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Optimization Model of Distribution Network Investment Scale Based on Transmission and Distribution Prices Constraints

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Abstract. The traditional profit model of the grid companies has changed due to the reform of transmission and distribution prices. In this context, it is of great practical significance to determine a reasonable distribution scale for distribution networks. Based on the research method of system dynamics, this paper constructs a distribution network investment capacity measurement model and investment demand measurement model based on transmission and distribution prices constraints, and proposes an optimization strategy for distribution network investment scale under the constraints of transmission and distribution prices.

1. Introduction

Circular No. 9 of the new power system reform pointed out that the transmission and distribution prices should be verified in accordance with the principle of permitted cost and reasonable income. As one bright spot of the new power system reform, the goal of the reform of transmission and distribution prices is to change the traditional profit model of the grid to earn the profit of the difference between the purchase and sale of electricity[1]. The reform of transmission and distribution prices can affect the verification of effective assets of the grid, thus affecting the investment level of the grid. Therefore, it is of great significance to carry out research on distribution network investment decision under the constraint of transmission and distribution prices[2].

At present, there are a lot of researches on the optimization of grid investment scale, and there are some researches on grid investment scale optimization under the background of transmission and distribution prices. Li Chen et al. established an investment optimization model with the maximum accumulated earnings value in the minimized service period as the optimization goal[3]. Kai Chen et al. constructed a relationship model of investment, electricity, and electricity price, and simulated the trend of transmission and distribution prices under different scenarios, different investments and electricity levels[4]. Huiru Zhao et al. constructed a quantitative evaluation model for the investment capacity of power grid enterprises based on the technical economic theory method[5].

Although there are many studies on the relationship between transmission and distribution prices and grid investment, it is rare to study the optimization of grid investment scale under the constraints of transmission and distribution prices. In view of this, considering the investment capacity and investment demand of distribution network under transmission and distribution price, this paper proposes a scale



model of distribution network investment based on transmission and distribution prices constraints to achieve the companies' precise, sophisticated and lean distribution network investment.

2. Relationship between distribution network investment and transmission and distribution price

There is a mutual influence and interaction between distribution network investment and transmission and distribution prices. On the one hand, transmission and distribution prices have an important influence on the determination of grid investment scale. Based on the research method of system dynamics and according to the verification rules of transmission and distribution price, this paper combs the specific relationship between grid investment and distribution prices as shown in Figure 1. The analysis shows that grid investment in the last regulatory cycle is an important factor in determining the current transmission and distribution prices of the regulatory cycle. On the other hand, considering the company's income and the game relationship between the company and the government and users, the transmission and distribution prices of the distribution network is controlled within a reasonable range without excessive fluctuations. If the transmission and distribution prices remain stable, it will be difficult to further increase the investment income if the excess investment is made. Therefore, the transmission and distribution prices can be regarded as the upper limit of grid investment, which is of guiding significance for improving the efficiency and effectiveness of grid investment.

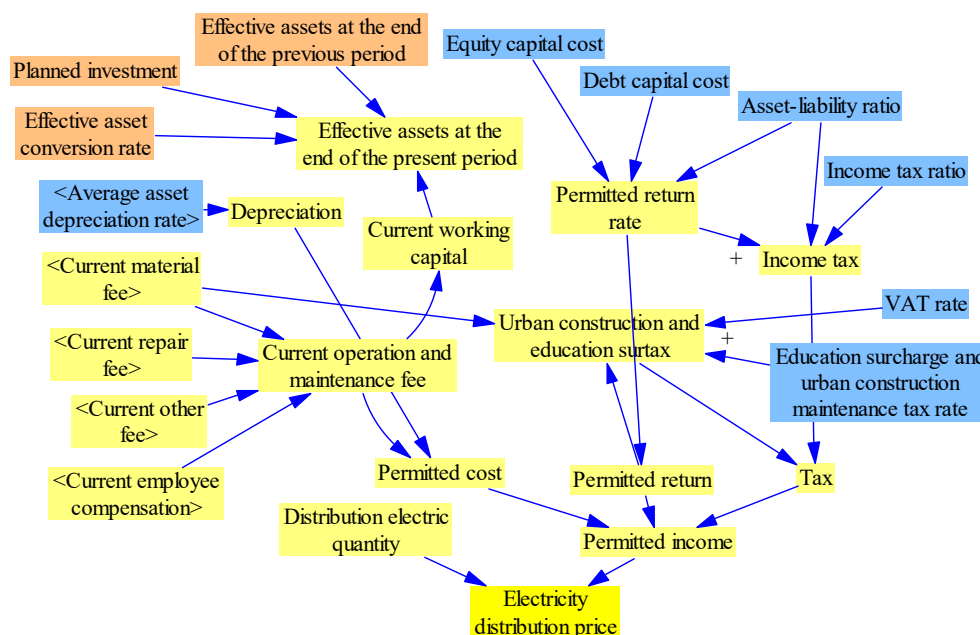


Figure 1. Logical graph between distribution network investment and distribution price

