_i of the item indicator i, I_i^0 and I_i^1 represents the indicator values before and after project implementation, respectively, $I_i^{\min}$ is the ideal values of cost indicators.

The ideal value for interval type indicators is $[I_i^{\min}, I_i^{\max}]$, and the degree of improvement of the indicators ΔI_i is:

$$\Delta I_i = \begin{cases} \dfrac{I_i^1 - I_i^0}{I_i^{\min} - I_i^0} \times 100\% (I_i^0 < I_i^{\min}) \\ \dfrac{I_i^0 - I_i^1}{I_i^0 - I_i^{\max}} \times 100\% (I_i^0 > I_i^{\max}) \end{cases} \tag{1}$$

In the formula, $I_i^{\max}$ and $I_i^{\min}$ represent the ideal values of interval type indicators, while the other parameters have similar meanings.

The relative importance of each indicator obtained using the improvement degree method is:

$$\varphi_i^j = \Delta I_i^j / \sum_{i'=1}^{17} \Delta I_i^j \tag{2}$$

In the formula, φ_i^j is the relative importance I_i of the annual indicator j, and ΔI_i^j is the degree of improvement I_i of the annual indicator j.

Based on the relative importance of each indicator, pairwise comparisons are made between the differences of each indicator, and the Analytic Hierarchy Process is used to construct a judgment matrix to calculate the weights of each evaluation indicator.

In addition to using the above improvement degree method to calculate weights, another three methods including Delphi method and entropy weight method were selected to determine weights.

combined weight. The combination weight ω_i is:

$$\omega_i = \alpha\omega_{ia} + \beta\omega_{ib} + \gamma\omega_{ic} \tag{3}$$

In the formula, ω_{ia} is the weight of the indicator using the improvement degree method. ω_{ib} is the weight for Delphi method indicators. ω_{ic} is the weight of the entropy weight method indicator. α、β、γ are weight coefficients that are determined through expert meeting method based on relevant historical data. It is known that with the implementation of the project, ω_{ia} will be updated year by year.

Weight correction coefficient. Divide the combination weight by the improvement degree method weight to obtain the weight correction coefficient k_i:

$$k_i = \omega_i / \omega_{ia} = (\alpha\omega_{ia} + \beta\omega_{ib} + \gamma\omega_{ic}) / \omega_{ia} = \alpha + (\beta\omega_{ib} + \gamma\omega_{ic}) / \omega_{ia} \tag{4}$$

Due to ω_{ia} annual updating, k_i will be updated annually. Set k_i^0 is the weight correction coefficient for initial year evaluation index, k_i^j is the weight correction coefficient for the j th year evaluation index i, which can be obtained as follows:

$$\omega_i^j = k_i^{j-1}\omega_{ia}^j \tag{5}$$

In the formula, ω_i^j is the weight of the evaluation index i in the j th year, k_i^{j-1} is the weight correction coefficient of the evaluation index i in the j-1 th year, and ω_{ia}^j is the weight of the improvement method index in the j th year.

2.3 Indicator score calculation

The score of individual indicators is based on a percentage system.

$$s = 100y(y \in [0,1]) \tag{6}$$

In the formula, s represents the score of a single indicator, y is the score individual indicator.

The formula for calculating the comprehensive score is:

$$S = \sum_{i=1}^{17} s_i\omega_i \tag{7}$$

In the formula, S is the comprehensive score. i is number the indicators. S_i is the core for indicator i. ω_i is the weight for indicator i.

3 Investment allocation calculation

3.1 Improvement effect of investment by distribution network units

Based on recent J year's historical data, calculate the actual values of various indicators before and after project construction and the total investment in the distribution network by year, and calculate the overall improvement effect of unit investment in the distribution network for each year. Then, the historical unit investment in the distribution network improvement effect is weighted as the target year's unit investment improvement effect.

$$E = \sum_{j=1}^{J} \lambda_j \times (S_j / V_j) \tag{8}$$

$$\lambda_j = \lambda_{J+1-j'} = (J + 1 - j') / \sum_{j'=1}^{J} j' \tag{9}$$

In the formula, E represents the improvement effect of investment by the distribution network unit. J is the number of selected years. S_j provides a comprehensive rating for the overall distribution network in the j th year. V_j is the total investment in the distribution network for the j th year. λ_j is weight coefficient for the year, considering the time value of funds, the closer the selected year is to the reference year, the higher the weight. j' is the number of years from the historical year to the reference year, for example, the reference year is 2020, and 2017's j corresponds to 3.

