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To cite this article: Bin Ye *et al* 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **237** 062013

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# Research on investment input-output benefit of distribution network planning considering micro-grid and multi-load development under the new power reform

YE Bin<sup>1</sup>, WANG Xu-li<sup>1</sup>, MA Jing<sup>1</sup>, ZHU Shu-yu<sup>2</sup>, QIU Xin-fu<sup>3</sup>, YIN Chen-xu<sup>1</sup>, XU Shan<sup>2</sup>, LI Yang<sup>2</sup>

<sup>1</sup>State Grid Anhui Electric Power Co., Ltd. Economic and Technological Research Institute, Hefei 230000, China

<sup>2</sup>School of Electrical Engineering, Southeast University, Nanjing 210096, China

<sup>3</sup>State Grid Maanshan Power Supply Company, Maanshan 243000, China)

**Abstract.** This paper studies the input-output model considering microgrid and multi-load microgrid. Combined with the new power reform, the investment strategy of the distribution network is analyzed and evaluated. The input model considers depreciation of fixed assets, operation and maintenance fees, and electricity purchase costs. The output model considers the benefits of distribution services and the benefits of electricity sales. On this basis, the uncertain factors in grid investment are studied, and the probability distribution function is constructed. The “incremental method” is used to analyze the influence of uncertain factors on the evaluation index of the reform scheme, and the most sensitive factor is obtained. Finally, the case study shows that the input-output model can better reflect the evaluation indicators of the transformation plan and provide decision-making basis for the grid investment transformation plan.

## 1. Introduction

In March 2015, the Central Committee of the Communist Party of China and the State Council issued Some Opinions on Further Deepening the Electricity Reform (Document No.9 [2015] issued by the General Office of the CPC Central Committee) and clearly put forward a framework for the electricity reform of “unlashing both ends” and “controlling the middle”. Under the policy background of nationally deepening the reform in an all-round way, the profit model, the development environment and the power market pattern, etc. of power grid enterprises will undergo profound changes<sup>[1-2]</sup>. Further, the microgrid and the multi-load represented by distributed photovoltaic and electric vehicles are booming, technically. Exemplified by electric vehicles, the Guide to Development of Electric Vehicle Charging Infrastructure (2015-2020) predicts that there will be over 5 million electric vehicles owned in China by 2020, and the scale of electric vehicles to be promoted will reach 2.66 million in Beijing, Shanghai, Jiangsu, Zhejiang, Anhui and Fujian, among others, requiring 7,400 new charging stations and 2.5 million charging piles. The large-scale popularization of multi-load has transformed the original form of distribution network, which will exert a tremendous impact on economic benefits and overall efficiency of power grid enterprises.

External severe policy situations and complex technical situations will together bring forth more risks and challenges to distribution network investment. To achieve efficient operation and healthy development, power grid enterprises must change the previous model of “emphasizing technology and



ignoring economic benefits” in distribution network planning, “emphasizing demand, ignoring economic benefits” in distribution network investment, and strengthening input and output analysis in distribution network planning and investment<sup>[3-4]</sup>. They must fully identify investment risks, formulate distribution network planning and investment strategies, adapt to new situations, and provide strategic guidance for grid enterprise investment in a more market-oriented and intelligent distribution network in the future.