3. Optimization strategy of distribution network investment scale under the constraint of transmission and distribution price

3.1. Optimization logic of distribution network investment scale

If the company blindly expands the investment scale under the constraints of transmission and distribution prices, it may reduce the effective asset conversion rate, increase investment risk and reduce investment efficiency; and if the investment scale is blindly reduced, there may still be room for potential improvement of effective assets, then the key investment needs cannot be met. Therefore, the company needs to consider the transmission and distribution prices as the upper limit constraint of the distribution network investment, and consider the comprehensive investment demand as the lower limit of the distribution network investment, and further optimize the investment scale of the distribution network.

Therefore, the company needs to consider the transmission and distribution prices as the upper limit constraint of the distribution network investment, and consider the comprehensive investment demand as the lower limit of the distribution network investment. Then further optimize the investment scale of the distribution network. The logic diagram of the optimization of distribution network investment scale is shown in Figure 2. The rectangular frame represents the traditional distribution network investment mode, and the company independently invests in the distribution network according to its own operation targets and load conditions. The circular box represents the distribution network investment mode under the constraint of transmission and distribution price.

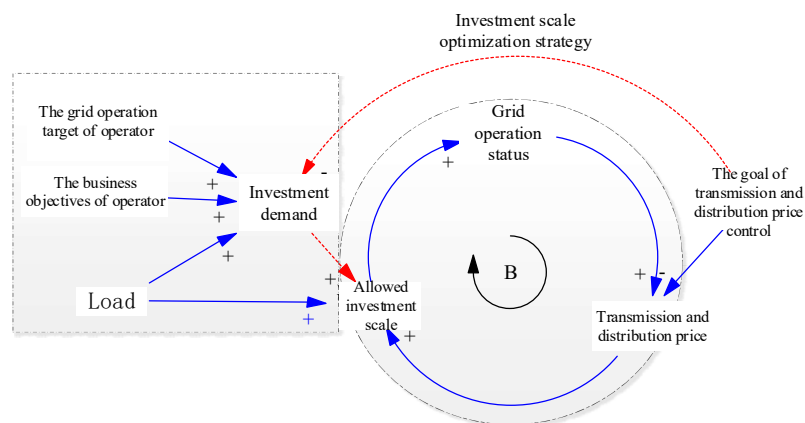


Figure 2. Optimization logic causal diagram of distribution network investment scale

3.2. The process of optimizing the scale of investment in the distribution network

Relying on the internal and external environment faced by the grid company in the field of distribution network investment planning in the future, this paper designs the optimization strategy of power grid company's distribution network investment scale, which is mainly divided into three steps: First, according to the simulation model of grid investment scale under the supervision of transmission and distribution price, the investment capacity of the grid company within the target supervision period is determined. Second, the investment demand of the distribution network used to meet the new load is measured, and then the investment demand of the distribution network and the demand for public welfare investment to meet the reliability of power supply within the target supervision period are determined. Third, comparative analysis of investment capacity and investment demand, and time determine the grid company investment grid investment scale optimization strategy under different circumstances. The optimization process of distribution network investment scale is shown in Figure 3.

