The Operation Mode of Distributed Energy System under the Background of Energy Interconnection

ZHOU Changcheng¹, GUO Zuogan¹, YUAN Zhiyong¹, LUO Junping², LEI Jinyong¹, HUANG Andi¹, MA Jianxun²

¹Electric Power Research Institute, China Southern Power Grid, Guangzhou 510663, China;  
²China Southern Power Grid Company Limited, Guangzhou 510623, China;  
³State Key Laboratory of Alternate Electrical Power System with Renewable Energy Sources, North China Electrical Power University, Beijing 102206, China

*Corresponding author’s e-mail: 1738236572@qq.com

Abstract. This paper analyses the typical operation mode of distributed energy system under the background of energy interconnection and proposes the “monopoly of purchase and marketing” operation mode and the “aggregation service provider” operation mode of energy interconnection. Between them, the latter covers two main auxiliary services including frequency regulation service and reserve service. Then, the method for calculating the expected cost and benefit of the illustrated model is proposed in this paper. Taking the Pearl Industrial Park of Guangdong Province as an example, the numerical analysis is carried out to obtain the cost and benefit of the distributed energy system under the above two modes. Finally, we use the control variable method to analyse the impact of key parameters on the static investment payback period, including grid price, PV subsidy price, auxiliary service price, output distribution coefficient, etc.

1. Introduction

With the global shortage of fossil energy sources and the continuous escalation of environmental pollution issues, energy and environmental issues have attracted increasing attention. Among them, distributed energy generation can make full use of renewable energy, which is an important measure to achieve China's energy conservation and emission reduction goals. And it is also an effective supplement to centralized power generation. With the rapid development of distributed energy sources such as photovoltaics, wind power, and energy storage, various distributed energy sources have affected the distribution network's operation, control and protection to varying degrees. Within a certain range, distributed energy has formed a cluster effect. The impact on the intelligent distribution network will produce new changes.

The current research on distributed energy can be divided into two categories: research on the development of distributed energy itself [1-4] and the impact of distributed energy on the power grid.[5-8]. At the same time of vigorously developing distributed new energy, the information and communication technology has broken the application form of traditional energy. The concepts of energy Internet and ubiquitous power Internet of things have sprung up, so as to promote the development of power system towards the direction of intelligence and transparency [9-11]. In this context, the traditional distributed energy system is developing in the direction of subject diversification and form diversification, and the operation mode and transaction type of energy market will be more
flexible. Internet of things technology puts forward higher requirements for the operation mode of traditional distributed energy system. How to give full play to the inherent advantages of Internet of things technology and expand the market-oriented operation mode of distributed energy system in the new situation needs to be further studied.

Based on the current operating mode of distributed energy systems in China under the background of the Internet of Things, this paper designs and analyses the economics of a distributed energy system operating system incorporating IoT technology. The impact of the sharing model quantifies and analyses in detail the economic benefits of distributed energy under the unified purchase and marketing operation model and the aggregation service provider operation model. Finally, taking Guangzhou Mingzhu Industrial Park as an example, numerical calculations are performed to obtain key results such as the benefits and costs of the distributed energy system under various operating modes.

2. Model and calculation

2.1 Analysis of the operation mode of distributed energy systems

2.1.1 monopoly of purchase and marketing operation model
The monopoly of purchase and marketing operation model belongs to the traditional operation model of distributed energy systems. Distributed power and distribution networks are uniformly dispatched by power grid companies. Distributed power supply services covering users are provided by power grid companies, and distributed energy investors are responsible for the investment and construction of distributed energy systems. Power grid companies are responsible for the cost of upgrading the distribution network caused by the integration of distributed energy clusters.

2.1.2 Aggregation service provider operation model
In the context of the ubiquitous Internet of Things, based on the traditional monopoly of purchase and marketing operation model, a distributed energy system aggregation service provider operation model is proposed. The specific structure is shown in Figure 1. Aggregator Service Provider (ASP) aggregates all distributed energy sources in a decentralized energy system, analyses the auxiliary service capabilities of aggregated distributed energy sources and assists in the settlement of market prices for services. Meanwhile, it participates in the provision of auxiliary services required by the large power grid, thereby ensuring the balance and stability of the power system. In addition, distributed energy providers actively innovate auxiliary service technologies, reduce the cost of auxiliary services, and increase the value of auxiliary services. They will obtain more auxiliary service compensation under this model, and the two will achieve mutual benefit and win-win results.

2.2 Calculating the costs and benefits of market-based operations for distributed energy services
Among the two operating modes introduced above, the monopoly of purchase and marketing operation model serves as the basis for the aggregated service provider model, providing a cost calculation method and basic transaction benefits for the aggregated service provider model. Different models vary. This paper proposes a simple method to calculate the costs and benefits of the unified purchase and marketing method. It also models and analyses the main auxiliary services in the distributed energy system to accurately estimate the economics of the project.

