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Economic Analysis of Generation and Distribution Integrated System with High Penetration Distributed Generation

Junxian Li¹, Xuenan Li², Wenjun Cheng¹, Cunqiang Huang¹ and Wei Wang²

¹State Grid Qinghai Electric Power Company Economic Research Institute, Xining, China

²Tsinghua University Sichuan Energy Internet Research Institute, Chengdu, China

E-mail: hhbibl@163.com

Abstract. With the rapid development of distributed generation and advancement of power system, the integration of generation and distribution becomes an important operation mode in the future and distributed generation helps to improve the economy of incremental distribution. This paper quantifies the main cost-benefit of generation and distribution integrated system, then proposes an economic analysis method of the distribution integration system, which takes into account the transformation of power grid caused by high penetration distributed generation. Based on the analysis of typical scenarios, the conclusions can provide guidance for the planning and operating of generation and distribution integrated system.

1. Introduction

As a clean and efficient mean of energy utilization, distributed generation is an important way to promote the energy revolution and non-fossil energy development. It has been supported by national government and entered the stage of large-scale development. In the recent reform, the development of distributed generation and the opening of incremental distribution are closely integrated, allowing incremental distribution to invest in distributed generation and forming a generation and distribution integrated system. Generation and distribution integrated system will become an important operation mode of incremental distribution in the future, and will have a profound impact on the development of distributed generation.

Distributed generation can help to reduce transmission and distribution network losses, delay grid transformation and reduce the costs of electricity purchase from the upper grid. However, compared with low penetration, high penetration distributed generation may also bring additional costs by grid transformation and power curtailment. Therefore, the economic analysis of generation and distribution integrated system needs to consider various factors, which can provide guidance for the optimal planning and operating of high penetration distributed generation[1][2].

An analysis method of cost-benefit composition and quantification for generation and distribution integrated system is proposed in this paper. Then a typical case of high penetration distributed photovoltaic is analyzed and some viewpoints to promote the coordinated development of high penetration distributed photovoltaic and power grid are put forward.

2. Composition and Quantification of the Economy in Generation and Distribution Integrated System



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Generally speaking, the economic factors in generation and distribution integrated system mainly includes the costs of initial investment, maintenance, power purchase, power grid upgrading, as well as the benefit of generation subsidy and sales income.

2.1. Costs and quantification

2.1.1. Initial investment costs. The initial investment costs of generation and distribution integrated system mainly includes the costs of distributed generation projects and distribution network. The DG component, inverter, network integration equipment, as well as infrastructure costs such as roof brackets and leak-proof treatment, are included in the distributed generation project costs. While the distribution network costs are composed of power line, transformer and secondary equipment such as relay protection, as well as the construction costs.

The distributed generation project and distribution network costs can be both expressed by the product form of installed capacity or network capacity and unit capacity costs, as shown in figure (1).

$$C_g = \sum_{i=1}^n C_{kw_i} P_i + C_{netkw} P_{net} \quad (1)$$

Where, C_g is the total initial investment costs. C_{netkw} is the distribution network average costs of per unit capacity. P_{net} is the rated capacity of distribution network. C_{kw_i} is the i^{th} distributed generation project costs of per unit capacity. P_i is the i^{th} distributed generation project capacity. n is the number of distributed generation projects.

2.1.2. Maintenance costs. Distributed generation projects and distribution network need to be maintained. It brings the corresponding costs, which is usually estimated according to a certain proportion of investment costs.

$$C_{om} = \sum_{i=1}^n C_{kw_i} P_i K_{omi} + C_{netkw} P_{net} K_r \quad (2)$$

Where, C_{om} is the total maintenance costs. K_{omi} is the ratio of maintenance costs to investment costs for i^{th} distributed generation project costs of per unit capacity. K_r is the ratio of maintenance costs to investment costs for distribution network.

