# Research on Grid Investment Effectiveness Assessment Methodology and Investment Strategy Optimization of Power Grid Companies

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**Abstract.** As China's electricity transmission and distribution tariff reform deepens, power grid companies at the current stage are shifting from the idea of "high investment, heavy assets, and fast growth" to making a precise investment and ensuring its effectiveness. As the investment in power grids is characterized by a long investment cycle and payback period, and the investment decisions made during each regulatory cycle have an impact on the transmission and distribution tariff in both the current cycle and the future, the establishment of grid investment assessment methodology by power grid enterprises is significant for improving investment decisions. This paper first proposes an investment effectiveness assessment methodology and specific indicators based on an understanding of the power industry and financial economy. and examines how the investment plan is affected by the depreciation of effective fixed assets used in transmission and distribution pricing. Then, adopting the maximum principle, this paper designs and presents the flow chart for optimizing grid investment based on the primary constraints affecting the transmission and distribution tariff. The final section of this paper reviews and makes recommendations for grid companies' future investments, including strengthening power grid construction, improving regulation capacity, enhancing intelligence level, raising grid interconnection standards for renewable energy, and so forth.

**Keywords:** Transmission and Distribution Tariff, Grid Investment, Power Demand, Investment Capacity.

## 1 Introduction

Since the National Development and Reform Commission and the National Energy Administration jointly released the 14th Five-Year Plan for Modern Energy Systems (hereafter referred to as the 14th Five-Year Plan) in March 2022, carbon peaking and carbon neutrality have become important goals for the electric power industry, and the electric power market for electric power is in an acceleratingly transitioning stage to green energy.


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Electricity is the foundation and driving force for the economic development of a country and region, and the main function of the power grid is to optimize the distribution of energy resources and supply enough electric power to enable social and economic growth. As the level of transmission and distribution tariff depends on the scale of effective assets, and thus the investment activities of grid companies in the previous regulatory cycle will affect the tariff level in the regulatory cycle, grid companies need to examine their investment strategy and aim at increasing effective assets as much as possible, so that they can obtain a greater revenue with the same amount of investment. During each regulatory cycle, the amount of new investment that can be converted into effective assets is the focus of grid companies, and thus the new investment planned should be consistent with the tariff regulatory cycle.

Because investment decisions and transmission and distribution pricing are closely related, grid companies should develop a grid investment assessment methodology, which can provide feedback on investments, aid in continuous improvement of investment decisions, and provide experience for future investment decisions.

For the current cost supervision measures of electricity transmission and distribution pricing, the literatures [1-4] comprised the currently effective rules for electricity transmission and distribution pricing and factors impacting the profit of power grid companies, where literature [4] elaborated this round of transmission and distribution tariff reform from the perspective of cost attribution and analyzed the status of cost accounting and supervision for grid companies. In terms of investment, the literatures [5-7] comprised the revenue control and precise investment that need to be considered in grid investment and gave investment recommendations. The existing literature has made much summary of this round of transmission and distribution tariff reform and cost supervision measures, but relatively little work has been done on the process of investment strategy optimization of grid enterprises. In the context of the transmission and distribution tariff reform, it is of great practical significance for grid enterprises to develop a grid investment assessment methodology and conduct research on investment strategy optimization.

## 2 Grid Investment Effectiveness Assessment Methodology

The key aspects of social benefits, economic benefits, grid coordination, and power demand constraint are used for grid investment effectiveness assessment. The specific indicators in the model can be assessed using the qualitative approach and the quantitative approach. The calculation of the indicators is shown in Table 1.

