Comprehensive Benefit Analysis of Distributed Power Grid Connection

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Abstract. Distributed generation can not only improve the utilization level of energy, but also bring huge economic and environmental benefits, which is conducive to the sustainable development of economy and society [1]. With the expansion of distributed generation scale and the implementation of market-oriented trading pilot, it is necessary to accurately evaluate and analyze the economic and environmental benefits of distributed generation, so it is necessary to establish an accurate evaluation model to guide grid companies and government departments to better develop and utilize distributed generation technology. As a whole, the connection between distributed generation and large power grid is helpful to save investment, reduce energy loss and give full play to their respective advantages. From the perspective of distributed generation project, it is helpful for investors to construct cost, invest reasonably and quote accurately. The benefits of distributed generation access to power grid mainly include reducing line loss, reducing power construction cost, reducing electricity price, delaying the construction of distribution and transmission cost, and improving environment and climate.

1. Introduction
With the continuous advancement of China’s power system, a large number of distributed power sources are connected to the large power grid. Distributed power sources have the advantages of low cost, flexible power generation, environmental friendliness and so on. Its comprehensive benefits of grid connection are reflected in many aspects. Through the research on the comprehensive benefits of distributed power sources, we can choose distributed power sources for investment and construction. Through the study of distribution network planning with distributed power and the systematic evaluation of its impact after grid connection, and we can make full use of limited energy, ensure the safety and stability of power system operation, and reduce the impact of distributed power on distribution network planning. Therefore, it is of great significance to study the comprehensive benefits of distributed generation and the distribution network planning including distributed generation.

Reference [1] describes the cost and application of several common distributed power sources at present, and analyzes the environmental benefits of grid connection of distributed power sources. According to the cost-benefit theory, the reference [2] discusses the investment cost, environmental cost, network loss benefit and comprehensive benefit of the grid connection of distributed generation, but lacks the relevant benefit evaluation index and quantitative analysis. Reference [7] establishes the cost-benefit analysis model of investment and construction of distributed power generation, puts
forward the corresponding quantitative indicators, and analyzes the benefits of distributed power generation in improving the reliability of power supply, saving energy, reducing line loss, optimizing the investment and construction of power transmission and distribution.

2. Research and significance of grid connection of distributed generation

DG can operate independently with large power grid and directly provide power for users. Distributed power generation equipment includes small internal combustion engine, energy storage equipment, wind power generation, photovoltaic power generation, gas turbine, small and medium-sized hydropower generation, marine energy generation, biomass energy generation, etc. In addition, through the study of the comprehensive benefits of the grid connected distributed power, we can choose the distributed power for investment and construction. Through the study of distribution network planning with distributed power and the systematic evaluation of its impact after grid connection, we can make full use of limited energy, ensure the safety and stability of power system operation, and reduce the impact of distributed power on distribution network planning. Therefore, it is of great significance to study the comprehensive benefits of grid connected distributed generation and the distribution network planning including distributed generation.

3. Economy of grid connection of distributed generation

Distributed generation can not only improve the utilization level of energy, but also bring huge economic and environmental benefits contribute to the realization of sustainable economic and social development [2]. With the expansion of distributed generation scale and market-oriented trading trial. The implementation of the point requires accurate evaluation and analysis of the economic and environmental benefits of distributed generation, so it is necessary to establish a standard. The accurate evaluation model can guide grid companies and government departments to better develop and utilize distributed generation technology. From whole in general, the connection between distributed generation and large power grid helps to save investment, reduce energy consumption and give full play to the energy consumption. From the perspective of distributed generation project, it is helpful for investors to build cost and rationality investment and accurate quotation. The benefits of distributed generation connected to power grid mainly lie in reducing line loss and electricity source construction cost, reducing electricity price, delaying the construction of distribution and transmission cost and improving environment and climate.

3.1. Electricity price benefit

DG power grid will affect the user's electricity purchase cost. After a large number of DG are connected to the distribution network, the power users' demand for electricity in the traditional power supply mode will be reduced to a certain extent, and the dependence on the traditional power supply mode will be reduced accordingly. Environmental benefits

With the increasingly serious environmental pollution caused by the use of traditional fossil energy, especially the frequent occurrence of ecological and environmental problems such as large-scale haze outbreak caused by the limitation of coal based resource endowment in China, the adjustment and optimization of energy structure and the efficient use of energy sources have become the basic issues for the sustainable development of society. As a clean and efficient new energy utilization technology, distributed energy has attracted more and more attention in many aspects; the combination of distributed energy and large power grid is also considered by many experts and scholars at home and abroad as the main way to reduce energy consumption and improve the reliability and flexibility of power system, which is an important direction in the development of the world energy industry and the future power market. It is also one of the future development directions of China's electric power industry.