2.1.3. Costs of power purchase. In addition to utilizing its own distributed generation, the generation and distribution integrated system also needs to purchase electricity from the upper power grid to meet the demand of local users. According to the current incremental distribution management, it is necessary to pay capacity and electricity costs to the upper power grid.

$$C_{buy} = C_{netkw} P_{cap} + E_{buy} P_{buy} \quad (3)$$

Where, C_{buy} is the costs of power purchase. P_{cap} is the per unit capacity reserve costs in distribution network. E_{buy} is the electricity purchased from the upper grid, and P_{buy} is the corresponding per unit electricity costs.

2.1.4. Costs of power grid upgrading caused by high penetration of distributed generation. High penetration integration of distributed generation may lead to over-voltage, equipment overload and short-circuit current exceeding the limit. It is necessary to upgrade the power grid, which resulting in the corresponding costs[3]-[6]. At present, distributed generation mainly uses renewable resource. So the upgrading of power lines and transformers are mainly concerned, ignoring the short-circuit current problem caused by distributed natural gas generation.

$$C_r = \sum_{i=1}^m C_{km_i} L_i R_i \quad (4)$$

Where, C_r is the upgrading costs of power grid. C_{km_i} is the costs of per unit length(capacity) for power lines (transformers). L_i is the length(capacity) of the i^{th} power line(transformer). R_i indicates whether the i^{th} equipment needs to be upgraded, with 1 for need and 0 for not. m is the equipment number in the power grid.

2.2. Income and quantification

2.2.1. Generation subsidy. The subsidy of distributed generation can be expressed as the product of power generation and unit electricity subsidy. Generally, distributed generation is not curtailed, but it might happen when the penetration is high enough[7]. The wind and photovoltaic power curtailment cannot be subsidized. So the subsidy should be calculated based on the annual electricity by distributed generation.

$$B_t = \sum_{t=1}^{8760} \sum_{i=1}^n EG_{i,t} \cdot PG_t \quad (5)$$

Where, B_t is the income of generation subsidy. $EG_{i,t}$ is the actual generation at time t by DG_i . PG_t is the unit power subsidy.

2.2.2. Sales income. The self-generating power by distributed generation and the power purchased from the upper power grid, are sold to the users by generation and distribution integrated system.

$$B_s = \sum_{t=1}^{8760} \sum_{i=1}^n EL_{i,t} \cdot PL_{i,t} \quad (6)$$

Where, B_s is the income of electricity sales. $EL_{i,t}$ and $PL_{i,t}$ are the electricity consumption and price of user i at time t .

3. Comprehensive Economic Calculation of Generation and distribution integrated system

Considering the costs and income analysis of generation and distribution integrated system mentioned above, the comprehensive economy with high penetration distributed generation is as follows:

$$C_{CF} = B_t + B_s - C_g - C_{om} - C_{buy} - C_r \quad (7)$$

Where, C_{CF} is the total benefit of generation and distribution integrated system.

Considering that the benefit is related to the operation status of power grid, the calculation of benefit in this paper is based on the annual operation status of 8760 hours.

4. Case Study on Optimal Planning of High Penetration Photovoltaic

4.1. Case

A rural area in northern China is selected as a typical case. There are 4 public distribution transformers in the village, located in south, east, northeast and interior. They are named T1, T2, T3 and T4 respectively. The total capacity of the transformers is (3×100+200) kVA. There are more than 160 households in the village. 102 of them are suitable for installing photovoltaic generation system. The number of households that can install photovoltaic generation system for each transformer is 3, 33, 24 and 42. Limited by space, only the network structure and suitable location of T2 and T3 are given as follows.

