Research on Incremental Distribution Network Operation Model Based on Cost-Benefit Perspective

Lei An¹, Caixia Tan²*, Mianbin Wang¹, Xuan Liu¹, Zhongfu Tan²,³
¹Economic and Technical Research Institute of State Grid Jibei Electric Power Co., Ltd., Beijing, 100038, China
²North China Electric Power University, Beijing, 102206, China
³Yan'an University, Shanxi, 716000, China
*Corresponding author’s e-mail: 2858877150@qq.com

Abstract. In order to select the optimal mode of incremental distribution network and increase the revenue of the incremental distribution network, incremental distribution network cost-benefit model in three scenarios were established: non-sales company investment + operation, electricity sales company investment + operation, non-sales company investment + electricity sales company operation. At the same time, the three operating models are evaluated using three indicators: net present value, dynamic investment payback period, and net present value rate. Finally, take an incremental distribution network as an example to verify the effectiveness of the model. The result of the calculation example is that the electricity sales company's investment + operation model has higher economic benefits than other models, the investment payback period is shorter, and the unit investment income is higher.

1. Introduction
With the promulgation of the "Measures for the Orderly Opening of Distribution Network Business Management" and "Notice on Further Promoting the Reform of Incremental Distribution Business (Draft for Comment)" , the rights, obligations and scope of the incremental distribution network are clarified, promoting the construction of 404 incremental distribution network reform practice pilots³[1-2]. But the ensuing exploration of incremental distribution network investment construction model and operation mode has become an urgent problem to be solved in the incremental distribution network park. Scholars at home and abroad have carried out certain research on the operation of incremental distribution parks.

Literature [3-4] analyzes the operator's bidding decision of incremental distribution network based on non-cooperative game theory, and uses particle swarm algorithm to solve the equilibrium solution. Literature [5] based on the electricity deviation assessment mechanism, analyzed mainstream electricity price packages, and proposed an electricity distribution model for incremental distribution network. Reference [6] from the perspective of distributed energy storage in incremental distribution network park, and studies the typical profit model and operation mode of incremental distribution network. Literature [7] proposes new technologies for the operation of the Internet of Things + Incremental Distribution Network to achieve integrated management of quality, safety and efficiency with the goal of improving the incremental distribution network management system. On the one hand, the above research mostly discusses the operation mode of the incremental distribution network from a qualitative perspective, but does not quantitatively analyze the operation mode of the incremental
distribution network. On the other hand, the above research studies the distributed energy storage and distribution network as a whole, but few studies have been conducted from the perspective of electricity sales companies.

Based on the existing incremental distribution park operation research, this paper builds a cost-benefit model under the three modes of non-sales company investment + operation, electricity sales company investment + operation, non-sales company investment + electricity sales company operation. On this basis, the net present value, dynamic investment recovery period, net present value rate are used to evaluate the above three operating modes.

2. Cost-benefit model of incremental distribution network with different operation modes
Incremental distribution networks are divided into three operating modes according to whether they are invested and operated by electricity sales companies, namely non-electricity sales company investment + operation, electricity sales company investment + operation, non-electricity sales company investment + electricity sales company operation. In order to choose the operation mode that best matches the incremental distribution network, cost-benefit models under these three operation modes are constructed.

2.1. Non-sales company investment + operating cost-benefit model
Non-sales company investment + operation refers to the investment of incremental distribution network and the operator is not a power sales company. Therefore, the development of the power distribution business of the incremental distribution network needs to be carried out by signing a corresponding contract with the power sales company outside the park. The main sources of revenue for incremental distribution networks under this model are collection of transmission and distribution fees, guaranteed power supply fees, medium- and long-term power transaction contract revenue, new energy power generation subsidies, new energy green card subsidy revenue, CCER transfer discount carbon emission quotas, etc. Costs include incremental distribution network investment costs, operating costs, network loss costs, power generation costs, and transaction costs. The details are shown in Figure 1:

![Non-sales company investment + operating cost-benefit chart](image)

Figure 1. Non-sales company investment + operating cost benefit chart
2.1.1. The income model of non-sales company investment + operating
The income of non-sale company investment and operating is shown in equations (1)-(2):

\[ R_{1,y} = R_{1,y}^{\text{trans}} + R_{1,y}^{\text{gua}} + R_{1,y}^{\text{cap}} + R_{1,y}^{\text{trac}} + R_{1,y}^{\text{gene}} + R_{1,y}^{\text{green}} + R_{1,y}^{\text{CCER}} \]  

\[ R_{1,y} = \sum_{d=1}^{365} \sum_{t=1}^{24} (\theta_{1,t,d}^{PV} Q_{1,t,d}^{PV} + \theta_{1,t,d}^{\text{wind}} Q_{1,t,d}^{\text{wind}} + \theta_{1,t,d}^{\text{bio}} Q_{1,t,d}^{\text{bio}}) \]  