Currently, there have been a certain amount of studies focusing on the investment strategy of distribution network. Wang Jinbin [5] et al. probed the risk variables affecting the investment benefits of power grid enterprises, constructed a probability distribution function upon the physical meanings of variables, changed the practice of taking factors such as the power sales and electricity price as fixed values in the traditional technical and economic evaluation of power grids, and quantified investment risks by using the “incremental method” to furnish a reference for the decision-making of power grid reconstruction projects. Wang Jinbin [6] et al. deployed the set pair analysis theory to calculate the set pair coefficients of risk factors, which problem-solved the ambiguity and conflict of each and every risk factor and afforded the decision support for the investment of power grid enterprises to some extent. Wang Jianchong [7], Hong Qiu [8] et al. proffered a model for evaluating the strategy of distribution network investment by use of post-evaluation. For all that, the practice that power grid enterprises profit from the purchase and sale price difference obtained through buying and selling electricity is not in conformity with the new profit model that power grid enterprises should charge the wheeling cost as per the approved power transmission and distribution (PTD) price at various voltage levels under the new electricity reform (NER), and also fails to take into account the marketization trend. Wang Weiping [9] regarded the income from PTD services as the operating income of power grid enterprises under the NER, thoroughly considered construction costs, operation and maintenance costs, etc., established an incremental life-cycle investment risk evaluation model for distribution network based on Monte Carlo methods, and systematically evaluated the investment scheme. Even so, it none the less lost sight of the impact of microgrid and multi-load development on the distribution network investment. Liao Zhiwei et al. [10], Li Rui [11], Zeng Ming [12] et al. [13] took into account the impact of the development of distributed energy resources (DER) and microgrid on the benefits of power grid enterprises, such as delaying the benefits of distribution network reconstruction and the benefits of reliability improvement. The aforesaid researches take microgrid or DER as the research object but fail to perform the detailed analysis from the point of power grid enterprises.

To sum up, most of available references have neglected the new profit model of power grid enterprises under the NER, or the references have only delved into the strategy of distribution network investment under the NER or under microgrid and multi-load development, homogeneously. By contrast, the studies on the strategy of distribution network investment still have left much to be desired under combined consideration of the policy situation of NER and the technical development of microgrid and multi-load. In this regard, this paper starts with analyzing the impact of the NER as well as microgrid and multi-load development on distribution network from four perspectives: network loss, planning and construction, costs, and economic benefits, then on this basis, the input-output model of distribution network planning under the new situation is established, and various risk factors in the model are identified and probabilistic modeled. The “incremental method” is used to simulate the uncertain factors. The impact of the project's net present value greater than zero probability. Through the positive and negative fluctuations of uncertain factors, the impact of fluctuations of various uncertain factors on the transformation project is studied.

## **2. Impact analysis of microgrid and multi-load development on distribution network**

### *2.1. Network loss*

The appearance and development of microgrid and multi-load have undoubtedly changed the original load characteristics and power flow distribution of distribution network, thus affecting the network loss of distribution system.

On the one hand, the development of new forms of technology may play a role in reducing the network loss of original distribution network. Taking the microgrid as an example, the voltage level of microgrid is low, and its operation mode of “self-generation for self-use, surplus on grid” neatly avoids the large network loss arising from long-distance transmission. Meanwhile, power flow optimization and regulation can also be implemented via microgrid optimization operation technology<sup>[13]</sup>.

On the other hand, the new technology may increase the network loss of original distribution network. Taking the multi-load as an example, the distribution network has changed from a passive network to an active network due to the large access to distributed photovoltaic devices, etc. If the devices such as distributed photovoltaic devices are not properly laid out, it may result in increased network loss.

## *2.2. Planning and construction*

Power grid planning is an extremely important link in power grid construction and development. In the wake of the advance of microgrid and multi-load, traditional distribution network planning will be confronted with significant challenges, mainly in the following two aspects.

One is to increase uncertainty. The DER such as wind and light in microgrid may cause fluctuations in microgrid output. Additionally, with the increasing electric vehicles owned, fluctuations in charging powers will be aggravated. These uncertainties make it more difficult for planners to accurately predict power requirements and seriously affect the accuracy of planning.

The other is to increase the difficulty in problem solving. Planners need to consider the regulation strategy between the distribution network and the microgrid as well as between the distribution network and the DER, which renders the planning more dimensional and more difficult-to-solve.

## *2.3. Costs*

The appearance and development of microgrid and multi-load will have a positive or negative impact on the cost of distribution network.

Exemplified by the microgrid, in the negative side respect, Article 14 of the “Trial Measures for Promoting Grid-connected Microgrid Construction” stipulates that “the access of microgrid to public distribution network and the construction and reconstruction of resulting public distribution network shall be financially undertaken by power grid enterprises”, thereby the access of microgrid will bring additional capital expenditure and operating costs to power grid enterprises as external distribution network operators.

