Concepts, Technical Characteristics and Construction Experiences of Energy Internet: A Review

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Abstract. As the foundation and core driving force of the third industrial revolution, Energy Internet plays an important role in the energy revolution. Based on the key technical characteristics of Energy Internet, this work teases out and analyses the basic connotations, concepts, and core characteristics of Energy Internet. On this basis, taking Tokyo Electric Power Company, Direct Energy and ENN Group as examples, this work also analyses the typical cases and practice activities of Energy Internet conducted by energy companies at home and abroad, and summarizes the experiences encountered by enterprises in conducting energy Internet. Finally, all these key issues are introduced and taken as a reference for other energy companies to build an Energy Internet.

1. Introduction

Since the 21st century, the global energy transformation has been happening, driven by the dual imperatives of limiting climate change and fostering sustainable growth [1]; the energy dependence has been deepening, the scale of energy development and utilization have continued to increase. In the meanwhile, the new energy technologies based on renewable energy have developed rapidly. In addition, the diversification of energy structure has become more and more obvious, and consumption and utilization are more flexible. An energy revolution characterized by the development of clean energy, energy security, climate change and sustainable development is being nurtured and developed in the whole world.

At the same time, through the integration of a new generation of information and communication technologies and energy systems, such as the Internet of Things, big data, cloud computing, and information physics systems, we will build a system with the diversified structure, the clean development, the consumption electrification, and the intelligent system. It has become an important way to get rid of the industrial and economic development model that relies on fossil energy. In this context, American energy economics expert Rifkin introduced the basic concept and vision of Energy Internet in the book *The Third Generation Industrial Revolution* [2], which is widely recognized and considered to be a solid foundation and core driving force of the third industrial revolution.

Considering the important position in the energy revolution, the Energy Internet has been widely concerned by domestic and foreign research institutions since its introduction. In U.S., the National Energy Renewable Energy Laboratory has developed an open source data bus for large-scale energy system data management and established a research centre, which focuses on large-scale clean energy grid-connected research and seeks to achieve a clean, economical and safe hybrid energy supply [3]. With the establishment of the EU’s 20-20-20 and 2050 CO2 free electricity production development...
goals, the EU issued a new roadmap for the European electricity grid initiative at the end of 2012, striving to interconnecting energy systems in various countries. It means that EU wants to build a unified energy ecosystem across Europe to achieve clean and efficient use of energy [3]-[4]. Other countries are also actively exploring the construction of energy Internet. Taking Denmark as an example, by means of responding to electricity prices, Eco-Grid makes a beneficial attempt to the real-time electricity markets in the energy grids with high proportion of renewables. The Power Matching City demonstration project in Netherlands also seeks to achieve breakthroughs in the coordinated and intelligent management among different energies, including natural gas power generation, hybrid heat pumps, and cogeneration [3].

At present, many scholars have made some progress in the area of Energy Internet. In work [4], the traditional mode is abandoned which solely relies on the power system to accommodate high penetration of renewables, and a smart Energy Internet is proposed, which integrates the power grid, natural gas network, thermal system and transportation system to achieve 100% renewable energy supply. Based on the concepts of Internet, the literature [5] gives the basic structure of the energy Internet by analysing the three important characteristics of distributed intelligent management system of distributed power in the Energy Internet, including the plug-and-play, energy router and open specification. The emphasis on the principles of open and interaction is recognized by many other scholars. The authors in [6] believe that based on the smart grid, Energy Internet is a wide-area energy ecosystem with complementary multiple energies, and it mainly emphasizes the coordination and complementary operation among multiple energies.

However, what should be mentioned that, at present, the researches on Energy Internet mainly focuses on concepts, architecture, and other aspects, and there are few studies on the typical cases and construction experiences of Energy Internet. How to summarize the current experiences of Energy Internet construction and give a scientific and rational development path to build Energy Internet, have an important theoretical and practical significance.

2. Basic concepts and technical characteristics of Energy Internet

2.1. Basic concept of Energy Internet

Rifkin believes that, the construction of Energy Internet mainly requires the following five aspects; firstly, we should promote the transformation of petroleum and coal-based fossil energy to green renewable energy, such as wind energy, solar energy, hydro energy and biomass energy; Secondly, we should explore the important role buildings can play in achieving the large-scale, multiple forms of distributed power supply; Thirdly, we should use multiple forms of energy storage, such as hydrogen energy storage and other energy storages to ensure continuous and stable supply of electricity energy; Fourthly, we should use Internet technologies to promote the wide-area interaction and the information sharing; Last but not least, we should use a mass of electric vehicles to achieve the interconnection between transportation systems and power systems [2].

