Functional Requirements Analysis and Practical Design of Plug-and-Play Energy Interconnect Terminals

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Abstract. The energy Internet is a new form of energy supply and a practice of “Internet + energy”. Similar to the information internet, plug-and-play is one of the most important features of the Energy Internet, and also is one of the most important purposes of the construction of Energy Internet. Many attempts have been made to achieve this purpose. Power system is the most suitable natural carrier to construct Energy Internet, but the physical laws of power flow and information flow are different, so plug-and-play is hard to achieve and it is the primary problem to solve. This paper analyses the specific functional requirements of plug-and-play, and presents a practical design of plug-and-play energy interconnect terminals, which can realize the plug-and-play of energy terminals. The thought put forward in this paper will contribute to the construction of Energy Internet and promote the effective utilization of distributed energy.

1. Introduction
The rapid development of the Internet has not only profoundly changed people's lives, but also changed many traditional industries. The Energy Internet is the product of the integration of energy and the Internet. As a new development direction and important subject of energy industry after smart grid, Energy Internet, as an effective technology to solve the problem of distributed energy consumption, has become a new research hotspot in academia and industry.

Energy Internet was first proposed by American economist Rifkin. Research for Energy Internet has been carried out in recent years, e.g. FREEDM project in US [1] and E-Energy project in Germany [2].

Energy Internet is also a hot research topic in China. The Institute of science and technology for development of China regards the Energy Internet as one of the emerging industries of national strategy. China's State Grid cooperation and Tsinghua University both set up an Energy Internet Research Institute. In April 2016, the State Council issued the "Energy Internet innovation action roadmap". In recent years, China is gradually carrying out power market reform, which means that the development of Energy Internet will be prospective.

Currently, the definition, characteristics and implementation methods of Energy Internet are not unified. The final conclusion about the concrete morphology of Energy Internet is not yet formed. But considering the convenience of transmission, utilization and conversion of electric energy, power grid will play a main role in future Energy Internet. And distribution network will also develop from a pure electric power distribution network to a new type of power distribution network with the function of multi-energy (e.g. electricity, gas, cooling, heating, etc.) conversion, substitution and utilization. With the clean substitution at supply side and the electric energy substitution at demand side, electricity will be the main form of energy production and consumption.
So Energy Internet can be considered as a new power network composed of distributed energy acquisition devices, distributed energy storage devices and various types of loads, which integrates advanced power electronics technology, information technology and intelligent management technology to realize energy exchange and sharing network with bidirectional energy flow.

Plug-and-play is an important feature of the information Internet. Each individual is not only the consumer of information, but also the producer of information. Plug-and-play of heterogeneous devices is realized. Plug-and-play is also one of the basic requirements of the function of the Energy Internet, and is also one of the main purposes of the development of the Energy Internet.

Energy Internet needs to break the monopoly, decentralize, so that different participants in the position of equal trading. It requires plug-and-play of energy generation and consumption and a balance of energy from time to time, which requires that the Energy Internet should be a peer-to-peer, flat and bi-directional flow of energy sharing network, generating devices, energy storage devices and loads can be "plug-and-play".

2. Existing Solutions

Plug-and-play of energy equipment is more complex than Plug-and-Play of information, involving energy and information synergies. Referring to Internet devices, the concepts of “energy router”, “energy switch”, “energy hub”, and “energy network card” are proposed in [3], to solve the plug-and-play problem, which are widely recognized as basic components of Energy Internet.

However, the physical characteristics of power flow and Internet information flow are completely different.

Internet is a computer technology that supports information flow. It refers to a network connection between different computers to establish a common language, a bunch of communication protocols, so as to achieve communication between computers. For a particular information exchange process, a specific receiver can be specified and their delivery path can be scheduled. It can buffer, preserve or delay delivery. Electricity is injected into the grid by generating sets and consumed power loads that must be balanced at all times without any cushioning, savings or delays.

If we want to feature the Internet in the power system, we need to store, buffer, and dispatch electricity as easily as information. To achieve this goal, we need to make breakthroughs in two key technologies, power electronics and energy storage technology.

