Key Technologies of Smart Energy System

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The Energy Internet is the representative achievement and product of the smart energy system. It is the product of the deep integration of energy and the Internet. It is a new energy system with the characteristics of open interconnection of multi-energy, free energy transmission, open peer-to-peer access and so on, based on electrical engineering technology represented by power electronics technology and combined with relatively mature information technology and intelligent management technology at the present stage. Therefore, the Energy Internet is another important topic after smart grids in the field of energy.

Keywords: smart energy system ; Energy Internet ; information technology

1. Characteristics of the Energy Internet

1.1. Essential Feature

Based on the construction concept and practical application of the Energy Internet, it mainly has five basic characteristics, namely renewable, distributed, interconnected, open and intelligent [1]. The renewable feature stems from the fact that renewable energy is the main energy supply of the Energy Internet [2]; the distributed feature comes from the fact that renewable energy has various and geographically dispersed characteristics [3]; interconnection is the most distinctive and fundamental feature of the Energy Internet [4]; openness is the requirement of the development mode of the global Energy Internet; and the intelligent characteristic is the guarantee for the Energy Internet to be at the forefront of the energy field. **Table 1** explains the connotation of the five basic characteristics of the Energy Internet.

Table 1. Five basic features of the Energy Internet.

Essential Feature	Specific Connotation
Renewable	Renewable energy is the main source of energy supply for Energy Internet. Renewable energy power generation is intermittent and volatile, and its large-scale access will impact the stability of the power grid, thus promoting the transformation of the traditional energy network into Energy Internet [5].
Distributed	Renewable energy sources are diverse and geographically dispersed. For the most efficient collection and use of renewable energy, networks for on-site collection, storage and use of energy need to be established. These energy networks are individually small in scale and widely distributed, and each micro energy network constitutes a node of the Energy Internet. These elements constitute the distributed characteristics of the Energy Internet [6].
Interconnectivity	Large-scale distributed micro-energy networks cannot guarantee self-sufficiency and need to be connected for energy exchange to balance energy supply and demand [7].
Openness	Energy Internet should be a peer-to-peer, flat and two-way energy flow sharing network. Power generation devices, energy storage devices and loads can be “plug and play”, which can achieve real-time and efficient transmission of energy [8].
Intelligent	Energy generation, transmission, conversion and use of energy in Energy Internet should have a certain level of intelligence. The existence of intelligence makes the monitoring, management and maintenance of Energy Internet more convenient [9].

1.2. Technical Feature

The composition of the Energy Internet shows that it is a new form of energy industry development that deeply integrates the Internet, energy production, transmission, consumption, storage and the energy market [10]. It has many technical features, including multi-capability collaboration, information interaction, supply and demand dispersion, equipment intelligence, transaction openness, etc. [11]. In the upcoming new round of global technological revolution and the great transformation of the energy industry, the deep integration of the energy industry with highly developed information technology and advanced Internet concepts will highly promote the development of new models, new business forms and new technologies in the energy field [12]. The specific technical characteristics of the Energy Internet can be analyzed from two specific levels.

The physical layer: At the physical level, the intelligent energy system represented by the Energy Internet mainly relies on control technology, cloud platform monitoring and maintenance technology and high-performance energy technology to achieve the purpose of optimized cooperative operation of various energy sources and efficient and green operation of the whole system [13]. The Energy Internet consists of multiple energy systems, including electricity, heat, gas and various renewable energy sources, serving many fields such as production, transportation and engineering [14]. Considering its composition and application scenario, it is not difficult to deduce that the technical characteristics of the physical layer lie in the fact that it supports the intelligent interconnection of multiple networks and the mutual transformation of all kinds of energy [15], realizes the optimal scheduling and optimal operation of energy systems through the mutual transformation of various energies and the complement of supply and demand [16] and finally realizes the optimal configuration of the whole energy system [17]. As mentioned above, the Energy Internet has the basic characteristics of distribution [18]. In the future of highly developed distributed energy, it has a strong advantage of convenience to directly convert all kinds of distributed energy into all kinds of energy required by users through technical means [19]. Therefore, the construction of the Energy Internet will take the construction of micro-grid units as the main technical characteristic [20]. After comprehensive analysis of the technical characteristics of the Energy Internet at the physical layer, the main advantages of the Energy Internet at the physical layer can be summarized as follows:

(1)A variety of energy systems achieve complementary advantages, avoid the second conversion of energy and consumption loss and effectively improve the utilization efficiency of comprehensive energy, which meet the requirements of the era of energy conservation and low carbon [21].

(2)All kinds of small-scale renewable energy are incorporated into the grid of the energy system, which improves the level of consumption and fully mobilizes all environmentally friendly energy sources that can be put into use [22].

