A review of the global energy internet and the suggestions to China

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Abstract. Energy internet projects can participate in demand response, distributed renewable energy resources, and “source-grid-load-storage”. Some developed countries, such as the United States, Denmark, and Germany, have accumulated some experience in energy internet projects. In these projects, the electricity market mechanisms have been adjusted according to the character of energy internet. Firstly, some typical projects of energy internet are introduced. In addition, different electricity market mechanisms are analyzed. Finally, combined with the current electricity market in China and foreign experience, suggestions are proposed to the development of the electricity market and energy internet in China.

1. Introduction

With the continuous development of energy Internet technologies such as information technology, distributed power generation, renewable energy power generation and energy storage, energy Internet projects have been equipped with technical conditions to participate in power market links such as demand response and auxiliary service market [1]. In the global mature power market environment, the relevant market mechanism and policies have been constantly improved to promote the development of China's energy Internet. In 2015, China established the leading group of energy Internet action under the National Energy Administration to make overall planning for the development of energy Internet, and make top-level design and key technology research and development plans [2]. In 2017, the trial measures for promoting the construction of grid-connected micro-grid and the work plan for improving the compensation (market) mechanism of power auxiliary services are proposed to promote the local consumption and consumption of distributed renewable energy, guide the construction of "source-net-load storage" integrated main body, encourage energy storage equipment and demand-side resources to participate in providing power auxiliary services, and allow the third party to participate in providing power auxiliary services by the National Energy Administration [3]. However, China's electric power market system is still not perfect. With the further promotion of the reform of the electric power market, various technologies of energy Internet will have broader application prospects in many aspects, such as demand-side response, distributed consumption of renewable energy, and efficient interaction of "source-net-load storage".
2. Energy Internet in foreign power market environment

Foreign developed countries such as the United States, Germany, and the Nordic countries have been operating the electricity market for many years. These countries have deep experience in energy Internet construction, which has important reference significance for China's construction of the electricity market and energy Internet technology. This article takes the United States, Denmark, and Germany as examples to introduce the development process and practical projects of the energy Internet in the electricity market environment [4].

2.1. US energy internet practice project

The US Energy Internet practice project was launched earlier, and while promoting various technological developments. It also promoted the construction of the energy Internet through the electricity market mechanism. The development of the US energy Internet focuses on the demand side response and the effects of technologies such as renewable energy generation, distributed generation, electric vehicles, and energy storage to reduce energy consumption. The two-way information flow between the power generation side and the user side is constructed by focusing on the construction of the transmission side, the power distribution system, and the smart equipment on the user side [5].

In terms of theoretical construction, the American Electric Power Research Institute proposed the concept of the smart grid in 2001 to promote the intelligentization and informationization of power grids. In 2008, the National Science Foundation led the Future Renewable Electric Energy Demand and Management (FREEDM) program and built a physical information architecture for large-scale access to distributed energy.

In terms of project construction, the US PJM power market operator has gradually promoted line monitoring and enhanced system communication on the transmission side since 2003 [6]. At the same time, they also installed a large number of synchronous vectors measuring devices. In 2008, Boulder gradually promoted the construction of smart grid cities, introduced wind power generation storage systems, and vigorously promoted the use of electric vehicles. Miami City launched the “Miami Smart Energy” project in 2009, installing 1 million smart meters on the user side to improve user-side power management capabilities, and opening a smart meter management platform to lay the foundation for different power management solutions.