Where, \( R_{1,y} \) is the total income of non-sale company investment and operating model in year \( y \); \( R_{1,y}^{\text{trans}}, R_{1,y}^{\text{gua}}, R_{1,y}^{\text{cap}}, R_{1,y}^{\text{trac}}, R_{1,y}^{\text{gene}}, R_{1,y}^{\text{green}}, R_{1,y}^{\text{CCER}} \) is the transmission and distribution fee, guaranteed power supply fee, distribution network capacity fee, medium and long-term power transaction contract revenue, new energy power generation subsidy, new energy green card subsidy income, CCER transfer discount carbon emission allowance income obtained by non-sale company investment and operating model in year \( y \); \( Q_{1,t,d}^{\text{trans}} \) is the incremental distribution network transmission and distribution capacity, the guaranteed power supply to users, the contracted electricity with the electricity sales company, the number of green certificates sold by the incremental distribution network, and the carbon emission allowances sold at the time of \( t \) on day \( d \).  

2.1.2. The cost model of non-sales company investment + operating
The cost of non-sales company investment + operating is as follows:

\[ C_{1,y} = C_{1,y,\text{cons}} + C_{1,y,\text{opec}} + C_{1,y,\text{loss}} + C_{1,y,\text{gen}} + C_{1,y,\text{trac}} \]  

\[ C_{1,y,\text{cons}} = C_{\text{ins}} + C_{\text{pur}} + C_{\text{extra}} + C_{\text{dyn}} \]  

\[ C_{1,y,\text{opec}} = C_{\text{ope}} + C_{\text{mc}} + C_{\text{pf}} + T_{\text{e}} + C_{\text{oe}} \]  

\[ C_{1,y,\text{loss}} = C_{\text{uf}} + C_{\text{run}} + C_{\text{dp}} \]  

\[ C_{1,y,\text{gen}} = \sum_{d=1}^{24} \sum_{t=1}^{24} (w_{1,t,d}^{PV} Q_{1,t,d}^{PV} + w_{1,t,d}^{\text{wind}} Q_{1,t,d}^{\text{wind}} + w_{1,t,d}^{\text{bio}} Q_{1,t,d}^{\text{bio}}) \]  

\[ C_{1,y,\text{trac}} = \sum_{d=1}^{365} \sum_{t=1}^{24} \phi_{1,t,d}^{\text{trans}} Q_{1,t,d}^{\text{trans}} \]  

Where, \( C_{1,y,\text{cons}}, C_{1,y,\text{opec}}, C_{1,y,\text{loss}}, C_{1,y,\text{gen}}, C_{1,y,\text{trac}} \) is the total cost, investment construction cost, operation cost, network loss cost, power generation cost, transaction cost of the non-sales company investment + operation cooperation model in the \( y \) year; \( C_{\text{ins}} \) is construction and installation engineering fees; \( C_{\text{pur}} \) is equipment purchase fee; \( C_{\text{extra}} \) is other fee; \( C_{\text{dyn}} \) is dynamic cost; \( C_{\text{ope}} \) is operating costs; \( C_{\text{mc}} \) is maintenance cost; \( C_{\text{pf}} \) is power outages and loss costs; \( C_{\text{uf}} \) is transformer loss cost; \( C_{\text{run}} \) is operating loss cost; \( C_{\text{dp}} \) is dispatch cost; \( w_{1,t,d}^{PV}, w_{1,t,d}^{\text{wind}}, w_{1,t,d}^{\text{bio}} \) is the unit power generation cost of photovoltaic units, wind turbines, and biomass energy units at the time of \( t \) on day \( d \); \( \phi_{1,t,d}^{\text{trans}} \) is the cost of a unit of electricity traded between the incremental distribution park and the electricity sales company.
2.2. **Sales company investment + operating cost-benefit model**

Sales company investment + operation means that the investment and operators of the incremental distribution network are carried out by the electricity sales company. Incremental distribution park can develop electricity sales and integrated energy supply business without additional agreements and contracts. At the same time, the incremental distribution park can also obtain corresponding income through demand response, and can also provide energy-saving services to users through big data. Therefore, in this scenario, the revenue sources of incremental distribution parks include transmission and distribution fees, guaranteed power supply fees, distribution network capacity fees, comprehensive energy service revenues, new energy power generation green card subsidy revenues, and CCER transfer credits. Deduction of carbon emission allowances, income from power demand response services and income from power value-added services. Corresponding costs include incremental distribution park investment construction costs, operating costs, network loss costs, power generation costs, comprehensive energy service costs, and the cost of providing value-added service benefits. As shown in Figure 2.