**Table 1.** Indicators for grid investment effectiveness assessment.

Source: Basic financial equations, their derivations, and Provincial Grid Transmission and Distribution Pricing Measures.

| Aspect | Indicator | Calculation |
|---|---|---|
| Social benefits | Environmental quality impact | / |

| | | |
|---|---|---|
| | Public satisfaction | / |
| | Employment | The number of jobs available per unit of investment = the number of jobs available of investment projects ÷ increment of new fixed assets |
| | Direct contribution to GDP | Direct contribution rate of GDP = permitted revenue ÷ local GDP |
| Economic benefits | Cost markup | Cost markup = total profit ÷ total cost and expenses |
| | Revenue-investment ratio | Revenue-investment ratio = revenue gained from investment ÷ total investment |
| | Average profit rate of investment | $\frac{1}{N}\sum_{t=1}^{N}\frac{Permitted\ profit\ in\ year\ t}{Investment\ increment\ in\ year\ t}$ |
| | Capacity increment | Capacity increment per unit of investment = capacity increment ÷ total investment |
| | Fixed asset increment | Fixed asset increment per unit of capacity = origin value increment of new fixed assets ÷ capacity increment |
| | Cost increment | Cost increment per unit of fixed asset investment = operation & maintenance cost increment ÷ origin value increment of new fixed assets |
| Grid coordination | Average substation quantity ratio | $\frac{1}{N}\sum_{t=1}^{N}\frac{Quantity\ of\ low\ voltage\ substation\ in\ year\ t}{Quantity\ of\ high\ voltage\ substation\ in\ year\ t}$ |
| | Average substation capacity ratio | $\frac{1}{N}\sum_{t=1}^{N}\frac{Capacity\ of\ low\ voltage\ substation\ in\ year\ t}{Capacity\ of\ high\ voltage\ substation\ in\ year\ t}$ |
| Power demand constraint | Transforming capacity demand | Demand increment of electricity transforming capacity = demand increment of the maximum power load × corresponding capacity-load ratio of the voltage level |

### 2.1 Social Benefits

The construction of a power grid will occupy land and space, and produce noise, electromagnetic, and radio interference, impacting the local environment. On the other hand, the construction of the power grid and its subsequent operation can provide employment opportunities. After its completion, the power grid will provide electricity services for local residents and enterprises, which will receive feedback concerning public satisfaction.

The primary metrics to assess grid investment from the social benefits aspect include environmental quality impact, public satisfaction, the number of jobs available per unit of investment, and the direct contribution rate of GDP, etc. Among them, environmental quality impact and public satisfaction are mostly assessed qualitatively or by creating weights for comprehensive scoring; the number of jobs available per unit of investment and the direct contribution rate of GDP can be examined by more quantitative analysis.

Public satisfaction can be evaluated in the form of questionnaires for residents, enterprises, and regulatory departments, which can reflect the feedback of residents on the effect of grid construction and renovation, the satisfaction of business clients on the grid and their specific needs, and the satisfaction of regulatory authorities on the overall effect of the grid investment in the area and its impact on the local economy.

The number of jobs available per unit of investment refers to the number of jobs that can be provided by each investment program; the direct contribution rate of GDP, on the other hand, indicates the contribution of the grid to the economic growth of other industries and can be used as the primary indicator to evaluate the socio-economic development of a region.

## 2.2 Economic Benefits

The main goal of grid investment is to ensure its effectiveness, which means that each investment can produce benefits as planned, preventing over-investment and waste of resources. In this paper, based on the requirements of transmission and distribution pricing cost supervision, we have chosen common economic efficiency indicators for power grid investment: cost markup, revenue-investment ratio, average profit rate of investment, capacity increment per unit of investment, fixed asset investment per unit of capacity increment and cost increment per unit of fixed asset investment.

The cost markup shows how much profit there is per unit of cost. The advantages to the eoconomic benefits increase as this indicator rises. However, this indicator is not the higher the better, but needs to be considered in conjunction with the industry average level. The efficiency of investments made during the current regulatory cycle is shown by the revenue-investment ratio, which can help with the planning of the subsequent regulatory cycle. The average profit rate of investment and capacity increment per unit of investment are used to evaluate the rationality and input-output efficiency of the grid investment, respectively.