In the positive side respect, the access of microgrid enables distribution network to be provided with potential technical services. Taking the peaking service as an example, in areas with high transmission and distribution construction costs, it may be necessary to build new transmission and distribution lines and supporting equipment to meet the small or short-term load growth, which will increase the financial burden of the grid enterprises. If the microgrid is deployed on the load side, the reasonable operation of the microgrid can effectively reduce the system's requirements on the grid transmission capacity when the peak load is applied, avoid the blockage of the transmission and distribution lines, and delay the construction of the transmission and distribution facilities.

## *2.4. Economic benefits*

The microgrid and multi-load as new technologies will influence the income from distribution network in various ways.

New forms of technology may spawn the benefit loss of distribution network. Exemplified by microgrid, to date, microgrid mainly adopts the operation mode of “self-generation for self-use, surplus on grid”. In this view, electricity purchase is actualized from external distribution network only in the case of insufficient internal electricity, and hence the power sales of power grid enterprises are reduced. Also, the decrease of electricity purchase will lead to corresponding reduction in the usage rate of equipment such as distribution transformers and cable lines in external distribution network, and accordingly, distribution service fees will be reduced.

At the same time, the progress of new forms of technology such as microgrid under the NER is likely to pose daunting challenges to the power sale business of power grid enterprises. Exemplified by microgrid, social enterprises can become the subject of microgrid operation, and operate as power sale companies (type II power sale companies) after meeting admittance conditions and performing admittance procedures for power sale companies. It is important to highlight that power grid enterprises will suffer from gradual disintegration of their monopoly on the power sale-side market and will be up against the operating pressure of sharply decreased power sales in all likelihood.

### 3. Input-output model of distribution network considering microgrid and multi-load development under NER

#### 3.1. Distribution network input model

It is assumed that the original distribution network needs to be reconstructed in future due to load growth, but the microgrid and multi-load development is bound to make a difference to the distribution network expansion and planning scheme and the overall benefits of distribution network. Therefore, it entails establishing the overall input model and output model of distribution network under the distribution network reconstruction and planning scheme.

##### (1) Investment cost of fixed assets

The investment cost of fixed assets of distribution network is classified into the initial investment cost and the reconstruction investment cost. The initial investment cost refers to the construction cost required by power grid enterprises in response to satisfy the load demand and ensure the safety and reliability of power supply at the project initiating stage. The reconstruction investment cost refers to the cost required by power grid enterprises to reconstruct the built part in response to enhance the power supply capacity and ensure the reliability of power supply in the case of external circumstance changes. To facilitate modeling, it is assumed that the initial investment and reconstruction investment of distribution network are both one-time investments.

Assuming that the investment cost of fixed assets can be converted into fixed assets at the capital conversion rate of  $\partial$ , the fixed assets of distribution network in the  $t$ -th year are:

$$C_{cap,t} = \begin{cases} \partial C_{inv} & 1 \leq t \leq T' \\ \partial(C_{inv} + C'_{inv}) & T' < t \leq T \end{cases} \quad (1)$$

where,  $C_{cap,t}$  denotes the initial fixed assets of distribution network in the  $t$ -th year;  $C_{inv}$  denotes the investment cost of initial fixed assets of distribution network;  $C'_{inv}$  denotes the investment cost of fixed assets of distribution network reconstruction;  $\partial$  denotes the ratio of investment into fixed assets, which can be determined by referring to the historical capital transfer of PTD fixed assets of power grid enterprises;  $T'$  denotes the occurrence year of distribution network reconstruction;  $T$  denotes the project calculation period.

##### (2) Financial cost

The financial cost refers to the fund-raising cost during the construction and operation of distribution network planning project, mainly including the annual interest reimbursement.

If any power grid enterprise applies for bank loans, the initial self-financing fund and reconstruction self-financing fund of distribution network are:

$$C_{inv,self} = (1 - k_{loan})C_{inv} \quad (2)$$

$$C'_{inv,self} = (1 - k_{loan})C'_{inv} \quad (3)$$

where,  $C_{\text{inv,self}}$  and  $C'_{\text{inv,self}}$  denote the initial self-financing fund and reconstruction self-financing fund of power grid enterprises, respectively;  $k_{\text{loan}}$  denotes the loan ratio (assuming the initial loan ratio is identical with the reconstruction loan ratio).