With the use of a large number of intelligent devices and the development of intelligent management methods, the United States has also continuously improved the market mechanism. As a result, the US issued relevant policies to enhance the response potential of demand-side load resources and achieve overall energy consumption reduction [7-9]. Taking the PJM power market as an example, the service types of demand-side load participating in the auxiliary service market are shown in Table 1.

| Ancillary services | Type | Implementation |
|--------------------|------|----------------|
| Frequency adjustment | Regulation A | Doing market clearing and sending adjustments in PJM, which are usually unchanged within one hour. |
|                    | Regulation D | PJM sends real-time control signals, and the participants complete the adjustment in five minutes. |
| Electrical backup  | Synchronous backup | Responding within ten minutes, clearing every five minutes at real-time market price |
|                    | Asynchronous backup | Responding within ten minutes, clearing every five minutes at real-time market price |
|                    | Secondary backup | Responding in ten to thirty minutes |
The ancillary services market has high responsiveness to market players. PJM requires market entities to be able to aggregate resources and participate in the market in the form of reduced communications service providers (CSPs) [9]. The CSP needs to sign a contract with PJM to complete the agreed auxiliary service project. It should also sign a contract with the end-user to allow the end-user to participate in the auxiliary service market indirectly by means of a prior agreement or direct load control. For large industrial load and regional distribution companies, they can participate in the market as CSPs. On the country, for small end-users, they participate in the market by participating in load integrators or load service entities.

Therefore, the United States provides a profitable environment and space for the practical application of various technologies of the energy Internet through the electricity market. The development of energy Internet technology has broadened the service form of the electricity market and activated the market body of the electricity market, providing new resources for market stability and vitality.

2.2. Danish energy internet practice project
The Danish Energy Internet is focused on adjusting energy mix, increasing the proportion of renewable energy and developing distributed energy. In order to promote the use of renewable energy, Denmark has passed the Renewable Energy Utilization Act and the Energy Supply Act, which has clearly defined support for renewable energy and focused on the application of wind power [10]. In addition, in order to promote the development of the energy Internet, Denmark focuses on the development of wind power, energy storage, smart meters, and communications. Meanwhile, other related technologies also get development. Denmark promotes the consumption of renewable energy through electricity market mechanisms and subsidy policies.

In terms of technology, Denmark has been vigorously promoting the installation of wind turbine real-time measuring equipment and the development of wind power forecasting technology since 2004 [11]. It’s marvelous that Denmark can predict the fan output without measuring equipment in real-time according to the wind speed and output of the wind turbine. In 2011, Denmark installed smart meters and smart appliances for 2,000 homes on Bornholm through the Fast Track project, which connected the weather forecast system to the intelligent electrical control system to maintain a comfortable living environment. The running time and power consumption of the household appliance can be automatically adjusted according to the load of the entire power grid and the price of the energy source [11-12]. In 2018, the Danish University of Science and Technology launched the MEGA-STORE project to convert wind energy into methane gas and transport it to the natural gas network through a biogas plant to construct a new energy storage method to achieve a coordinated allocation of power resources and natural gas resources.

The Danish Energy Internet project not only emphasizes the advancement of wind power technology but also uses intelligent communication networks to increase the ability of loads to participate in demand-side responses and to promote energy storage technologies and energy conversion technologies to achieve multi-energy complementarity [13].

In terms of the market mechanism, in order to make domestic wind power producers more competitive in the Nordic electricity market transactions, Denmark provides direct economic subsidies for every kilowatt of electricity generated by wind power, making wind power almost “free”. In addition, under the guidance of the Danish government, Denmark has established a wind power forecasting company on the power generation side and an energy service company that provides load reduction services on the demand side. Wind Power Forecasting provides forecasting services for wind power companies, assisting wind power companies to use more accurate wind power forecasts to participate in quotations in the Nordic market and the day market and to develop a power generation plan and adjust the power generation plan. Energy service companies can use online inspection and management software to perform direct load control on contract users' electric vehicles, heat pumps, refrigerators and more. While saving users money on electricity, they participate in the Nordic
balanced electricity market to obtain additional revenue. In the Nordic electricity market environment, Denmark’s wind power resources and demand-side resources are mainly involved in the Nordic electricity market through the way of Figure 1.

Figure 1. Participation of wind power and demand resources in the Nordpool.

2.3. German energy Internet practice project

The construction of the German energy Internet is characterized by a high degree of informationization. Using information technology to promote the regional integration of renewable energy in the energy supply, a big system of Energy Internet is formed by a set of generator sets, renewable energy, power grid equipment, electrical equipment and household electrical equipment [14].