2.2.1 Costs and benefits of the monopoly of purchase and marketing operation model
Under this model, the expected costs of distributed energy systems are mainly divided into initial investment costs $C_T$, operation and maintenance costs $C_r$, and distribution network upgrade costs $C_{dn}$. The initial investment cost $C_T$ includes distributed power, energy storage and gas turbines.

$$C_m = C_T + C_r + C_{dn}$$ (1)
The income of distributed energy systems includes annual revenue from online access $S_{PV}^S$, annual subsidy revenue $S_{PVsub}^S$, energy storage revenue $S_{ES}^S$, and gas turbine revenue $S_{CCHP}^S$.

$$S_p = S_{PV} + S_{PVsub} + S_{ES} + S_{CCHP}$$  \(2\)

### 2.2.2 Costs and benefits of aggregation service provider operating model

This model is based on the monopoly of purchase and marketing model. The grid company sets up an aggregated service provider, aggregates distributed energy, and considers auxiliary services that it can propose to settle at market prices of auxiliary services. Therefore, this model needs to increase the secondary system terminal equipment installation costs $C_{sum_{-td}}$ and ASP operating costs $C_{d_{-asp_{-bus}}}$ based on the original cost of the unified purchase and marketing model.

$$C_A = C_m + C_{sum_{-td}} + C_{d_{-asp_{-bus}}}$$  \(3\)

In addition to the benefits under the unified purchase and marketing model, due to the existence of aggregation service providers, distributed energy sources will be aggregated to participate in ancillary services, which will bring some revenue from ancillary services, including frequency modulation services and backup services.

$$S_{Agsp} = S_p + S_{R} + S_{B} = R_f^f(i) + E_f^f(i) + \xi_f^f(i) + R_b^b(i) + E_b^b(i) + \xi_b^b(i)$$  \(4\)

In the formula, frequency regulation service income mainly includes frequency regulation capacity income $R_f^f(i)$, reverse discharge energy income $E_f^f(i)$ and compensation income $\xi_f^f(i)$. Reserve service income includes reserve capacity income $R_b^b(i)$, reverse discharge energy income $E_b^b(i)$ and compensation income $\xi_b^b(i)$.

### 3. Case study

In this paper, the Mingzhu Industrial Park in Guangdong Province is selected as a typical case for numerical analysis.

#### 3.1 Comparison of costs and benefits under different operating models

Since the aggregation service provider model is a monopoly of purchase and marketing model with auxiliary services, the two have the same cost in physical investment. In terms of revenue, the main revenue of this model is still composed of basic Internet revenues and subsidy revenues, and participates in auxiliary services. The energy is 20% of the total energy, and this part of energy has auxiliary service income.
Table 1. Costs and benefits of generators under the unified purchase and marketing model

| Category                                           | Cost (CNY)       |
|----------------------------------------------------|------------------|
| Initial investment cost of power generation enterprises | 368924.5K        |
| Annual operation and maintenance costs              | 1475.74K         |
| Annual Total Revenue of Distributed PV              | 30394.36K        |
| CCHP Annual Total Revenue                           | 148767.7K        |
| Annual total revenue of power generation enterprises | 179161.76K       |
| Grid enterprise investment in energy storage costs   | 184300K          |
| Energy storage operation and maintenance costs      | 4471.8K          |
| Total revenue of energy storage system              | 12517.9K         |
| Grid company power supply revenue                   | 20751.7K         |
| Grid company investment payback period              | 6.5 year         |

Table 2. Auxiliary service income of the market players under the mode of aggregator service provider

| Category                  | Capacity distribution coefficient |
|---------------------------|----------------------------------|
| Standby income (CNY)      | 0.400                            | 0.500                            | 0.600                            |
| Frequency income (CNY)    | 15389.22K                       | 12824.35K                       | 10259.48K                       |
| Total income (CNY)        | 26474.11K                       | 33092.64K                       | 39711.16K                       |
| Investor income (CNY)     | 4186.333K                       | 45916.99K                       | 49970.65K                       |
| Grid income (CNY)         | 2086.016K                       | 22880.07K                       | 24899.97K                       |
|                           | 2100.317K                       | 23036.93K                       | 25070.68K                       |

3.2 Profit and loss sensitivity analysis

This section analyzes the sensitivity of the revenue under different models based on the static investment payback period. For the benefits of distributed photovoltaic power generation systems, the annual utilization hours and cost of the system will affect it. In addition, there are some indirect factors. Such as the impact of the environment and policies. Energy storage and gas turbines also have this feature. Different parameters will affect their benefits and costs, and then affect the static investment payback period. The following uses the control variable method to study the influence of some parameters on the static investment payback period.

![Static payback period of investment for investors under the model of aggregator service provider](image1)

![Static payback period of power grid company for investors under the model of aggregator service provider](image2)
It can be seen from Fig. 2 that the higher the auxiliary service price, the greater the auxiliary service output, the greater the frequency modulation output, and the shorter the investment recovery period of the power generation enterprise; the change in the capacity allocation coefficient has a small impact on the investment recovery period of the power generation enterprise.

It can be seen from Fig. 3 that in the ASP mode, the auxiliary service price, auxiliary service output, and auxiliary service allocation coefficient are all positively related to the daily income of the auxiliary service of the power grid company. That is, the increase in the price of ancillary services, the increase in the ancillary service output, and the higher frequency modulation output will increase the daily revenue of ancillary services of the power grid company. Among them, the change in the ancillary service output has a very significant impact on the revenue; and when the ancillary service output is constant, the larger the capacity to participate in the FM service, the smaller the capacity to participate in the standby service, and the higher the final revenue.

4. Conclusion
This article analyzes the sharing mode of distributed energy systems, and proposes an operation mode of "aggregation service providers" for distributed energy systems that incorporates the Internet of Things technology based on the existing "uniform purchase and marketing" operation model. A case study is performed, and the results show that the proposed "aggregation service provider" operating model for distributed energy systems for ubiquitous Internet of Things, based on the existing "uniform purchase and marketing" model, further leverages the cluster advantages of distributed energy systems and improves comprehensive system benefits. At the same time, through the analysis of the static investment payback period, it is concluded that the price of auxiliary services has the greatest impact on costs and benefits, and has a negative impact.

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