By reason of the long-time loan repayment period of construction projects, it is generally assumed that the loan repayment period is equal to the operation period, and hence the distribution network reconstruction will occur before the end of initial loan repayment period. Assuming that the equal principal and interest repayment is adopted, the annually repaid principal and interest can be expressed as:

$$C_{\text{loan},t} = \begin{cases} \frac{12 \left[ k_{\text{loan}} C_{\text{inv}} \beta (1 + \beta)^{12N_{\text{loan}}} \right]}{(1 + \beta)^{12N_{\text{loan}}} - 1} & 1 < t \leq T' \\ \frac{12 \left[ k_{\text{loan}} (C_{\text{inv}} + C'_{\text{inv}}) \beta (1 + \beta)^{12N_{\text{loan}}} \right]}{(1 + \beta)^{12N_{\text{loan}}} - 1} & T' < t \leq T_{\text{loan}} \\ \frac{12 \left[ k_{\text{loan}} C'_{\text{inv}} \beta (1 + \beta)^{12N_{\text{loan}}} \right]}{(1 + \beta)^{12N_{\text{loan}}} - 1} & T_{\text{loan}} < t \leq T \end{cases} \quad (4)$$

where,  $C_{\text{loan},t}$  denotes the annually repaid principal and interest;  $\beta$  denotes the monthly loan interest rate;  $T_{\text{loan}}$  denotes the repayment period.

### (3) Depreciation cost

After the project completion, the construction investment will be converted into fixed assets upon the formation rate of fixed assets. The depreciation cost of fixed assets refers to the accrued depreciation cost upon the depreciation rate determined by the service life of power grid projects specified in the annex to the “Measures for Supervision and Examination of Power Transmission and Distribution Pricing and Costs (Trial)”. The fixed value is extracted per annum by using the straight-line method.

It is assumed that the fixed assets generated from the initial investment can continue to be utilized after depreciation until the end of the whole distribution network project. For the initial fixed assets of distribution network that have been depreciated but are still in use, if depreciation is stopped, the annual depreciation cost is as shown in Equation (5) that:

$$C_{\text{depr},t} = \begin{cases} \frac{C_{\text{cap},t} (1 - k_{\text{rest}})}{T_{\text{depr}}} & 1 < t \leq T_{\text{depr}} \\ \frac{\partial C'_{\text{inv}} (1 - k_{\text{rest}})}{T_{\text{depr}}} & T_{\text{depr}} < t \leq T \end{cases} \quad (5)$$

where,  $C_{\text{depr},t}$  denotes the depreciation cost of fixed investment in the t-th year;  $T_{\text{depr}}$  denotes the depreciation period;  $k_{\text{rest}}$  denotes the residual value rate, which represents the ratio of the average residual value of fixed assets to the initial investment of fixed assets, with reference to the notice of “Measures for Supervision and Examination of Power Transmission and Distribution Pricing and Costs (Trial)”, where the residual value rate of fixed assets is determined by 5%.

### (4) Operation and maintenance cost

The distribution network operation and maintenance cost refers to the cost necessary to maintain the normal operation of distribution grid, which mainly encompasses the maintenance and repair cost, the material cost, the staff salary and otherwise.

$$C_{\text{oper},t} = k_{\text{oper}} C_{\text{cap},t} \quad (6)$$

where,  $C_{\text{oper},t}$  denotes the maintenance cost corresponding to the fixed assets of distribution grid in the t-th year;  $k_{\text{oper}}$  denotes the operation and maintenance cost coefficient. In general case, the operation and maintenance cost coefficient takes the relevant empirical value or the historical statistics of local operation and maintenance cost.

#### (5) Electricity purchase cost

In addition to basic PTD services, power grid enterprises can also set up their power sale companies to conduct the power sale business. Therefore, the distribution network planning project should take into full account the distribution-side and power sale-side costs and benefits related to the power grid enterprise, so as to screen out the optimal scheme for the overall profits of power grid enterprises.

After the new round of electricity reform, it is worth mentioning that the electricity purchase price of power grid enterprises is no longer the power generation-side benchmark on-grid price, but the generation-side benchmark on-grid price plus the PTD-side PTD price. Since PTD prices are determined by voltage level after the NER, the electricity purchase cost is also calculated in line with the voltage level accordingly.