Since the vision of Energy Internet was introduced, different research institutions, universities, and enterprises propose different comprehensions about the Energy Internet [7]-[9], as shown in Table 1.

Table 1. Energy Internet Concepts and Connotations.

| Institution | Concept and Connotation |
|-------------|-------------------------|
| National Development and Reform Commission | Energy Internet is a new form of energy industry development, which deeply integrates Internet technologies and all links of energy system, including production, transmission, storage, consumption and energy markets. The key features of Energy Internet consists of equipment intelligence, multiple functions, information symmetry, dispersion between supply and demand, flat organizational... |
Energy Internet is a new form of energy industry development, which deeply integrates Internet technologies and all links of energy system, including production, transmission, storage, consumption and energy markets. It is a network with high integration between new information network and energy grid based on the concepts of Internet. Energy Internet is a smart energy network, where the power grid is infrastructure, and various energy sources are integrated such as cold, heat, and gas.

Global Energy Interconnection Development and Cooperation Organization

Global Energy Interconnection (GEI) is a globally interconnected robust and smart grid which takes Ultra-high voltage grid as its backbone. It serves as a global platform for extensive development, delivery and utilization of clean energy. In essence, GEI is “smart grid + UHV grid + clean energy”. Smart grid is the foundation, UHV grid is the key, and clean energy is the priority. Establishing GEI and implementing Two Replacements (Clean Replacement and Electrical Replacement) could build a new energy structure dominated by clean energy, centred on electricity and allocated globally, realize global energy transition from fossil energy dominating to clean energy dominating.

State Grid Corporation of China

Based on a strong smart grid and the ubiquitous power Internet of Thing, Energy Internet is the smart energy with advanced energy technologies, modern information and communication technologies and control multiple-energy, intelligent and ubiquitous interconnections.

According to Rifkin's vision of the Energy Internet and the different comprehensions about the concepts and connotations of Energy Internet, we can find out that power systems are the core and tie of Energy Internet and the renewable energies are the main energy forms, such as wind energy, solar energy and natural gas. In the meanwhile, in Energy Internet, the large-scale, multi-form distributed generations and energy storage systems are integrated widely, and advanced information and communication technologies are the key means of energy utilization and management such as cloud computing and big data. Energy Internet is the comprehensive energy system that integrates multiple systems, including power systems, transportation system, natural gas systems, and information and communication systems, to achieve coordinated and complementary as well as “clean replacement” and “electricity replacement”.

2.2. Key technical characteristics of Energy Internet

Compared with the traditional power grids and the concept of smart grid, as a future smart energy system, Energy Internet has the following new features, shown as following.
2.2.1. **Multi-energy coordination.** On the basis of traditional fossil energy power generations, Energy Internet has increased a variety of renewable energy generations such as wind energy, solar energy, hydro energy and biomass energy. By means of the scientific allocation of multiple energies, the complementary features enable clean transition and the stability of energy supply [8].

2.2.2. **Collaborative interaction among Sources, Grids, Loads, and Storages.** Using energy routers and intelligent energy management systems, through the active management of flexible and controllable loads in energy demand side and distributed generations, supplemented by multiple types and multiple forms of energy storages, the collaborative interaction among sources, grids, loads, and storages in Energy Internet is realized. In the meanwhile, the coordinated optimization of energy demand and supply and optimal allocation of resources are achieved.

2.2.3. **Highly integrated among multiple systems.** Energy Internet takes the power system as the core and hub, and realizes integration with the transportation system through the vehicle to grid, with natural gas systems through natural gas power generation and power to gas, with heating systems by the combined cooling, heating and power technology. The various physical devices involved in the above systems are also integrated with information communication systems by means of Energy Hub to realize integration between energy flow and information flow.

2.2.4. **Wide area interconnection among massive equipment.** Energy Internet deeply interconnects wide-area and massive distributed equipment such as power generations, energy storages and flexible loads, achieving end-to-end diversified energy sharing and energy open market, improving management refinement of demand side resource, and economic operation level of energy systems [10]-[11].

3. **Typical practices of Energy Internet**

In order to cope with the new challenges, new situations and new requirements, many power companies and energy companies have carried out the practice activities to build the Energy Internet enterprises.

