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The SAGE Encyclopedia of the Internet

Energy Use and the Internet

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This entry introduces the Internet's relation to energy use by focusing on the energy Internet. The energy Internet is a proposed Internet-style solution for bottom-up construction of energy infrastructure and applications. Key features of the energy Internet include decentralized coordination of energy production and consumption that enables open and peer-to-peer energy sharing.

The aim of the energy Internet is to maintain an iterative balance among energy generation, storage, and consumers in real time. By allowing high-level awareness and involvement in the form of cooperation and interaction, secure and reliable delivery of energy would be achieved through efficient scheduling, distribution, and routing across peers of energy cells. This entry opens with an overview of how the Internet can shape energy use. It then introduces the energy Internet, including smart grids. Third, it examines how the energy Internet is structured and scenarios for its use.

The industrialization of production and the modernization of human lives are based on energy, which largely means fossil fuels at present. Since the Industrial Revolution of the 18th and 19th centuries, nearly half of the coal, oil, natural gas, and other fossil fuels on earth have been used with an increasing speed of consumption. According to the International Energy Agency, reserves of fossil fuels are limited and can support human activities for the next 100 years only. In the meantime, accompanied by the excessive emission of carbon dioxide and various other kinds of pollution, people are suffering from serious climate problems such as global warming and acid rain.

Apart from the decrease in reserves, the cost of conventional energy resources is escalating. This has led to the introduction of distributed renewable energy resources. Renewable energy sources include hydro, wind, solar, geothermal, ocean, air, and biomass energy, which have advantages over conventional fossil fuels. For example, almost all of these kinds of energy can be used forever without any limit, and except for biomass, they are clean to use without emission or pollution. As one of the significant components of the energy industry, the electric power industry transforms the primary energy source such as fossil fuel, nuclear, hydro, wind, and solar energy into electricity, supplying customers via power systems of transmission, transformation, and distribution. Classified as secondary energy, electric power is clean, secure, and efficient and is critical to the sustainable development of the economy and society.

The Internet has developed rapidly over the past several decades and is gradually changing the operation of many conventional industries. In the past few decades, research on distributed computing and network technology has attracted much attention. Starting from performance modelling and the analysis and optimization of parallel and distributed computing, researchers have endeavored to improve the utilization efficiency of resources and the quality of services. Later, the development of distributed cluster computing, metacomputing, grid computing infrastructure, and services computing brought the potential to improve the performance of the computing system and provide more extensive service capabilities.

Along with the increasing scale of the construction of data centers and cloud computing, the interaction between information and energy technology development has received a great deal of attention. It was power-aware computing that opened the connections between the performance improvement of computer systems and resources outside the field of information technology. If the use of new energy technologies for information system services is seen as one aspect of the relevance of information and energy, then the other aspect is the use of information technology for energy infrastructure services.

Definition of the Energy Internet

With the development of renewable energy, people's dependence on conventional energy is gradually weakening. Meanwhile, how to satisfy customers' requirements for electric power services, and how to solve the contradiction between energy use peaks and valleys when using electric power, remains challenging. Apart from that, requirements such as security, reliability, energy conservation, and environmental protection have to be satisfied also. Under such circumstances and inspired by the development of the Internet, a new concept named the energy Internet has been proposed. The energy Internet is designed to achieve efficient usage of renewable energy, to satisfy the increasing demand for energy, and to reduce damage to the environment.

The energy Internet involves the integration of new energy technology and information and communication technologies (ICTs) to generate interconnections among a large number of distributed energy sources and energy storage devices. Through intelligent management, the energy Internet can achieve the energy exchange and the sharing network via the exchange of information. It is a complex network that integrates the power system, transportation system, natural gas network, and information network. Based on the idea of being open, equal, interactive, cooperative, and participative, in the future, energy is expected to be treated as information that can be shared, in the sense that everyone is acting as not only the producer but also the consumer.