#### ① Initial electricity purchase cost

$$C_{\text{buy},t} = \sum_{i=1}^I \left( \frac{p_{\text{gen},t} k Q_{\text{sale},t,i}}{1 - \text{Loss}_{t,\text{sum}}} + \frac{p_{\text{trdi},t,i} k Q_{\text{sale},t,i}}{1 - \text{Loss}_{t,i}} \right) \quad 1 < t \leq T' \quad (7)$$

$$Q_{\text{sale},t,i} = Q_{\text{load},t,i} \quad (8)$$

where,  $C_{\text{buy},t}$  denotes the electricity purchase cost of power grid enterprises in the t-th year; I denotes the number of voltage level categories accessed by distribution network users;  $p_{\text{trdi},t,i}$  denotes the government-approved PTD electricity price at the voltage level i in the t-th year;  $p_{\text{gen},t}$  denotes the benchmark on-grid electricity price of power generation enterprises in the t-th year; k denotes the power sale-side market share;  $Q_{\text{sale},t,i}$  denotes total annual power sales of distribution network at the voltage level i in the t-th year;  $Q_{\text{load},t,i}$  denotes the quantity of loads of distribution network at the voltage level i;  $\text{Loss}_{t,i}$  denotes the line loss rate of distribution network at the voltage level i in the t-th year;  $\text{Loss}_{t,\text{sum}}$  denotes the comprehensive line loss rate of distribution network in the t-th year.

#### ② Electricity purchase cost after reconstruction

After reconstruction, the electricity purchase cost of the power sale company of a power grid enterprise should include two parts: one is the cost of electricity purchased from the power generation enterprise and transmitted through PTD, and the other is the cost of purchasing the on-grid electricity through microgrid and DER, assuming that the on-grid electricity through microgrid and DER is directly consumed nearby.

$$\begin{cases} C_{\text{buy},t} = (C_{\text{buy},1,t} + C_{\text{buy},2,t}) \\ C_{\text{buy},1,t} = \sum_{i=1}^I \left( \frac{p_{\text{gen},t} k Q_{\text{sale},t,i}}{1 - \text{Loss}_{t,\text{sum}}} + \frac{p_{\text{trdi},t,i} k Q_{\text{sale},t,i}}{1 - \text{Loss}_{t,i}} \right) \quad T' < t < T \\ C_{\text{buy},2,t} = \sum_{i=1}^I p_{\text{up},t} k Q_{\text{up},t,i} \\ Q_{\text{sale},t,i} = Q_{\text{load},t,i} + Q_{\text{EV},t,i} - Q_{\text{DG},t,i} \end{cases} \quad (9)$$

where,  $C_{\text{buy},t}$  denotes total annual electricity purchase cost of the power sale company of a power grid enterprise in the t-th year;  $C_{\text{buy},1,t}$  denotes the electricity purchase cost for the purchase from a power

plant and the transmission through PTD;  $C_{\text{buy},2,t}$  denotes the purchase cost of on-grid energy of microgrid and DER.  $kQ_{\text{sale},t,i}$  denotes the power sales at the voltage level  $i$  corresponding to the electricity purchase part of a power plant;  $Q_{\text{up},t,i}$  denotes the annual quantity of on-grid energy of microgrid and DER at the voltage level  $i$  in the  $t$ -th year;  $P_{\text{up},t}$  denotes the on-grid price;  $Q_{\text{EV},t,i}$  denotes the annual power consumption of electric vehicles at the voltage level  $i$  in the  $t$ -th year;  $Q_{\text{DG},t,i}$  denotes the annual energy output of microgrid and DER at the voltage level  $i$  in the  $t$ -th year.