3.1. **Tokyo Electric Power Company**

Tokyo Electric Power Company is the first of 10 power companies in Japan and one of the most famous power companies in the world. In order to actively respond to the challenges brought about by changes in the external business environment, such as the full liberalization of the power and gas market systems, Tokyo Electric Power Company, based on the continuous expansion of traditional energy services and the development of energy-related technologies, strives to exploit the potentialities of customers. The company provides a variety of power energy products and new energy services to transform into a global leading Energy Internet company.

Tokyo Electric Power Company deems that the power industry is gradually shifting from providing energy products to providing energy services, and will continue to shift from providing single services to providing comprehensive services. In this regards, the company actively adjusts the business strategy, generates a new strategic vision to be an integrated energy service provider, and builds a “four-in-one” information system platform to support the development of the integrated energy services business, including the transmission and distribution platform, the infrastructure platform, the energy platform and the data platform. The construction of the “four-in-one” information system platform breaks through the traditional boundary between the power system and other systems in the energy and other related systems, and realizes the cooperation and the distributed interaction between the insides and the outsides of energy sources.
3.2. Direct Energy
Founded in 1986, Direct Energy is the most competitive power, gas and energy service provider in the United States, with more than six million residents and business users. Direct Energy adheres to the principle of providing customers with multiple energy solutions as a whole, and customizes services, products and services according to customer needs. The company is committed to developing, investing, constructing, operating and managing more energy service product portfolios to form a multi-energy business scale, to realize the transition from energy supplier to integrated energy service provider.

3.3. ENN Group
In order to be an Energy Internet company, ENN group introduced the concept of the ubiquitous energy network, which is an intelligent collaborative network that integrates information network, energy network and physical network. The integrated cascade utilization of energy is the basis of the ubiquitous energy network. The essence of the ubiquitous energy network is to use the “mutual information” to measure, control and modulate the system to improve the system energy efficiency of the entire energy system. ENN group has built an energy eco-city in Langfang with the goal of optimizing and maximizing the comprehensive utilization of energy, including microalgal cultivation, coal gasification, biogas, combined supply system of cooling, heating and power, ground-source heat pump system, electricity storage, CNG gas storage, water treatment systems, photovoltaic power generation, intelligent buildings and other projects.

3.4. China Southern Power Grid Corporation
In order to transform into an Energy Internet enterprise, China Southern Power Grid (CSG) established CSG Energy Company, which strives to build a “3+N” business system. “3” denotes energy-saving, new energy, and comprehensive utilization of energy. “N” denotes electrical energy replacement, energy storages, carbon trading, and electric vehicles. Among them, the energy-saving business is mainly aimed at industrial and mining enterprises, focusing on energy-saving renovation and energy custody of urban buildings, rail transportation, road lighting, etc.. New energy and renewable resources development business accounts for the largest proportion, including photovoltaic projects, and offshore wind power generations. The energy comprehensive utilization business consists of the comprehensive utilization of coal, mine and gas as well as the comprehensive utilization of heat, cooling, and electricity. Furthermore, "Internet+" energy business includes the charging operation services for electric vehicles and demand side management, etc..

4. Summary of Energy Internet Construction Experience
In order to cope with the new challenges, new situations and new requirements of the international energy industry reform and development, traditional power companies have begun the practice of transforming and upgrading to build an Energy Internet companies [12].

With the gradual development of markets, policies, technologies and integrated energy service providers, the future comprehensive energy service business will undergo major changes in the market development, the business competition, the service model and the technology research and development. From the perspective of business competition, the integrated energy service market is shifting from technology-focused to customer-focused. From the perspective of interactive service model, the mainstream service model of integrated energy service business will change from a weak interactive service model based on things to a strong interactive service model based on relationship. From the perspective of technology development, the focus of integrated energy service technology research and development will change from integrated innovation that emphasizes the principle of optimizing technology and improving the efficiency of equipment operation, to integrated system innovation that emphasizes the integration of multi-source technologies and energy big data systems for customer needs.
After several decades of development, the comprehensive energy service market has formed a mature independent market segment. In contrast, China's comprehensive energy service market is still in its infancy. Learning from the experience of foreign comprehensive energy service development, we should consider the differences of national conditions, stages and market environment in the development of integrated energy services and Energy Internet [13].

5. Conclusion
As a solid foundation and core driving force of the third industrial revolution, Energy Internet technologies can promote the rapid transformation of the global energy structure, and ultimately achieve "clean alternative" and "electrical energy replacement" of the entire energy system.

This paper contrastively analyses the concept and characteristics of energy internet from a new perspective, summarizes the experience and enlightenment of domestic and foreign enterprises on the construction of Energy Internet, which provide references for the direction for enterprises to build an Energy Internet.

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