Views & Comments

Engineering 2015, 1(4): 405–408
DOI 10.15302/J-ENG-2015120

Basic Ideas of the Smart Grid

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Electrical power grids have encountered many challenges in recent years, including global warming, the quest for energy security, increasing cultural conservation, and the stringent power reliability and quality requirements of the digital age. Many studies have been conducted on the development and implementation of the smart grid (SG) to address these issues.

In terms of power grids, the development of the SG is aimed at achieving at least four major objectives: ① the secure operation of large power grids under disturbances, the minimization of the risk of blackouts, and enhanced resilience; ② the seamless accommodation and efficient utilization of vast amounts of distributed energy resources (DERs); ③ the facilitation of an advanced electric power market and demand response; and ④ the provision of electric power with high reliability, high quality, and high efficiency for a digital society.

From a broader perspective, considering that the implementation of the SG draws on many technical and business fields, the key goal is to encourage the innovation of relevant technologies and business models in order to create an industrial revolution.

Considering the many ideas that underlie the SG, their clarification will facilitate the scientific and efficient implementation of SG projects. This article elaborates on some basic ideas.

1 Essential technical characteristics of the SG

The essential technical characteristics of the SG are: the two-way flow of electricity and information in order to establish a highly automatic and widely distributed energy exchange network; and the utilization of distributed computation, communication, and Internet within power grids in order to realize the real-time exchange of information and a near-instantaneous balance between power demand and supply at the device level. The following four features are important in this regard.

1.1 Flexible network topology and integrated energy and communication system architecture (IECSA)

Because of the wide integration of DERs, the power flow of each line of the power grid (including the transmission and distribution grids) is likely to be bidirectional and time-varying. Hence, to maximize the potential benefit of the SG, the topology of the distribution grid should be flexible and reconfigurable. In addition, it should use flexible alternating current (AC) and direct current (DC) power transmission and distribution devices, as well as other electronic power devices such as the intelligent universal transformer (IUT), which is a type of energy router that is regarded as the cornerstone of smart distribution grids. Furthermore, where there is electricity, there is a reliable two-way communication network. From the sensors and intelligent agents in the basic layer, the energy grid and the information and communication network are deeply integrated.

1.2 Huge quantities of DERs

DERs include distributed generation, distributed energy storage, and demand response. Among these, solar power, wind power, and demand response are distributed according to natural geography. With regard to demand response, the electricity consumption of end-users may change with the retail price of electricity, or decrease when the electricity price in the retail electricity market is high or the power grid is insecure. The following observations are thus worthy of note.

(1) As distributed generation is close to the power load, power and energy can be balanced on-site in order to reduce the investment requirement, network loss, and operation and maintenance cost of the grid. In addition, with the increasing price of traditional power, the cost of photovoltaic (PV) devices decreases rapidly, and is accompanied by a gradual reduction of the cost of distributed energy storage. At the same time, the utilization efficiency of the distributed energy system, such as the combined heat and power (CHP), may increase to higher than 80%. All these factors indicate that parity between the cost of distributed generation and the retail price is within sight. At the same time, distributed generation can be used to improve the reliability of consumer service and strengthen the security of the power grid. Consequently, the vast majority of studies on the development and implementation of the SG worldwide have focused on the "distributed."

Indeed, studies conducted at Tianjin University have shown that in present-day China, the total social cost of a "distributed PV + active distribution" scheme (i.e., distributed PV stations without energy storage, locally integrated

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into an active distribution grid) has fallen below the total social cost of a "large-scale base of centralized renewable generation + long-distance transmission" scheme (i.e., a large-scale base with a combination of wind power and thermal power, integrated into a bulk power system at a load center through a ±800 kV ultra high voltage (UHV) DC 2000 km long-distance transmission line).

Hence, the development of a future power grid is faced with the challenge of dealing with tens of millions of distributed power resources with intermittency, variability, and uncertainty, while ensuring the security and reliability of the power grid, human and equipment safety, and market viability.

(2) Studies have revealed the presence of a significant shiftable load in the time coordinate in a power grid, and that such a load, like a virtual power resource, is a favorable measure for reducing the peak load and filling the valley load in order to improve asset utilization and power generation efficiency, and reduce grid losses. This measure enables the achievement of a near-instantaneous balance between power supply and demand at the device level. For example, demand response and load control can be used to compensate for the intermittency, variability, and uncertainty of solar and wind power. This represents a revolutionary change compared to the constraints of a traditional power grid, which requires strictly imposed generation to meet the load demand at any time. In facilitating demand response and load control, the SG would employ advanced metering infrastructure (AMI), plug-and-play technology, and an advanced power market. The control and management of the load and power distribution would be comprehensively taken into account.