### 3.2. Distribution network output model

#### (1) Income from distribution services

After the new round of electricity reform, the profit model of power grid enterprises has changed from the original purchase and sale price difference obtained through buying and selling electricity to the “wheeling cost” charged according to the government-approved PTD price. For the distribution network, the “Administrative Measures for Orderly Opening the Distribution Network Business” stipulates that before the PTD price is approved, the provisional price is subject to the PTD price of the provincial power grid shared network corresponding to the accessed voltage level of the power sale company or electricity user deducted from the PTD price of the provincial power grid shared network corresponding to the accessed voltage level of the distribution network. Therefore, the income from distribution services by the distribution network is shown in Equation (10) that:

$$R_{\text{dis},t} = \sum_{i=1}^I \left( \frac{p_{\text{trdi},t,i} Q_{\text{sale},t,i}}{1 - \text{Loss}_{t,i}} - \frac{p_{\text{trdi},t,I+1} Q_{\text{sale},t,i}}{\prod_{j=i}^{I+1} (1 - \text{Loss}_{t,j})} \right) \quad 1 < t \leq T \quad (10)$$

where,  $R_{\text{dis},t}$  is the income from distribution services by the distribution network in the  $t$ -th year, and  $p_{\text{trdi},t,I+1}$  is the PTD price of the provincial power grid shared network corresponding to the accessed voltage level of the distribution network.

#### (2) Income from selling electricity

$$R_{\text{sale},t} = \begin{cases} \sum_{i=1}^I p_{\text{sale},t,i} kQ_{\text{sale},t,i} & 1 < t < T' \\ \sum_{i=1}^I p_{\text{sale},t,i} k(Q_{\text{sale},t,i} + Q_{\text{up},t,i}) & T' < t < T \end{cases} \quad (11)$$

where,  $R_{\text{sale},t}$  is the income from selling electricity of the power sale company of a grid corporation in the  $t$ -th year;  $p_{\text{sale},t,i}$  is the selling price at the level  $i$  voltage in the  $t$ -th year.

## 4. Distribution network investment strategy model based on Monte Carlo simulations

### 4.1. Identification of risk factors

The identification of risk factors is the first step in risk analysis. For the distribution network investment project, there are various risk factors at all stages of the life cycle due to its complex objective conditions and limited predictive and cognitive abilities, and meanwhile, the risk factor identification process is more complicated.

To simplify the identification and modeling processes of risk factors and weaken the correlation between various risk factors, only risk factors that can be reflected in the calculation process of cash



flow statement and quantified in input and output items are selected here, and each and every risk factor is further classified. Among that, the “Costs” category includes the investment cost of fixed assets, loan interest rate, and operation and maintenance cost coefficient; the “Electricity prices” category includes the PTD price at each voltage level, on-grid price, and selling price at each voltage level; the “Quantity of electricity” category includes the power sale-side market share, annual power consumption of loads at each voltage level, annual energy output of microgrid and DER, and annual power consumption of electric vehicles; the “Technology” category includes the comprehensive line loss rate at each voltage level.

#### *4.2. Probability distribution function of risk factors*

In accordance with identification results of risk factors and common probability distribution forms, the probability distribution function of each risk factor is determined for use in Monte Carlo simulations.

For the investment cost of fixed assets and operation and maintenance cost coefficient, power grid enterprises generally set a general range for the actual investment size and operation and maintenance cost size, and have an estimate of the most likely values. Therefore, it is assumed that the investment cost of fixed assets and operation and maintenance cost coefficient both follow triangular distribution, and the values of the specific lower limit, mode and upper limit are determined depending on the actual situation of the planned project.

For the loan interest rate and PTD price at each voltage level, the values depend on the bank and the government respectively, and power grid enterprises can only roughly estimate the possible value range. Therefore, it is assumed that the loan interest rate and PTD price both follow uniform distribution.

For the generation-side on-grid price, the data of actual electricity prices from the electricity markets in California, USA, PJM and Zhejiang, China show that the electricity price approximately follows normal distribution in the case of a loose power supply-demand relationship<sup>[14]</sup>. Judging from the current situation of investment in power supply and power grid construction in China, it is entirely possible to believe that the future supply-demand relationship is very loose, so it is assumed that the on-grid price follows normal distribution.

For the selling price, it should not be fixed but it should be a continuous random variable. The change of continuous random variables is usually simulated by random numbers. And after using the Monte Carlo method to simulate the selling price randomly, it can be concluded that its distribution function follows continuous normal distribution.

For the power sale-side market share, since the power sale-side market competition has not yet been fully developed, it cannot be analyzed and estimated through historical data. It is assumed here that the annual market share of the power sale company of a power grid enterprise follows normal distribution.