Power electronic technology is the foundation of power electronic transformer, which is considered as the key equipment in Energy Internet. It can achieve energy dispatching and flexible transformation of voltage and frequency. It has obvious technical advantages in improving power quality and system stability, realizing flexible transmission mode and real-time control of power flow. However, the current power electronics technology is mainly used in the case of low voltage and low power, and is doubtful at reliability and efficiency.

Energy storage technology is another critical technology, which improves the quality and the economic efficiency of distributed power generation unit, and ensures the stability of system. Energy storage has been widely used in distributed energy sources but still has obvious bottleneck at present. Although kinds of energy storage technologies are developing, the related technologies and performance are immature with high cost. The developing of key materials, process of manufacture and efficiency of energy conversion are also facing with challenges.

Completely copying the Internet model requires fundamental changes in the overall development of power grids, power electronics and energy storage technologies. But its feasibility, economy and effectiveness are doubtful.

Completely copying of the Internet mode for Energy Internet requires fundamental changes of power grid and the fully developments of power electronics and energy storage technology. But its feasibility, economy and efficiency are doubtful.

It is worth exploring how to realize plug-and-play function required by Energy Internet under the existing power system framework.
3. Functional Requirements Analysis

Plug-and-play of energy equipment is more complex than Plug-and-Play of information, which involves the coordination of energy and information. In order to realize plug-and-play, the security and stability of the energy network should be guaranteed automatically. In addition, the following contents should be studied: (1) Standard interface and protocol for plug-and-play of energy and information; (2) Self-organizing management of distributed devices, including automatic perception and recognition of devices, generation and splicing of device models, and automatic communication. (3) Autonomous control of the equipment itself to reduce adverse effects on the system.

Therefore, plug-and-play interconnected terminals should have the following functional characteristics: unified physical information interfaces, unified power quality requirements, accurate and rapid protection and control means, as well as distributed measurement and trading means. In addition, the energy terminal should also facilitate remote monitoring, control and operation and maintenance, improving the efficiency of operation and maintenance.

3.1. Unified Physical & Information Interfaces

Whether it is photovoltaic power generation, wind power generation, or energy storage devices, electric vehicles connected to the grid, all need different types of power conversion, the external interface is divided into strong electricity connected electrical interface and weak electricity connected communication interface. Due to the lack of unified specifications and standards, equipment manufacturers now define their own product interface forms, standards are not unified, a wide range of engineering applications are complex.

3.2. Unified Power Quality Requirements

Energy terminal is the gateway of energy exchange, and its quality needs to meet the unified requirements. Power-centric Energy Internet, energy quality requirements are the requirements of power quality. It is a basic requirement for energy interconnected terminals to establish a unified power quality requirement system, monitor the power quality situation at all times and make corresponding adjustments according to different power quality conditions.

Specific quality indicators can include voltage quality and current quality. Voltage quality includes voltage frequency, voltage harmonics, voltage deviation, three-phase unbalance, voltage fluctuation and flicker. Current quality includes current frequency, harmonic current, negative sequence current, impulse current, DC component and so on. In addition, it also contains EMC indicators for specific needs. Energy interconnect terminals should be able to monitor the parameters of these voltage waveforms and current waveforms, and in the case of poor indicators, can identify the causes and sources.

3.3. Protection and Automation Control

As the interface between terminal energy and Energy Internet, energy interconnected terminals should have comprehensive protection and control functions, which are mainly embodied in the requirements of islanding protection, component protection, system protection, fault protection, restoration of grid-connected function and so on. It should meet the requirements of reliability, selectivity, sensitivity and speediness. In addition, in some cases, the interconnected terminals should have power control function, voltage control function, frequency response function and so on, which can realize the function of virtual generator.

3.4. Distributed Metering And Trading

The interconnected terminal shall have the function of electric energy metering, and its configuration and accuracy shall meet the requirements of relevant national technical standards and regulations.