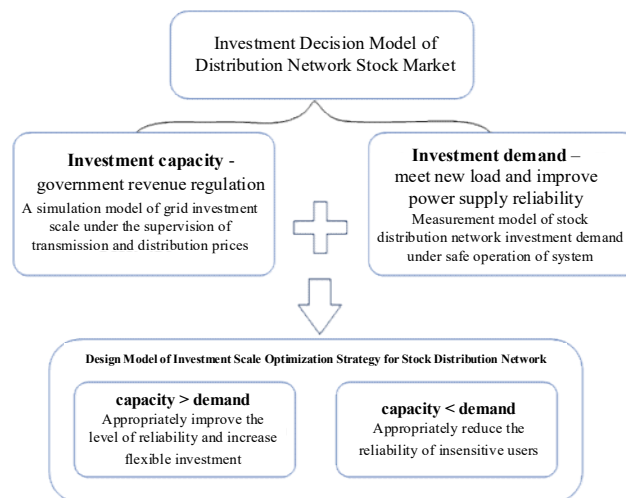


Figure 3. Optimization process of distribution grid investment scale

3.3. Optimization strategy for distribution scale of distribution network

When the investment capacity is greater than the investment demand, it is recommended to select an open investment strategy, which is mainly reflected in the following two aspects: First, improve the reliability of users. When the investment capacity surplus, the grid company can focus on improving the reliability of power supply for high-sensitivity power users. According to the size of the over-investment, the power supply reliability level of power users can be moderately increased, focusing on investment in power users with high reliability sensitivity. Second, increase investment in new technologies. When the investment capacity surplus, grid companies can invest in new technologies such as distribution network automation technology, intelligent line switching technology, and power electronics technology.

When the investment capacity is less than the investment demand, it is recommended to choose a conservative investment strategy, which is mainly reflected in the following two aspects: First, moderately reduce the level of reliability. On the basis of sorting the power users according to the classification of power supply reliability sensitivity from high to low, the power supply reliability level of power users is moderately reduced according to the gap of investment scale. Second, based on the investment gap, moderately reduce public welfare investment. When the investment capacity cannot meet the investment demand, the grid company can adopt a way of communicating with the government to moderately reduce public welfare investment or obtain relevant subsidies.

4. Calculation model of the investment capacity of the distribution network based on the transmission and distribution prices constraints

In this section, this paper constructs a financial model for the estimation of distribution network investment capacity based on transmission and distribution prices constraints. Mainly based on the permitted cost with reasonable income, with the “Evaluation of medium-to-long-term grid permitted revenue and transmission and distribution prices” issued by the provincial power grid as the main tool, combined with “Measures for the Supervision of Transmission and Distribution Pricing Costs (Trial)” and “Verification Method for Transmission and Distribution Prices of Provincial Grid Sharing Network”, relying on the research ideas and methods of system dynamics, the model constructs an effective asset foundation sub-model. And finally, the financial model for measuring the investment capacity of the grid under the constraints of transmission and distribution prices is constructed.

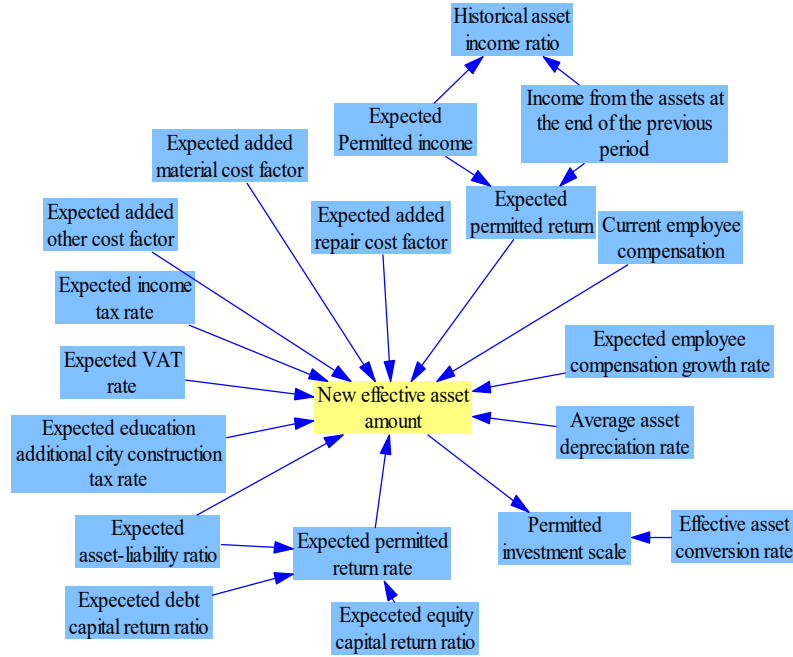


Figure 4. Financial model for measuring investment capacity of power grids under the constraints of transmission and distribution prices

The basic equation of the model is as follows:

4.1. Calculation of effective assets and depreciation expenses

$$A_{e,p} = A_{e,f} + C_p \quad (1)$$

$$\Delta A_{e,p} = I_p * r_{et} \quad (2)$$

$$D_A = A_{e,f} * r_d \quad (3)$$

$$A_{e,f} = \text{INTEG}(+\Delta A_{e,p} - D_A, A_{e,p}^*) \quad (4)$$

$$D = A_{e,f} * r_d \quad (5)$$

Among them, $A_{e,p}$ represents the current effective assets, $\Delta A_{e,p}$ represents the new effective assets in the current period, $A_{e,p}^*$ represents the initial value of the effective assets in the current period, $A_{e,f}$ represents the effective assets at the end of the period, C_p represents current working capital, I_p represents current grid investment, r_{et} represents effective asset conversion rate, r_d represents average asset depreciation rate, D_A represents asset depreciation, and D represents depreciation fee. $\text{INTEG}(a,b)$ represents the integral function, a represents the integral increment, and b represents the initial value.