Information layer: A high degree of information interaction is an essential requirement for the construction of the Energy Internet [23]. Therefore, the most prominent technical characteristics of the Energy Internet at the information level are information transparency and information sharing [24]. The main embodiment of information transparency is to make it open and transparent for the running state of energy network, the healthy state of energy equipment and the trading state of the energy market [25]. One of the problems of traditional energy networks represented by the power grid is that the actual information held by power grid companies and power users is seriously unequal [26]. The user side has a serious lack of information about the energy system, which can easily lead the operator to exploit the information monopoly [27]. Under the construction of the Energy Internet, real-time information sharing will be established between operators and users [28]. Users and all the main parties in the energy market will fully grasp the real-time information of the energy system [29], break the information monopoly of the energy system operators and ensure fair, just and open energy transactions [30].

1.3. Potential Problem

Security and privacy problems are important in the development and construction of the Energy Internet. In the future Energy Internet construction stage, in order to achieve a high degree of information of the entire energy system, it is inevitable to use some intelligent equipment and communication equipment in hardware, including smart meters, advanced metering infrastructure (AMI) and so on. However, although the use of these facilities will provide effective help for the construction of the Energy Internet, they will also generate potential risks in the security and privacy of the Energy Internet. For example, smart meters will be used in the construction of the Energy Internet. While smart meters can provide households with more autonomy regarding their energy consumption, they can also be a significant intrusion into the household’s privacy [31]. In addition, advanced metering infrastructure (AMI) will be used in the measurement system of the Energy Internet. It plays an important role in providing near real-time two-way communication between consumers and energy systems, as well as providing a range of value-added services to increase customer satisfaction. However, given that its existing services are implemented in a centralized manner, it will still have security and privacy issues [32]. The construction of the Energy Internet should be based on full respect for human rights and protection of the privacy of each user. Therefore, security and privacy issues are problems that must be solved. Therefore, in the subsequent construction process, the technical means of giving consideration to both performance and security and privacy protection represent the key content of the study.

2. Energy Internet Technology System and Specific Related Technologies

The Energy Internet has the nature of multi-disciplinary intersection, so the technology of constructing the Energy Internet involves a wide range of fields [33]. Based on the current global conceptual consensus on the Energy Internet, the architecture of the standard system of Energy Internet technology can be divided into four layers, namely basic universality, energy grid, information support and value creation [34]. There is information interaction between every two parts. The basic universality part is the basic support part of the whole technical system, which mainly includes basic commonality, industrial control chips, new materials and devices, etc. [35]. The main contents of the energy grid include the distribution network and distributed energy, high-end power transmission and transformation equipment, renewable energy friendly access, safe operation and protection of the system, engineering design and environmental protection, equipment operation and maintenance, grid configuration and planning [36]. In addition to the information interaction between every two parts in the above seven parts, there are also energy and power flows between the distribution network and distributed energy, high-end power transmission and transformation equipment and renewable energy friendly access [37]. The function of the information support part is mainly to undertake the operation and management of the system, platform and information, including artificial intelligence, sensing and measurement, network and information security, automation system, digital platform and communication. There is information interaction between every two parts [38]. The final technical dimension is value creation. This level is based on the energy grid level and emphasizes the integration and application of emerging technologies and energy technologies [39]. The most distinctive feature is the integration and application of the power grid and information technology reflected in smart grid technology. The specific components include the electricity market, energy storage technology and application, user supply and demand interaction, energy blockchain, multi-energy conversion and comprehensive utilization, as well as business model innovation and decision support [40]. Similarly, there is information interaction between every two of the six parts mentioned above. **Figure 1** shows the conceptual model of the Energy Internet technology standard system.

