4 Smart Grid for Renewable Energy

Jin Zhong
Department of Electrical & Electronic Engineering, University of Hong Kong

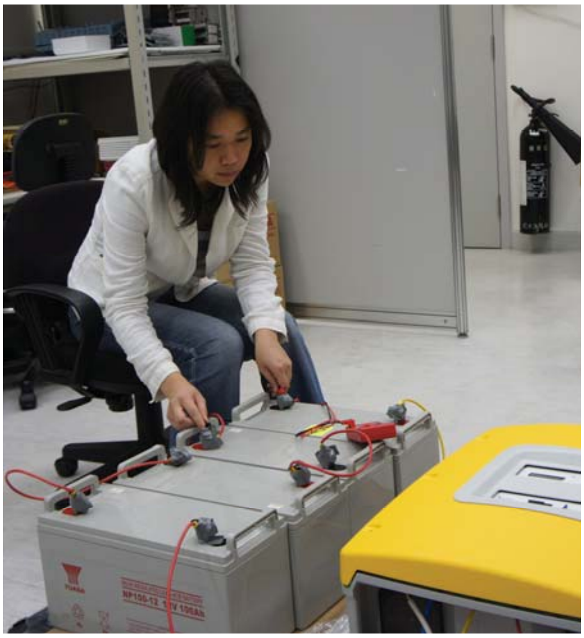

Figure 4-1Dr. Jin Zhong in the Smart Grid Lab

4.1 Introduction

With the development of electricity generation and transmission technologies in the past century, electrical energy has become the most important secondary energy utilized in the modern society. Nowadays, electricity is a necessity of daily life. In the early development of power industry, the electricity generation is dominated by large-scale centralized power plants due to economies of scale. These power plants are usually fossil-fuel based thermal power plants. By 2009, around 66% of the electricity over the world is generated by fossil fuel based energy sources. Traditional fossil-fuel power plants are major emitters of pollutants and green house gases. According to the statistic data, one-third of the carbon emission is contributed by power plants, and coal-fired generators are responsible for three quarters of the sulfur oxide emissions. The environmental and fossil fuel depletion issues are the incentives to develop renewable energy generation technologies and integrate renewable energy to power grid.

Although the high cost of renewable energy generation is a bottleneck of renewable energy entering the electricity market, the recent renewable energy certificate (REC) and renewable portfolio standard (RPS) applied in the USA provide an obligate mechanism to power companies to supply certain percentage of the electricity from renewable energy sources. The mechanism of REC is to trade the renewable green power in separated markets:

regular electricity market and green attributes / REC market, which are independent markets. The RPS is usually mandated by the government with a percentage requirement of electricity supply from renewable energy. Renewable energy targets vary in different countries. Both EU and Australia target to have 20% of energy from renewable energy by 2020. China targets 15% by 2015. Thirty-two states of the USA have setup their own renewable energy targets from 2% to 25% instead a national target [1].

The other bottleneck of utilizing green electricity in a wide range is the grid-integration issue of renewable energy generation to power grid. Due to the un-forecastable and un-controllable characteristics of intermittent renewable energy sources, the penetration level of renewable energy generation in a power grid is limited by the security and reliability requirement of system operation unless new technologies are developed to accommodate intermittent renewable energy generation. Smart grid provides the platform for renewable energy integration to power grid. Besides the requirement of renewable energy integration, the other need of smart grid is to improve power grid reliability and aging infrastructure, hence improve the quality of power supply and customer services.

Renewable energy generation can improve total energy efficiency whereas mitigate the environmental problem. The other method to improve energy efficiency is two-way demand side management (DSM). For example, distributed generation, smart home and electrical vehicle (EV) are well accepted as an environmentally friendly way of demand response. The intermittent renewable energy increases generation uncertainties in power grid. Energy storage is necessary to a grid with a high penetration of renewable energy generations. The real time control on distributed generation, storage charging / discharging and demand response requires fast, two-way modern information and communication technologies. The international trend in smart grid development is to start from distribution network and demand side by installing advanced metering infrastructure (AMI), smart home, distributed renewable generation, and distributed storages. Smart grid technologies include the latest information and communication technologies (ICTs), power electronics, control and energy storage technologies, etc. In this chapter, we will discuss these issues and the application of smart grid technologies in power systems.

4.2 Power Industry and Smart Grid

Electricity generation and power industry were started from late 1880s. Power system automation technologies have been developed and applied in power grid operation and control since 1960s. The existing power system automation techniques support automatic generation control, automatic fault clearance, automatic voltage regulation, large system interconnection, etc. The reliability of power supply has been improved significantly due to the application of automation and control techniques in the past decades.

Nowadays, power industry is facing new challenges from various aspects. With the development of economy, there is an increasing demand for electricity. However, we are facing energy issues caused by energy depletion and environmental problems. The modern society has higher requirements on reliability, security and quality of power supply. However, many transmission and distribution facilities currently on operation were built decades ago. Infrastructures for power generation and delivery need to be upgraded.