The energy Internet is expected to change the structure of both the supply and the demand for energy. It transforms the current top-down concentrated energy supply system into a combination of concentrated and distributed energy supply. This means that each area can obtain energy supplements independently by using its own energy resources from solar, wind, or natural gas. The goal of the energy Internet is to construct a new energy system that allows energy to be treated in the same way as information on the Internet, so that any legal unit is able to get connected and share with others.

There are three major modes of the energy Internet. The first is actually a new type of energy network, operating under the philosophy of openness and peer-to-peer connections. One typical example is the U.S. Future Renewable Electric Energy Delivery and Management (FREEDM) system, which is designed to develop a new type of power grid that is constructed using renewable energy and distributed energy storage devices. Following the core router of network technology, researchers proposed the concept of the energy router and completed its prototype. The goal of the FREEDM system is to achieve the construction of smart microgrids and to create interconnections among them.

The power electronic transformer (also called a solid-state transformer) is the core energy router in the FREEDM system. The power electronic transformer performs the smart control of switching on and off the microgrids or the network via the remote controllable fast smart switch. This energy router communication module uses Zigbee, Ethernet, and wireless local area networks to establish communication among energy routers.

The second mode emphasizes that the nature of the energy Internet is indeed the information network. The Internet is used to collect relevant information about energy supply and demand, which then instructs the operation of the energy network. The classic example is e-Energy in Europe, which aims to build an energy supply system based on ICT. Each link of the energy supply chain is connected digitally, and computers are able to control and monitor data.

The e-Energy network is designed in such a way that the requirements of the electric power system characterized by the distributed energy supply structure will be satisfied in the future. It will realize the intercommunication and coordination between the grid infrastructure and household electric applications. Also, it will improve the intelligence of the power grid. In other words, its target is not only to ensure the stability and efficiency of the power supply for the digital network but also to optimize the whole energy supply system by using modern ICTs. The e-Energy network has enabled Germany since 2015 to transform its conventional centralized power generation mode into a combination of the centralized and the user-side distributed renewable energy power generation. Finally, by 2020, the information network will be fully integrated with power systems.

The third mode can be understood as the synthesis of the two modes just discussed. One typical example is the digital grid with the digital grid router (also known as electric router) in Japan. The digital grid is constructed on the basis of the Internet. It is gradually reorganizing the national power system in Japan, transforming the current synchronous power grids into the asynchronously independent but interconnected power grids. It assigns the corresponding Internet Protocol addresses to power generators, power converters, wind farms, energy storage systems, rooftop solar panels, and other grid infrastructures. Similar to information transmission via the Internet, the open and peer-to-peer energy sharing is achieved by the electric router.

The electric router connects the existing power grid to the local area energy network and is able to recognize the power supply and bases. Thereby, it aims to deliver the electric power generated by the wind farms in one place to an electric router somewhere else. When the power grid stops supplying electricity in case of disasters, the electric power can be stored in a battery. It can also be intelligently scheduled via electric routers, so that power failure is prevented.

The Smart Grid

The development of the energy Internet is closely connected with that of the smart grid. The development of digital technology allows for two-way communication between the utility and its customers. The smart grid may be described as an electrical grid that includes a variety of operational and energy measures, including smart meters, smart appliances, renewable energy resources, and energy efficiency resources.

There are two important aspects of the smart grid: (1) electronic power conditioning and (2) control of the production and the distribution of electricity. The operational mechanism of the smart grid is similar to that of the Internet, since it also consists of controls, computers, automation, and new technologies.

The benefits associated with the smart grid are summarized as follows. It achieves a more efficient method for transmitting electricity. In case there are power disturbances, electricity can be restored faster. The smart grid reduces the costs of operations and management, and consequently, it lowers the power costs for consumers. The other reason why it is able to reduce electricity rates is that it reduces the peak demand. In addition, it increases the integration of various renewable energy systems. When power is not available from the utilities, the customer-owned power generators can be used to produce power, and this is regarded as one major advantage of the smart grid. Meanwhile, compared with the traditional electric grid, it improves the level of security.

