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Fusion between the Internet and Energy Systems: Morphology and Technology

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Abstract: Based on Internet technology and thinking, a new trend in energy systems development has emerged that promotes the deep integration of energy and information in constructing open and shared energy systems and ecosystems, with mutual complementation and optimization between multiple energy types and an interactive supply and demand relationship. In the context of the development of Internet technology, this paper expounds on the drivers and morphology of the fusion between the Internet and energy systems. Also, a three-level progressive thinking mode for the fusion morphology—from smart energy systems to transparent ones, and then to intelligent ones—is put forward. Finally, key technologies involved in the fusion of the Internet and energy systems are proposed.
Keywords: Internet thinking; Internet technology; energy systems; fusion

1 Introduction

Due to multiple pressures related to resources, the environment, and the climate, the transformation and upgrading of China's energy system have been included in the national strategy for an energy revolution. This strategy includes the decarbonization of the energy structure, improved cleanliness of fossil energy, greater control of total energy consumption, and more convenient energy services [1–4]. Applying Internet technologies and mechanisms to the transformation of the production, transmission, and consumption processes of the traditional energy industry, and the realization of the innovative "Internet plus" smart energy notion is an academic and engineering frontier that has drawn much attention in recent years.

Recently, the Internet has been widely used to transform traditional industries due to its convenience, open sharing of resources, and real-time interaction [5–7]. Compared with other fields, energy systems are relatively closed, and their transformation and innovation based on the Internet face a series of technical and industrial barriers [8–10]. Representative examples both locally and globally include the following: the United States developed a future renewable energy transmission and management system (the FREEDM system), proposed the concept of energy routers, and carried out prototype implementation [11]; the German Federal Ministry of Economics and Technology launched the E-Energy program to create an efficient energy system based on ICT technology [12]; and Japan has focused on the construction of a "digital grid," whose core lies in the development of power routers [13]. China has taken the energy revolution strategy and power system reform as an opportunity to initiate a wave of new research and practices related to "Internet plus smart energy" [14–16]. These include: the State Council issuing guidance on actively promoting the integration of the Internet, with an emphasis on the promotion of energy systems through the Internet, namely "Internet plus" smart energy; the National Energy Administration's National Development and Reform Commission launching the *Action Plan for Energy Technology Revolution and Innovation (2016–2030)*, which lists "Internet

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of energy" technology innovation as a key task; and the launch of a series of demonstration projects on the construction of the "Internet of energy." The exploration of the above measures has taken energy systems and the Internet in a new direction. However, the overall vision and implementation path for the integration of the Internet and energy systems is still lacking definition.

2 Drivers of the fusion of the Internet and energy systems

2.1 Promoting the energy supply revolution and improving new energy consumption

The energy supply revolution, which provides important support for the energy revolution, involves the clean and efficient use of coal, the development of alternative energy sources, and the formation of a multi-energy supply system that utilizes a combination of coal, oil, gas, nuclear, new energy, and renewable energy [17]. Facing the basic demands of the energy supply revolution, the goal of transforming and upgrading the energy supply systems is to increase the utilization ratio of renewable energy and adjust the energy utilization structure based on the increase in the proportion of new energy. As a result, the energy structure can be changed from high-carbon to low-carbon, solving the problems of the unsustainability of energy resources and environmental resource exhaustion. China's installed capacity of new energy is growing rapidly and it generates the most solar power in the world, but the current new energy consumption capacity must be improved. The traditional power grid has limited regulation capabilities, and in the face of the continuous penetration of new energy in the future, it may be unwise to rely solely on it for energy consumption. However, the integration of the Internet and energy systems will bring together common Internet technologies, such as cloud computing and big data, to enhance the flexibility of energy systems and utilize a high proportion of intermittent and distributed renewable energy to build sustainable and diverse energy supply systems.

