Power Line Communication Challenges in the Energy Internet

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Abstract. Energy Internet is a new hot topic in the research of industry and academia at home and abroad. It is also the development direction of the energy industry, and it is possible to innovate the way of human life. The paper summarized the concept and connotation by surveying the domestic and international development of the Internet of Energy. The information technology architecture of the Internet of Energy is reviewed from the perspective of the integration of energy system and information technology. This article described the characteristics of power line carrier communication, and analyzed the role and status of power line carrier communication technology in the Internet of Energy. The challenges and opportunities that power line carrier communication faces in the Internet of Energy are analyzed. In the end, this paper discussed the future development of Internet of Energy. Through the “Internet +” technology though, it will integrate advanced information technology and energy systems, coordinate multi-energy networks, innovate energy system operation modes, promote industrial upgrading, and generate new economic growth points.

1. Introduction

Energy is an important material foundation of the national economy. The future of the country depends on the control of the energy. The development and progress of mankind have relied on the use of energy, and the use of energy has greatly improved social productivity, promoted the progress of human civilization, and changed people's lifestyles. Throughout every industrial revolution, it is always accompanied by tremendous changes in energy utilization. During the first industrial revolution, the large-scale utilization of coal, oil and natural gas provided sufficient impetus for social development. The second industrial revolution made electricity gradually become a new energy resource to replace steam energy, and the use of electricity energy greatly promoted the development of productivity and technological progress. It caused revolutionary changes in the economic, cultural, political, and technological fields of human society. Nowadays, the third industrial revolution is happening quietly. This third industrial revolution driven by the large-scale application of information and communication technologies, new materials and Internet technology will definitely cause innovation in energy consumption and utilization.

Energy Internet is a nascent thing that integrates new technologies and energy systems. So its concept, characteristics, architecture and other key technologies are all frontier topics that are still under discussion and development. This paper first combs the development history of Energy Internet...
at home and abroad, trying to summarize the concept and characteristics of Energy Internet. Then, by analyzing the architecture of the Energy Internet, the advantages and characteristics of power line carrier communication in the Energy Internet are explained. The role of power line carrier communication in the Energy Internet is briefly described. Combining the characteristics of power line carrier communication, this paper analyses the opportunities and challenges faced by power line carrier communication technology in the background of the Energy Internet. In the end, this paper looks forward to the future development path of energy Internet.

2. Development History of Energy Internet at Home and Abroad

In 2004, "The Economist" magazine first proposed the concept of the Energy Internet in an article. That article proposed to transform the traditional power grid with reference to the characteristics of the Internet, and build it into a digital network with self-healing capabilities, intelligence, rapid response, and support for distributed power generation and energy storage. Then countries around the world began extensive research on the Energy Internet.

2.1. America

In 2008, the United States initiated the FREEDM (Future Renewable Electric Energy Delivery and Management) project[4], funded by the National Science Foundation. The National Science Foundation established the FREEDM research center. The purpose of the FREEDM system is to build a revolutionary intelligent power grid architecture. Support the grid to absorb a large amount of distributed energy through high-speed broadband communication technology and modern electronic power technology. By optimizing the "source-grid-load-storage" operation of the power grid, the efficient use of renewable energy can be achieved. The feature of the FREEDM project is the use of electronic power technologies such as solid state transformers[5,6]. It refers to the router in Internet communication and puts forward the concept of energy router. The energy router can realize the bidirectional exchange of energy and the sharing of energy information. The FREEDM project is mainly to carry out Energy Internet research based on the integration of information technology in the medium voltage distribution network. The system architecture of the FREEDM project is shown in Figure 1.