The development of the smart grid has drawn the attention of scientists in many countries, and it has become a vital strategy for some developed countries, including the United States and Japan. The smart grid is expected to be one type of the energy Internet, in the sense that energy can be delivered to different destinations through energy switches, routers, and gateways. A smart grid chooses the best pathway in consideration of information such as load states and price. It also takes the supply status within a local district into consideration. The Internet-style smart grid allows a real-time balance between the local generator and the storage capacity, whereas the energy Internet includes but is not limited to this feature. Additionally, it allows a high level of consumer awareness as well as cooperation and interaction.

The configuration of the smart grid for the balance of energy between supply and demand focuses on the informatization of the existing power grid, solving essential issues such as the rate of equipment utilization, safety and reliability, power supply quality, and new energy access. Nevertheless, the smart grid is still based on traditional power grids, and the mode of the smart power configuration is still restricted to the centralized energy supply. What makes it different is that the energy Internet adopts the Internet-style methodology and technology to change the energy infrastructure architecture so as to build a new type of network where information and energy are integrated.

Based on the smart grid, the energy Internet includes more functions. By adopting the smart energy configuration mode of multiple suppliers corresponding to multiple demanders, the energy Internet allows for the existence of the centralized as well as a large number of distributed energy suppliers and also that of the distributed energy demanders. In other words, the energy Internet allows for plug-and-play access and maximizes the sharing of energy with respect to distributed power equipment or renewable energy.

Structure of the Energy Internet

Before the architecture of the energy Internet is introduced, three construction principles are considered first. The first one is the cyberphysical system. It is a multidimensional complex system that synthesizes the computation, the network, and the physics environments to achieve real-time perceiving, dynamic control, and information services with reliability, efficiency, and collaboration. In an energy system, the efficient bidirectional transmission of information via various kinds of physical equipment is the basis for realizing coordination and interconnection, and the cyberphysical system provides new approaches to dealing with this issue.

The second principle emphasizes the combination of the traditional centralized energy system with the distributed energy systems. The third principle addresses the balance between supply and demand. The main energy supply of the energy Internet originates from wind, solar, and other renewable energy resources, the access to which in a large scale will transform the conventional energy system. The distribution of renewable energy sources requires the construction of microgrids that can locally collect, store, and use energy. These microgrids are individually small scaled and widely distributed, and together, they form one segment of the energy Internet. The large-scaled distributed energy microgrids are alone not sufficient to meet a nation’s energy needs. Hence, they tend to make an alliance with the backbone network in order to exchange energy so as to ensure the balance between energy supply and demand.

Microgrids, distributed energy, and other energy autonomous units are the fundamental elements of the energy Internet. They form a local area network (LAN) by their system of energy power generation—that is, the collection and sharing of energy as well as the energy storage or electricity usage within the microgrids. Based on the LAN, the energy Internet takes the form of a wide area network (WAN), which includes arbitrary small or microsized distributed energy.

Although the microgrids, or the access, interconnection, and transmission of distributed energy, have advantages such as flexibility, the reliability of the power supply is still not guaranteed, whereas large power grids have a relatively reliable power supply. However, large power grids have difficulty in adapting to access new energy and bidirectional interactions.

The energy LAN corresponds to the user side of the current power grid infrastructure, and it controls the transformation and sharing of multiple forms of energy. It appears in the microgrids and the distributed energy or in intelligent residential districts. One goal of the future energy Internet is to make it possible for people to produce green and renewable energy in their houses, offices, and factories. The redundant energy will be shared with others, just like how we share information online. The energy microgrids are the basic elements when distributed energy is transformed into electric power. The energy microgrids are also crucial for consumers' local usage, as well as for the storage and transmission within the microgrids. The most outstanding advantage of the energy Internet is that it offers access to green, environmentally friendly, and sustainable distributed energy on a large scale. Potentially, it can be the solution to the energy crisis.