2.2 Promoting the energy consumption revolution and improving the efficiency of comprehensive energy utilization

Transferring the traditional energy saving transformation at the source end to the user terminal is another important measure in the transformation and upgrading of an energy system. In a traditional power grid, improving the energy efficiency of power terminals entails general upgrading to more energy-efficient equipment and power-demand-side management. Power-demand-side management refers to the administrative, technical, or economic methods that power companies use to work with users to improve terminal power efficiency and change power usage. In recent years, China's user-side power efficiency improvement technology has developed rapidly, playing a vital role in saving energy and preserving the environment. However, there are still a number of problems, such as incomplete data on users' energy consumption and outdated equipment for controlling energy systems, that need to be solved. In addition to electricity, users also have demands for natural gas, heating, and cooling. If comprehensive optimization of these forms of energy can be carried out, the efficiency of comprehensive energy utilization will be further improved. The integration of the Internet and energy systems can enable the analysis of massive amounts of energy data and further enhance users' energy saving potential.

2.3 Promoting the energy system revolution and providing technical support for marketization

The energy system revolution is an institutional guarantee for the energy revolution. The energy system revolution proposes the creation of an effective, competitive market structure and market system, the formation of a mechanism that determines energy prices primarily based on the market, a shift in governments' regulation of energy, and the establishment of a sound energy rule system [17]. Reducing the commodity attributes of energy is key to achieving these objectives. Using market mechanisms and economics to guide energy production and consumption will effectively increase the efficiency of energy utilization.

Compared with a single power market, the opening of multiple energy markets will better allow for interoperability and the effective use of energy resources. The integration of the Internet and energy systems provides a technical environment in which, based on its open and shared nature, it is possible to break down the barriers of the industry and realize the transparency in energy information. In addition, by using big data technology to analyze all aspects of the energy flow, the integration of the Internet and energy systems can make it possible to perceive users' demands and provide technical support for the establishment of energy markets.

3 Morphology of the fusion of the Internet and energy systems

3.1 Basic description of the fusion morphology

A broad energy system includes five links: energy production, transmission, storage, conversion, and consumption. The various types of energy sources include primary energy sources such as coal, petroleum, gas, and renewable energy sources, and secondary energy sources such as electricity and hydrogen. An energy transmission network includes a grid, a natural gas network, and a cooling and heating network. The integration of Internet technology and energy systems refers to the realization of the monitoring and operational optimization of the entire energy system by utilizing the information acquisition and processing technology of the Internet. Also, the integration of Internet thinking and

energy systems is intended to promote industrial upgrading of entire energy systems through a shared and open Internet platform.

Fig. 1 depicts two networks in which the energy system is integrated with the Internet in the form of two overlapping circles. The overlap represents the degree of integration of the Internet and the energy system. The more the parts overlap, the deeper the integration. The gradual penetration of Internet technology and thinking into energy systems will gradually promote the integration of the Internet and energy systems. In addition to describing the degree of integration of the Internet and energy systems, this paper proposes a phased integration of the two—described in detail later.

3.2 Fusion morphology 1: Smart stage

The smart stage is the primary form of integration between the Internet and energy systems. Fusion morphology involves the following: the use of a large-scale, long-distance, AC-DC transmission system as a carrier to realize cross-regional, large-scale resource allocation of fossil energy and renewable energy; the development of distributed grid energy systems to achieve a high proportion of renewable energy consumption and reduce the abandonment of wind and solar energy; and, based on highly automated and intelligent assisted decision-making, the improvement of power transmission capacity, operational reliability, and the safety and stability of the power grid to avoid large-scale blackouts.

Specifically, the key path to the realization of this phase involves promoting the application of big data technology in energy systems, and improving the intelligence level of energy systems using big data technology. On the energy production side, big data technology and the integration of multi-dimensional information about meteorology, geography, the environment, and energy, can be used to more accurately understand the output of renewable energy and achieve a higher proportion of it in the energy mix. Also, these developments can support the optimization of the energy structure. On the energy consumption side, we should pay attention to the promotion and application of smart meters. By obtaining users' energy usage information through smart meters and big data technology, we can fully tap the potential of users' energy saving efforts and guide them through the development of high-quality energy use plans.

3.3 Fusion morphology 2: Transparent stage

Transparency is a further upgrade of the integration of the Internet and energy systems from the smart stage. A transparent energy system uses advanced Internet technologies, such as chip sensing, to achieve information monitoring and real-time observation of all types of equipment involved in energy production: transmission, conversion, and storage. This enables the operational information on the equipment, energy system, and energy market to be shared transparently and equally. It is the intermediate developmental form of the energy system under the deep integration of the Internet and technology of the "energy of Internet".