4.2. Calculation of operation and maintenance fees

$$C_{om,p} = C_{r,p} + C_{m,p} + C_{w,p} + C_{o,p} \quad (6)$$

$$C_{op,p} = a' * C_{om,p} \quad (7)$$

Among them, $C_{om,p}$ represents the current operation and maintenance fee, $C_{o,p}$, p represents the current operating fee, $C_{r,p}$ represents the current maintenance fee, $C_{m,p}$ represents the current material fee, $C_{w,p}$ represents the current employee compensation, $C_{om,p}$ represents other fees in the current period, and a' represents the conversion ratio coefficient of current operating fee.

The cost calculations in the operation and maintenance fees are as shown in equations (8) to (11):

$$C_{r,p} = \text{INTEG}(+\Delta C_{r,p}, C_{r,p}^*) \quad (8)$$

$$C_{m,p} = \text{INTEG}(+\Delta C_{m,p}, C_{m,p}^*) \quad (9)$$

$$C_{w,p} = \text{INTEG}(+\Delta C_{w,p}, C_{w,p}^*) \quad (10)$$

$$C_{o,p} = \text{INTEG}(+\Delta C_{o,p}, C_{o,p}^*) \quad (11)$$

Among them, $\Delta C_{r,p}$, $\Delta C_{m,p}$, $\Delta C_{w,p}$, represent repair fee, material fee and employee compensation, respectively. $\Delta C_{o,p}$ represents the net increment of other fees, that is, the difference between the added value and the reduced value. $C_{r,p}^*$, $C_{m,p}^*$, $C_{w,p}^*$, $C_{o,p}^*$ represent repair fee, material fee, and employee compensation and the historical value of other fees.

The asset retirement can bring about a reduction in the cost of operating and maintenance fees in addition to employee compensation. And this amount is based on the rate of the asset corresponding to the historical asset size of the unit. The formula for calculating the asset retirement rate r_r in the model is shown in (12), and the corresponding calculation of the reduction in operation and maintenance fees is as shown in equation (13):

$$r_r = (NAV_r / r_{rv}) / A_{e,p}^* \quad (12)$$

$$\Delta C_{om} = A_{e,p}^* r_r^* r_{hom} \quad (13)$$

Among them, r_r represents the asset retirement rate, NAV_r represents the net value of asset retirement, r_{rv} represents the residual rate of asset retirement, ΔC_{om} represents the reduction of the operation and maintenance fees, and r_{hom} represents the historical operation and maintenance fees rate.

4.3. Calculation of permitted income

$$r_{pi} = C_{ec}^* (1 - r_{da}) + C_{dc}^* r_{da} \quad (14)$$

$$PI_p = A_{e,p}^* r_{pi} \quad (15)$$

Among them, C_{ec} represents the cost of equity capital, C_{dc} represents the cost of debt capital, PI_p represents the permitted income, r_{pi} represents the permitted rate of return, and r_{da} represents the asset-liability ratio.

4.4. Calculation of taxes

$$T_{cea} = (PI_p^* r_{vat} - C_{m,p}^* r_{vat})^* r_{cea} \quad (16)$$

$$T_i = A_{e,p}^* (1 - r_{da})^* r_{pi}^* r_i^* (1 - r_i) \quad (17)$$

$$T_p = T_{cea} + T_i \quad (18)$$

Among them, T_{cea} represents the additional tax on urban construction and education, and T_i represents income tax. T_p represents the current tax, r_{vat} represents the added-value tax rate, r_{cea} represents the tax rate for education and surcharges, and r_i represents the income tax rate.