In 2008, Germany launched the E-Energy project, which opened up pilot projects for energy Internet core technologies in multiple regions. Based on different energy structures and functional structures, the project emphasizes the efficient use of distributed energy in the region. The coordination and complementarity of different energy sources have achieved good practical results [14-16]. A typical E-Energy pilot project is shown in Table 2.

Table 2. Typical E-Energy program.

| Projects    | Regional energy characteristics                          | Measures                                             |
|-------------|--------------------------------------------------------|------------------------------------------------------|
| eTelligence | A large amount of heating and cooling demand           | Intelligent power conditioning for large cold storage and boilers in the region |
|             | A large number of wind power resources                 | Intelligent adjustment of power generation according to user needs |
| Meregio     | A large amount of distributed renewable energy         | Install variable transformers to improve distributed energy consumption |
|             | Traditional thermal power and fuel cells               | Install smart meters to locate weak links in the distribution network |
| RegModHarz  | A large amount of renewable energy                     | Impairing the uncertainty of renewable energy through energy storage methods such as pumped storage power stations |
|             | Rich hydropower resources                              | Home equipment intelligently adjusted according to renewable energy output |
These projects have adopted a centralized management approach to distributed energy and load, namely “virtual power plants”. Similar to CSPs in the PJM market and Danish energy service companies, these virtual power plants are primarily responsible for integrating demand-side resources and participating in demand-side responses. The difference is that virtual power plants are divided into regions, which not only manage the load but also manage distributed energy such as wind power, solar energy, cogeneration and even traditional thermal power in the region.

Within a single virtual power plant, this management method weakens the factors that power producers make priority transactions based on their own interests, and can better adjust the regional power demand. For large power grids with multiple virtual power plants, different virtual power plants have different energy consumption and output characteristics. In the process of participating in the power market, virtual power plants in different regions have formed a greater range of versatile complementarity.

In order to better optimize the energy consumption inside the virtual power plant and realize the local consumption of renewable energy, each demonstration project uses a large number of intelligent equipment for demand-side management. Meanwhile, it also establishes a corresponding market price mechanism. Guide the demand-side load to respond actively [16-17]. The market price mechanism adopted in each demonstration project is shown in Table 3.

Table 3. Tariff mechanism in a typical virtual power plant.

| Projects     | Tariff mechanism                                                                 |
|--------------|----------------------------------------------------------------------------------|
| eTelligence  | Based on the new energy power generation situation, the peak electricity price and preferential electricity price, combine the time-of-use electricity price and real-time electricity price, |
| Meregio      | Traffic light price mechanism, respectively, indicates high electricity prices, mid-Electricity Price and low Electricity Price |
| RegModHarz   | Dynamic electricity price, 9 levels of reward and punishment system              |

3. Suggestions on the development of China's electricity market and energy Internet

The development of the energy Internet is closely related to the construction of the electricity market. The advancement of various technologies of the energy the Internet has brought more service types, products and market entities to the power market. The power market provides relevant policies and mechanisms to ensure that the entire market is full. Based on the experience of foreign energy Internet projects, the following suggestions for the development of China's electricity market and energy Internet are proposed from the demand side response.

3.1. Demand Response

The power market mechanism is the main means to promote the development of the demand side. Therefore, the first step in promoting the construction of the energy Internet is to establish a sound power market mechanism. With the advancement of the construction of the power market, real-time electricity prices and real-time markets that are more responsive to the real-time status of the system will continue to mature, creating conditions for the development of demand-side responses. The introduction of the real-time electricity price mechanism allows power users to face the risk of rising electricity costs, which in turn encourages users to actively participate in the demand side response to reduce energy costs. On the other hand, the continuous opening of the power retail market will create a more diversified power market entity, and promote the transition from traditional administrative demand-side management to market demand-side response. The variable electricity price can
encourage the demand side entities to actively develop and participate in the demand-side response business and obtain economic benefits.