3.2 Calculation of total investment scale

Calculate the overall comprehensive rating of the distribution network based on the current and ideal values of various indicators. Based on the unit investment effect of the target year, the overall investment scale of the distribution network in the target year can be determined:

$$V^* = S^* / E \tag{10}$$

In the formula, V^* represents the total investment demand for the target year's distribution network planning. S^* provide a comprehensive score for the target year. E is improvement effect of investment by distribution network units.

3.3 Calculation of the Importance of Investment Direction

Due to the fact that projects with the same investment direction can improve multiple indicators, and the same indicator can also be improved by multiple projects with different investment directions, it is necessary to associate investment direction with evaluation indicators. The mapping between investment direction and evaluation indicators is shown in Figure 1.

The formula for the importance of investment direction is:

$$c_l = \sum_{i=1}^{n_l} \omega_{l,i} \tag{11}$$

In the formula, c_l represents the importance of the type of investment direction l. n_l is the number of indicators in the set of related indicators for the type of investment direction l. $\omega_{l,i}$ is the weight of the i th indicator in the set of indicators related to the type of investment direction.

3.4 Calculation of investment direction allocation ratio

Calculate the investment ratio for each investment direction in the target year based on the improvement effect of each investment direction in the historical year.

The improvement effect of the l th investment direction in the j th year is:

$$e_{j,l} = \sum_{i=1}^{n_l} \omega_{j,l,i} s_{j,l,i} \tag{12}$$

In the formula, $e_{j,l}$ represents the improvement effect of the l th investment direction in the j th year. l is the number the investment direction. $s_{j,l,i}$ is the score for the i th indicator in the set of the l th investment direction related indicators in the j th year. $\omega_{j,l,i}$ is the weight of the i th indicator in the set of the l th investment direction related indicators for the j th year.

The improvement effect of unit investment in each investment direction is:

$$e_l = \sum_{j=1}^{J} \lambda_j \times e_{j,l} / v_{j,l} \tag{13}$$

In the formula, e_l represents the improvement effect of unit investment in the l th investment direction. J is the number of selected years. λ_j is the weight coefficient for the previous year. $v_{j,l}$ represents the total investment amount in the l th investment direction of the j th year.

Combined with the importance of investment direction, determine the proportion of investment allocation:

$$\delta_1^* : \delta_2^* : \cdots \delta_7^* = c_1 e_1 : c_2 e_2 : \cdots : c_7 e_7 \tag{14}$$

In the formula, δ_1^*、δ_2^*...... represents the proportion of investment allocation. c_1, c_2 ... represents the importance of investment direction, and e_1, e_2 ... represents the unit investment improvement effect of each investment direction.

4 Case application

(1) Basic data. The current status of the distribution network in the region (2018) and the target year for 2020 are shown in Table 1.

Table 1. Current value and Target value of distribution network in some region

Indicator No	weight	2018(%)	2020(%)	ideal value (%)
I1	0.0377	6.53	[8,12]	[10, 15]
I2	0.0492	12.53	[20,30]	[20, 25]
I3	0.0281	81.50	100	100
I4	0.1690	73.15	90	100
I5	0.0204	88.23	95	100
I6	0.0299	89.31	95	100
I7	0.0372	10.11	0	0
I8	0.0422	70.74	85	100
I9	0.0527	7.82	9.15	10
I10	0.0255	7.93	9.26	10
I11	0.0971	89.21	95	100
I12	0.0436	11.25	5	0
I13	0.1140	10.77	5	0
I14	0.0307	10.06	0	0
I15	0.0385	4.58	0	0
I16	0.0972	7.88	0	0
I17	0.0870	76.85	90	100

Table 2 shows the weight coefficients and initial weight correction coefficients obtained using three methods.