2.2. Germany

In the same year that the FREEDM project was launched in the United States, in 2008, the German Federal Ministry of Economics and Technology and the Ministry of Environment launched the E-Energy project plan[7]. The project is based on ICT (Information and Communication Technology,) to build an Energy Internet System, called IOE (Internet Of Energy, IOE). As shown in Figure 2. The E-Energy plan lasts for 4 years and 6 demonstration projects are selected. Among the 6 projects, the
The eTelligence project is chosen in Cuxhaven, where is rich in wind energy resources. The eTelligence project studies the automatic adjustment of wind power and heating load demands. It introduces the concept of virtual power plant to centrally manage distributed power sources and loads; The Meregio project uses ICT technology to analyze the real-time load of users uploaded by smart meters, and the efficiency of the grid is improved through flexible and real-time adjustment and configuration of resources; The Moma project builds a virtual energy market to study consumer participation in energy management, and proposed a concept of cellular grid[8]. The purpose of the RegModHarz project is to achieve the effect of optimizing and recycling renewable resources by coordinating and scheduling renewable resource power generation and pumped energy storage power stations.

2.3. Japan
In 2011, Professor Rikiya Abe of the University of Tokyo established a "Digital Grid Alliance" with members including Hitachi Yokohama Research Laboratory, National Instruments and NEC. They successfully demonstrated a key technology of the Energy Internet - DRG[9] (Digital Grid Router, DRG). The digital grid is composed of multiple DRG connections. DRG manages the power in a certain area. Power generation, power consumption and storage devices and digital routers in a certain area composed an independent microgrid ("cell"). In this microgrid, different generators, power converters, storage devices and other grid distributed generation infrastructure are assigned "IP addresses" by DRG. Each device in the power grid can be identified and dispatched through the "IP address". Through unified digitization, the power energy system and the information control system are virtualized and integrated. The structure of the digital grid is shown in Figure 3.
2.4. China

In 2012, the first domestic Energy Internet Development Strategy Forum was held, which initially discussed the basic concepts and connotations of the Energy Internet. In 2013, the State Grid Corporation of China pointed out that the future smart grid is the "Energy Internet", which has the characteristics of a strong grid, extensive interconnection, high intelligence, and open interaction. In July 2014, at the IEEE Electric Power and Energy Association Annual Meeting held in the United States, the State Grid Corporation of China proposed the concept of the Global Energy Internet[10]. They pointed out that the Global Energy Internet is a smart grid with UHV power grid as its backbone. It is a smart grid that can be interconnected across states, countries, and regions. It is a smart grid that is based on clean and renewable energy sources such as hydropower, wind power, and solar energy, and can be delivered to users around the world [10]. In April 2015, Tsinghua University established the Energy Internet Innovation Research Institute to study the morphological characteristics, key technologies and standards of Energy Internet. In July 2017, the National Energy Administration announced the first batch of 55 "Internet +" Energy Internet demonstration projects, marking China's official start of the Energy Internet pilot construction.

3. Energy Internet concept and architecture characteristics

3.1. The connotation and characteristics of the Energy Internet

Regarding the concept of the Energy Internet, from the perspective of its development at home and abroad, the Energy Internet is an innovation in a multidisciplinary field. Although each country has a different focus on the development of the Energy Internet, this can be understood as the development method of the Energy Internet at different levels. But in essence there are common connotations and characteristics. In summary, the Energy Internet has the following connotations and features:

- the power system and smart grid have become the core of the Energy Internet. However, the Internet of Energy is not equivalent to a smart grid, and is more open and interconnected than a smart grid. It can realize the interconnection of multiple energy sources and the bidirectional conversion of renewable energy.

- A large number of renewable distributed energy power generation equipment and distributed power storage devices are connected to the grid to form a new power network, which is decentralized, intermittent and "plug and play". The virtual power plant based on the “Internet +” concept can coordinate and optimize the dispatch of distributed power generation, energy storage systems and user loads through the Energy Internet.

- Advanced information and communication technology, big data analysis and Internet technology are applied to the whole process of energy production, transmission and consumption, realizing intelligent management and optimization of all aspects of power, balancing the volatility and randomness of renewable energy power generation, and users widely participate in energy production and consumption.

