Research on the Development of the Ubiquitous Power Internet of Things

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Abstract. The dawn of the new century has witnessed the tremendous advancement of society. In response to the requirement of the progress of technologies and enterprise development, the Ubiquitous power Internet of things (UPIOT) is boosting to develop and playing a significant role in China’s power grid which not only connects all aspects of the power system, but also promotes the application and innovation of various new techniques. As time goes by, UPIOT has been the key part to realize the transformation of energy production and consumption which will achieve green and healthy progress of power grid. This paper analyses in detail the concept, main characteristics, construction goals and existing problems of the UPIOT. Besides, the key technologies that contain the big data, cloud computing, the internet of things, 5G, blockchain, artificial intelligence and other technologies are also proposed. Furthermore, this paper introduces different application scenarios of UPIOT and offers some suggestions to accelerate the development of UPIOT.

1. Introduction
China has a vast territory and abundant natural resources which have become advantage factors to economic growth. However, the level of resources possessed by different regions varies widely.

Figure 1. China's generators installed capacity and year-on-year growth rate
For one thing, the mineral resources are mostly distributed in underdeveloped regions. For another, industrial and energy consumption are concentrated in the eastern coastal areas [1]. Figure 1 shows that China's generators installed capacity and year-on-year growth rate.

In Figure 1, non-fossil energy power generation has accelerated growth that means the government has promoted the development of clean energy and the end-use energy electrification level. Although China's power grid is developing, it still faces some problems and challenges. For instance, the coordination issues between power supply and grid, power transmission as well as distribution. In addition, there are still problems such as abandoning water, wind and light in clean power generation. So the power system still needs to be reformed continuously [2-5].

According to the data of the National Bureau of Statistics [6], the power installation structure of China in 2019 is shown in Figure 2.

![Figure 2. Structural Chart of China Electric Power Installation in 2019](image)

At present, China's wind power installed capacity, photovoltaic and electric vehicle ownership rank first in the world. In [7], the 2019 edition of the BP World Energy Outlook is expected that world will continue to be electrified and power consumption is going to grow strongly in 2040. By then, the global power generation structure may undergo substantial changes. Renewable energy will become the largest source of electricity that will account for about 30% of the global power generation industry.

The construction of the UPIOT is going to improve the overall equipment’s intelligence level of the power grid system comprehensively. It could use a variety of modern technologies to build an energy ecosystem [8]. In the future, the data generated by terminal equipment will be more timely interacted. Then the existing energy consumption model and grid management model will change, too. This article introduces the concept and system of the UPIOT, analyses the existing problems as well as the related technologies. Besides, the application scenarios and some advice are also proposed.

2. The concept and main characteristics of UPIOT

2.1. The definition of UPIOT
Ubiquitous linkage refers to the connection and interaction of information between people and things no matter when and where. The ubiquitous power internet of things refers to the interconnection and interaction of many parts which is consisted of the power users, the equipment, power grid enterprises, power generation enterprises, suppliers, people as well as things.

2.2. The main characteristics of UPIOT
The UPIOT has the characteristics of ubiquity, intelligent, platform and sharing.
Ubiquity refers to the wide range of UPIOT connections in the future, which will integrate power optical fibre networks and mobile communication networks. In addition, it can also connect various terminal devices to accelerate the comprehensive integration of information, improve the consumer experience of customers and promote technological innovation.

Intelligent means that the mobile communication technology of power business terminals and consumer terminals will be increasingly informationalized. Then, with the continuous upgrade of smart chips, software and hardware that will enhance the accuracy and immediacy of data transmitted as well as the intelligence and performance of the systems.

The UPIOT is going to form a huge integrated service platform for timely services. Because it integrates different networks, devices, technologies, resources and users. It could standardize the interface and technology connection standardization that will save time and avoid uncertain risks. Based on this platform, an energy ecosystem is able to be built, companies related to the power system can be opened up to enhance the competitiveness of the industry and the level of service to users.