![Figure 2. Electricity sales company investment + operating cost-benefit chart](image)

2.2.1. **The income model of sales company investment + operating**

Under this mode of operation, comprehensive energy service income refers to the income obtained by incremental distribution parks providing users with cold, heat, electricity and gas. Value-added service revenue includes incremental distribution network parks to design energy-saving solutions for energy efficiency management for users through user energy consumption big data, centralized operation and maintenance services for user energy-using equipment, and the benefits of formulating various types of package services for users’ individual needs.
\[ R_{2,y} = R_{2,y}^{\text{trans}} + R_{2,y}^{\text{gas}} + R_{2,y}^{\text{ele}} + R_{2,y}^{\text{hot}} + R_{2,y}^{\text{cold}} + R_{2,y}^{\text{green}} + R_{2,y}^{\text{CCER}} + R_{2,y}^{\text{ies}} + R_{2,y}^{\text{vas}} \]  

(5)

\[
\begin{align*}
R_{\text{ies}}^{\text{y}} & = R_{\text{gas}, \text{inte}} + R_{\text{ele}, \text{inte}} + R_{\text{hot}, \text{inte}} + R_{\text{cold}, \text{inte}} + R_{\text{EES}, \text{inte}} \\
R_{\text{vas}}^{\text{y}} & = R_{\text{gas}, \text{y}} + R_{\text{ele}, \text{y}} + R_{\text{hot}, \text{y}} + R_{\text{cold}, \text{y}} + R_{\text{EES}, \text{y}}
\end{align*}
\]

(6)

Where, \( R_{2,y}, R_{2,y}^{\text{ies}}, R_{2,y}^{\text{vas}} \) the total income, comprehensive energy service income, and value-added service income obtained by the incremental distribution network in the \( y \) year of the investment and operation mode of the electricity sales company; \( R_{\text{ie}, \text{inte}}, Q, P, \) \( R_{\text{vas}, \text{y}}, R_{\text{ies}, \text{y}} \) is the total income, energy supply, and unit price of the \( i \)-th energy supply in the incremental distribution network park; \( R_{\text{ies}}^{\text{y}}, R_{\text{vas}}^{\text{y}} \) is the energy-saving service income, information service income, and personalized package service income obtained in the \( y \) year.

2.2.2. The cost model of sales company investment + operating

The investment cost, operating cost, network loss cost, and power generation cost of the electricity distribution company’s investment + incremental distribution network in the operation mode are calculated as shown in equation (4). The cost of integrated energy services and value-added services are as follows:

\[
\begin{align*}
C_{2,y} = C_{2,y,\text{cost}} + C_{2,y,\text{opex}} + C_{2,y,\text{loss}} + C_{2,y,\text{gen}} + C_{2,y,\text{ies}} + C_{2,y,\text{vas}}
\end{align*}
\]

(7)

\[
\begin{align*}
C_{2,y,\text{ies}} = C_{\text{gas}, \text{inte}} + C_{\text{ele}, \text{inte}} + C_{\text{hot}, \text{inte}} + C_{\text{cold}, \text{inte}} + C_{\text{EES}, \text{inte}} \\
C_{2,y,\text{vas}} = C_{2,y,\text{vas}} + C_{2,y,\text{indiv}}
\end{align*}
\]

(8)

Where, \( C_{2,y}, C_{2,y,\text{ies}}, C_{2,y,\text{vas}} \) is the total cost, integrated energy service cost, and value-added service cost of the incremental distribution network park in the \( y \) year of the investment and operation of the electricity sales company; \( C_{\text{ie}, \text{inte}} \) is the total cost of the energy source \( i \).