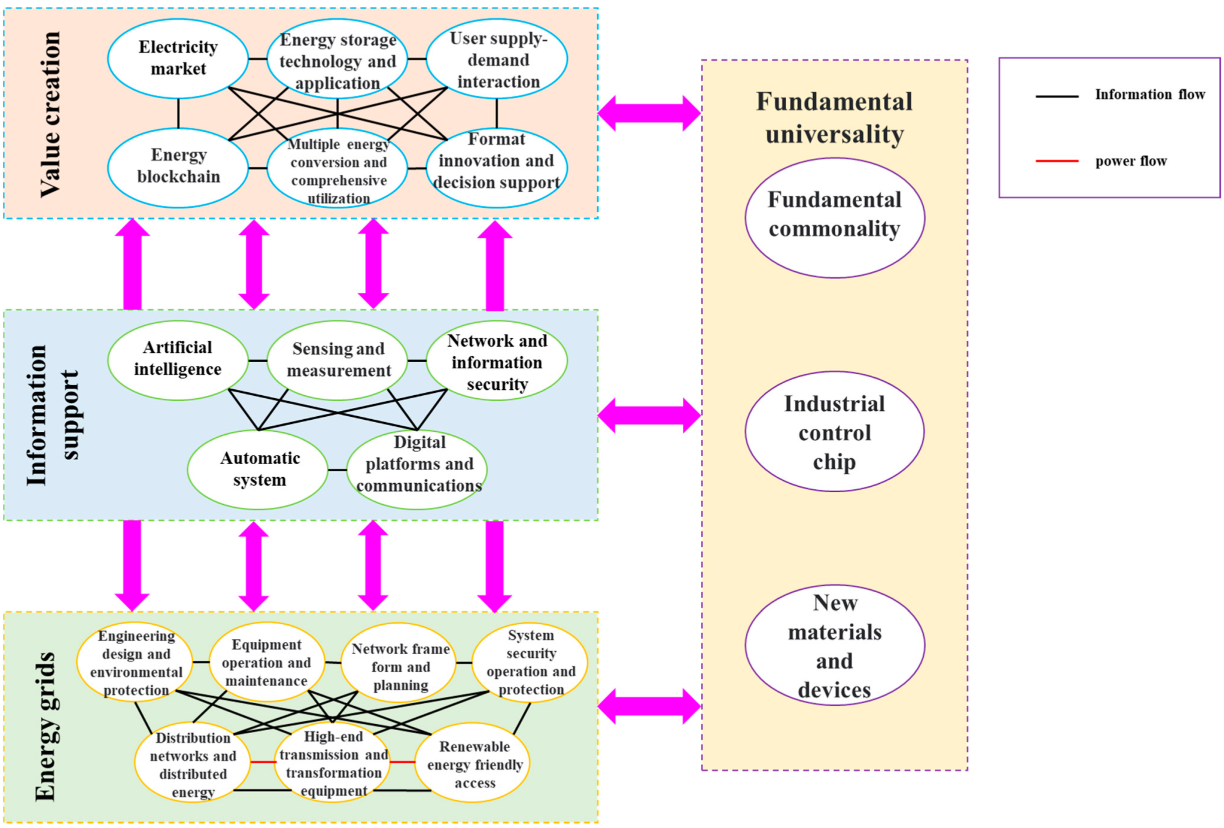

Figure 1. Conceptual model of the Energy Internet technology standard system.

According to the situation reflected by the concept of the Energy Internet technology standard system, the related technology of building the Energy Internet mainly involves the existing technology fields, including electrical engineering, communication engineering, computer and Internet of Things engineering, artificial intelligence and so on [8]. Related technologies in the field of electrical engineering are still power electronic technology, power system relay protection, power system overvoltage and other technical means applied in the current power grid construction (the main reason is that although the Energy Internet has added many new elements compared with the power grid, energy supply from the traditional power grid is still one of the core energy supplies of the Energy Internet; the traditional grid is still an important part of the Energy Internet) [41]. Related technologies in the field of communication engineering mainly include information sensing technology [42], wireless communication technology and so on (due to the large geographical span of energy deployment, condition monitoring and other problems, information interaction is required; therefore, some important technologies in the field of communication engineering are also essential elements for the construction of the Energy Internet [43]). The Energy Internet itself has many similarities to the Internet of Things. Both have the essential characteristics of high interconnection of each component element, but the objects are different (the Energy Internet targets all forms of energy, while the Internet of Things targets entities or various electronic products) [44]. Therefore, blockchain, network technology and programming in the field of computer and Internet of Things engineering are also important technologies for building the Energy Internet [45]. In particular, blockchain technology can play a key role in sustainable energy systems [46]. The technology in the field of artificial intelligence determines the upper limit of the development of the Energy Internet [47]. Applying AI and machine learning techniques to various traditional operational models of the Energy Internet can effectively promote its intelligent transformation. For example, considering the excellent real-time control and robustness of reinforcement learning method, it can be applied to the security and stability control of the power system. Through the design of online and offline control modes, or the design of more intelligent power system security and stability devices based on the algorithm, the control characteristics of the security and stability system can be further optimized. Then, the application of deep learning technology in the Energy Internet can play an important role in load prediction and control of the power grid and energy storage devices, fault diagnosis of power equipment, transient stability assessment of the power system, power big data fusion and anomaly detection and image recognition of power equipment. In addition, deep learning has advantages in feature extraction and model fitting. Considering the actual situation that a large number of new energy power stations, electric vehicles and energy storage devices are connected to the Energy Internet, the application of deep learning will effectively solve the power system problems with high dimensional, complex and coupling relations. The application of intelligent management technology and intelligent robot technology can provide effective help for the inspection and diagnosis of hardware equipment and the optimization of energy transmission and deployment of the Energy Internet. The existence of artificial intelligence technology can not only save human resources in the process of building the Energy Internet, but also complete some tasks that cannot be completed by human resources in the context of a large geographical span [48]. The related technologies required for the construction of the Energy Internet and their fields are displayed in **Figure 2**.