4.5. Calculation of the permitted investment scale of the transmission and distribution price-grid investment model

$$\Delta R_{ei} = R_{pi} - PC_p - PI_p - T_p \quad (19)$$

$$\Delta A_{e,p} = (\Delta R_{pi} - C_{w,p} * r_{wg}) / 1.25 * (r_{mn} + r_{rn} + r_{on}) + r_{pi} + r_d + (1 + r_{da}) * r_{pi} * r_i + (r_{pi} - r_{mn}) * r_{vat} * r_{cea} \quad (20)$$

$$I_e = \Delta A_{e,p} / r_{et} \quad (21)$$

Among them, ΔR_{ei} represents the expected increase in revenue from grid investment, r_{pi} represents the expected permitted income, PC_p represents the current permitted cost, $\Delta A_{e,p}$ represents the expected effective asset increase, ΔR_{pi} represents the expected new permitted income, and r_{wg} represents the expected employee compensation growth rate. r_{rn} , r_{mn} , r_{on} respectively represent the expected new repair cost factor, the expected new material cost factor, and other new cost factors are expected. e represents planned grid investment.

5. Measurement model for investment demand of distribution network

The reform of transmission and distribution prices constrains the upper limit of distribution network investment, which can be regarded as the company's distribution network investment capacity. Considering the coordinated development of both sides of supply and demand, this section analyzes the calculation of investment demand for distribution network. Under the background of new power system reform, the investment demand of distribution network is more diversified, mainly including three parts of policy public welfare projects such as meeting load growth, improving power supply reliability, investing in electric energy replacement, and distributed power supply. The calculation methods for distribution network investment demand of each part are as follows:

First, the distribution network investment to meet the new load power supply demand can be obtained by multiplying the product. First, determine the value of the two indicators of the increased power supply investment and the newly increased power consumption. Secondly, calculate the product of the two to determine the distribution network investment demand for the new load power supply demand, the calculation formula is shown as (22).

$$I_{load,p} = I_{unit,p} * Q_{load,p} \quad (22)$$

Among them, $I_{load,p}$ represents the new load investment in the current period, $I_{unit,p}$ represents the electricity investment of the unit increase in the current period, $Q_{load,p}$ represents the new electricity consumption in the current period.

Second, get the difference between the target power supply reliability and the reference one. Then, based on the actual research situation, an average value can be obtained, which is the index value of the investment required for the average power outage time of the user for each minute of reduction. The product of this indicator and the above difference is the investment in the distribution network for improving the reliability of the power supply. The calculation formula is shown in (23).

$$I_{reality,p} = I_{powercut} * b_{reality,p} \quad (23)$$

Among them, $I_{reality,p}$ represents the investment of the distribution network used to improve the reliability of power supply. $I_{powercut}$ represents the investment required to reduce the average power

outage time per minute for every minute. $b_{reality,p}$ represents the difference between the target power supply reliability and the reference power supply reliability.

Third, according to the overall plan of the provincial company's overall power grid planning and related policies, the sum of the total investment of the distribution network of each project is measured, and this is used as the total investment of the distribution network for the policy public welfare project. The calculation formula is shown in (24).

$$I_{commonweal,p} = \sum_{i=1}^n I_{commonweal,i} \quad (24)$$

Among them, $I_{commonweal,p}$ represents the total investment of the distribution network of the current policy public welfare project, $I_{commonweal,i}$ represents the investment of the distribution network of the i -th policy public welfare project, and n represents the number of policy public welfare projects in the current period.

6. Case study

6.1. Basic data

Based on the actual situation of a province in China, the study case selects the data of the “13th Five-Year Plan” investment plan of a certain province, and makes the following assumptions on the data within the supervision period of 2020-2022. As shown in Table 1.

Table 1. Basic data in the study

Indicator	Value	Unit	Calculation base
Average distribution price	190	yuan/kW·h	/
Asset retirement rate	7.5	%	/
Effective asset conversion rate	85	%	/
Asset depreciation rate	18	%	/
Overhaul fee factor	0.03	/	Original value of fixed assets
Operation and maintenance fee coefficient	0.06	/	Original value of fixed assets
Working capital coefficient	0.25	/	Overhaul operation and Maintenance fees
Employee compensation growth coefficient	0.09	/	Employee compensation
Income tax rate	25	%	/
Urban construction maintenance and education surtax rate	12	%	/
Added-value tax rate	17	%	/
Asset-liability ratio	67.6	%	/
Debt capital cost	4.8	%	/
Cost of equity capital	4.8	%	/
Annual growth rate of electricity sales	3.62	%	/

6.2. Results of the calculation

The results of the calculation of this case are shown in Table 2.

Table 2. Results of the calculation

	Investment demand (100 million yuan)	Investment capacity (100 million yuan)
New load power supply requirements	142.27	
Power supply reliability requirements	50.65	266.92
Public welfare project needs 7	74.00	248.83

In terms of investment capability, it can be calculated that in order to ensure the stability of transmission and distribution prices in the next supervision period, the company's distribution network investment capacity is about 24.883 billion yuan.