(3) Plug-in hybrid electric vehicles (PHEVs) and vehicle-to-grid (V2G) technology have the double attributes of being both a load and a source, and their charging power and energy storage are very large. In addition, compared with distributed PV and wind power, the location and capacity of these electric vehicles have a higher uncertainty. On one hand, as a new type of load, the integration of many electric vehicles significantly increases the load and complicates the load characteristics of distribution grids, thus presenting challenges to the planning and operation of the future power grid. On the other hand, as a type of energy storage device, electric vehicles are important potential control measures for reducing the peak load and filling the valley load, for frequency regulation, and so on. For this purpose, the SG should provide electric vehicles with a plug-and-play platform, including advanced market and novel technology support.

In addition to electric vehicles, distributed energy storage can be used in many aspects of distribution grids, for increasing operation reliability, improving power quality, enhancing the ability to accommodate renewable resources, and so on. The SG will provide the basic platform for the interaction and coordinated control between distributed energy storage and distribution grids.

It is gratifying that the innovative process of the new distributed energy storage technology is developing rapidly in recent years, and is expected to break through the bottleneck of the high cost of energy storage.

1.3 Distributed intelligent infrastructure

(1) Power infrastructures that were built before the age of the microprocessor were based on centralized planning and control, which significantly limited the flexibility of the power grid, and also reduced the efficiency, security, and reliability. Furthermore, because the number of DERs will be huge and DER outputs are difficult to forecast, the traditional centralized control mode will be unable to adapt. Consequently, the smart distribution grid will be a distributed intelligent infrastructure.

As shown in Figure 1, a smart distribution grid is divided into several cells. The exchange power in the normal operation between two cells can be scheduled according to the schedule. Each cell incorporates several intelligent network agents (INAs) such as relay protection devices and DERs, which are interconnected through the cell communication network. The INAs collect and exchange system information, make independent decisions regarding local control such as relay protection by themselves, and coordinate decisions such as voltage control, reactive power optimization by itself, and network reconfiguration through the distribution fast simulation and modeling (DFSM) of each cell. There are also communication links among cells, thus each cell can make independent decisions and the operation center of the distribution grid with DFSM coordinates the decision-making between cells. Furthermore, the dispatching center of a transmission grid and the operation centers of distribution grids supplied by the transmission grid are linked through the communication network. The dispatching center of the transmission grid with transmission fast simulation and modeling (TFSM) enables coordinated decision-making based on the regional system requirements, and hence smart control across organizational and geographical boundaries. The entire grid is thus self-healing and resilient.

(2) The resilience of the system includes the ability to withstand and recover from

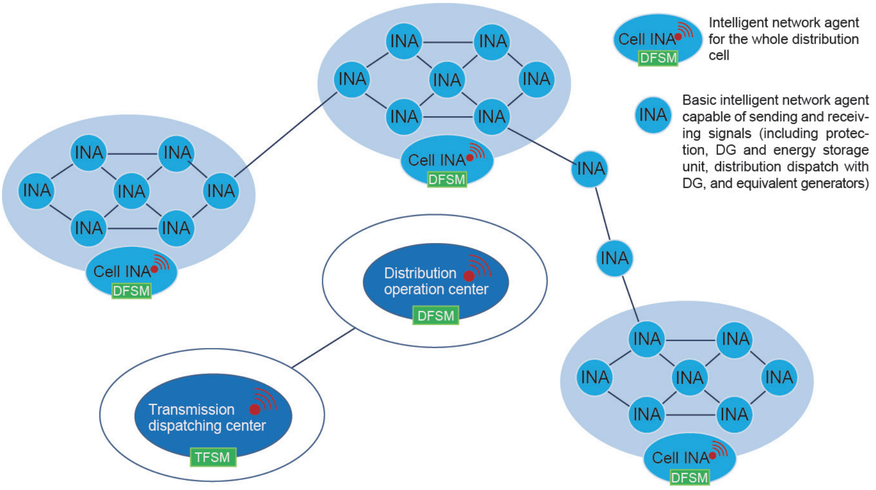

Figure 1. Distributed intelligent infrastructure.