According to the regulations on fixed assets in the Provincial Grid Transmission and Distribution Pricing Measures (hereinafter referred to as the Pricing Measures), the fixed asset investment per unit of capacity increment reflects the efficiency of power grid investment strategy and operation, while the cost increment per unit of fixed asset investment reflects the economic benefits.

## 2.3 Grid Coordination

The coordination of grid investment projects of various voltage levels is closely related to the smooth and steady growth of the grid. Grid coordination is mainly evaluated in two dimensions: the ratio of the quantity of substations of different voltage levels and the ratio of total substation capacity of different voltage levels. Commonly used indicators are average 110kV-220kV substation quantity ratio, average 110kV-220kV total substation capacity ratio, average 110kV-500kV substation quantity ratio, and average 110kV-500kV total substation capacity ratio.

The average 110kV-220kV substation quantity ratio indicates the average number of 110kV substations that can be driven by each 220kV substation, and the average 110kV-220kV total substation capacity ratio indicates the matching degree of 220 kV substation capacity and 110kV substation capacity, as is shown in equations (1) and

(2). The average 110kV-500kV substation quantity ratio and the average 110kV-500kV total substation capacity ratio are calculated similarly.

$$\text{Average } 110kV-220kV \text{ substation quantity ratio} = \frac{1}{N}\sum_{t=1}^{N}\frac{\text{Quantity of } 110kV \text{ substation in year } t}{\text{Quantity of } 220kV \text{ substation in year } t} \quad (1)$$

$$\text{Average } 110kV-220kV \text{ total substation capacity ratio} = \frac{1}{N}\sum_{t=1}^{N}\frac{\text{Capacity of } 110kV \text{ substation in year } t}{\text{Capacity of } 220kV \text{ substation in year } t} \quad (2)$$

### 2.4 Power Demand Constraint

Power demand also needs to be taken into account when making investment decisions of power grids. The power demand constraint means that the investment strategy of the regional power grid should meet the needs of the power supply capacity, and the capacity-load ratio is a key indicator to reflect the status of power supply of the power grid. The power supply capacity corresponding to different investment project portfolios needs to be maintained in the reasonable capacity-load ratio range specified in the Code of Planning and Design of Urban Electric Network (see Table 2), which is considered to meet the needs of power load growth.

**Table 2.** The range of capacity-load ratio of different voltage levels. Data source: Code of Planning and Design of Urban Electric Network.

| | Slow growth | Medium growth | Fast growth |
|---|---|---|---|
| Average annual growth of power load (recommended) | Less than 7% | 7 to 12% | More than 12% |
| 500 kV and above | 1.5 to 1.8% | 1.6 to 1.9% | 1.7 to 2.0% |
| 220 to 330 kV | 1.6 to 1.9% | 1.7 to 2.0% | 1.8 to 2.1% |
| 35 to 110 kV | 1.8 to 2.0% | 1.9 to 2.1% | 2.0 to 2.2% |

The capacity-load ratio of different voltage levels is closely tied to the local power load growth in each region. In areas with slower growth in power loads, the capacity-load ratio should be lower; in areas with faster growth in power loads, the capacity-load ratio should be higher. As the resources and geographical environment are different in each region, the corresponding characteristics of power load are also distinctive, resulting in different usage rates of equipment. Therefore, the power grid companies should base their investment decisions on the payback of investment and take into account the power load of each region, to minimize the waste of electricity transforming capacity, as well as the depreciation of transformers.

As the proportion of renewable energy generation increases year by year, the uncertainty of power load brought by the tertiary industry and household electricity consumption makes it more difficult to forecast power supply and demand, and it is important and urgent to improve the level of power supply and demand forecast. The demand increment for the capacity of different voltage levels can be determined by multiplying the increment of the maximum power load of each voltage level by the corresponding capacity-load ratio.