Figure 4-2 Traditional transmission and distribution grid

In traditional power systems, power flows from generators to transmission and distribution (T&D) grid then to consumers. With the installation of distributed generations at customer sides, power could also flow from customer side to power grid. Generators, grid companies and customers all have information exchange with the control center through communication networks.

Figure 4-3 Power flows from generators to transmission and distribution grid

Smart grid technologies apply to all sections of the power system, generation, transmission and distribution, and consumer, as well as control center. Customers' role in smart grid is mainly demand response. Smart meters and advanced metering infrastructure provide hardware support of demand response. The role of generation section in smart grid is renewable energy integration. For transmission and distribution systems, smart substations and the installation of phasor measurement units (PMU) and wide area management system (WAMS) provide the possibility of forecasting fault events in advance. As the brain of the power system, control center plays an important role in smart grid. A smart control center requires integrated ICT, advanced control and improved interfaces for decision making supports. On the other hand, a mature electricity market as well as regulations and policies are needed to facilitate the functions of smart grids.

4.3 Customers Demand Response in Smart Grid

In the U.S. and some European countries, the implementations of smart grid start from customer sides. Electricity consumers, in the past, are passive users. By installing smart meters and AMI, a customer could adjust his energy consumption pattern according to real-time electricity prices. If the customer has his own distributed renewable energy generation, e.g. solar panels and small wind turbines, he can even sell surplus electricity to the grid during the peaking-load hours. In this case, smart meters will be the smart agent with optimization functions as well as two way communication functions. The AMI system installed over a distribution system will enable consumers to participate in demand response programs. With a well designed economic incentive mechanism, electricity users' energy consumption patterns could be adjusted to an optimum way. For example, some appliances are scheduled to run during the hours of low electricity prices, which are usually non-peaking periods. The surplus electricity generated by customer-owned distributed generators is stored in batteries for selling to the grid during the peaking load hours at higher electricity prices. Customer demand response can help shaving peak load, hence reduce the capacity reserve requirement due to increasing demand. The implementation of demand response requires 1) AMI and smart meters to measure electricity consumption and response to the electricity prices and commands sent by the system operators; 2) real-time (RT) or time of use (TOU) pricing mechanisms to encourage consumers to participate in the program.

Figure 4-4 Smart meters for battery management

The AMI in smart grid is different from the automatic metering reading (AMR) that has been applied in some utilities. AMI has two-way communication and control functions. For an

AMI system, all smart meters at a smart home (electricity, gas, heat and water meters) communicate with the data concentrator through local area network (LAN). Through the wide area network (WAN), the concentrator exchange data with AMI host server, which is managed by the meter data management system (MDMS). Installing smart meter is the first step of implementing smart grid. In some countries, electricity utilities have started to install smart meters for their customers. In Italy, smart meters have been installed in over 30 million homes, which lead to 5% energy saving per year. In the U.S., 13 million smart meters have been installed by 2010, more will be installed in the near future. Tokyo Electric Power plans to install smart meters to their 27 million customers free of charge. Some other countries are also planning to start smart meter and AMI projects.

4.4 Renewable Energy Integration to Power Grid

Renewable energy generation is an effective solution to environmental and energy issues. However, there are some technical concerns of connecting renewable energy generation. Smart grid provides a technical platform for renewable energy grid integration.

Renewable energy generation could be installed either at the generation side, such as large wind farms and solar farms, or at the customer side as distributed generation (DG). Distributed generations refer to those small-scaled generators installed close to customers. DGs are usually clean energy or renewable energy based generators, such as, combined heat and power (CHP), micro turbine, fuel cell, wind turbine and photovoltaic panel, etc. To a traditional power grid, the concern of connecting DGs to the distribution network is the reverse power flow from DGs to the grid when a local microgrid generates more power than it consumes. Traditional protection schemes need to be re-designed to accommodate the bi-directional power flow.

Large-scale renewable energy generation connecting to power grid is constrained by the security and reliability operation requirements of power systems. Renewable energy, e.g. wind and solar, has intermittent characteristics. The generations of wind farm and solar panels are unstable and uncontrollable. Although power system automatic generation control (AGC) and spinning reserve capacity can compensate some load deviations in a short term, the sudden changes of power outputs due to intermittent wind power and solar energy require a much higher amount of compensation in a short time. The traditional AGC and reserve criteria may not be enough. More ancillary services and fast generation compensations are needed. A large installed capacity of wind turbines could also cause voltage problems and harmonic issues. Until these technical issues are solved, the total capacity of wind farm connecting to a power grid will be limited under certain penetration levels.

Energy storage is the solution to compensate intermittent renewable energy generation once practical and inexpensive energy storage methods are developed maturely. Electric energy could be stored mechanically through pump storage, compressed air, and fly wheel; or stored electro-magnetically through superconducting magnetic storage, and super-capacitor; or stored electron-chemically through lead-acid battery, flow battery and other advanced battery technologies.