Specifically, the key path to the realization of this stage

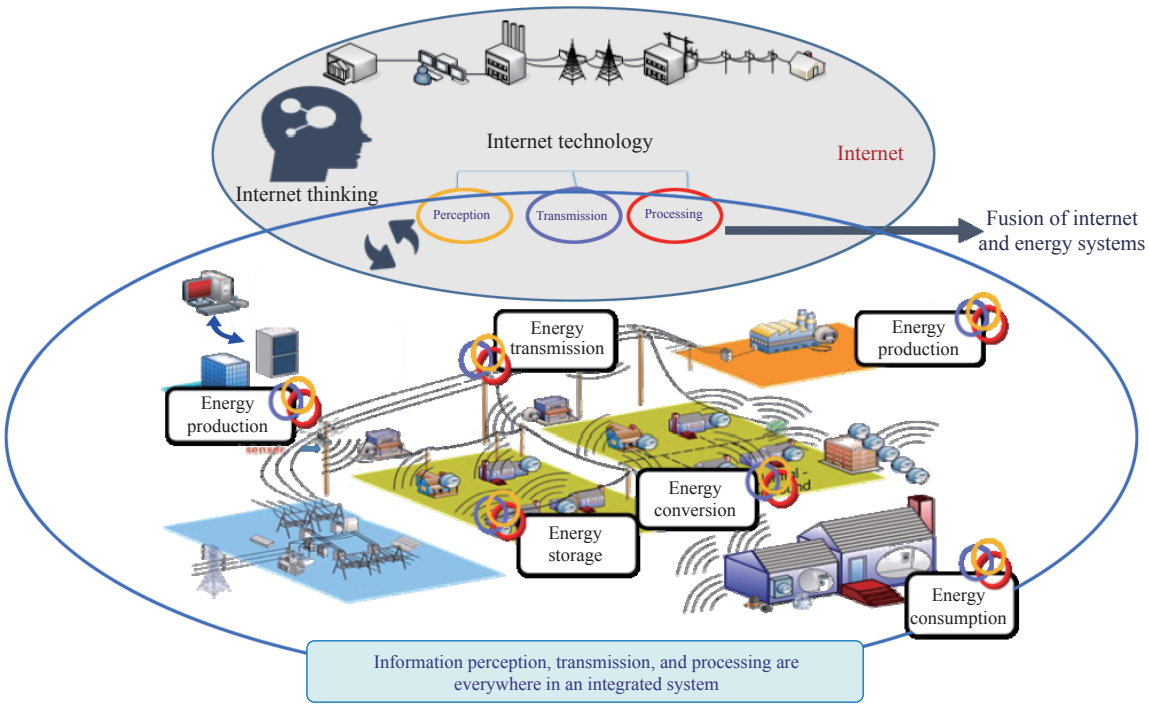

Fig. 1. Schematic diagram of the fusion of the Internet and the energy system.

is the development of chip sensing and intelligent decision-making technologies. A transparent energy system has advanced information sensing and processing technologies that make the current state of the grid and energy network readily observable. Moreover, the application of intelligent decision-making techniques in energy systems, such as artificial intelligence, makes the state of the entire energy system highly visible, controllable, and optimized.

3.4 Fusion morphology 3: Intelligent stage

The intelligent stage entails an advanced form of integration of the Internet and energy systems. This stage achieves the following: a high proportion of renewable energy connected to the energy system based on intelligent energy equipment and control technology; the integration of production and sales on the user side to make energy production, transmission, conversion, consumption, and trading tend toward zero marginal cost; optimal energy system efficiency and the maximization of energy value; and, finally, the formation of a ubiquitous energy network that is smart, deeply optimized, and highly reliable, with energy being ubiquitous.

Specifically, the key path to the realization of this stage is to establish an energy trading market based on the Internet platform and to promote the transformation and upgrading of the energy industry. On one hand, energy systems can be supported by Internet-based information platforms to fully realize the intelligence of the entire energy system. That is, new energy sources such as solar and wind energy can be plug-and-play, energy demands can be met, and energy can be used anywhere, any time. On the other hand, it is necessary to combine energy systems and the Internet platform to expand a variety of new energy business models, such as energy futures, energy group purchases, energy customization, energy reviews, etc., to activate the energy industry and form new areas for economic growth.