At present, the indicators to measure the harm of energy consumption to environmental pollution can be divided into two categories: one is the annual emissions of SO2, NO2, CO, PM10 and other pollutants caused by energy consumption and the other is the annual emissions of CO2, CH4, N2O.
and other greenhouse gases that cause climate warming due to energy consumption [3].

The environmental values of main pollutants such as SO2, NOx, CO2 and CO and slag are given in Table 2. The installation investment cost and unit energy fuel cost of various power generation modes are shown in Table 1 [4]; the maximum value of each cost is taken in the range, and the operation and maintenance cost is 0.01 $/kWh.

Table 1. Installation cost and fuel cost per unit energy of common power generation methods.

| Type of generation          | Installation investment costs/($) | Electricity cost/($) |
|-----------------------------|-----------------------------------|----------------------|
| Coal fired power generation | 100–200                           | 0.045                |
| Internal combustion unit    | 200–800                           | 0.060                |
| Gas turbine                 | 1000–1500                         | 0.080                |
| Fuel cell                   | 3000–4000                         | 0.125                |
| Wind turbine                | 1000–1500                         | 0                   |
| Photo-voltaic cell          | 1500–6000                         | 0                   |

Table 2. Environmental value of main pollutants.

| Contaminants | CO | CO2 | SO2 | NOx, TSP | Slag |
|--------------|----|-----|-----|---------|------|
| Environmental value ($/kg) | 0.130 | 0.003 | 0.690 | 1.100 | 0.280 | 0.02 |

\[
C_h = \frac{r (1+r)^n}{(1+r)^n - 1} \cdot \frac{C_{az}}{87.6k} + C_{om} + C_f + C_e
\]

\[
C_e = \sum_{i=1}^{h} (V_i \cdot Q_i)
\]

In the above formula, \(K\) is the average capacity coefficient; \(n\) is the investment repayment period; \(C_{om}\) is the operation and maintenance cost; \(C_{az}\) is the installation cost; \(r\) is the fixed annual interest rate; \(C_f\) is the fuel cost per unit of electricity; \(C_e\) is the environmental cost; \(h\) is the number of pollutant types; \(Q\) is the unit emission of pollutants.

According to the data in the table, combined with the calculation formula 1 and 2 of power generation cost; the total cost of unit power of different types of power generation can be calculated after considering the environmental benefits, which is listed in Table 3. It can be seen that distributed power generation has the advantages of environmental protection, which can save a lot of power generation cost while being environmentally friendly.

Table 3. Total cost per unit of electricity after considering environmental benefits for common power generation methods.

| Type of generation          | Total cost per unit of electricity ($/kWh) |
|-----------------------------|------------------------------------------|
| Internal combustion unit    | 0.196                                    |
| Micro gas turbine           | 0.180                                    |
| Fuel cell                   | 0.137                                    |
| Photo-voltaic cell          | 0.143                                    |
| Wind turbine                | 0.120                                    |
| Coal fired power generation | 0.249                                    |

4. Reliability analysis of grid connection of distributed generation

4.1. Impact on relay protection

The traditional centralized power supply mode makes the distribution network mainly a radiation
network structure, and its distributed power flow presents single-phase liquidity, so its protection mode is relatively easy to achieve [5]. Three section current protection includes instantaneous current quick break protection, definite time current quick break protection and over-current protection. These three protection methods are applicable to the current power grid structure. When the distributed power generation is connected: The connection mode of the power grid and the system operation mode, especially the power flow distribution, have changed the current protection mode accordingly[6]. The influence of DG access to the distribution network on line protection is mainly reflected in the following aspects: different capacity and location of DG access to the distribution network will have different degrees of impact on the power flow of the distribution network system, and the size and direction of the power flow will change; when the system fails, the size and direction of the power flow of the system will also be different from the current distribution network; therefore, the fault protection of DG connected distribution network will be more complex. The location and capacity of DG need to be considered When connected to the middle or the end of the distribution network and it is likely to cause the protection misoperation under non fault conditions, or the failure to act in time in case of fault, resulting in the protection selectivity and sensitivity of the distribution network can not meet the requirements, or even expand the scope of fault hazards. Taking inverse time overcurrent protection as an example, it is a protection mode that the protection action time is related to the fault current of the fault line. For the distribution network connected by distributed power sources, the fault current of the fault line may become smaller, thus prolonging the fault protection time and reducing the timeliness and selectivity of the fault protection action [7].