During the development of the UPIOT, the entire energy ecosystem will generate massive data resources which will help companies to find blind spots in information and open up barriers to develop between various industries. On the other hand, it will also optimize inter-industry collaboration capabilities, improve product design and expand new business models.

3. The construction and basic architecture of UPIOT

3.1. The construction Goals of UPIOT
UPIOT would adapt to local conditions and apply modern advanced technologies to complete the interconnection and interaction of all links in the power system. For one thing, the quality of data transmission and the management level will be improved. Transparent management will be completed. For the other thing, internal and external service resources will be extensively connected to create an energy internet ecology and emerging power service industry. As a result, a comprehensive perception of all equipments in the energy link could be realized that can link each member of the energy ecosystem.

3.2. The basic architecture of the UPIOT
The platform layer, network layer, perception layer and application layer constitute the basic technical framework of the UPIOT.

First, the platform layer integrates the data centre and the IoT management centre to enhance the collection and utilization of data. Then, the network layer uses a variety of modern technologies to achieve the links between diverse power systems. Next, the perception layer takes advantage of smart equipment and advanced intelligent computing methods to complete the collection and circulation of data in all aspects of the power system. Finally, application layer to serve new platforms and systems that could optimize the operation of enterprises and boost the new energy utilization efficiency [9].

4. The construction problems of UPIOT

4.1. Strong HVDC and weak AC
Currently, China has built a number of UHV DC lines in central and southwest China to solve the power transmission problem. We could find the construction of China UHVDC transmission project in Figure 3. However, the slow development of UHV AC lines has made the problem of strong HVDC and weak AC in China's power grids increasingly serious. Since in terms of operating mechanism, the situation of AC and DC grids will be more complicated that indicates the power system is facing problems such as DC bipolar blocking, damage to power generation equipment and cascading failures which could affect the overall safety and stability of the grid [10, 11].
4.2. Intellectualization of power equipment

The intellectualization of power equipment can integrate a variety of advanced technologies, which will be not only conducive to the construction of a more modern and efficient energy ecosystem but also improve the profitability and stability of the power grid. Besides, China needs to further develop electrical equipment that could improve equipment measurement and control functions, strengthen the operation’s maintenance capabilities and quality [12]. Currently, the technologies that still need to be developed that contain the intelligent technology of primary and secondary equipment, measurement and monitoring technique of intelligent electrical equipments, online monitoring techniques of power system devices and sensors, fault protection technology, etc.

4.3. Insufficient installation of sensors and other equipments

At present, grid companies have only selected key nodes of power lines to monitor the safe operation of the grid. In some places, due to the limitation of geology, as well as the large area of the sensors and the difficulty of transportation, enough measuring equipments has not been installed. What’s more, new sensor technologies require to be developed [13]. Grid companies need to create new matching sensor devices for diverse user-sides and combine other technologies to boost user-side environmental data, consumption data collection and the quality management level of grid monitoring [14].

4.4. Network security

Due to the integration of multiple technologies, this places higher requirements on the overall network security level of the power system. The power system involves a wide range of equipments and users. For once a network attack or a software loophole to cause security problems, it will generate both immeasurable economic losses and social security [15]. Therefore, power grid companies should continue to develop new technologies, upgrade network security systems in a timely manner and strengthen the operation’s maintenance of network equipment.

4.5. Other questions

For power grid companies, there are a large number of aspects to change which include the operation and dispatch of power grids, equipment control and management systems. Besides, the company's employees need to strengthen the ability to regulate operations, the level of service platforms and customer satisfaction require to be increased continuously. Next, the power production and working
methods, resource allocation of power generation equipment and inter-provincial large-scale grid safe operation methods still need to be optimized [16].

5. The key technologies of the UPIOT
UPIOT has adopted a number of significant technologies that are introduced in this paper. Then, the relationship between them is shown in Figure 4.