4 Technical system for the fusion of the Internet and energy systems

To promote the integration of the Internet and energy systems, it is necessary to first strengthen the development of energy information support technology. Second, it is necessary to pay attention to the application of Internet technology and thinking in the production, transmission, and consumption of energy. The key technical system is shown in Fig. 2.

4.1 Information support platform

The information support platform, which includes technologies for Internet infrastructure construction, information perception, processing, interaction, and security, is an important technology for the integration of the Internet and energy systems.

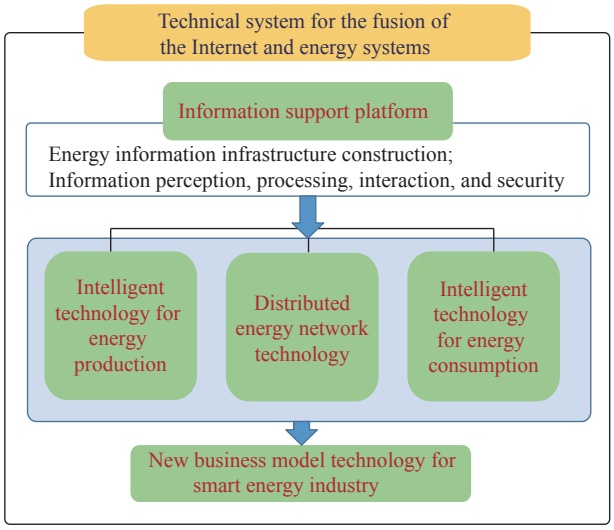

Fig. 2. Technical system for the fusion of the Internet and energy systems.

In terms of infrastructure construction, the information system requires a fiber-to-the-home energy information transmission to promote social resource sharing and break through the "last mile" bottleneck that is characteristic of information networks.

In terms of information perception technology, the development of fiber-optic temperature sensors and chip-level sensing technology must be strengthened, and their popularization and application must be realized in practical engineering. It is important to carry out research on optical fiber sensing technology based on nano-optics and a state detection system for all optical fiber equipment based on optical fiber sensing technology to realize instantaneity, accuracy, and completeness in monitoring the results of data collection, to promote the development of information perception technology, and to realize the transparency of information in the energy system.

In terms of information processing technology, research must be carried out on cloud computing and big data technologies, including virtualized application technologies that support information construction and key technologies for the application of enterprise cloud platforms. Furthermore, it is important to carry out research on big data technology, including analyses based on mass information mining technology, and to establish "intelligent, efficient, reliable, and green" data management systems through intelligent technology. In addition, it is necessary to study high-performance computing technology and develop a basic environment simulation platform for high-performance computing. Through virtualized, standardized, and automated means, the hardware and software resources of energy systems are integrated organically, effectively supporting the reliable and effective transmission, storage, and processing of basic data.

It is crucial to promote the application of mobile Internet for enhanced information interaction technology. Through informa-

tion exchange on multiple platforms such as handheld terminals, servers, and personal computers, the energy business, management, and services are mobilized, informationized, electronified, and networked. Research must also be conducted on the application of artificial intelligence in information interaction technology. Through artificial intelligence technology, the intelligent interaction interface between humans and energy systems can be realized, enabling energy systems to be adjusted to improve their operating efficiency and best meet the needs of users.

In terms of information security technology, it is necessary to carry out research on cloud security systems to solve the security problems faced by cloud computing in practical applications, including cloud security technology, management, and evaluation detection, to ensure the stable operation of cloud computing systems. The security architecture for the Internet of things for energy systems must be built and research should explore the application of an information security system for the Internet of things. Additionally, there is a need to plan the data security systems on the client side and solve the security protection problems caused by the blurring of system boundaries due to cloud computing and the mobile Internet.