### 2.5 Summary

Grid companies can choose multiple indicators from above for analysis according to specific projects when assessing the effectiveness of grid investment. By sorting out and analyzing the indicators in chapters 2.1-2.4, the following two indicators are derived for reference, as is shown in equations (3) and (4).

$$Ratio\ A = \frac{Capacity\ increment}{Revenue\ gained\ from\ investment} \tag{3}$$

$$Ratio\ B = \frac{Operation\ \&\ maintenance\ cost\ increment}{Capacity\ increment} \tag{4}$$

The variance in project effectiveness can be measured and compared using ratio A. Priority can be given to projects with greater efficacy when making investment selections. By measuring and comparing the cost difference between projects, ratio B aids in cost variance analysis and assists grid firms in continuously improving their projects. To further ensure that power demand stays within a reasonable range, it is also required to strike a balance between power demand constraints and the coordination of power grids of different voltage levels.

## 3 The Impact of Effective Assets and Their Depreciation on the Transmission and Distribution Tariff and Grid Investment

The Pricing Measures stipulates that the average transmission and distribution tariff (including VAT) of the provincial grid equals permitted revenue (including VAT) gained through the transmission and distribution tariff divided by the transmission and distribution volume of the provincial grid, where the permitted revenue consists of permitted cost, permitted profit, and taxes. Provincial power grid enterprises then set their own transmission and distribution tariff by voltage level on the basis of approved overall transmission and distribution tariff.

According to the equations for calculating permitted revenue, the key variables that have an impact on the permitted revenue are: the original value of fixed assets in the base period, the original value of new fixed assets during the regulatory cycle, and the overall depreciation rate, where the original value of fixed assets in the base period is a non-variable constant, therefore the key indicators are set as the original value of new fixed assets in the regulatory cycle and the overall depreciation rate.

Therefore, the more depreciation is incurred in a regulatory cycle, the correspondingly higher the level of transmission and distribution tariff in this cycle. If investment timing is arranged to be late in the regulatory cycle so that less depreciation is incurred for new fixed asset investment, then the effective asset size will become larger when entering the next regulatory cycle, and the corresponding transmission and distribution tariff for the next cycle will be at a higher level.

When considering the transmission and distribution tariff measurement for the next cycle, with the overall scale of investment already determined, to make the expected tariff higher, it is necessary to arrange construction projects with low depreciation rates, such as main network construction, first, followed by investment projects with high depreciation rates, such as distribution network, metering instruments, automation equipment, etc., so that the net value of fixed assets comprised in effective assets of the next cycle is larger. When selecting projects with lower investment amounts but still unable to make investment scale in line with demand, priority should be given to projects with low depreciation rates.

When the adjusted investment capacity cannot meet the demand for investment, the investment timing of effective assets should be adjusted. The power grid enterprises, by adjusting the investment sequence of fixed assets, should give priority to the projects requiring less investment and with lower depreciation rates, to ensure a higher effective asset base under the premise of satisfying the basic investment demand, and thus make the permitted revenue relatively higher. When the investment capacity is more sufficient in the following year, higher investment projects can be scheduled.

## 4 Grid Investment Optimization Strategy

Since the level of transmission and distribution tariff depends on the scale of effective assets, the grid investment should be structured to create effective assets as much as possible. To accomplish precise power grid investment, the scale of investment can be broken down by region, voltage level, and project type. Investment demand needs to be measured by region since there are regional variations in power demand and equipment usage efficiency, which would otherwise result in wasteful investment.

The expected amount of new investment in the investment strategy of each regulatory cycle directly affects the value of permitted revenue for the cycle. This new investment is converted into fixed assets and included in the permitted revenue for the next cycle, and the sales revenue generated by the transmission and distribution tariff is also included as part of the permitted revenue in the base period for the next cycle. The future investment strategy should take into account the growth of electricity demand, grid planning, and the approved targets for transmission and distribution tariff.

For new projects, expansion projects, and technological transformation projects at the same voltage level, the transfer rate of fixed assets is characterized as "transfer rate of expansion projects > transfer rate of new projects > transfer rate of technological transformation projects". When deciding which projects to invest in under a new regulatory cycle, power grid firms must take the fixed asset transfer rate into account.