2.3. Non-sales company investment + electricity sales company operating cost-benefit model

Non-sales company investment + electricity sales company operation refers to the investment and construction of the incremental distribution network park without electricity sales company participated, but the operation of the incremental distribution network park is entrusted to the electricity sales company. Therefore, the income source of the incremental distribution park under this model is the same as the electricity sales company's simultaneous investment and operation, including transmission and distribution fees, guaranteed power supply fees, distribution network capacity fees, comprehensive energy service income, and new energy power generation green card subsidy income, CCER transfer deduction of carbon emission allowances, electricity demand response service income and electricity value-added service income. However, the cost is higher than the electricity sales company's investment + operation model. Shown in Figure 3:
2.3.1. The income model of non-sales company investment + electricity sales company operating

The income of non-sales company investment + electricity sales company operating is as follows:

\[ R_{3,y} = R_{3,y}^{\text{trans}} + R_{3,y}^{\text{gua}} + R_{3,y}^{\text{cap}} + R_{3,y}^{\text{dr}} + R_{3,y}^{\text{gene}} + R_{3,y}^{\text{ies}} + R_{3,y}^{\text{vas}} + R_{3,y}^{\text{agent}} \]  

Where, \( R_{3,y}^{\text{trans}} \), \( R_{3,y}^{\text{gua}} \), \( R_{3,y}^{\text{cap}} \), \( R_{3,y}^{\text{dr}} \), \( R_{3,y}^{\text{gene}} \), \( R_{3,y}^{\text{ies}} \), \( R_{3,y}^{\text{vas}} \), \( R_{3,y}^{\text{agent}} \) is the total revenue, transmission and distribution fees, guaranteed power supply fees, distribution network capacity fees, demand response service revenues, new energy power generation subsidies, new energy generation green card subsidy income, CCER transfer deduction carbon emission allowance income, comprehensive energy service income, value-added service income which the incremental distribution network park select the electricity sales company's investment and operation model obtained in \( y \) years.

2.3.2. The cost model of non-sales company investment + electricity sales company operating

The cost of non-sales company investment + electricity sales company operating is as follows:

\[ C_{3,y} = C_{3,y,\text{cons}} + C_{3,y,\text{oper}} + C_{3,y,\text{loss}} + C_{3,y,\text{gen}} + C_{3,y,\text{ies}} + C_{3,y,\text{vas}} + C_{3,y,\text{agent}} \]  

Where, \( C_{3,y,\text{cons}} \), \( C_{3,y,\text{oper}} \), \( C_{3,y,\text{loss}} \), \( C_{3,y,\text{gen}} \), \( C_{3,y,\text{ies}} \), \( C_{3,y,\text{vas}} \), \( C_{3,y,\text{agent}} \) is the investment construction cost, operating cost, network loss cost, power generation, comprehensive energy service cost, value-added service cost and agency cost of the incremental distribution network park invested by non-sales company investment + electricity sales company operating model in \( y \) year.
3. Economic evaluation model of incremental distribution network with different operating models

3.1. net present value

The net present value is the sum of the present value of the project’s net income during the project calculation period converted to the initial stage of the project using the discount rate. The net present value \( NPV_{inc} \) of the incremental distribution network is shown in formula (11):

\[
NPV_{inc} = \sum_{y=1}^{N} (R_{i,y} - C_{i,y})(1 + r)^{-y}
\]  

(11)

Where, \( r \) is the benchmark discount rate; If \( NPV_{inc} > 0 \) and a large value is reached, it indicates that the economic benefits of distribution network operation are good; otherwise, the economic benefits of operation are poor.

3.2. Dynamic payback period

Assuming that the cumulative net present value from year \( y_0 \) is greater than zero, the calculation method of the dynamic investment payback period is shown in equation (12). The numerator represents the absolute value of the cumulative net present value in year \( y_0-1 \), and the denominator represents the net present value in year \( y_0 \).

\[
Y_{pp} = y_0 - 1 + \sum_{y=1}^{y_0-1} (R_{i,y} - C_{i,y})(1 + r)^{-y} / (R_{i,y_0} - C_{i,y_0})(1 + r)^{-y_0}
\]

(12)

The benchmark investment payback period is a reasonable investment payback period of the project under normal circumstances, which is calculated by the industry or department according to many years of practice, and can be used as a reference for calculating the investment payback period. Assuming that the benchmark investment recovery period of the incremental distribution network project is \( Y_b \), if \( Y_{pp} \leq Y_b \), it means that the project can recover the investment within the required time, otherwise it is feasible.