![Figure 4. Key Technologies in UPIOT](image)

5.1. Big data technology and its application in power system
Big data is a huge amount of data that is difficult for mainstream software to fully process. It can assist business operators to make effective measures in a short period of time and enhance business efficiency. Power big data refers to the huge amounts of data will be generated throughout the operation of the power system. Processing data flow by rational utilization of power big data technology, the power companies could analyse and evaluate the data of the entire power system. Following this, based on the analyses of large power data, reasonable electric energy working indicators and early warning data can be monitored timely which is able to ensure the normal operation of diverse equipment. Eventually, this technology will also optimize production scheduling, predict new energy generation power and consumer power consumption effectively [17].

5.2. Cloud computing technology and its application in power system
The cloud computing means the evolutionary process of the grid computing, distributed computing and parallel computing. It has used widely in power systems. On the one hand, the cloud computing could be integrated with other progressive technologies to make power equipment smart. On the other hand, it is able to enhance the efficiency of data collection timely. In this way, some researchers could not only make use of various algorithms for power flow calculation, but also build power electronics simulations and plenty of power system models to increase the safety of electric systems [18].

5.3. Internet of things technology and its application in power system
The internet of things means that by using some sensor devices and network for information fusion which based on the agreed protocols to complete the functions of identification, supervision, etc. Due to take the internet of things technology, the links between equipment, personnel and the network are closer in the power system that enhance the intelligence level of the entire power system. What’s more, this way is able to combine with modern communication systems to achieve intelligent power distribution networks and the dynamic online monitoring of the substations [19, 20].
5.4. 5G communication technology and its application in power systems
5G is the fifth generation cellular mobile communication technology. Compared with 4G, it combines the new wireless access technology with the existing communication way that could enhance the efficiency of information transmission quickly and own a faster response time as well as a larger system capacity. 5G will become a bridge for the rapid dissemination of information in the UPIOT from now to the future that could realize the technology fusion to improve the performance of the equipment, data transmission, smart measurement and analysis. Moreover, this technique also could lay a good foundation to build the smart grids and cities. Afterwards, we can make full use of the 5G to develop the 6G and power network [21].

5.5. Blockchain technology and its application in power systems
Blockchain is a decentralized database essentially which is an application model of new computer technology, too. It integrates encryption algorithms, point-to-point transmission and other techniques. Because of using the distributed storage and accounting, the confidentiality of grid enterprise data and the security of the grid information system could be ensured [22]. Besides, it can be applied to the power trading platform that could achieve not only the open and transparent transaction but also safety transaction [23].

5.6. Artificial intelligence technology and its application in power system
Artificial intelligence is a technology that simulates and studies the behaviour of human theory, thinking methods and other subjects on the basis of mathematics, psychology, computer science as well as neurology [24]. To begin with, it can reinforce the ability to analyse data in the power system, and find weak links to take ways make more accurate decisions in a timely manner. Moreover, it could enhance the system’s stability and build an expert system to avoid various failures [25].

5.7. Other technologies and their applications in power systems
Furthermore, UPIOT also includes various technologies that consist of the edge computing technology, presence sensing and information interaction technology, sensor-transmission integration technology, digital twin technology and integrated communication network architecture, etc. Then, power grid companies should standardize the use of diverse technologies and pay attention to improving technical security steadily [26].

6. The future application scenarios of UPIOT
According to the white paper released by the State Grid Corporation of China [27], the construction of the UPIOT will focus on the construction of service ecosystems in the future that include electric vehicles, new energy, finance, etc. The corresponding application scenarios of UPIOT are described below.

6.1. New energy automobile industry
The future development of new energy vehicles is broad. Smart car networking platform can be built around electric vehicles that will become one of the vital components of the UPIOT. Besides, it could link cars, charging piles, power grids, enterprises and customers. The specific application scenarios are as follows:

- The construction of intelligent charging piles that will connect users with grid companies and collect information about users, cars and charging facilities. By this way, we can control charging facilities, aggregate and integrate transaction information flow remotely [28].
- According to the dynamics of the power grid and the power demand of electric vehicles, the power grid scheduling can be optimized in time [29]. Apart from that, the trading platform of the power system is able to connect the electric vehicles and achieve green power trading as well as the tasks of reducing peak and filling valley [30].
With the help of some certain technologies, researchers is able to make use of the decommissioned batteries to form and energy storage power station which would realize the stepwise utilization of used batteries and reduce energy storage costs effectively. Currently, China tower group has used waste batteries effectively to construct 5G communication base stations [31].