However, the distributed energy itself has defective features such as the energy production intermittence and the output instability. If measures are not taken, especially when the distributed energy is accessed in a large scale, it will influence the stability of the backbone network. As an approach to resolve this issue, and also in order to realize flexible electric transmission, the concept of the microgrid and its relevant basic technologies are proposed. As per this proposal, each energy microgrid forms a complete energy system, which operates autonomously. It satisfies different consumers' requirements for reliable energy. It is mainly composed of smart energy management facilities, distributed renewable energy, energy storage devices, and converter devices. In terms of power generation efficiency, when the distributed power generation is being processed, the redundant energy can be used to heat and cool buildings, simultaneously. This corresponds to the system of combined cooling, heating, and power (CCHP) described later in this entry.

The energy WAN corresponds to the distribution network in the current power grid infrastructure. It controls energy exchanges and routing based on microgrids or energy autonomous units. Openness and interconnection are the main characteristics of the energy Internet on the layer of the WAN.

The energy Internet is an automated and intelligent energy system network. The energy backbone network and the energy microgrids can be connected only if the interconnection protocol and the distributed facilities are achieved. The energy Internet emphasizes interaction, interoperability, and bottom-up flexible interconnection, all of which are based on the interconnection protocol. The electrical system forms the connection among various sorts of power grids, microgrids, and smart grids by using information and communication technology.

The energy backbone network corresponds to the transmission network in the current power grid infrastructure. It gradually transforms a synchronized and centralized controlled large power grid into an asynchronous autonomous interconnected power grid. Through the development of high voltage direct current technology for connecting regional alternating current power grids using the direct current back-to-back technology and separating the existing centralized and unified large power grid, problems with safety and stability can be avoided, especially when the dynamic balance of supply and demand is not achieved.

The energy backbone network guarantees the stability of the energy microgrids. Moreover, it makes the connections between the energy production and the energy consumption segments on a large, centralized scale. Its target is to achieve a transmission network such as that of a smart grid. The construction of the smart grid transforms a series of processes, including power generation, transmission, storage, distribution, sale, and usage. The construction of power transmission of the smart grid is the main task of the energy backbone network.

Standard Criteria

From a technical point of view, the establishment of standard criteria is crucial. For the Internet, it is the Transmission Control Protocol/Internet Protocol and other protocols that lay the foundation for openness and interconnection, which led to its rapid development. New applications and modes have emerged over the past few decades. It is well recognized that for any new subject, further development criteria can be obtained only if the industry has reached a consensus regarding the basic conceptual model and the architecture of the energy system. This makes the formulation of the standard criteria in the energy Internet urgent.

The standard criteria of the energy Internet can be divided into four layers. The first layer refers to the general basic criterion of the energy Internet. The second layer is the common supportive criterion of the energy Internet, including terminologies and abbreviations, methodology, case analyses, conceptual model, architecture, and technical guidance. The third layer stands for the professional basic standards, which are also the common requirements of various subjects, including networking and procession management, measurement and evaluation, interoperability, safety, market, monitoring, and technical supports. The fourth layer focuses on the individual standard with respect to each subject.

Scenarios of the Energy Internet

The energy Internet represents the direction of the future, but its development still has a long way to go. This section describes a potential scenario of the energy Internet. In this scenario, the energy Internet is composed of three energy LANs and large power grids. The microgrid energy network is the basic unit of the energy supply model of the energy Internet, and it contains home users, commercial users, and various kinds of electricity consumers. In short, from the electricity consumers' perspective, the microgrids can be viewed as a small society.

The power supply of microgrids is supported by distributed energy and large power grids together. Distributed generation is the main approach, whereas the power supplied by large power grids is the supplemental one. Each microgrid contains wind energy, solar energy, energy storage devices, electric vehicles, and other basic energy units, all of which are regarded as the basic elements of the microgrids. It also includes the construction of information infrastructure, such as optical fibers, mobile communications, sensors, and a data center. The information layer collects the information of power usage and generation. Utilizing environmental information and historical data, scheduling decisions are made according to the current users' demand for electricity.

The energy LANs display the energy exchange and routing throughout the microgrids. The large power grids connect the microgrids, which also guarantees the electricity use for the microgrids. When the distributed energy generation of one microgrid fails to satisfy its demand for electricity, the other microgrids or the large power grids may help supply power, entirely depending on the local strategies. It is notable that such an operation mechanism reflects the essential features of the energy Internet—that is, its openness and peer-to-peer nature. The components of a potential scenario of the energy Internet can be described as follows.