For the above reasons, it is necessary to forecast the power demand by voltage level and region, analyze the share of new, expansion, and technological transformation projects in total fixed assets, and assess the demand for grid investment, which will affect the forecast and confirmation of permitted profit rate, effective assets, and permitted profit. Power grid firms need to measure their investment capacity, which is associated with grid companies' internal funds and borrowings, and the funds and borrowings are primarily impacted by retained earnings, new current assets, and depreciation. Based on the relationship between the permitted amount of new investment, effective assets, and permitted revenue, the new investment shall not exceed the investment capacity during the regulatory cycle.

In summary, when making transmission and distribution investment decisions, the optimal investment strategy for grid enterprises is established by maximizing the permitted revenue and taking into account the investment demand constraint, investment capacity constraint, and new investment constraint. The flow chart of the transmission and distribution investment optimization strategy is shown in Fig. 1.

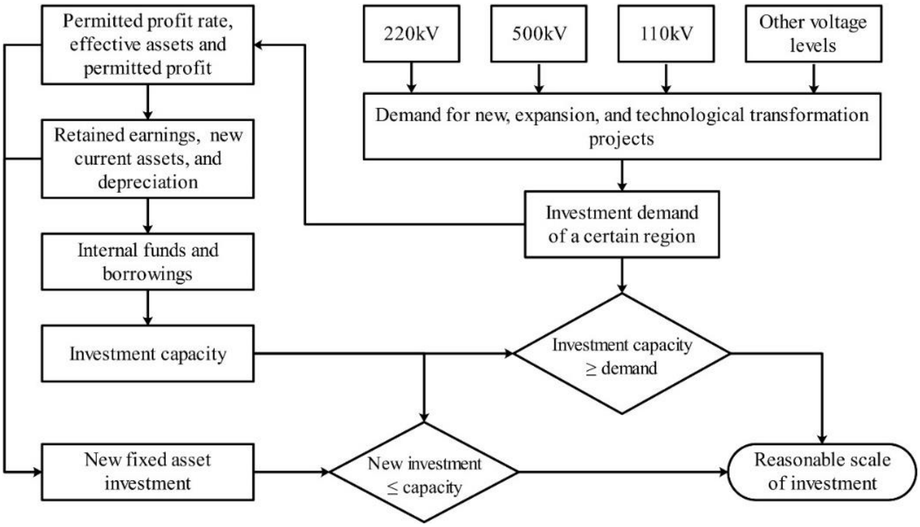


**Fig. 1.** Flow chart of investment optimization strategy.
Image source: self-created.

## 5 Conclusions

As the transmission and distribution pricing reform deepens, the investment strategy of power grid enterprises should aim to form effective assets that conform to the relevant regulations as much as possible. This paper establishes a framework for assessing the efficacy and efficiency of power grid investment and prompts pertinent thoughts based on the strong relationship between investment decisions and transmission and distribution pricing. The framework is mainly constructed from various aspects such as social benefits, economic benefits, grid coordination, and power demand constraints, among which there are both qualitative and quantitative indicators, and each element is interrelated with one another.

In addition, as the transfer rate of fixed assets differs depending on project types and voltage levels, grid investment timing should be arranged in accordance with the scale of depreciation of different fixed assets. In this paper, with the objective of maximizing the permitted revenue of the grid and comprehensive consideration of factors such as investment capacity, investment demand, and new investment constraint, the flow chart of investment optimization strategy is sorted out for grid enterprises to refer to.

According to the policy guidelines of the 14th Five-Year Plan and the trend and characteristics of the electricity transmission and distribution tariff reform, such as refinement of cost supervision, rationalization of investment scale control and transparency of transmission and distribution tariff, and combined with the investment status of most power grid enterprises, this paper suggests that power grid enterprises need to continuously improve the benefits and effectiveness of investment in power grid from various aspects, such as strengthening power grid construction, improving regulation capacity, enhancing intelligence level, raising grid interconnection standards for renewable energy, upgrading power grid dispatch control system and actively expanding financing channels.

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