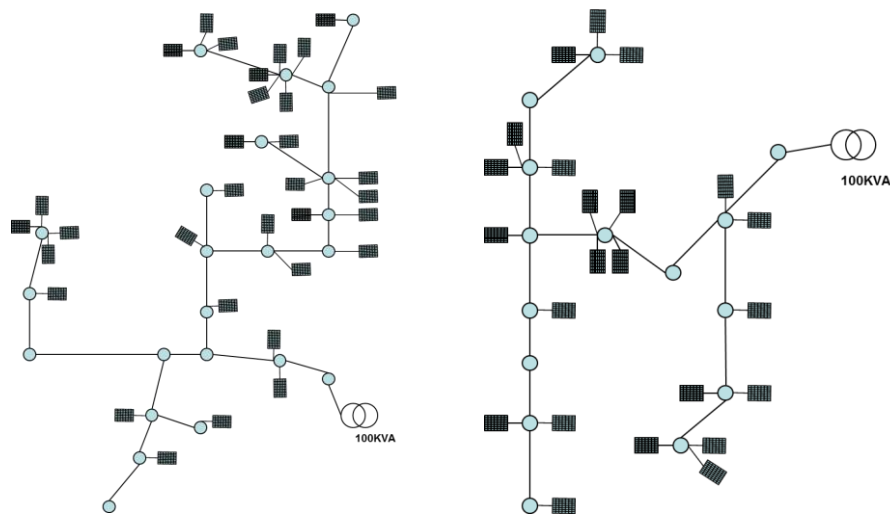


Figure 1. Network structure and suitable location of T2 and T3

4.2. Scenarios

In these scenarios, 60 photovoltaic generation systems are installed on the roof of 102 households, with each system 3 kW. The optimization goal is to obtain the best cost-benefit.

Considering the difference of location, capacity, power grid and curtailment policy, the typical scenarios are proposed as follows. Taking into account the only 3 households connected to south village transformer, they have the installation priority because there is no possibility of overvoltage.

Scenario 1: Distributed photovoltaic is preferentially connected to T1, T3 and T4, while the remaining is connected to the T2.

Scenario 2: Distributed photovoltaic is preferentially connected to T1, T2 and T4, while the remaining is connected to the T3.

Scenario 3: Distributed photovoltaic is preferentially connected to T1, T2 and T3, while the remaining is connected to the T4.

Scenario 4: Distributed photovoltaic is optimally connected to the 4 transformers to avoid overvoltage and overcurrent as far as possible.

4.3. Results Analysis

The economic analysis of various scenarios in the village is carried out, and the results are shown in table 1. The data in table 1 are annualized, with the unit of 10,000 yuan.

Table 1. Annual cost-benefit in different scenarios (unit of 10,000 yuan)

Scenarios	Generation Subsidy	Sales Income	Investment Costs	Maintenance Costs	Power Upgrading Costs	Power Purchase Costs	Total Profit
Without PV	0	36.4	3.17	1.0	0	35.25	-2.99
Scenario 1	5.77	36.4	8.57	3.7	0.66	26.68	2.6
Scenario 2	5.79	36.4	8.57	3.7	0	26.57	3.39
Scenario 3	5.94	36.4	8.57	3.7	1.94	26.33	1.83
Scenario 4	5.81	36.4	8.57	3.7	0	26.53	3.44

Based on the above results, the conclusions can be obtained as shown below:

(1) The benefit of generation and distribution integrated system is higher than distribution. Through the construction of distributed generation, the subsidized income can be obtained. Meanwhile the costs of power purchase and the loss of transmission and distribution can be reduced.

(2) The optimal layout of distributed photovoltaic has a great impact on the economy, which needs to be paid more attention in the actual implementation. Under different scenarios, the annual benefit has a maximum difference of nearly 50%. In scenario 4, distributed photovoltaic is integrated into four transformers in the whole village, which is matched with power grid and load and obtains the best costs-benefit.

(3) In the case of a small proportion curtailment, no power grid upgrading is needed for economy improvement.

5. Conclusion

There are few researches on generation and distribution integrated system. And most of the works do not consider the costs of power grid upgrading caused by high penetration distributed generation integration. Based on the benefit composition and quantification of cost-benefit for generation and distribution integrated system, a benefit calculation method is proposed in this paper, considering high penetration distributed generation. Then it is verified by a practical case. The results show that economy of the integrated system can be improved through the planning and operating optimization of distributed generation.

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