4.2 Energy production intelligentization technology

4.2.1 Establishing an open, shared, standard, and integrated public service network for energy production information

In the future, an open, shared, standard, and integrated public service network for energy production information should be established to provide an information platform for all aspects of energy production, transmission, and consumption. “Open” means it can be freely accessed by all users across the entire energy production chain, who can then access energy production information at any time. “Shared” refers to information such as the operational status of the energy production, transmission, and consumption, and the transaction interaction, which can be transmitted and obtained through links and without barriers. “Standard” means that the exchange of energy data must be achieved through standardized data sharing protocols. Finally, “integrated” indicates that the energy service network integrates the monitoring, operation, management, and scheduling of energy production.

4.2.2 Big-data-based intelligent scheduling technology for renewable energy power generation

To increase the consumption of new energy and reduce, or even avoid, the phenomenon of wind and solar curtailment, an intelligent scheduling technology for intermittent generation should be established based on device status data, power system operation data, meteorological data, and other multi-source forms of data. In addition, high-precision new energy generation prediction methods should be studied through data mining and intelligent analysis methods based on multi-source data. An adaptive intelligent random scheduling strategy could be studied by synthesizing the data on the new energy power supply and the operation of power systems. Furthermore, considering the spatial and temporal distribution characteristics of renewable energy, a centralized decision and distribution control method for renewable energy should be studied further.

4.3 Distributed energy network technology

4.3.1 Energy management technology based on the Internet and big data

Energy management technology can use the Internet and big data platforms to build adaptive and distributed multi-energy systems. The energy management system of the flow energy network realizes the coordinated operation and optimal allocation of energy resources for electricity, gas, heating, and cooling. To establish an energy management system that is adapted to distributed multi-energy networks, some key technologies are used, including an intelligent advanced measurement system to achieve accurate measurement, data analysis, information interaction, and real-time settlement. Intelligent scheduling technology is also utilized to take into account the historical behavior and real-time status of intermittent power supplies and random loads and to integrate multi-network information on electricity, gas, heating, cooling, and intelligent transportation. On this basis, the intelligent scheduling potential prediction and mining technology for matching source-loads have been studied. Research has also been conducted on energy optimization scheduling technology for the production, transmission, consumption, storage, multi-energy flow in a distributed energy network to achieve the complementarity of diverse energy resources and the coordinated management of the energy supply.

4.3.2 Information transparency in distributed energy systems

The information transparency technology of distributed energy systems includes using advanced “Internet Plus” technology to realize information monitoring and real-time visualization of various types of equipment in distributed energy systems, so that equipment operation information, energy system operation information, and energy market information can be transparently shared and easily accessed. Using the massive amount of real-time status data generated through information transparency, this technology can perform intelligent scheduling decisions and support extensive access to accurate power generation predictions related to renewable energy. Additionally, it can realize a high proportion of renewable energy consumption, scientifically distribute the demand-side load, and extract key information for state estimation and fault identification. A transparent distributed energy system is also supported by information transparency equivalence, which can promote nearby transactions and

acquisitions of distributed energy. Users gradually become the producers and sellers of energy, promoting energy transactions and value-added services through Internet trading and sharing.

4.3.3 Ubiquitous distributed energy network

The ubiquitous distributed energy network is a deep fusion of energy and information systems. It features all-access devices in the energy network and secondary devices like node units in the information network. These have the characteristic parameters of storage devices and can monitor in real-time and record their own running state and parameters. According to unified communication rules and protocols, information can be fully shared and interacted within the small and micro energy network through the Internet of things. A ubiquitous distributed energy network provides highly flexible accessibility, scalability, and breadth and security of information sharing for access devices. Therefore, it can adapt to the access of all kinds of micro energy sources and break time and space restrictions to realize energy use at any time, anywhere. The key technologies in a ubiquitous distributed energy network include sensor, data transmission, and embedded system technology. With sensor technology, the terminal information needs to be accurately obtained at any time through sensing technologies such as radio frequency identification. Data transmission technology is the transmission of information through wired or wireless networks to terminals. Embedded system technology sorts and processes received information using integrated computer software and hardware, as well as integrated circuit technology.