5. Simulation example

5.1. Internet fee
According to the supplementary notice on carrying out the pilot market-oriented transaction of distributed generation issued by the national development and Reform Commission and the National Energy Administration in December 2017, it can be calculated that the transmission and distribution price of the highest voltage level involved in the market-oriented transaction of distributed generation, which is the transmission and distribution price corresponding to the voltage level of power users before verification. According to the provincial transmission and distribution price table in the notice of ZheJiang Provincial Price Bureau on the transmission and distribution price of AnHui provincial grid in 2017-2019, we can determine the "network fee" for each voltage level: the network fee for the photovoltaic project connected to 110kV is 0.035 yuan, and the network fee for the photovoltaic project connected to 35kV is 0.03 yuan.

5.2. Example transaction subject
For the power generation enterprises in the transaction subject, they should choose the power generation enterprises that meet the scale of distributed market-oriented transaction. Among the wind power enterprises, Jiangsu Sansi wind power plant and Sinovel wind power plant meet the requirements, and photovoltaic enterprises meet the requirements of the combined network. The new energy project and yueyangguang photovoltaic power generation project in Huzhou, Zhejiang Province are selected as representatives. For the users in the transaction subject, because the retail market is only open to industrial and commercial users at present, the representative industrial and commercial users with certain power consumption in the region are selected as the transaction object. Generally speaking, industrial and commercial users should have good credit status, independent legal personality, and be able to settle accounts independently in terms of finance.

5.3. Transaction example
Distributed generation companies directly trade with power users and match with both parties to form a transaction price. Finally, the electricity price of DG includes three parts: charging electricity from users, paying grid fees to the grid and government subsidies for electricity consumption. The matching
price between distributed generation companies and customers can be obtained through centralized bidding on the trading platform. According to the supplementary notice on launching the pilot market-oriented transaction of distributed generation issued by the national development and Reform Commission and the national energy administration and the government subsidy shall be reduced by at least 10% for the generation scale not exceeding 20MW, 20% for the generation scale between 20MW and 50MW, and the final subsidy shall be about 0.25 yuan [9].

In the simulation, the above-mentioned four distributed generation parties and six large users are selected to simulate. In the transaction process, the centralized matching transaction is selected on the transaction platform. Under this transaction mode, the distributed generation company reports the electricity price and electricity sales, and the user reports the electricity price and electricity purchase. The transaction platform matches the transactions between the distributed generation company and the user according to the reported situation, and develops and implements the scheduling plan.

Taking the current electricity price in Jiangsu and Zhejiang as an example, the average daily sales price of large industrial users is 0.7 yuan / kWh, and the average daily sales price of general industrial and commercial users is 0.75 yuan / kWh; the average daily sales price of general industrial and commercial users is 0.85 yuan / kWh, and the average sales price of peak electricity is 0.9 yuan / kWh. (the above data is from the notice on reducing general industrial and commercial electricity price issued by the national development and Reform Commission in 2019, taking the average value of Zhejiang and Jiangsu provinces.). Table 4 shows the declared electricity price and quantity of each distributed power producer and user.

### Table 4. Electricity price and quantity declared by DG and customers.

| Number | Distributed generators     | Sale price (yuan / kWh) | Electricity sales (10000 KWH) | Large users | Purchase price (yuan / kWh) | Power purchase (10000 KWH) |
|--------|---------------------------|-------------------------|-------------------------------|-------------|-----------------------------|-----------------------------|
| 1      | Zhejiang Huzhou new energy | 0.453                   | 1.9                           | a           | 0.533                       | 2.5                         |
| 2      | Yueyang photovoltaic      | 0.417                   | 2.4                           | b           | 0.543                       | 1.9                         |
| 3      | Jiangsu Sansi wind power  | 0.518                   | 4.9                           | c           | 0.535                       | 2.7                         |
| 4      | Huarui wind power         | 0.509                   | 4.4                           | d           | 0.530                       | 1.8                         |
| 5      | e                         |                         |                               |             | 0.538                       | 2.9                         |
| 6      | f                         |                         |                               |             | 0.524                       | 2.3                         |

As for the trading results, the matching results of the electric power trading platform adjusted through the centralized transaction matching are shown in table 5 and 6.