In terms of investment demand, the distribution network investment to meet the new load power supply demand is 14.227 billion yuan, the distribution network investment to meet the power supply reliability is 5.065 billion yuan, and the public welfare project investment is 7.40 billion yuan. By summing the three investment amounts, it can be concluded that the investment demand for distribution network under the safe operation of the system is 26.692 billion yuan.

Analysis of the above calculation results, we can know that the company's distribution network investment capacity under the constraints of transmission and distribution price can not meet the investment demand of the distribution network under the safe operation of the system. Therefore, the company needs to adopt a conservative investment strategy.

Above all, the following suggestions are proposed: First, it is recommended that the company appropriately reduce the level of power supply reliability of local power users based on the difference in reliability sensitivity of power users. Second, it is recommended that the company moderately reduce investment in public welfare projects.

6.3. Sensitivity analysis of investment capacity of distribution network

Table 3 shows the measurement result data of the sensitivity analysis of the investment capacity of the distribution network. Figure 5 shows the sensitivity comparison of different parameters to the investment capacity of the distribution network. In order to reflect the behavior of the three parties, including user needs, company operations and government regulation, this paper selects three representative indicators for the impact of distribution network investment, which are electricity sales, asset-liability ratio and permitted rate of return.

Table 3. Results data of sensitivity analysis of investment capacity of distribution network

	-10%	-5%	0	5%	10%
Electricity sales	0.905	0.954	1.000	1.049	1.098
Asset-liability ratio	0.993	0.998	1.000	1.005	1.007
Permitted return rate	1.010	1.005	1.000	0.995	0.990

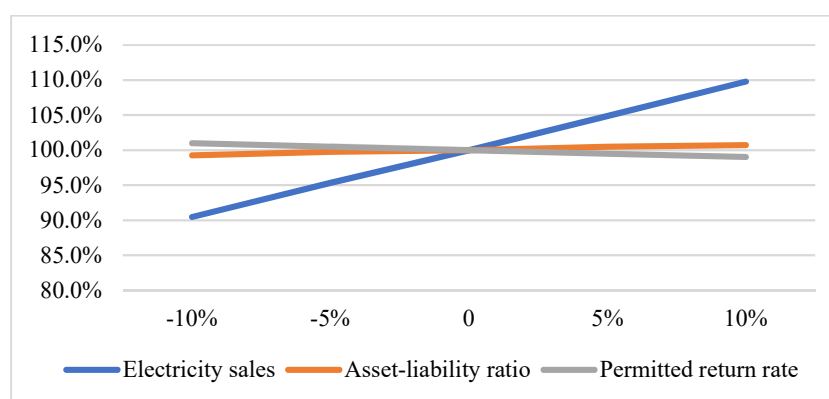


Figure 5. The impact of different indicators on the investment capacity of the distribution network

As shown in Figure 5, the power sales index has the greatest impact on distribution network investment. The sale of electricity can directly increase the company's revenue, which in turn provides a capital base for further distribution network investment. Therefore, grid investment is more sensitive to electricity sales. The asset-liability ratio is an important financial indicator that reflects the company's

operations. However, the company's funds are mainly used for the daily operations and expenses of the company, so there is no direct mapping relationship between the ability of funds to conduct business activities and investment in distribution networks. Therefore, this indicator is less sensitive to distribution network investment. For the permitted rate of return, on the one hand, allowing the increase in the rate of return may lead to an increase in the revenue of the grid company and promote investment in the grid. On the other hand, in order to maintain the stability of transmission and distribution prices, the government can reduce the growth of effective assets of the grid companies by controlling and controlling, thereby curbing the investment in the grid. Therefore, under the checks and balances of the two parties, the allowable rate of return is less sensitive to the investment capacity of the grid.

7. Conclusion

For the optimization of distribution scale of distribution network under the reform of transmission and distribution price, with the theoretical method of system dynamics and the actual operation of the company, this paper establishes an optimization model of distribution scale based on transmission and distribution price constraints. Based on the calculation model of investment capacity of distribution network and the calculation model of investment demand constructed, the study case studies the investment capacity and investment demand of a provincial power grid company under the hypothetical supervision period are measured, and corresponding investment strategy recommendations are given. The example verifies the effectiveness of the proposed method in solving practical problems. In addition, the research content of this paper needs to be further deepened in the aspect of mathematical modelling.

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