- Energy router[11] uses advanced electronic power technology to become the core equipment of the integrated Energy Internet infrastructure. It integrates energy flow and information flow, and can control the bidirectional flow of energy flow through information flow in the equipment.

3.2. Architecture of Energy Internet

The architecture of the Energy Internet is shown in Figure 4. Energy Internet is a "wide area network" [12] with high integration of energy and information built with the concept of "Internet +". The Energy Internet takes the smart grid as the "backbone network". Through the advanced information technology such as big data and cloud computing, the energy and information integration platform is built to truly realize the real-time dynamic balance adjustment of energy. The energy Internet architecture shown in Figure 4 is also applicable to a "local area network" in the form of a microgrid.
composed of distributed energy sources. It uses information technology to control the nearby consumption and storage of distributed energy.

Fig 4 The architecture of the Energy Internet

The real-time dynamic control of energy and information relies on the integration of cyber-physical systems\cite{13}. The physical information integration of the Energy Internet can be divided into three stages. The first stage is the information collection and digitization stage. A large number of Internet of Things devices are connected to collect the data of the Energy Internet to the information data center to facilitate online monitoring and real-time troubleshooting. The second stage is the intelligent stage, which uses big data and AI technology to mine massive data to realize intelligent power and energy monitoring and distribution. The third stage is the fundamental integration stage of energy information, to realize the automation and intelligent distribution of electric energy, form a multi-energy collaborative management system, and build an open Energy Internet energy trading platform.

4. Power line carrier communication technology
In the first stage of the development of Energy Internet, the collection of massive data and information is completed through the Internet of things and mobile Internet composed of various sensors, distributed generation and energy storage equipment. Power line carrier communication plays an important supporting role in the power grid because of its unique advantages, such as relying on the power grid, no need to rewire the network, plug and play.

4.1. features of power line carrier communication
Power line carrier communication is a kind of communication technology which uses power line as communication transmission channel for data transmission, which meets the requirements of energy and information integration facilities of Energy Internet. Due to the high coverage rate of power line network, power line carrier communication has the advantages of no need to rewire, convenient and flexible, and low communication cost. Therefore, power line carrier communication has become one of the most advantageous solutions to solve the problem of a large number of sensors, distributed power and energy storage equipment connected to the Energy Internet.

However, the construction of the power network is not for the transmission of communication information but the transmission of power energy, so its network topology may not be the optimal path for power line carrier communication; and the power line as a data transmission channel has weaknesses such as poor transmission characteristics, that is, power line channel has strong time-varying, frequency selectivity and multipath effect is obvious\cite{14}. In recent years, with the development of modern communication technology, low-voltage power line carrier communication has gradually become a hot research topic in the field of electric power. There are mainly two aspects in solving the reliability of power line carrier communication.
4.1.1. Research on power line channel characteristics
The research focus of power line channel characteristics is noise research and modeling \[16\]. Due to the mismatching of input impedance of power line and the random access of a large number of electrical equipment, all kinds of random and complex noises are produced. They are mainly divided into several categories as shown in Figure 5: coloured background noise, narrowband interference noise, periodic noise synchronized with power frequency, periodic noise asynchronous with power frequency, and sudden single event random impulse noise independent of frequency.

$$X(t) + Y(t)$$

narrowband noise random impulse noise

coloured background noise

periodic noise synchronized with power frequency

periodic noise asynchronous with power frequency

Fig 5 Power line channel model

4.1.2. Power line carrier communication networking technology
There are not many researches on power line communication application layer networking algorithms. The main method is to ensure the reliability of communication by adding relay nodes. However, the static designation method is often used to determine the relay node, which is not ideal for power line channels. When the power line channel noise is complex and the attenuation is large, the success rate of point-to-point communication between two nodes is very low. When the network scale becomes larger, the number of communication links between nodes increases exponentially. Dynamic selection of relay nodes has become a research hotspot in networking technology \[20\]. The main methods of power line communication network optimization are: ant colony algorithm; spanning tree routing algorithm based on graph theory; cluster routing algorithm. Among these algorithms, the ant colony algorithm is a random search algorithm. The ant colony algorithm simulates the foraging behavior of ants. The detection package simulates artificial ants. The artificial ants distribute the pheromone on the detection path it passes. When multiple iterations meet the requirements, The path with the highest pheromone in the statistical results is the optimal path of the communication route.