### Table 5. Matching results of distributed generators and users.

| Number | Distributed generators     | Sale price (yuan / kWh) | Electricity sales (10000 KWH) | Large users | Purchase price (yuan / kWh) | Power purchase (10000 KWH) |
|--------|---------------------------|-------------------------|-------------------------------|-------------|-----------------------------|-----------------------------|
| 1      | Zhejiang Huzhou new energy | 0.453                   | 1.9                           | b           | 0.543                       | 1.9                         |
| 2      | Yueyang photovoltaic      | 0.417                   | 2.4                           | e           | 0.538                       | 2.8                         |
| 3      | Jiangsu Sansi wind power  | 0.509                   | 4.4                           | c           | 0.535                       | 2.7                         |
According to the above transaction, the user's electricity cost and saved electricity fee can be calculated, as shown in table 7.

| Number | Large users | Electricity cost (yuan / kWh) | Electricity saving (10000 yuan) |
|--------|-------------|-------------------------------|---------------------------------|
| 1      | a           | 0.533                         | (0.7-0.533) x 2.5 = 0.4175     |
| 2      | b           | 0.543                         | (0.7-0.543) x 1.9 = 0.2983     |
| 3      | c           | 0.535                         | (0.7-0.535) x 2.7 = 0.4455     |
| 4      | d           | 0.530                         | (0.7-0.530) x 1.8 = 0.306      |
| 5      | e           | 0.538                         | (0.7-0.538) x 2.8 = 0.4536     |
| 6      | f           | 0.524                         | (0.7-0.524) x 1.5 = 0.264      |

From the above data, it is not difficult to see that the electricity purchase price formed by centralized bidding is lower than the electricity price set by the government according to the region, so that the power users can save a lot of costs, and the user benefits are guaranteed. Apparently, for power producers, including government subsidies and network fees, their profits have increased accordingly, as shown in table 4.5.

| Number | Distributed generators | Selling price (yuan / kWh) |
|--------|------------------------|----------------------------|
| 1      | Zhejiang Huzhou new energy | 0.543+0.25-0.03=0.763    |
| 2      | Yueyang photovoltaic    | 0.538+0.25-0.03=0.758    |
| 3      | Huarui wind power       | (0.538×0.4+0.535×2.7+0.533×1.2) / (0.4+2.7+1.2) +0.25-0.03=0.754 |
| 4      | Jiangsu Sansi wind power| (0.533×1.3+0.530×1.8+0.524×1.5) / (1.3+1.8+1.5) +0.25-0.03=0.749 |

It can be seen from the above table that for the distributed generation companies, the generation revenue increases, and for the users, the cost of electricity consumption decreases. With the deepening of the competition in the power market; the proportion of distributed generation participating in the transaction will be higher and higher, and the price of electricity transaction will tend to be more economic and reasonable, which is conducive to the development of distributed energy, to the solution of social capital, and to the promotion of social economy sustainable development.
6. Conclusion
In this paper, aiming at the research on the value of grid-connected operation of distributed generation, based on the research on its reliability and various benefits, a centralized trading model of simulated power trading platform is designed.

The conclusion of this paper is that, from the perspective of economic benefits, grid connection of distributed power sources is helpful to save investment and reduce energy consumption, and can give full play to the respective advantages of distributed power sources and power grids. From the perspective of environmental benefits, distributed power generation is to reduce energy consumption and improve the reliability and flexibility of the power system, which is an important development direction of world energy in the future. At the same time, the paper shows that the grid connection of distributed generation has a positive impact on power grid dispatching and power quality. Finally, a simulated transaction example is used to verify the cost-saving effect of grid-connection of distributed generation on power producers and consumers. The model in this example is applicable to other power producers and consumers and has certain reference value for the future power market.

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References
[1] Liu Xing. (2018) Market based trading of distributed generation promotes rapid development of roof photovoltaic [J]. Electrical technology, 19 (01): 10
[2] Zhang Yanbo. (2012) Impact of distributed energy access on distribution network [J]. Modern electronic technology, 21: 173-175
[3] WalidEl Khattam, Y. Ghézazy, M.M.A. Salama. (2005) An Integrated Distributed Generation Optimization Model for Distribution system Planning. IEEE Transactions on Power Systems, 20(2): 1158-1165.
[4] Yang Wenyu, Yang Xuying, Yang Junjie. (2008) Distributed generation and its application in power system [J]. Progress in grid and hydropower, 02: 39-43
[5] Wang Aijun. (2013) Influence of distributed power on distribution network [J]. Application of power technology, 03: 8-9
[6] Lei Jinyong, Xie Jun, Gan Deqiang. (2009) Energy optimization and energy saving and emission reduction benefit analysis of distributed generation energy supply system [J]. Power system automation, 33 (23): 29-35
[7] Cui Hong, Guo Yiyun, Xia Chengjun. (2010) Study on the optimal configuration of distributed generation considering environmental benefits [J]. Huadong electric power, 38 (12): 1968-1971
[8] Shi Bangsong, Zhang Jing, Li Bowen, et al. (2018) Study on market equilibrium of competitive power sales under the coexistence of multiple types of power sales companies [J]. Power system protection and control, 46 (05): 62-67
[9] National Development and Reform Commission, national energy administration. (2017) Notice on carrying out pilot market-based transaction of distributed generation [EB/OL]