The interconnected terminal shall be able to communicate with bus measurement systems and plug-and-play energy interconnect terminals, obtain information, performance logical computing, verifying and solving energy online trading by units of generation, transmission, storage, consumption, and achieving the best trading results through flexible pricing policy.
4. A Practical Design
We proposed a design of energy interconnect system which can satisfactorily compatible with the existing power grid structure. The proposed design abandons energy routers and power electronic transformers which are depended on the existing power grid and linear elements. And the functions of frequency conversion, energy storage and energy active dispatching are not considered.

![Figure 1](image1.png)

**Figure 1.** The architecture of plug-and-play energy interconnect system.

![Figure 2](image2.png)

**Figure 2.** The architecture of plug-and-play energy interconnect terminal

The architecture of plug-and-play energy interconnects system shown as Fig.1. Based on the existing power system measurement system, a plug-and-play energy interconnect terminal is connected in series at the front end of the end user.

The plug-and-play energy interconnect terminal is the energy and information interface of power grid and energy terminal devices (such as distributed energy generator, electrical equipment and energy storage devices). Meanwhile, energy interconnect terminal is the combination of energy flow and information flow and connected in series.
The plug-and-play energy interconnect terminal includes:

- Standard electrical interface: the electrical interface can achieve the universal interface for various electrical sources with standard voltage and frequency.
- Standard communication interface: through standard interface and protocol, energy terminal devices can transmit state and instruction to the terminal.
- Measuring module: by monitoring the voltage and current signals flowing through the standard power interface, the real-time metering of electricity and the monitoring of power quality parameters are obtained. Verifying and solving energy online trading by units of generation, transmission, storage, consumption, and achieving the best trading results through flexible pricing policy.
- Switch: performing a current cut-off to achieve the isolation of equipment and power grid.
- Addressing module: getting the location of the equipment access point in the power grid by Power Line Carrier or other communication methods.
- Control unit: achieving protection and control function through logically calculation of the information from measurement modules of terminal, power systems or other terminals. According to the power flow information of the terminal accessing location, giving the instructions of terminal accessing, terminal breaking, and storage charged or discharged, etc.
- Communication and authentication module: performing the communication with power system and other terminals and achieving the corresponding security authentication and identity authentication of the terminal.
- Energy online trading: verifying and solving energy online trading by units of generation, transmission, storage, consumption, and achieving the best trading results through flexible pricing policy.

The design of these components can achieve the function of plug-and-play for power generation, consumption and storage equipment. With its characteristics such as less investment, economy, convenience, efficiency and practicality, the proposed design can be well compatible with current power supply system, improving the effective utilization of distributed energy and promoting the construction and development of Energy Internet.

5. Conclusion

Energy Internet is a wide-area system integrating variety of new energy technologies, information technologies, and new energy trading models. Its development is not accomplished overnight.

Judging from the objective law of the development of things, first of all, we should carry out researches on various innovation-enabled technologies within the framework of existing power system. And then, we should integrate relevant technologies to conduct comprehensive demonstration applications within a smaller region, and gradually expand them to a larger scope.

This paper analysed the plug-and-play needs in the Energy Internet and the key elements of its implementation. The plug-and-play energy interconnect terminal proposed in this paper utilizes the measurement information of the existing power system. In the framework of the existing power system, the plug-and-play effect is achieved. Based on the existing power system, the Energy Internet can be realized step by step. The analysis and design provided in this paper will be helpful to the construction of the Energy Internet.

References

[1] Huang A Q, Crow M L, Heydt G T, Zheng J P, Dale S J. The Future Renewable Electric Energy Delivery and Management (FREEDM) System: The Energy Internet. Proceedings of the IEEE, 2011, 99(1):133 - 148.
[2] Vermesan O, Blystad L C, Zafalon R, Moscatelli A, Kriegel K, Mock R, et al. Internet of energy: connecting energy anywhere anytime. Springer Berlin Heidelberg, 2011: 33-48.
[3] Geidl M, Klokl B, Koeppel G, Andersson G, Frohlich K. Energy hubs for the futures. IEEE Power & Energy Magazine, 2007, 5(1): 24-30.