4.4 Energy consumption intelligentization technology

4.4.1 Energy trading and multiple interactions based on the Internet platform

To achieve fairness, liberalization, and transparency in information sharing and transaction interactions among the various market entities, an energy trading and energy service platform, based on the characteristics of energy exchange and the multi-element interaction of the Internet, should be established. Its establishment should take advantage of the features of information sharing and real-time interaction on the Internet. This service platform would be for energy suppliers, energy users, big data service providers, and other multi-dimensional entities. Its key technologies would include building an online energy trading business platform for PC and mobile to provide real-time access and interaction channels; and establishing various types of energy customer management systems for providing technical support for new service forms, such as the public release of energy and resources information, reasonable and accurate matching of energy and resources, and personalized customization of energy and resources. These various customer management systems would help with conducting customer marketing statistical analysis, mining and tracking potential customers, establishing digital information files of "green energy" and "green power" for customers, and providing value-added services such as a personalized information customization service and energy optimization solutions, among others.

4.4.2 Efficiency management and demand-side responses based on data mining

With big energy data as the core, in-depth exploration and analysis are carried out around the energy characteristics of the user side, the energy efficiency level, scheduling potential, and other problems, to realize integrated control, optimization, diagnosis, maintenance, and other types of comprehensive energy efficiency management. Through intelligent metering and Internet of things technology, data collection, processing and displaying of energy equipment, household distributed power supply, and energy storage systems are realized. A real-time scheduling system, considering the optimization of configurations for battery storage and the orderly charging and discharging of electric vehicles, was established to make the user-side load flexible, meet the demand of peak load, and provide peak load shifting and grain filling response capability. To achieve energy efficiency management, big data technology should be used to excavate user-side energy features. Additionally, based on cloud computing and intelligent decision-making technology, users' energy behavior characteristics (like user behavior patterns and adjustable potential) are identified and the energy market is linked in real-time to participate in the demand-side response with the goal of reducing energy costs and improving energy efficiency.

4.5 New business model technology for the smart energy industry

4.5.1 Promote "resource" integration of four networks based on power fiber to the home

The integration of information resources from telecommunications networks, the Internet, radio, and the power network based on power optical fiber technology is encouraged. Power fiber to the home refers to the use of the optical fiber load low-pressure cable (OPLC) and other cables used in low-voltage communication, which can enable access to meters and homes. With the characteristics of high precision and fast transmission of optical fiber data, the collection of users' carrying information is realized. It integrates optical fiber and power transmission and distribution to avoid secondary wiring and reduce the cost of information reaching the "last mile" of users. Multiple services, such as interactive network television, Internet, and phone can be realized on a single transmission line by using OPLC in conjunction with corresponding devices and components.

4.5.2 Development of the business model of electric vehicles to realize cross-border integration

As a new technology, the new business model created by

the large-scale marketing of electric vehicles has promoted the cross-border integration of energy, transportation, finance, and the Internet. The establishment of a comprehensive information management system for charging stations can make charging estimation possible, which can also open up a charging business model and mobile terminal management. The electric vehicle model can be utilized to improve the integration of infrastructure between energy and transportation networks and to improve the universality and diversification of service subjects. To realize the consumption–electronic business model, it is necessary to build an ICT platform and enhance the connection and interaction between the participants in the value chain of electric vehicles. The perfect integration of electric vehicles and electric power systems has become one of the core matters of the intelligent energy system and has played multiple roles in it.

4.5.3 Value-added service technology for energy systems

The new business model refers to developing value-added energy services such as online operation and maintenance, energy customization and leasing, energy financial services, and media advertising services based on Internet data processing. Based on intelligent user equipment operation data, the operation and maintenance company can manage the user's power generation equipment online, reduce the failure rate and the need for door-to-door maintenance, and greatly improve the operation and maintenance production efficiency. According to users' needs and energy consumption characteristics, providing customized and professional energy services to users can improve asset utilization efficiency. Based on the integration of energy and financial resources, we will continuously integrate the advantages of the energy and finance sectors, thus to realize the optimization and development of the energy industry. Through various channels, such as an energy management platform and an intelligent transportation platform, the effective analysis and management of customer group information and accurate advertising can be achieved.