Table 2. Determination of evaluation index weight

Indicator No.	urgency method	Delphi method	Entropy weighting	correction coefficient
I1	0.0329	0.0450	0.0495	1.145
I2	0.0501	0.0450	0.0499	0.982
I3	0.0216	0.0300	0.0521	1.3
I4	0.2366	0.0150	0.0551	0.716
I5	0.0054	0.0450	0.0556	3.772
I6	0.0208	0.0450	0.0514	1.439
I7	0.0315	0.0450	0.0520	1.18
I8	0.0425	0.0300	0.0533	0.993
I9	0.0597	0.0250	0.0525	0.883
I10	0.0219	0.0150	0.0506	1.166
I11	0.0944	0.1500	0.0549	1.028
I12	0.0141	0.1500	0.0549	3.089
I13	0.1449	0.0400	0.0652	0.788
I14	0.0236	0.0400	0.0497	1.3
I15	0.0247	0.0800	0.0520	1.557
I16	0.0841	0.1200	0.1269	1.156
I17	0.0913	0.0800	0.0745	0.949

When calculating the initial weight, take α=0.333, β=0.333, γ=0.333.

(2) Calculation of investment direction importance. The calculation results of the importance of various investment directions are shown in Table 3.

Table 3. Importance of investment direction and investment allocation

Direction No	Importance efficient	Investment allocation rate(%)	Investment limit (10^8)
1	0.116	0.109	4.786
2	0.326	0.31	13.592
3	0.043	0.074	3.254
4	0.282	0.266	11.668
5	0.029	0.029	1.278
6	0.128	0.13	5.708
7	0.076	0.082	3.601

(3) Total investment and investment allocation calculation. Based on the data from 2013 to 2017, the overall unit investment improvement effect of the distribution network for each year was calculated, as shown in Table 4.

Table 4. Overall unit investment improvement effect in historical years

year	Improvement effect of unit investment (point/10^8 yuan)
2013	0.631
2014	0.646
2015	0.765
2016	0.689
2017	0.683

The weighted value of the improvement effect of the unit investment in the distribution network for the target year is 0.693 points/108 yuan. According to formula (10), the estimated investment scale of the 2020 distribution network planning project is 4.389×10^9 yuan. Calculate the allocation ratio and investment limit for each investment direction according to formula (14) as shown in the last column of Table 3.

(4) Power grid investment calculation. The investment allocation amounts for 7 investment directions are calculated and shown in Table 5. The error between investment allocation value and actual value is shown in Table 6.

Table 5. Investment amount of grid A~K in different investment directions Unit: 10^8 yuan

direction No.	Entire region	Grid A	Grid B	Grid C	Grid D	Grid E	Grid F	Grid G	Grid H	Grid J	Grid K
1	4.79	0.051	0.053	0.044	0.049	0.044	0.044	0.046	0.047	0.056	0.046
2	13.59	0.144	0.139	0.132	0.126	0.131	0.140	0.145	0.138	0.132	0.131
3	3.254	0.033	0.035	0.031	0.033	0.033	0.031	0.033	0.033	0.032	0.032
4	11.67	0.112	0.118	0.121	0.114	0.123	0.123	0.116	0.114	0.113	0.114
5	1.278	0.013	0.013	0.013	0.013	0.014	0.013	0.012	0.012	0.014	0.013
6	5.708	0.059	0.058	0.058	0.056	0.059	0.063	0.060	0.050	0.055	0.055
7	3.601	0.035	0.038	0.037	0.038	0.034	0.035	0.035	0.040	0.032	0.038

Table 6. Grid A~K calculation of investment in 2020 (10000yuan)

	Entire	A	B	C	D	E	F	G	H	J	K
Calculate amount	43887	4465	4525	4360	4281	4366	4476	4456	4337	4341	4276
Actual amount 2020	40739	4170	4165	4047	4000	4099	4068	4119	4053	4009	4010
Error (%)	1.13	0.98	1.34	-.46	-.96	1.34	0.79	1.04	2.94	2.30	1.97

5 Conclusion

This article proposes a hierarchical classification investment allocation method for distribution networks. On the basis of determining the overall scale of investment in distribution network planning and the allocation limits for each investment direction, a project optimization model was constructed. The project optimization considering the inter project correlation was achieved within the power grid, fully utilizing the spatial independence between power grids and avoiding the problem of projects not being able to reasonably cover the studied distribution network area. Not only that, but also the total investment amount was calculated.

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