For the annual power consumption of loads at each voltage level, since the power grid enterprise will forecast the quantity of loads in the coming years, and the general forecast will have the “high, medium, and low-level” schemes, the set future loads conform to the continuous triangular distribution function, and the specific values of lower limit, mode and upper limit can be obtained by a forecast model established using the data of the distribution network's loads over the years, local economic development level and industrial structure, among others.

For the microgrid and DER, the annual energy output depends on the scale of microgrid and DER, local wind and light conditions and other factors. For the annual power consumption of electric vehicles, it depends on the car parc that year, the type of electric vehicles and other factors. These factors can be predicted by using local relevant historical data, and the general plan will get the “high, medium, and low-level” predicted values, so they can be expressed by using a triangular distribution function.

For the comprehensive line loss rate, it is difficult to determine the general line loss rate. Some kinds of possible line loss rate values and corresponding probabilities can be obtained by using the expert experience method, i.e. they follow probability distribution of discrete random variables.

Table 1. Summary and contrast of various risk factors

Category	Risk factors	Distribution function
Costs	Investment cost of fixed assets	Triangular distribution
	Loan interest rate	Normal distribution
	Operation and maintenance cost coefficient	Triangular distribution
Electricity prices	PTD price	Normal distribution
	On-grid price	Normal distribution
	Selling price	Normal distribution
Quantity of electricity	Power sale-side market share	Normal distribution
	Annual power consumption of loads	Triangular distribution
	Annual energy output of microgrid and DER	Triangular distribution
	Annual power consumption of electric vehicles	Triangular distribution
Technology	Comprehensive line loss rate	Discrete distribution

#### 4.3. Input-output benefit evaluation indexes

##### (1) Internal rate of return

Internal rate of return (IRR) is expressed as:

$$\sum_{t=1}^T (CI - CO)_t (1 + IRR)^{-t} = 0 \quad (12)$$

where,  $T$  denotes the life cycle of the project, including the construction period and operation period;  $CI$  denotes the cash inflow for year  $t$  with relevant data obtained according to the cash flow statement;  $CO$  denotes the cash outflow for year  $t$  with relevant data obtained according to the cash flow statement. If IRR is higher than or equal to the benchmark rate of return (RR) in the sector, it is deemed that the project profitability has met the minimum requirements and is financially acceptable.

##### (2) Net present value

Net present value (NPV) is expressed as:

$$NPV = \sum_{t=1}^T (CI - CO)_t (1 + i_e)^{-t} \quad (13)$$

where,  $i_e$  is the benchmark RR. If NPV is greater than 0, the project is considered financially feasible, otherwise it is not feasible. Moreover, the larger NPV value demonstrates the stronger project profitability.

##### (3) Dynamic payback period

Dynamic payback period, also known as investment return period, is expressed as:

$$\sum_{t=1}^{P_t} (CI - CO)_t (1 + i_e)^{-t} = 0 \quad (14)$$

where,  $P_t$  presents the dynamic payback period. If  $P_t$  is less than or equal to the benchmark payback period in the power industry, the project is considered financially feasible.

#### 4.4. Sensitivity analysis

The key risk factors that have an significant impact on the economic benefits of the project are screened out through sensitivity analysis to guide the accurate investment of power grid enterprises as an important basis for investment decisions. The sensitivity equation is:

$$S_{AF} = \frac{\Delta A / A}{\Delta F / F} \quad (15)$$

where,  $S_{AF}$  is the degree of sensitivity;  $\Delta F / F$  indicates the change rate (%) of each risk factor  $F$ ;  $\Delta A / A$  indicates the change rate (%) of the financial evaluation index  $A$  corresponding to the change of each risk factor  $F$ .

#### 5. Example analysis

Taking the distribution network of a province as an example, the above model is used to evaluate the input and output benefits of the distribution network. The provincial company invested in the project in 2014. According to the plan, the distribution network was invested and rebuilt in early 2019, and the microgrid was put into operation, using distributed power to generate electricity, and adopting the mode of “spontaneous use and restroom”. Assume that the initial construction project investment amount is 1.5 billion, the investment fund for the renovation project is estimated to be 3.5 billion, and the planning period is 2020~2024.