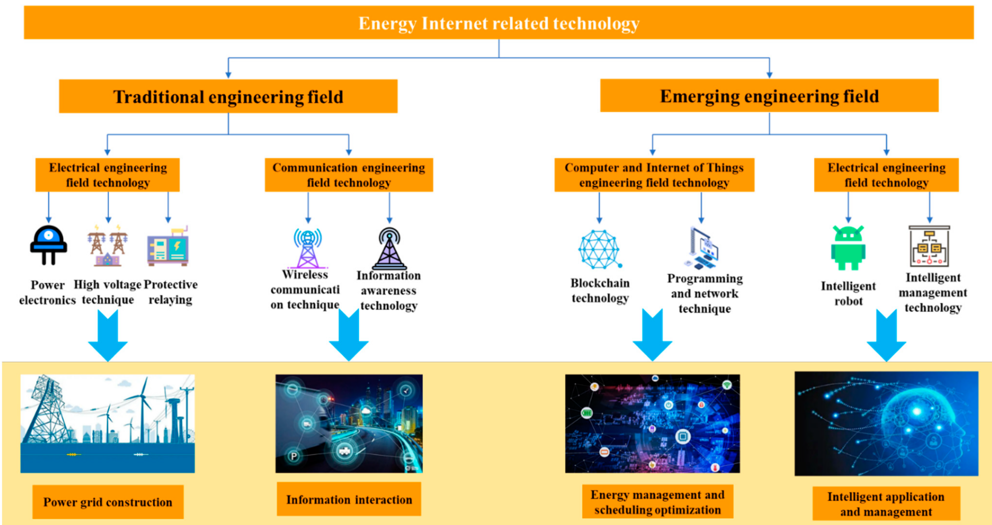

Figure 2. The related technologies required for the construction of the Energy Internet and their fields.

3. The Important Pillar of the Energy Internet—Electric Vehicles

Up to now, electric vehicle-related technology has achieved exceptional results, and conventional energy vehicles are gradually being replaced. Electric vehicles are not only important means of transportation, but also important electric facilities and energy storage equipment, so they play an important role in the development of the Energy Internet. Through the connection with distributed and cooperative energy interaction network, electric vehicles not only give full play to the advantages and characteristics of the Energy Internet, but have also become an important pillar in the development of the Energy Internet [49].

One of the characteristics of electric vehicles is the function of mobile distributed energy storage, which is mainly reflected in that electric vehicles belong to a large number of widely distributed small power consumption facilities and energy storage facilities. In the interaction between electric vehicles and the power grid, not only the charging requirements can be completed, but also the load of the power grid can be reduced. The combination of production and marketing in the Energy Internet is realized through the power grid's power transmission and electric vehicles' participation in the power grid dispatch. Another feature of electric vehicles is its full coverage of communication facilities. The integrated development of energy and communication is the core of the current Energy Internet development. The development of electric vehicles and charging piles needs complete coverage of communication facilities. Thus, in order to guarantee the precision of the measurement and realize real-time communication and integration of the energy system, the Internet of Things and the Internet should be included in the development of electric vehicles. This will guarantee that the Internet contains information on the vehicles' location and the initial power and charging demands during vehicle running [50]. As important power facilities and energy storage facilities, the effectiveness of communication between electric vehicles and other power suppliers should be ensured. Only in this way can important technical support be provided for the development of Energy Internet.

The key methods to promote the integration of electric vehicles and the Energy Internet include pile matching, power market development and intelligent integration. The main way to achieve vehicle pile matching is to promote the construction of electric vehicle charging piles in the Energy Internet system. To develop the power market, it is necessary to accelerate the large-scale development of urban distributed photovoltaic and promote the development of the power sales market. The realization of intelligent integration mainly depends on the development of unmanned driving technology. The main role of electric vehicles is to achieve integrated and intelligent development. Only by meeting the development requirements of the energy sharing economy can they have a greater economic and social advantage in the Energy Internet [51].

To summarize, electric vehicles constitute a key component and pillar of the Energy Internet. In order to promote the full development and construction of the Energy Internet, the research and development of electric vehicle-related technologies are indispensable.

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