Large-scale energy storage system could be installed at the generation side coordinating with wind and solar generation. For example, a combined renewable energy system with wind farms, solar panels and storage systems (e.g. pump storage station) will provide a stable output profile of renewable energy to the power grid. A well-developed storage system could also be used to provide ancillary services to power grid. The optimization and coordination of renewable energy generation and storage charging and discharging is a key issue of improving the energy efficiency of the combined renewable energy system. The other challenge is developing mature storage techniques that are practical and inexpensive for large-scale storage usage.

Distributed energy storage as well as distributed renewable energy generation is the key component in customer demand response in addition to consumption pattern adjustments using smart meters. Battery is a popular storage method for distributed energy storage. The combination of small renewable energy generators and batteries could be used as a stand-alone system or used for grid-connected micro-grid system.

Electric vehicle (EV), especially EV to Grid (V2G) technique, is a very important issue in smart grid. EV could perform as generator as well as storage with a V2G control system. EV could be used for leveling peak load, and as a backup for power failure. EV is an effective means of street CO2 reduction. V2G is a promising technique for the future. However, to use EV in a wide range, some issues need to be considered (1) a high penetration of EVs may affect the existing power system operation, a smart power grid should have the capability of accommodating high penetration of EVs; (2) standards need to be set to solve the problem of reverse power from EVs; (3) more charging stations and replacing stations are needed for drained batteries, so it is convenient for customers to use EVs.

Renewable energy and storage integration to power grid will provide a solution to energy and environmental issues. The coordination of renewable, storage and EV will significantly reduce the fluctuation of renewable energy generation. However, there are some barriers of accommodating all generation and storage options in a power grid. The cost of owning these generation sources and storages are high. Consumers and investors may not be motivated to invest. The techniques of grid-connection with high penetrations are not mature. To break the barriers, the smart grid needs to have (1) applications and standards that support Plug and Play functionality; (2) operation and planning tools; (3) smart sensors and smart controllers; and (4) real-time pricing mechanisms.

Figure 4-5 EV to Grid (V2G) technology enables more EV applications in the future

4.5 Future Control Center and ICT Applications

Information and communication technologies (ICT) are the fundamental of power system automation. The existing power system automation consists of: supervisory control and data acquisition (SCADA), energy management system (EMS), distribution management system (DMS), distribution automation (DA), substation automation (SA), and feeder automation (FA), etc. Most utility companies started to construct their automation systems since 1980s. The automation techniques significantly improved system reliability and service of power supply.

In the past decade, the information revolution has changed human's living styles. Applying the latest ICT to power system automation will significantly improve the efficiency of energy usage, improve power quality and reduce total cost. According to the DOE, the capabilities of smart grid include: self healing, consumer participation, high quality of power, resist attack, accommodate diversified generation options, enable power market, optimize asset, and enable high penetration of intermittent generation sources [2]. ICT will be the fundamental and necessary techniques to implement these functions of smart grid.

Substations are important nodes in a power grid that assemble all monitoring, protection and control devices. Substations also play a role as collecting data from feeders and consumers, and communicating information with upper level control centers. Smart substations widely dispersed in the grid are key elements of a smart grid. A smart substation should be equipped with accurate data measurement units and data analysis tools for online network analysis. The standard communications inside the station and among stations are also important for information exchange. Phasor measurement unit (PMU) will increase the accuracy of data measurement in power grid. The data measured by traditional remote terminal unit (RTU) is not synchronized. PMU data is synchronized by a global positioning system (GPS). A phasor data concentrator (PDC) collects data from PMUs and sends data to SCADA and wide area management system (WAMS). Using data from PMUs and applying wide area control, power system operating conditions can be accurately monitored and simulated; hence it is possible to forecast fault events before the event occurs. That will significantly increase the system security and reliability.

Figure 4-6 The System Control Center of CLP Power

The future control center, by applying smart grid technologies, will be able to monitor operation conditions of primary devices, diagnose fault events, clear faults before they occur, support demand response, support intermittent renewable generations using real-time on-line data analysis and system control.

4.6 Conclusions

Renewable energy and customer demand response are the major solutions of energy and environmental issues. Smart grid provides the platform for renewable energy integration to grid and customer participation. Latest information and communication technologies will improve power system operation though online data analysis and real-time control, hence improve power system security and reliability, and the quality of power supply. Various smart grid technologies applied in power generation, transmission, distribution and consumption will change customers' life styles, improve energy consumption pattern and the environment of the earth.

References

[1] A. Ipakchi and F. Albuyeh, "Grid of the Future", *IEEE Power and Energy Magazine*, March 2009.

[2] "A system view of the modern grid", reported by the NETL Modern Grid Initiative, 2007. Available at: http://www.netl.doe.gov/smartgrid/referenceshelf/whitepapers/ASystemsViewoftheModernGrid_Final_v2_0.pdf