3.3. Net Present Value Rate

The net present value rate reflects the profitability of unit investment, and the net present value rate \( \alpha_{NPVR} \) of the incremental distribution network is calculated by the following formula. The numerator represents the net present value of the project, and the denominator represents the present value of the project's full-caliber cost, including investment cost, operation and maintenance cost, power purchase cost and network loss cost. The greater the net present value rate, the higher the return on unit investment.

\[
\alpha_{NPVR} = \frac{NPV_{inc}}{\sum_{y=1}^{N} C_{i,y}}
\]

(13)

4. Example analysis

4.1. Basic data

Taking an incremental distribution network park as an example, it is assumed that the investment construction and operation period of the incremental distribution park is 20 years. The park's installed wind power capacity is 6 MW, and the total rooftop photovoltaic construction capacity is 20 MWp. It is assumed that the subsidies for wind power and photovoltaics are 0.05 $ / kWh, and the subsidies for biomass power generation are 0.02 $ / kWh. The unit energy supply prices of various types of energy in the park are shown in Figure 4:
4.2. Example results

4.2.1. Profit analysis of various operating models

The benchmark discount rate of the power industry is set at 10%, and the benchmark investment payback period is 12 years. The cost-benefit results in the above three scenarios are shown in Figure 5:

It can be seen from Figure 5 that the incremental distribution network park revenues of various types of operation models in the first three years are all less than 0, which shows that the incremental distribution network parks in the previous three years are in the stage of investment and construction, and have not yet provided services to users of the park to obtain income. From the fourth year onwards, the incremental distribution park revenue for all types of operating models is greater than zero. It can also be seen that the annual revenue ranking of each type of operation model is the sales company investment + operating > the income of non-sales company investment + electricity sales company operating > the income of non-sales company investment + operating. Taking the 20th year of operation as an example, the income of the sales company investment + operating is 59088.40 ten thousand dollars > the income of the non-sales company investment + electricity sales company operating.
operating is 49605.09 ten thousand dollars > the income of the non-sales company investment + operating is 41473.89 ten thousand dollars. Because compared with the incremental distribution park operated by non-sales companies, sales company operating can provide comprehensive energy services and various types of value-added services, expand incremental distribution network park business types, and increase revenue channels. On the other hand, compared with the incremental distribution network park constructed by non-sales companies, the incremental distribution network park constructed by electricity sales companies can save costs and agency fees incurred during the transaction of electricity. Therefore the incremental distribution network has higher returns.

4.2.2. Economic evaluation results analysis of various types of operation models
Through formulas (11)-(13), the economic evaluation results of incremental distribution parks under various operating modes are shown in Table 1:

| Operating Model | Net Present Value (ten thousand dollars) | Dynamic Payback Period (year) | Net Present Value Rate (%) |
|----------------|----------------------------------------|-------------------------------|---------------------------|
| Non-sales company investment + operating | 67451.55 | 11.22 | 146.94% |
| Sales company investment + operating | 98424.33 | 10.22 | 231.31% |
| Non-sales company investment + electricity sales company operating | 80606.07 | 10.87 | 175.59% |

It can be seen from Table 1 that from the perspective of net present value, the sales company investment + operating model is 98424.33 ten thousand dollars > the non-sales company investment + electricity sales company operating model is 80606.07 ten thousand dollars > the non-sales company investment + operating model is 67451.55 ten thousand dollars. It shows that the incremental distribution park has good economic benefits under sales company investment + operating model. From the perspective of dynamic investment recovery period, three models are less than 12 years, which is less than the benchmark investment recovery period, indicating that three operating models can recover investment within the benchmark period. The shortest dynamic payback period is the model of sales company investment + operating, about 10.22 years; The longest dynamic payback period is the model of non-sales company investment + operating, about 11.22 years. The highest net present value rate is the model of sales company investment + operating, about 23.31%, indicating that the unit investment income under this model is high.

Compared with other models, the model of sales company investment + operating has higher economic benefits, a shorter investment payback period, and higher unit investment income. Because, on the one hand, providing integrated energy services can fully mobilize the demand-side resources, achieve mutual benefits and win-win results for both sides, and expand the source of incremental distribution network revenue. On the other hand, incremental distribution parks provide users with value-added services, and designing personalized packages can also increase the income of incremental distribution parks.

5. conclusion
This paper presents the cost-benefit model of incremental distribution network under three different operation modes, and evaluates the three operation modes with economic indicators. Finally, a certain incremental distribution network park is used for example analysis to analyze the cost-benefit results and economic evaluation results of various types of operation models. The results shows that the model of sales company investment + operating has higher economic benefits, shorter investment payback period, and higher unit investment income. Because it can stimulate innovation and expand the source of income.
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