4.2. Challenges faced by power line carrier technology
With the access of a large number of distributed generation and massive sensors, the information flow of Energy Internet will grow exponentially. Therefore, power line carrier communication will be an important technical support for Energy Internet access network, especially in remote mountainous areas or other complex industrial environment where communication networks are not suitable. Power line carrier communication can achieve low-cost, fast and flexible communication network coverage. Under the background of Energy Internet, new services bring more challenges to power line carrier communication.

At present, high-speed and low-voltage broadband power line carrier communication is mainly used in "local area networks" such as smart homes. The frequency band of high-speed broadband power line carrier communication is mainly concentrated in 3~30MHz, and the available frequency spectrum of the frequency band is not continuous due to various narrowband noises, while power line carrier communication The capacity is closely related to spectrum utilization and bandwidth. The access of massive sensors, power distribution terminals and other equipment in the Energy Internet brings huge challenges to the bandwidth of power line carrier communication.

In terms of the safety and reliability of the Energy Internet, power line carrier communication also faces huge challenges. On the one hand, it is reflected in reliability. In terms of collaborative real-time
processing of energy production, transmission, consumption, and storage, communication failures directly affect the safe operation of the power grid. On the other hand, it is reflected in the security of communication. The open and sharing characteristics of the Energy Internet increase the risk of malicious attacks. Similar to attacks on the Internet, it may cause communication failures, leakage of user data and power grid system data, and even direct attacks on the power grid, tampering with power grid data, and endangering the safe operation of the power grid.

Research on the application of forward error coding and adaptive modulation and demodulation to power line carrier communication can improve the reliability of communication and the efficiency of bandwidth spectrum utilization. Using advanced information technology (ant colony algorithm, genetic algorithm, adaptive control theory, etc.) can improve the networking capabilities of the power line carrier communication system. It is one of the directions to solve the problems caused by the large-scale equipment access brought by the energy Internet. The progress of semiconductor technology can improve the baseband processing speed of power line carrier communication. The improvement of modulation and coding rate and RF performance will bring significant improvement to reduce the transmission delay of power line carrier communication. Finally, the security encryption method and reliability protection mechanism of the physical layer and application layer data of power line carrier communication will definitely become an important research topic in the communication technology of the Energy Internet access network.

5. Conclusions
Energy Internet will change the whole link of energy production, transmission, storage and consumption, forming a situation of coordinated development of centralized and distributed complementary; Energy Internet will realize real-time tracking and monitoring of energy flow by increasing the dimension of information flow. Ultimately improve the overall efficiency of energy conversion and promote industrial upgrading.

Starting from the development process of Energy Internet, this paper first analyzes the development status of Energy Internet technology in various countries at home and abroad, and concludes that European and American countries have different emphases on the construction of Energy Internet. Experts and scholars in China also have hundreds of opinions on the concept of Energy Internet, but they have a basic consensus on the connotation and characteristics of Energy Internet. Then it summarizes the characteristics of Energy Internet and analyzes the architecture of Energy Internet, and gives three stages of Energy Internet development. Information and communication technology is the key technology of Energy Internet, and power line carrier communication technology is an important supporting technology to realize the first stage of Energy Internet energy informatization. In this paper, combining the characteristics of power line carrier communication, the challenges and research directions of power line carrier communication under the Energy Internet are explained.

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