In order to promote the development of demand-side response business, the following work should be emphasized in the future: First, strengthen the construction of auxiliary service market, and ensure timely release of market price, real-time market price and auxiliary service market price information; second, increase user side Supporting hardware construction, such as installing smart meters and intelligent control systems, providing hardware support for developing demand-side response; third, establishing demand-side response incentive compensation mechanism, providing economic compensation for users to reduce load, and improving user enthusiasm for participating in demand-side response Fourth, support the demand-side response to the pilot project, and adopt incentives to encourage sales and grid companies to carry out demand-side response services at the distribution network level.

3.2. "Source network load storage" efficient interactive system and virtual power plant

The “source network load storage” efficient interactive system and virtual power plant have the characteristics of flexible regulation and multi-energy complementarity. With the advancement of power market construction, the introduction of real-time electricity price mechanism will bring a reasonable investment return path for the implementation of virtual power plant business; the perfect auxiliary service market mechanism can build an interactive interconnection system between the virtual power plant and the external power grid.

In order to promote the efficient interaction of “source network and storage” and the development of virtual power plant business, the following work should be emphasized in the future: First, establish an effective and reliable auxiliary service market trading system, and explore the flexible resources to participate in auxiliary services in “source network storage” Second, improve the supporting policies of virtual power plants in the power market, so that virtual power plants can represent internal distributed energy and users to participate in the external power market to purchase and sell electricity transactions. Ensure the return on investment of virtual power plant operation services; The design of the electricity market mechanism should focus on the effectiveness and timeliness of information disclosure, and guide the interaction of information between market entities through market signals to provide operational conditions for the efficient interaction of the “source network and storage” and virtual power plant business.

Since the capacity of the “source network and storage” interactive business and the virtual power plant business can be smaller than that of the generator set, it is recommended to participate in the auxiliary service market only in the initial stage of the power market. With the improvement of the electricity market and the establishment of the retail market, the capacity of the “source network and storage” interactive business and the virtual power plant business can be gradually extended from large to small, allowing them to participate in the auxiliary service market while participating in the energy market.

3.3. The high proportion of distributed renewable energy

With the increase of the proportion of renewable energy, in order to ensure the safe and stable operation of the power system and the electricity market, it is not only necessary to flexibly adjust the output of the generator set, but also to actively cooperate with the power grid and the demand side. A sound electricity market mechanism can ensure that market players profit from fair competition, thus providing a platform for the development of supply and demand interaction and the full consumption of high-proportion distributed renewable energy.

In order to promote the access of high-ratio distributed renewable energy, the following work should be emphasized in the future: First, the development of renewable energy leads to the rapid increase of uncertainty on both sides of supply and demand, the problem of grid blocking and utilization reduction, grid company The supply and demand interaction should be guided through a reasonable transmission and distribution price cost calculation and allocation mechanism. Second,
improve the market price mechanism and trading model, tap the flexibility of both sides of supply and demand, accelerate the construction of the ancillary service market, and enhance the competitive advantage of flexible power generation resources. Third, establish a flexible retail electricity price mechanism, aiming at the uneven distribution of renewable energy sources and the imbalance of source and load distribution, mobilizing the energy storage and energy flexibility under the coordinated demand side. Renewable energy is absorbed locally; Fourth, establish a renewable energy consumption responsibility mechanism, build a reasonable renewable energy power data tracking management platform, design and promote green power packages, explore the green card trading mechanism, and further promote renewable energy consumption.

4. Conclusions
This paper introduces the typical practice projects of the energy Internet in the electricity market environment in the United States, Denmark, and Germany, and summarizes the key points of energy Internet development, market incentives, and government guidance policies. In view of the current situation of China's power market construction, suggestions are made from three typical application scenarios of Energy Internet. In general, the construction of the electricity market and the energy Internet should focus on the promotion of the retail market and the auxiliary service market. It is important to strengthen the construction of various software supporting hardware and software for the energy Internet and improve the controllability of flexible resources such as user load and distributed power supply.

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