Distributed Energy (CCHP)

The system of CCHP uses natural gas as the primary energy to generate secondary energy such as electricity and heat energy. The burning of natural gas transforms chemical energy into thermal energy. The high-grade heat energy is used for electricity generation, whereas the low-grade thermal energy is used for the heating supply, or to provide the driving heat source for the adsorption refrigeration system. The system of CCHP has a relatively high utilization efficiency. For the current thermal power generation system, the utilization efficiency of the primary energy is 40%, with a 2% loss during the process of power transmission. However, in the case of this system, the utilization efficiency of the primary energy normally reaches 80% and above.

Microgrids (Wind, Solar, Storage)

As the main part of renewable energy, power generation from wind and solar energy must be supported by energy storage devices due to the intermittent nature of their supply. This issue has been widely studied via the technical research and development of the microgrids. Nonetheless, the microgrids themselves have difficulties in stabilizing their discreet operations and are restricted by the lack of flexibility of the current power grids. The energy Internet provides new ways to access and interconnect the microgrids. As cost problems still appear in the power generation and storage of the new energy resources, the energy Internet has the advantage of improving the economic feasibility of realizing the microgrids in a wider range.

Intelligent Community (Response and Management From the Demand Side)

The term *demand response* in the literature on the energy Internet refers to the phenomenon that electricity consumers actively change their daily electricity consumption patterns. For instance, when the price of electricity increases, or the reliability of the power system is threatened, electricity consumers tend to respond quickly to the information and instructions provided by the power grids. Normally, they would reduce their demand for electricity or change the time of consuming electricity. By this approach, electricity consumers are able to save money.

Both electric operators and electricity consumers usually communicate and negotiate with each other first, and then, a corresponding contract is signed. The content of such a contract includes the methods, solutions, and compensation measures that are desired and approved by consumers. According to the operation of the energy Internet, the electric operators first determine the demand response incidents, such as its time period and approach; then, the energy management system of the energy Internet is informed. Next, certain signals are sent to the consumers by the energy management system, based on which the consumers make judgments according to their own demand. Finally, in line with the results of the demand response, the electric operator obtains the operational situation of the energy Internet and then compensates the consumers based on the contracts.

The information layer makes the microgrids themselves into a complex energy supply sector. In fact, the microgrids turn out to be intelligent energy suppliers, leading to the coordination and balance among multiple kinds and sources of energy. More important, the existence of the information layer makes each microgrid no longer individually independent. It is the information layer that establishes the interconnection among various microgrids, which makes the networking of the microgrids possible, hence realizing the energy flow within the microgrids.

Based on the structure just described, when Microgrid A is short of electricity, it does not have to ask for power supplement or transmission toward the wide area large power grid. Instead, Microgrid A could propose power requirement toward Distributed Energy Grid B, which is more environmentally friendly and offers a cheaper electricity price. After evaluating its own situation of power generation and consumption, Distributed Energy Grid B would supply electricity to Microgrid A. In this sense, the energy Internet enables an equal exchange of energy and information.

The attributes of the energy Internet such as openness and interconnection are evident in the case just discussed. Similar to the natural diversification between the LAN and the WAN of the Internet, the WAN in the energy Internet must be based on plug-and-play devices and standard protocols that are open and concise. There may also exist a variety of controlled objective functions. They include electricity price, energy saving and environmental protection, maximization of output power, or some other objectives so as to realize an online dynamic, specific kind of energy management.

Compared with the traditional top-bottom power grids with modes of generation, the energy in a certain district has flexible access to the distributed energy system and the demand response interacted with consumers. Meanwhile, the energy Internet not only shields the source and usage to a great extent, but it also introduces large redundancy to the power grid in exchange for security and reliability. Therefore, the overall utilization efficiency of the large power grids is improved.

See also Smart Cities; Smart Energy Systems; Smart Grids

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Further Readings

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