6.2. Smart Business Hall
The construction of the UPIOT is able to not only upgrade the marketing service level of the power grid but also expand the electricity sales business [32]. The State Grid Dalian Power Supply Company has established the smart business hall by UPIOT that can achieve self-service transactions throughout the day and handle a variety of integrated energy services. Then, modern technology has been used to complete management systems which is composed of smart queuing, intelligent evaluation and media publicity. In this way, it has popularized the power culture of companies as well as the national energy strategy and enhanced customer service level [33].

6.3. Virtual power plant
By taking advantage of some corresponding technologies, the distributed energy is able to link with the power grid, electricity market as well as devices to establish the virtual plant together which could regulate the supply and demand balance intelligently. Besides, it can increase the consumption of new energy sources. Next Kraftwerke (German virtual power plant operator) has developed virtual power plant operations in terms of electricity trading and technology [34]. On the one hand, this company gathers low-cost photovoltaic, wind and other new energy sources effectively. On the other hand, it uses distributed energy sources which include the internal combustion engines and biomass power generation to provide frequency regulation services for the power grid. By this way, the enterprise is able to adjust the output of distributed energy sources that are based on real-time fluctuations of market electricity prices, so as to gain benefits [35, 36].

6.4. Smart Substation
Smart substations use more progressive technologies and can give full play to their technical advantages [37]. The collection of electrical and status data of substations will be more accurate as well as efficient. Besides, their real-time control capabilities will be stronger. On the other hand, the smart substation is able to improve the fault diagnosis capabilities, complete automatic drone inspections and strengthen information transmission by using more intelligent equipment that contain the unmanned aerial vehicle, robot, etc. Besides, the working efficiency, safety level and power supply quality of substations can improve continuously [38].

6.5. Smart Integrated Energy Service Platform
The smart integrated energy service platform is able to not only break the institutional and technical barriers between traditional energy systems in the past but also open up the upstream and downstream industrial chains of the power industry to provide various comprehensive energy services for customers. It optimizes the system management, power generation structure and promotes the industrial upgrading of the industry [39]. The State Grid customer service centre has built smart integrated energy service systems that are consisted of a green composite energy network operation control platform, a photovoltaic power generation system and a ground-source heat pump which has generated energy-saving benefits [40].

6.6. Expand emerging businesses
Relying on the UPIOT, grid companies would obtain big data of the entire system. In this way, they could develop a large number of services by studying various data from the power generation end to the power sales end and combined with meteorological as well as environmental conditions. It is
beneficial to enhance the efficiency of electricity transactions and create more value for enterprises [41].

7. Future development suggestions for the UPIOT

The advice for the future construction of UPIOT are as follows:

- The government should introduce more corresponding preferential policies for the power companies that is good for the progression of power grid construction. For one thing, the tax institutions can implement tax reduction and exemption policies for the relevant companies that have made profitable in UPIOT experimental areas. For the other thing, ministry of finance is able to establish corresponding strategic investment funds of UPIOT or attract other capital to support power construction jointly.

- With the help of the Belt and Road Energy Initiative and Power Management Platforms established by domestic universities, the government may organize the global universities and power companies timely to conduct academic exchanges, import and export trade exhibitions as well as explore activities that are conductive to the development of power market and the improvement of the technological level.

- Government needs to strengthen the platform construction, quality supervision, technology upgrade and other mechanisms continuously to prevent various risks that may occur during the construction process [42].

8. Conclusion

The construction of the UPIOT will not only help China to build and enhance energy ecosystem, but also boost the upgrading of China's industrial structure and technology which can promote energy revolution and realize green development. This paper analyses in detail the construction goals and existing problems of the UPIOT. Furthermore, the key technologies and various application scenarios of UPIOT are discussed. In the end, some suggestions for the future construction of UPIOT are proposed. It is hoped that this article could offer reference for the relevant researchers.

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