The scenario before the renovation of the study is taken in 2015-2018, and the post-reform scenario takes 2019-2024. The transformation plan was evaluated by comparing the internal rate of return, the net present value, and the dynamic investment payback period.

Table 2. Comparison of input-output benefit indicators before and after transformation

	before transformation	after transformation
Initial investment(billion)	15	35
Internal Rate of Return(%)	17.75	21.67
Net present value(billion)	8.3658	3.0822
Dynamic investment payback period(year)	4	5

The output value of the input-output benefits before and after the transformation of the distribution network is shown in Table 4. It can be seen from Table 4 that the internal rate of return after the transformation has been improved, indicating that the transformation plan has significantly improved the income of the program before the transformation. Although the net present value is lower than before the transformation, with the extension of the planning period, the distributed power generation capacity is increasing, the electric vehicle load is increased, and the revenue of the distribution network will continue to increase.

Therefore, for the transformation plan, considering the distributed power supply and the electric vehicle load, the investment should focus on the investment plan, and it should be compatible with the increase of the electric vehicle load and the growth of the distributed power generation, and rationally arrange the investment plan. The short-term investment risk is slightly larger, and the planning period can be appropriately extended to obtain considerable income and reduce investment risks.

Four typical uncertain factors of electricity sales, average electricity price, electricity price and line loss rate are selected to analyze the investment risk and consider the impact of uncertain factors on the net present value.

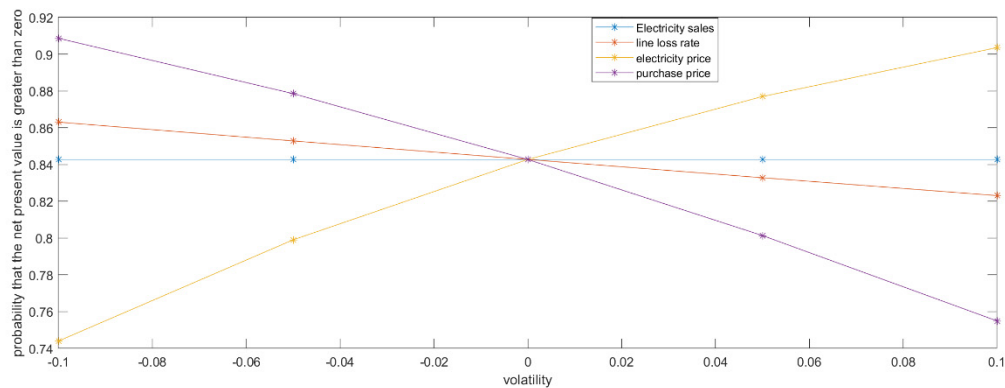


figure 1. Probability map of net present value greater than 0 for different uncertainties at different volatility rates

It can be seen from Figure 1 that the fluctuation of electricity price and electricity price has the most obvious influence on the probability that the net present value of the transformation project is greater than zero, that is, the net present value index is most sensitive to the two risk factors of electricity price and electricity price. Next is the electricity sold, the least sensitive is the line loss rate.

## 6. Conclusion

This paper first analyzes the impact of new power reform, microgrid and multi-load development on the distribution network from four aspects: network loss, planning and construction, cost and economic benefits. On this basis, the distribution network planning under the new situation is established. The input-output model, and the identification and probabilistic modeling of various risk factors in the model. Through the sensitivity analysis of typical risk factors, the factors that have a great influence on the distribution network transformation project are obtained. attention.

(1) Influencing factors such as microgrid, distributed power supply and electric vehicle were added to the distribution network transformation plan. The input model and output model were established respectively, and the multi-index evaluation of the transformation plan was carried out.

(2) Taking into account the risks of investment projects, identify the key risk factors that have a greater impact on the benefits of the distribution network planning investment projects, determine the probability distribution function of each risk factor, and use the "incremental method" to determine the uncertain factors for investment. The impact of the probability that the net present value of the project is greater than zero provides a basis for the grid to make investment decisions.

(3) Distributed power and electric vehicles are the trend of future social development. The power grid needs to actively formulate reasonable investment plans, consider the impact of sensitive factors on project risks, and reduce risks to obtain considerable returns.

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