5 Conclusions

The integration of the Internet and energy systems is the Internetization of the energy industry, which will allow an intelligent upgrade of the traditional energy industry. Realizing the intelligent new energy on the supply side is conducive to large-scale new energy consumption, while supporting intelligent energy on the demand side can improve energy efficiency. Achieving intelligence in the energy network will help ensure multi-functional complementarity and new energy plug-and-play. Additionally, based on Internet technology and the Internet platform, it can promote energy market reform, restore energy commodity attributes, drive energy industry upgrades, and create new opportunities for economic growth.

Guidance at the policy level is also necessary to achieve the integration of the Internet and energy systems. For example, we should strengthen the supply-side structural reform of multi-energy networks and make up for the shortcomings of the infrastructure of energy physics and the information interconnection of multi-energy resources. It is important to further liberalize the market for energy users, on the distribution and demand sides, and strengthen the top-level design of the industry. Finally, there is a need to improve market laws and regulations, form long-term mechanisms, speed up the formulation and improvement of laws and regulations related to the energy industry market, and pilot a negative list system for the energy industry market.

References

[1] Zhang D X, Yao L Z, Ma W Y, et al. Development strategies of smart grid in China and abroad [J]. Proceedings of the CSEE, 2013, 33(31): 1–14. Chinese.

[2] Li L C, Zhang Y J, Chen Z X, et al. Merger between smart grid and energy-net: Mode and development prospects [J]. Automation of Electric Power Systems, 2016, 40(11): 1–9. Chinese.

[3] Swaminathan M, Tarun D. Diffusion of innovation model of consumer behaviour—Ideas to accelerate adoption of renewable energy sources by consumer communities in India [J]. Renewable Energy, 2012, 39(1): 162–165.

[4] Liu J P. Development of the energy supply and demand pattern of China under the constraints of resources and environment [D]. Beijing: North China Electric Power University(Doctoral dissertation), 2013. Chinese.

[5] Huang Y J, Zhu Y Q. Analysis of development trend and technology of new generation Internet [J]. Telecommunications Science, 2013, 29(4): 1–6. Chinese.

[6] Dong D H, Fan Z L. Internet thinking [J]. Science-Technology and Management, 2016, 18(6): 1–8. Chinese.

[7] Wang J Y, Meng K, Cao J W, et al. Information technology for energy Internet: A survey [J]. Journal of Computer Research and Development, 2015, 52(5): 1109–1126. Chinese.

[8] Zhang Y J, Chen Z X, Cai Z X, et al. New generation of cyberenergy system: Energy Internet [J]. Electric Power Automation Equipment, 2016, 36(9): 1–7. Chinese.

[9] Tian S M, Luan W P, Zhang D X, et al. Technical forms and key technologies on energy Internet [J]. Proceedings of the CSEE, 2015, 35(14): 3482–3494. Chinese.

[10] Sun H B, Guo Q L, Pan Z G. Energy Internet: Concept, architecture and frontier outlook [J]. Automation of Electric Power Systems, 2015(19): 1–8. Chinese.

[11] Huang A Q, Crow M L, Heydt G T, et al. The future renewable electric energy delivery and management (freedm) system: The energy Internet [J]. Proceedings of the IEEE. 2011, 99(1): 133–148.

[12] Vermesan O, Blystad L C, Zafalon R, et al. Internet of energyconnecting energy anywhere anytime [J]. Active Learning in Higher Education, 2011, 11(11): 189–200.

[13] Boyd J. An Internet-inspired electricity grid [J]. IEEE Spectrum, 2013, 50(1): 12–14.

[14] Sun Y, Xu P, Shan B G, et al. Road map for "Internet plus" energy substitution in electricity retail market reform in China [J]. Power

System Technology, 2016, 40(12): 3648–3654. Chinese.

[15] Li L C, Zhang Y J, Xu M. Morphological evolution of energy system and development of distributed energy in China [J]. Distributed Energy, 2017, 2(1): 1–9. Chinese.

[16] Yu X D, Xu X D, Chen S Y, et al. A brief review to integrated energy system and energy Internet [J]. Transactions of China Electrotechnical Society, 2016, 31(1): 1–13. Chinese.

[17] Liu L H, Zhong S M. Energy revolution——Grasp study “forth revolution” & “one cooperative” [J]. Gas Turbine Technology, 2016, 29(1): 1–8. Chinese.